

Fortran 90/95 Explained

Second Edition

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Preface

Fortran has always been the principal language used in the fields of scientific, numerical, and engineering programming, and a series of revisions to the standard defining successive versions of the language has progressively enhanced its power and kept it competitive with several generations of rivals.

Beginning in 1978, the technical committee responsible for the development of Fortran standards, X3J3 (now called J3), laboured to produce a new, much-needed modern version of the language, Fortran 90. Its purpose is to “promote portability, reliability, maintainability, and efficient execution... on a variety of computing systems”. The standard was published in 1991, and work began in 1993 on a minor revision, known informally as Fortran 95. Now this revised standard is in use, it seems appropriate to prepare a definitive informal description of the language it defines. This continues the series of editions of this book – the two editions of *Fortran 8x Explained* that described the two drafts of the standard (1987 and 1989), and *Fortran 90 Explained* that described the Fortran 90 standard (1990).

The whole of Fortran 77 is contained in Fortran 90, but certain of its features are labelled ‘obsolescent’ in the standard, and their use is not recommended. The obsolescent features of Fortran 90 have replacements in Fortran 77 and some have been removed from the Fortran 95 standard. Other Fortran 77 features, with replacements in Fortran 90, are labelled obsolescent in Fortran 95. We have relegated the description of all these Fortran 77 features to Appendix C. They are falling into disuse and an understanding of them is required only when dealing with old programs.

In this book, an initial chapter sets out the background to the work on the new standards, and the ten following chapters describe Fortran 90/95 less the obsolescent features in a manner suitable both for grasping the implications of the new features, and for writing programs. Features that are available in Fortran 95 only are labelled as such. Where the word ‘Fortran’ is used, it means ‘common to both Fortran 90 and 95’. Some knowledge of programming concepts, although not necessarily of Fortran 77, is assumed. In order to reduce the number of forward references and also to enable, as quickly as possible, useful programs to be written based on material already absorbed, the order of presentation does not always follow that of the standard. In particular, we have chosen to defer to the final chapter the description of features that are redundant in Fortran 90 and whose

use we deprecate. It would impair the flow of the exposition if we were to describe them in the main body of the text. They may be encountered in old programs, but are not needed in new ones.

This edition differs from the first edition in that descriptions of Fortran 95 features are integrated into the body instead of being confined to a separate chapter. This book is thus suitable for the reader who wishes to learn only Fortran 95 as well as for one who wishes to learn just Fortran 90 or even both Fortran 90 and Fortran 95.

We have chosen to use lower-case letters instead of upper-case letters for all the Fortran keywords and names, since this is the preferred style of many Fortran programmers and there are very few processors still in use that support only upper case. Also, we have switched to a different typesetting system (now *LATEX*). These two changes give the book a very different (and in our opinion, improved) look.

This edition also differs from the first edition in that we have added two new chapters, 12 and 13, on official extensions of Fortran 95. Each is specified by an ISO Technical Report and WG5 has promised that the features of both will be included in the next revision of the language, apart from correcting defects found in the field. We expect Fortran 95 compilers increasingly to offer these features as extensions.

In order to make the book a complete reference work, it concludes with six appendices. They contain, successively, a list of the intrinsic procedures, a summary of Fortran statements, a description of the obsolescent and deleted features, an extended example illustrating the use of pointers and recursion, a glossary of Fortran terms, and solutions to most of the exercises.

It must be remembered that although the obsolescent features appear in an appendix, they were nevertheless an integral part of the Fortran 90 language, and some remain part of Fortran 95. However, the appendix includes advice on how to avoid their use, thereby enhancing the upwards compatibility of programs with respect to possible future standards. The same is true for the features whose use we deprecate, and which are described in Chapter 11.

It is our hope that this book, by providing a complete description of Fortran 90 and Fortran 95, will continue the helpful role that earlier editions played for the Fortran 90 standard, and will serve as a long-term reference work for Fortran 95 into the next decade.

Acknowledgements

The development of the Fortran 90 standard was a long procedure involving several hundred people in many countries. The main burden fell on the principal members of X3J3 (now called J3), and especially on its then chairman, Jeanne Adams, and on the then Convenor of WG5, Jeanne Martin. The work continued for Fortran 95 with Jerry Wagener as chairman of X3J3. We extend our thanks to them and all our colleagues on X3J3 and elsewhere for their devotion to this important but thankless task, and for creating such a friendly working atmosphere. We will long remember the week-long meetings held over such an extended period, as well as the personal contacts we made and valued. We have taken great pains to ensure that this book is a true and accurate representation of the final documents produced by the committee, and clearly any omissions or other errors or misrepresentations are entirely our responsibility.

We gratefully acknowledge the actual and former management of CERN and Harwell, and especially P. Zanella and D.O. Williams of CERN and the late A.E. Taylor of Harwell, for encouraging us to undertake this work, and for providing the necessary resources for its realization. JKR is also indebted to the Rutherford Appleton Laboratory for its subsequent support.

Conventions used in this book

Fortran displayed text is set in typewriter font:

```
integer :: i, j
```

and a line consisting of a colon indicates omitted lines:

```
subroutine sort
:
end subroutine sort
```

Informal BNF terms are in italics:

if (scalar-logical-expr) action-stmt

Square brackets indicate optional items:

end if [name]

and an ellipsis represents an arbitrary number of repeated items:

*[case selector [name]
block] ...*

The italic letter *b* signifies a blank character.

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1. Whither Fortran?

This book is concerned with the Fortran programming language (Fortran 90 and Fortran 95), setting out a reasonably concise description of the whole language. The form chosen for its presentation is that of a textbook intended for use in teaching or learning the language. Its description occupies Chapters 2 to 11, which are written in such a way that simple programs can already be coded after the first three of these chapters (on language elements, expressions and assignments, and control) have been read. Successively more complex programs can be written as the information in each subsequent chapter is absorbed. Chapter 5 describes the important concept of the module and the many aspects of procedures, Chapter 6 completes the description of the powerful array features, Chapter 7 considers the details of specifying data objects and derived types, and Chapter 8 details the intrinsic procedures. Chapters 9 and 10 cover the whole of the input/output features in a manner such that the reader can also approach this more difficult area feature by feature, but always with a useful subset already covered. Finally, Chapter 11 describes those features that are redundant in the language, and whose use we choose to deprecate. Here we emphasize that this deprecation represents our own opinion, and is completely unofficial. In a concluding section of each of Chapters 2 to 10, we summarize the differences from Fortran 77. Chapters 12 and 13 describe official extensions to Fortran 95 that we expect increasingly to be present in Fortran 95 compilers.

Fortran 95 is a minor revision of Fortran 90, so most of this book applies to both. Features of Fortran 95 that are not part of Fortran 90 are usually described in separate subsections, but sometimes we use separate paragraphs. Every example that is not applicable to Fortran 90 is labelled as such. Features of Fortran 90 that are not part of Fortran 95 are obsolescent in Fortran 90 and are described only in Appendix C.

This introductory chapter has the task of setting the scene for those that follow. The first section presents the Fortran language and its considerable evolution since it was first introduced over thirty years ago. The second continues with a justification for preparing the Fortran 90 standard, summarizes the important new features, and outlines how standards are developed; the third looks at the mechanism that has been proposed to permit the language to evolve. The fourth section considers the development of Fortran 95 and the fifth some related issues.

The sixth concludes by considering the requirements on programs and processors for conformance with the standard.

1.1 Fortran history

Programming in the early days of computing was tedious in the extreme. Programmers required a detailed knowledge of the instructions, registers, and other aspects of the central processing unit (CPU) of the computer for which they were writing code. The *source code* itself was written in a numerical notation, so-called *octal code*. In the course of time mnemonic codes were introduced, a form of coding known as *machine* or *assembly code*. These codes were translated into the instruction words by programs known as *assemblers*. In the 1950s it became increasingly apparent that this form of programming was highly inconvenient, although it did enable the CPU to be used in a very efficient way.

These difficulties spurred a team led by John Backus of IBM to develop one of the earliest high-level languages, Fortran. Their aim was to produce a language which would be simple to understand but almost as efficient in execution as assembly language. In this they succeeded beyond their wildest dreams. The language was indeed simple to learn, as it was possible to write mathematical formulae almost as they are usually written in mathematical texts. (In fact, the name Fortran is a contraction of Formula Translation.) This enabled working programs to be written faster than before, for only a small loss in efficiency, as a great deal of care was devoted to the construction of the compiler.

But Fortran was revolutionary as well as innovative. Programmers were relieved of the tedious burden of using assembler language, and were able to concentrate more on the problem in hand. Perhaps more important, however, was the fact that computers became accessible to any scientist or engineer willing to devote a little effort to acquiring a working knowledge of Fortran; no longer was it necessary to be an expert on computers to be able to write application programs.

Fortran spread rapidly as it fulfilled a real need. Inevitably dialects of the language developed, which led to problems in exchanging programs between computers, and so, in 1966 the then American Standards Association (later the American National Standards Institute, ANSI) brought out the first ever standard for a programming language, now known as Fortran 66.

Fortran brought with it several other advances, apart from its ease of learning combined with a stress on efficient execution of code. It was, for instance, a language which remained close to, and exploited, the available hardware rather than being an abstract concept. It also brought with it the possibility for programmers to control storage allocation in a simple way, a feature which was very necessary in those early days of small memories, even if it is now regarded as being potentially dangerous.

The proliferation of dialects remained a problem after the publication of the 1966 standard. There was a widespread implementation in compilers of features

which were essential for large-scale programs, but which were ignored by the standard. Different compilers implemented such facilities in different ways.

These difficulties were partially resolved by the publication of a new standard, in 1978, known as Fortran 77. It included several new features that were based on vendor extensions or pre-processors and it was, therefore, not simply a common subset of existing dialects. By the mid-1980s, the changeover to Fortran 77 was in full swing. It was a relatively simple matter to write new code under the new standard, and converting old standard-conforming code was usually easy as there is a large measure of compatibility between the two standards.

1.2 The drive for the Fortran 90 standard

After thirty years' existence, Fortran was far from being the only programming language available on most computers. In the course of time new languages had been developed, and where they were demonstrably more suitable for a particular type of application they had been adopted in preference to Fortran for that purpose. Fortran's superiority had always been in the area of numerical, scientific, engineering, and technical applications and, in order that it be brought properly up-to-date, the ANSI-accredited technical committee X3J3 (now known as J3) working as a development body for the ISO committee ISO/IEC JTC1/SC22/WG5 (which we abbreviate to WG5), once again prepared a new standard, formerly known as Fortran 8x and now as Fortran 90.

X3J3 itself is a body composed of representatives of computer hardware and software vendors, users, and academia. It is accredited to ANSI, the body that publishes final American standards, but reports directly to its parent committee, X3 (computer systems), which is responsible for actually adopting, or rejecting, the proposed draft standards presented to it. In these decisions, it tries to ensure that the proposals really do represent a consensus of those concerned. X3J3 acts as the development body for the corresponding international group, WG5, consisting of international experts responsible for recommending that a draft standard become an international standard. X3J3 maintains other close contacts with the international community by welcoming foreign members, including both the present authors.

What were the justifications for continuing to revise the definition of the Fortran language? As well as standardizing vendor extensions, there was a need to modernize it in response to the developments in language design which had been exploited in other languages, such as APL, Algol 68, Pascal, Ada, C and C++. Here, X3J3 could draw on the obvious benefits of concepts like data hiding. In the same vein was the need to begin to provide an alternative to dangerous storage association, to abolish the rigidity of the outmoded source form, and to improve further on the regularity of the language, as well as to increase the safety of programming in the language and to tighten the conformance requirements. To preserve the vast investment in Fortran 77 codes, the whole of Fortran 77 was retained as a subset. However, unlike the previous standard, which resulted almost

entirely from an effort to standardize *existing practices*, the Fortran 90 standard is much more a *development* of the language, introducing features which are new to Fortran, but are based on experience in other languages.

The main features of Fortran 90 are, first and foremost, the array language and abstract data types. The former is built on whole array operations and assignments, array sections, intrinsic procedures for arrays, and dynamic storage. It was designed with optimization in mind. The latter is built on modules and module procedures, derived data types, operator overloading and generic interfaces, together with pointers. Also important are the new facilities for numerical computation including a set of numeric inquiry functions, the parametrization of the intrinsic types, new control constructs – select case and new forms of do, internal and recursive procedures and optional and keyword arguments, improved I/O facilities, and many new intrinsic procedures. Last but not least are the new free source form, an improved style of attribute-oriented specifications, the implicit none statement, and a mechanism for identifying redundant features for subsequent removal from the language. The requirement on compilers to be able to identify, for example, syntax extensions, and to report why a program has been rejected, are also significant. The resulting language is not only a far more powerful tool than its successor, but a safer and more reliable one too. Storage association, with its attendant dangers, is not abolished, but rendered unnecessary. Indeed, experience shows that compilers detect errors far more frequently than before, resulting in a faster development cycle. The array syntax and recursion also allow quite compact code to be written, a further aid to safe programming.

1.3 Language evolution

The procedures under which X3J3 works require that a period of notice be given before any existing feature is removed from the language. This means, in practice, a minimum of one revision cycle, which for Fortran means about five years. The need to remove features is evident: if the only action of the committee is to add new features, the language will become grotesquely large, with many overlapping and redundant items. The solution finally adopted by X3J3 was to publish as an appendix to a standard a set of two lists showing which items have been removed or are candidates for eventual removal.

One list contains the *deleted features*, those that have been removed. Since Fortran 90 contains the whole of Fortran 77, this list is empty for Fortran 90 but is not for Fortran 95 (see Appendix C).

The second list contains the *obsolescent features*, those considered to be outmoded and redundant, and which are candidates for deletion in the next revision. The Fortran 90 and Fortran 95 obsolescent features are described in Appendix C.

1.4 Fortran 95

Following the publication of the Fortran 90 standard in 1991, two further significant developments concerning the Fortran language occurred. The first was the continued operation of the two Fortran standards committees, X3J3 and WG5, and the second the founding of the High Performance Fortran Forum (HPFF).

Early on in their deliberations, the standards committees decided on a strategy whereby a minor revision of Fortran 90 would be prepared by the mid-1990s and a further revision by about the year 2000. The first revision, Fortran 95, is a subject of this book.

The HPFF was set up in an effort to define a set of extensions to Fortran, such that it would be possible to write portable code when using parallel computers for handling problems involving large sets of data that can be represented by regular grids. This version of Fortran was to be known as High Performance Fortran (HPF), and it was quickly decided, given the array features of Fortran 90, that it, and not Fortran 77, should be its base language. The final form of HPF¹ is of a superset of Fortran 90, the main extensions being in the form of directives that take the form of Fortran 90 comment lines, and are thus recognized as directives only by an HPF processor. However, it did become necessary also to add some additional syntax, as not all the desired features could be accommodated in the form of such directives.

The work of J3 (as X3J3 became known) and WG5 went on at the same time as that of HPFF, and the bodies liaised closely. It was evident that, in order to avoid the development of divergent dialects of Fortran, it would be desirable to include the new syntax defined by HPFF in Fortran 95 and, indeed, the HPF features are the most significant new features that Fortran 95 introduces. The other changes consist mainly of what are known as corrections, clarifications and interpretations. These came about as it was quickly discovered, as Fortran 90 compilers were written and used, that the text of the Fortran 90 standard contained a number of errors that required correction, some obscure wording that required further textual clarification, and ambiguous statements that required interpretation. (J3 and WG5 processed about 200 requests for interpretation.) All the resulting changes have been included in the Fortran 95 standard and, where appropriate, they have been incorporated at the relevant places in this book. Apart from the HPF syntax and the corrections, only a small number of other pressing but minor language changes were made and these too are described.

Fortran 95 is backwards compatible with Fortran 90, apart from a minor change in the definition of `sign` (Section 8.3.2) and the deletion of some Fortran 77 features declared obsolete in Fortran 90 (as described in Appendix C). However, there are two new intrinsic procedures, `null` and `cpu_time`, which might also be names of external procedures in an existing Fortran 90 program.

¹*The High Performance Fortran Handbook*, C. Koebel et al., MIT Press, Cambridge, MA, 1994.

The details of Fortran 95 were finalized in November 1995, and the new ISO standard, replacing Fortran 90, was adopted in 1997, following successful ballots, as ISO/IEC 1539-1 : 1997.

1.5 Beyond Fortran 95

About the time of the publication of Fortran 95, another interesting development occurred. This was the specification of two (similar) subset versions of Fortran 90 that retain its modern features while casting aside its outmoded ones. The present authors were involved in the development of one of these, known as F, and that language's description can be found in "*The F programming language*" (OUP, 1996). These subsets can be regarded as important vehicles for the teaching of a safe and reliable style of modern programming.

At the same time, a formal standard, ISO/IEC 1539-2 : 1994, was developed for varying length strings. It defines the interface and semantics for a module that provides facilities for the manipulation of character strings of arbitrary and dynamically variable length. An annex contains a possible implementation in Fortran 90, which demonstrates its feasibility, but the intention was that vendors provide equivalent features that execute more efficiently. Unfortunately, none has done so. At the time of writing, this standard is being revised to take advantage of the Fortran 95 enhancements. In particular, this will allow a better implementation within the standard language.

Further, in 1995, WG5 decided that these three features:

- i) handling floating point exceptions,
- ii) permitting allocatable arrays as structure components, dummy arguments, and function results, and
- iii) interoperability with C,

were so urgently needed in Fortran that it established development bodies to develop 'Technical Reports of Type 2'. The intent was that the material of these technical reports be integrated into the next revision of the Fortran standard, apart from any defects found in the field. It is essentially a beta-test facility for a language feature. In the event, the first two have been completed and are the subjects of Chapters 12 and 13. Difficulties were encountered with the third, so the report mechanism has therefore been abandoned for interoperability with C, but the intent of inclusion in the next standard remains.

Another auxiliary standard, ISO/IEC 1539-3 : 1998, has been developed to meet the need of programmers to maintain several versions of code to allow for different systems and different applications. Keeping several copies of the source code is error prone. It is far better to maintain a master code from which any of the versions may be selected. This standard is for a very simple form of conditional compilation, which selects some of the Fortran lines from the source and omits the rest or converts them to comments. The process is controlled by 'coco lines'

in the source that are also omitted or converted to comments. It is hoped that the facilities will be built into compilers, but they may also be implemented by a preprocessor.

The next full language revision is planned for 2001 and is already being referenced as Fortran 2000, and the main features have been chosen:

- handling floating point exceptions, as in TR15580,
- permitting allocatable arrays as structure components, dummy arguments, and function results, as in TR15581,
- interoperability with C,
- parameterized data types,
- object-orientation: constructors/destructors, inheritance, and polymorphism,
- derived type I/O,
- asynchronous I/O,
- procedure variables, and
- various minor enhancements.

All this activity provides a means of ensuring that Fortran remains a powerful and well-honed tool for numerical and scientific applications for the next decade and beyond.

1.6 Conformance

The standard is almost exclusively concerned with the rules for programs rather than processors. A processor is required to accept a standard-conforming program and to interpret it according to the standard, subject to limits that the processor may impose on the size and complexity of the program. The processor is allowed to accept further syntax and to interpret relationships that are not specified in the standard, provided they do not conflict with the standard. Of course, the programmer must avoid such syntax extensions if portability is desired.

The interpretation of some of the standard syntax is *processor dependent*, that is, may vary from processor to processor. For example, the set of characters allowed in character strings is processor dependent. Care must be taken whenever a processor-dependent feature is used in case it leads to the program not being portable to a desired processor.

A drawback of the Fortran 77 standard was that it made no statement about requiring processors to provide a means to detect any departure from the allowed syntax by a program, as long as that departure did not conflict with the syntax rules defined by the standard. The new standards are written in a different style to the old one. The syntax rules are expressed in a form of BNF with associated

constraints, and the semantics are described by the text. This semi-formal style is not used in this book, so an example is perhaps helpful:

R609	<i>substring</i>	is	<i>parent-string</i> (<i>substring-range</i>)
R610	<i>parent-string</i>	is	<i>scalar-variable-name</i>
		or	<i>array-element</i>
		or	<i>scalar-structure-component</i>
		or	<i>scalar-constant</i>
R611	<i>substring-range</i>	is	[<i>scalar-int-expr</i>] : [<i>scalar-int-expr</i>]

Constraint: *parent-string* must be of type character.

The first *scalar-int-expr* in *substring-range* is called the **starting point** and the second one is called the **ending point**. The length of a substring is the number of characters in the substring and is $\text{MAX}(\ell - f + 1, 0)$, where f and ℓ are the starting and ending points, respectively.

Here, the three production rules and the associated constraint for a character substring are defined, and the meaning of the length of such a substring explained.

The standard is written in such a way that a processor, at compile-time, may check that the program satisfies all the constraints. In particular, the processor must provide a capability to detect and report the use of any

- obsolescent feature,
- additional syntax,
- kind type parameter (Section 2.5) that it does not support,
- non-standard source form or character,
- name that is inconsistent with the scoping rules, or
- non-standard intrinsic procedure.

Furthermore, it must be able to report the reason for rejecting a program. These capabilities are of great value in producing correct and portable code. They were not required for Fortran 77 programs.

2. Language elements

2.1 Introduction

Written prose in a natural language, such as an English text, is composed firstly of basic elements – the letters of the alphabet. These are combined into larger entities, words, which convey the basic concepts of objects, actions, and qualifications. The words of the language can be further combined into larger units, phrases and sentences, according to certain rules. One set of rules defines the grammar. This tells us whether a certain combination of words is correct in that it conforms to the *syntax* of the language, that is those acknowledged forms which are regarded as correct renderings of the meanings we wish to express. Sentences can in turn be joined together into paragraphs, which conventionally contain the composite meaning of their constituent sentences, each paragraph expressing a larger unit of information. In a novel, sequences of paragraphs become chapters and the chapters together form a book, which usually is a self-contained work, largely independent of all other books.

2.2 Fortran character set

Analogies to these concepts are found in a programming language. In Fortran (Fortran 90 and Fortran 95), the basic elements, or character set, are the 26 letters of the English alphabet, the 10 Arabic numerals, 0 to 9, the underscore, _, and the so-called special characters listed in Table 2.1. The standard does not require the support of lower-case letters, but almost all computers nowadays support them. Within the Fortran syntax, the lower-case letters are equivalent to the corresponding upper-case letters; they are distinguished only when they form part of character sequences. In this book, syntactically significant characters will always be written in lower case. The letters, numerals, and underscore are known as *alphanumeric* characters.

Except for the currency symbol, whose graphic may vary (for example, to be £ in the United Kingdom), the graphics are fixed, though their styles are not fixed. The special characters \$ and ? have no specific meaning within the Fortran language.

In the course of this and the following chapters, we shall see how further analogies with natural language may be drawn. The unit of Fortran information

Table 2.1. The special characters of the Fortran language

Character	Name	Character	Name
=	Equals sign	:	Colon
+	Plus sign		Blank
-	Minus sign	!	Exclamation mark
*	Asterisk	"	Quotation mark
/	Slash	%	Percent
(Left parenthesis	&	Ampersand
)	Right parenthesis	;	Semicolon
,	Comma	<	Less than
.	Decimal point	>	Greater than
\$	Currency symbol	?	Question mark
'	Apostrophe		

is the *lexical token*, which corresponds to a word or punctuation mark. Adjacent tokens are usually separated by spaces or the end of a line, but sensible exceptions are allowed just as for a punctuation mark in prose. Sequences of tokens form *statements*, corresponding to sentences. Statements, like sentences, may be joined to form larger units like paragraphs. In Fortran these are known as *program units*, and out of these may be built a *program*. A program forms a complete set of instructions to a computer to carry out a defined sequence of operations. The simplest program may consist of only a few statements, but programs of more than 100,000 statements are now quite common.

2.3 Tokens

Within the context of Fortran, alphanumeric characters (the letters, the underscore, and the numerals) may be combined into sequences that have one or more meanings. For instance, one of the meanings of the sequence 999 is a constant in the mathematical sense. Similarly, the sequence date might represent, as one possible interpretation, a variable quantity to which we assign the calendar date.

The special characters are used to separate such sequences and also have various meanings. We shall see how the asterisk is used to specify the operation of multiplication, as in $x*y$, and has also a number of other interpretations.

Basic significant sequences of alphanumeric characters or of special characters are referred to as *tokens*; they are labels, keywords, names, constants (other than complex literal constants), operators (listed in Table 3.4, Section 3.8), and *separators*, which are

/ () (/ /) , = => : :: ; %

For example, the expression $x*y$ contains the three tokens x , $*$, and y .

Apart from within a character string or within a token, blanks may be used freely to improve the layout. Thus, whereas the variable date may not be written as `d a t e`, the sequence `x * y` is syntactically equivalent to `x*y`. In this context, multiple blanks are syntactically equivalent to a single blank.

A name, constant, or label must be separated from an adjacent keyword, name, constant or label by one or more blanks or by the end of a line. For instance, in

```
real x
read 10
30 do k=1,3
```

the blanks are required after `real`, `read`, `30`, and `do`. Likewise, adjacent keywords must normally be separated, but some pairs of keywords, such as `else if`, are not required to be separated. Similarly, some keywords may be split; for example `inout` may be written `in out`. We do not use these alternatives in the main text, but the exact rules are given in the statement summaries in Appendix B.

2.4 Source form

Fortran 90/95 brings with it a new source form, well adapted to use at a terminal.¹ The statements of which a source program is composed are written on *lines*. Each line may contain up to 132 characters,² and usually contains a single statement. Since leading spaces are not significant, it is possible to start all such statements in the first character position, or in any other position consistent with the user's chosen layout. A statement may thus be written as

```
x = (-y + root_of_discriminant)/(2.0*a)
```

In order to be able to mingle suitable comments with the code to which they refer, Fortran allows any line to carry a trailing comment field, following an exclamation mark (!). An example is

```
x = y/a - b ! Solve the linear equation
```

Any comment always extends to the end of the source line and may include processor-dependent characters (it is not restricted to the Fortran character set, Section 2.2). Any line whose first non-blank character is an exclamation mark, or contains only blanks, or which is empty, is purely commentary, and is ignored by the compiler. Such comment lines may appear anywhere in a program unit, including ahead of the first statement (but not after the final program unit). A *character context* (those contexts defined in Sections 2.6.4, 9.13.4, and C.3.5) is allowed to contain !, so the ! does not initiate a comment in this case; in all other cases it does.

¹ Some hints on maintaining compatibility between the old and the new source forms are given at the end of Section C.1.1.

² Lines containing characters of non-default kind (Sections 2.6.4) are subject to a processor-dependent limit.

Since it is possible that a long statement might not be accommodated in the 132 positions allowed in a single line, up to 39 additional continuation lines are allowed. The so-called *continuation mark* is the ampersand (&) character, and this is appended to each line that is followed by a continuation line. Thus, the first statement of this section (considerably spaced out) could be written as

```
x = &
  (-y + root_of_discriminant) &
  /(2.0*a)
```

In this book, the ampersands will normally be aligned to improve readability. On a non-comment line, if & is the last non-blank character or the last non-blank character ahead of the comment symbol !, the statement continues from the character immediately preceding the &. Normally, continuation is to the first character of the next non-comment line, but if the first non-blank character of the next non-comment line is &, continuation is to the character following the &. For instance, the above statement may be written

```
x = &
  &(-y + root_of_discriminant)/(2.0*a)
```

In particular, if a token cannot be contained at the end of a line, the first non-blank character on the next noncomment line must be an & followed immediately by the remainder of the token.

Comments are allowed to contain any characters, including &, so they cannot be continued since a trailing & is taken as part of the comment. However, comment lines may be freely interspersed among continuation lines and do not count towards the limit of 39 lines.

In a character context, continuation must be from a line without a trailing comment and to a line with a leading ampersand. This is because both ! and & are permitted both in character contexts and in comments.

No line is permitted to have & as its only non-blank character, or as its only non-blank character ahead of !. Such a line is really a comment and becomes a comment if & is removed.

When writing short statements one after the other, it can be convenient to write several of them on one line. The semi-colon (;) character is used as a *statement separator* in these circumstances, for example:

```
a = 0; b = 0; c = 0
```

Since commentary always extends to the end of the line, it is not possible to insert commentary between statements on a single line. In principle, it is possible to write even long statements one after the other in a solid block of lines, each 132 characters long and with the appropriate semi-colons separating the individual statements. In practice, such code is unreadable, and the use of multiple-statement lines should be reserved for trivial cases such as the one shown in this example.

Any Fortran statement (that is not part of a compound statement) may be labelled, in order to be able to identify it. For some statements a label is mandatory.

A statement *label* precedes the statement, and is regarded as a token. The label consists of from one to five digits, one of which must be nonzero. An example of a labelled statement is

```
100 continue
```

Leading zeros are not significant in distinguishing between labels. For example, 10 and 010 are equivalent.

2.5 Concept of type

In Fortran, it is possible to define and manipulate various types of data. For instance, we may have available the value 10 in a program, and assign that value to an integer scalar variable denoted by *i*. Both 10 and *i* are of type integer; 10 is a fixed or *constant* value, whereas *i* is a *variable* which may be assigned other values. Integer expressions, such as *i*+10, are available too.

A *data type* consists of a set of data values, a means of denoting those values, and a set of operations that are allowed on them. For the integer data type, the values are $\dots, -3, -2, -1, 0, 1, 2, 3, \dots$ between some limits depending on the kind of integer and computer system being used. Such tokens as these are *literal constants*, and each data type has its own form for expressing them. Named scalar variables, such as *i*, may be established. During the execution of a program, the value of *i* may change to any valid value, or may become *undefined*, that is have no predictable value. The operations which may be performed on integers are those of usual arithmetic; we can write $1+10$ or $i-3$ and obtain the expected results. Named constants may be established too; these have values that do not change during a given execution of the program.

Properties like those just mentioned are associated with all the data types of Fortran, and will be described in detail in this and the following chapters. The language itself contains five data types whose existence may always be assumed. These are known as the *intrinsic data types*, whose literal constants form the subject of the next section. Of each intrinsic type there is a default kind and a processor-dependent number of other kinds. Each kind is associated with a non-negative integer value known as the *kind type parameter*. This is used as a means of identifying and distinguishing the various kinds available.

In addition, it is possible to define other data types based on collections of data of the intrinsic types, and these are known as *derived data types*. The ability to define data types of interest to the programmer – matrices, geometrical shapes, lists, interval numbers – is a powerful feature of the language, one which permits a high level of *data abstraction*, that is the ability to define and manipulate data objects without being concerned about their actual representation in a computer.

2.6 Literal constants of intrinsic type

The intrinsic data types are divided into two classes. The first class contains three *numeric* types which are used mainly for numerical calculations – integer,

real, and complex. The second class contains the two *non-numeric* types which are used for such applications as text-processing and control – character and logical. The numerical types are used in conjunction with the usual operators of arithmetic, such as + and -, which will be described in Chapter 3. Each includes a zero and the value of a signed zero is the same as that of an unsigned zero³. The non-numeric types are used with sets of operators specific to each type; for instance, character data may be concatenated. These too will be described in Chapter 3.

2.6.1 Integer literal constants

The first type of literal constant is the *integer literal constant*. The default kind is simply a signed or unsigned integer value, for example

```
1
0
-999
32767
+10
```

The *range* of the default integers is not specified in the language, but on a computer with a word size of n bits, is often from -2^{n-1} to $+2^{n-1} - 1$. Thus on a 32-bit computer the range is often from -2147483648 to +2147483647.

To be sure that the range will be adequate on any computer requires the specification of the kind of integer by giving a value for the kind type parameter. This is best done through a named integer constant. For example, if the range -999999 to 999999 is desired, k6 may be established as a constant with an appropriate value by the statement, fully explained later,

```
integer, parameter :: k6=selected_int_kind(6)
```

and used in constants thus:

```
-123456_k6
+1_k6
-2_k6
```

Here, `selected_int_kind(6)` is an intrinsic inquiry function call, and it returns a kind parameter value that yields the range -999999 to 999999 with the least margin (see Section 8.7.4).

On a given processor, it might be known that the kind value needed is 3. In this case, the first of our constants can be written

```
-123456_3
```

³Although the representation of data is processor dependent, for the numeric data types the standard defines model representations and means to inquire about the properties of those models. The details are deferred to Section 8.7.

but this form is less portable. If we move the code to another processor, this particular value may be unsupported, or might correspond to a different range.

Many implementations use kind values that indicate the number of bytes of storage occupied by a value, but the standard allows greater flexibility. For example, a processor might have hardware only for 4-byte integers, and yet support kind values 1, 2, and 4 with this hardware (to ease portability from processors that have hardware for 1-, 2-, and 4-byte integers). However, the standard makes no statement about kind values or their order, except that the kind value is never negative.

The value of the kind type parameter for a given data type on a given processor can be obtained from the kind intrinsic function (Section 8.2):

kind(1)	for the default value
kind(2_k6)	for the example

and the decimal exponent range (number of decimal digits supported) of a given entity may be obtained from another function (Section 8.7.2), as in

`range(2_k6)`

which in this case would return a value of at least 6.

In addition to the usual integers of the decimal number system, for some applications it is very convenient to be able to represent positive whole numbers in binary, octal, or hexadecimal form. Unsigned constants of these forms exist in Fortran, and are represented as illustrated in these examples:

binary (base 2):	b'01100110'
octal (base 8):	o'076543'
hexadecimal (base 16):	z'10fa'

In the hexadecimal form, the letters a to f represent the values beyond 9; they may be used also in upper case. The delimiters may be quotation marks or apostrophes. The use of these forms of constants is limited to their appearance as implicit integers in the data statement (Section 7.5.2). A binary, octal, or hexadecimal constant may also appear in an internal or external file as a digit string, without the leading letter and the delimiters (see Section 9.13.2).

Bits stored as an integer representation may be manipulated by the intrinsic procedures described in Section 8.8.

2.6.2 Real literal constants

The second type of literal constant is the *real literal constant*. The default kind is a floating-point form built of some or all of: a signed or unsigned integer part, a decimal point, a fractional part, and a signed or unsigned exponent part. One or both of the integer part and fractional part must be present. The exponent part is either absent or consists of the letter e followed by a signed or unsigned integer. One or both of the decimal point and the exponent part must be present. An example is

-10.6e-11

meaning -10.6×10^{-11} , and other legal forms are

1.
-0.1
1e-1
3.141592653

The default real literal constants are representations of a subset of the real numbers of mathematics, and the standard specifies neither the allowed range of the exponent nor the number of significant digits represented by the processor. Many processors conform to the IEEE standard for floating-point arithmetic and have values of 10^{-37} to 10^{+37} for the range, and a precision of six decimal digits.

To be sure to obtain a desired range and significance requires the specification of a kind parameter value. For example,

```
integer, parameter :: long = selected_real_kind(9, 99)
```

ensures that the constants

1.7_long
12.3456789e30_long

have a precision of at least nine significant decimals, and an exponent range of at least 10^{-99} to 10^{+99} . The number of digits specified in the significand has no effect on the kind. In particular, it is permitted to write more digits than the processor can in fact use.

As for integers, many implementations use kind values that indicate the number of bytes of storage occupied by a value, but the standard allows greater flexibility. It specifies only that the kind value is never negative. If the desired kind value is known it may be used directly, as in the case

1.7_4

but the resulting code is then less portable.

The processor must provide at least one representation with more precision than the default, and this second representation may also be specified as double precision. We defer the description of this alternative but outmoded syntax to Section 11.4.1.

The kind function is valid also for real values:

kind(1.0)	for the default value
kind(1.0_long)	for the example

In addition, there are two inquiry functions available which return the actual precision and range, respectively, of a given real entity (see Section 8.7.2). Thus, the value of

precision(1.7_long)

would be at least 9, and the value of

`range(1.7_long)`

would be at least 99.

2.6.3 Complex literal constants

Fortran, as a language intended for scientific and engineering calculations, has the advantage of having as third literal constant type the *complex literal constant*. This is designated by a pair of literal constants, which are either integer or real, separated by a comma and enclosed in parentheses. Examples are

`(1., 3.2)`
`(1, .99e-2)`
`(1.0, 3.7_8)`

where the first constant of each pair is the real part of the complex number, and the second constant is the imaginary part. If one of the parts is integer, the kind of the complex constant is that of the other part. If both parts are integer, the kind of the constant is that of the default real type. If both parts are real and of the same kind, this is the kind of the constant. If both parts are real and of different kinds, the kind of the constant is that of one of the parts: the part with the greater decimal precision, or the part chosen by the processor if the decimal precisions are identical.

A default complex constant is one whose kind value is that of default real.

The `kind`, `precision`, and `range` functions are equally valid for complex entities.

Note that if an implementation uses the number of bytes needed to store a real as its kind value, the number of bytes needed to store a complex value of the corresponding kind is twice the kind value. For example, if the default real type has kind 4 and needs four bytes of storage, the default complex type has kind 4 but needs eight bytes of storage.

2.6.4 Character literal constants

The fourth type of literal constant is the *character literal constant*. The default kind consists of a string of characters enclosed in a pair of either apostrophes or quotation marks, for example

`'Anything goes'`

`"Nuts & bolts"`

The characters are not restricted to the Fortran set (Section 2.2). Any graphic character supported by the processor is permitted, but not control characters such as “newline”. The apostrophes and quotation marks serve as *delimiters*, and are not part of the value of the constant. The value of the constant

'STRING'

is STRING. We note that in character constants the blank character is significant. For example

'a string'

is not the same as

'astring'

A problem arises with the representation of an apostrophe or a quotation mark in a character constant. Delimiter characters of one sort may be embedded in a string delimited by the other, as in the examples

'He said "Hello"'

"This contains an ' "

Alternatively, a doubled delimiter without any embedded intervening blanks is regarded as a single character of the constant. For example

'Isn''t it a nice day'

has the value Isn't it a nice day.

The number of characters in a string is called its *length*, and may be zero. For instance, '' and "" are character constants of length zero.

We mention here the particular rule for the source form concerning character constants that are written on more than one line (needed because constants may include the characters ! and &): not only must each line that is continued be without a trailing comment, but each continuation line must *begin* with a continuation mark. Any blanks following a trailing ampersand or preceding a leading ampersand are not part of the constant, nor are the ampersands themselves part of the constant. Everything else, including blanks, is part of the constant. An example is

```
long_string =
    'Were I with her, the night would post too soon;      &
     & But now are minutes added to the hours;            &
     & To spite me now, each minute seems a moon;          &
     & Yet not for me, shine sun to succour flowers!       &
     & Pack night, peep day; good day, of night now borrow: &
     & Short, night, to-night, and length thyself tomorrow.'
```

On any computer, the characters have a property known as their *collating sequence*. One may ask the question whether one character occurs before or after another in the sequence. This question is posed in a natural form such as 'Does C precede M?', and we shall see later how this may be expressed in Fortran terms. Fortran requires the computer's collating sequence to satisfy the following conditions:

- A is less than B is less than C . . . is less than Y is less than Z;
- 0 is less than 1 is less than 2 . . . is less than 8 is less than 9;
- blank is less than A and Z is less than 0, or blank is less than 0 and 9 is less than A;

and, if the lower-case letters are available,

- a is less than b is less than c . . . is less than y is less than z;
- blank is less than a and z is less than 0, or blank is less than 0 and 9 is less than a.

Thus we see that there is no rule about whether the numerals precede or succeed the letters, nor about the position of any of the special characters or the underscore, apart from the rule that blank precedes both partial sequences. Any given computer system has a complete collating sequence, and most computers nowadays use the collating sequence of the ASCII standard (also known as ISO/IEC 646:1991). However, Fortran is designed to accommodate other sequences, notably EBCDIC, so for portability, no program should ever depend on any ordering beyond that stated above. Alternatively, Fortran provides access to the ASCII collating sequence on any computer through intrinsic functions (Section 8.5.1), but this access is not so convenient and is less efficient on some computers.

A processor is required to provide access to the default kind of character constant just described. In addition, it may support other kinds of character constants, in particular those of non-European languages, which may have more characters than can be provided in a single byte. For example, a processor might support Kanji with the kind parameter value 2; in this case, a Kanji character constant may be written

`2_国内`

or

`kanji_標準`

where `kanji` is an integer named constant with the value 2. We note that, in this case, the kind type parameter exceptionally *precedes* the constant. This is necessary in order to enable compilers to parse statements simply.

There is no requirement on a processor to provide more than one kind of character, and the standard does not require any particular relationship between the kind parameter values and the character sets and the number of bytes needed to represent them. In fact, all that is required is that each kind of character set includes a blank character. As for the other data types, the `kind` function gives the actual value of the kind type parameter, as in

```
kind('ASCII')
```

Non-default characters are permitted in comments.

2.6.5 Logical literal constants

The fifth type of literal constant is the *logical literal constant*. The default kind has one of two values, `.true.` and `.false.`. These logical constants are normally used only to initialize logical variables to their required values, as we shall see in Section 3.6.

The default kind has a kind parameter value which is processor dependent. The actual value is available as `kind(.true.)`. As for the other intrinsic types, the kind parameter may be specified by an integer constant following an underscore, as in

```
.false._1
.true._long
```

Non-default logical kinds are useful for storing logical arrays compactly; we defer further discussion until Section 6.17.

2.7 Names

A Fortran program references many different entities by name. Such names must consist of between 1 and 31 alphanumeric characters (letters, underscores, and numerals) of which the first must be a letter. There are no other restrictions on the names; in particular there are no reserved words in Fortran. We thus see that valid names are, for example,

```
a
a_thing
x1
mass
q123
real
time_of_flight
```

and invalid names are

1a	First character is not alphabetic
a thing	Contains a blank
\$sign	Contains a non-alphanumeric character

Within the constraints of the syntax, it is important for program clarity to choose names that have a clear significance – these are known as *mnemonic names*. Examples are `day`, `month`, and `year`, for variables to store the calendar date.

The use of names to refer to constants, already met in Section 2.6.1, will be fully described in Section 7.4.

2.8 Scalar variables of intrinsic type

We have seen in the section on literal constants that there exist five different intrinsic data types. Each of these types may have variables too. The simplest way by which a variable may be declared to be of a particular type is by specifying its name in a *type declaration statement* such as

```
integer :: i
real :: a
complex :: current
logical :: pravda
character :: letter
```

Here all the variables have default kind, and `letter` has default length, which is 1. Explicit requirements may also be specified through *type parameters*, as in the examples

```
integer(kind=4) :: i
real(kind=long) :: a
character(len=20, kind=1) :: english_word
character(len=20, kind=kanji) :: kanji_word
```

Character is the only type to have two parameters, and here the two character variables each have length 20. Where appropriate, just one of the parameters may be specified, leaving the other to take its default value, as in the cases

```
character(kind=kanji) :: kanji_letter
character(len=20) :: english_word
```

The shorter forms

```
integer(4) :: i
real(long) :: a
character(20, 1) :: english_word
character(20, kanji) :: kanji_word
character(20) :: english_word
```

are available, but note that

```
character(kanji) :: kanji_letter ! Beware
```

is not an abbreviation for

```
character(kind=kanji) :: kanji_letter
```

because a single unnamed parameter is taken as the length parameter.

2.9 Derived data types

When programming, it is often useful to be able to manipulate objects that are more sophisticated than those of the intrinsic types. Imagine, for instance, that

we wished to specify objects representing persons. Each person in our application is distinguished by a name, an age, and an identification number. Fortran allows us to define a corresponding data type in the following fashion:

```
type person
    character(len=10) :: name
    real               :: age
    integer            :: id
end type person
```

This is the *definition* of the type. A scalar object of such a type is called a *structure*. In order to create a structure of that type, we write an appropriate type declaration statement, such as

```
type(person) :: you
```

The scalar variable *you* is then a composite object of type *person* containing three separate components, one corresponding to the name, another to the age, and a third to the identification number. As will be described in Sections 3.8 and 3.9, a variable such as *you* may appear in expressions and assignments involving other variables or constants of the same or different types. In addition, each of the components of the variable may be referenced individually using the *component selector* character percent (%). The identification number of *you* would, for instance, be accessed as

```
you%id
```

and this quantity is an integer variable which could appear in an expression such as

```
you%id + 9
```

Similarly, if there were a second object of the same type:

```
type(person) :: me
```

the differences in ages could be established by writing

```
you%age - me%age
```

It will be shown in Section 3.8 how a meaning can be given to an expression such as

```
you - me
```

Just as the intrinsic data types have associated literal constants, so too may literal constants of derived type be specified. Their form is the name of the type followed by the constant values of the components, in order and enclosed in parentheses. Thus, the constant

```
person( 'Smith', 23.5, 2541)
```

may be written assuming the derived type defined at the beginning of this section, and could be *assigned* to a variable of the same type:

```
you = person( 'Smith', 23.5, 2541)
```

Any such *structure constructor* can appear only after the definition of the type.

A derived type may have a component that is of a previously defined derived type. This is illustrated in Figure 2.1. A variable of type triangle may be declared thus

```
type(triangle) :: t
```

and t has components t%a, t%b, and t%c all of type point, and t%a has components t%a%x and t%a%y of type real.

Figure 2.1

```
type point
    real :: x, y
end type point
type triangle
    type(point) :: a, b, c
end type triangle
```

2.10 Arrays of intrinsic type

Another compound object supported by Fortran is the *array*. An array consists of a rectangular set of elements, all of the same type and type parameters. There are a number of ways in which arrays may be declared; for the moment we shall consider only the declaration of arrays of fixed sizes. To declare an array named a of 10 real elements, we add the dimension attribute to the type declaration statement thus:

```
real, dimension(10) :: a
```

The successive elements of the array are a(1), a(2), a(3), ..., a(10). The number of elements of an array is called its *size*. Each array element is a scalar.

Many problems require a more elaborate declaration than one in which the first element is designated 1, and it is possible in Fortran to declare a lower as well as an upper *bound*:

```
real, dimension(-10:5) :: vector
```

This is a vector of 16 elements, vector(-10), vector(-9), ..., vector(5). We thus see that whereas we always need to specify the upper bound, the lower bound is optional, and by default has the value 1.

An array may extend in more than one dimension, and Fortran allows up to seven dimensions to be specified. For instance

```
real, dimension(5,4) :: b
```

declares an array with two dimensions, and

```
real, dimension(-10:5, -20:-1, 0:1, -1:0, 2, 2, 2) :: grid
```

declares seven dimensions, the first four with explicit lower bounds. It may be seen that the size of this second array is

$$16 \times 20 \times 2 \times 2 \times 2 \times 2 = 10240,$$

and that arrays of many dimensions can thus place large demands on the memory of a computer. The number of dimensions of an array is known as its *rank*. Thus, *grid* has a rank of seven. Scalars are regarded as having rank zero. The number of elements along a dimension of an array is known as the *extent* in that dimension. Thus, *grid* has extents 16, 20,

The sequence of extents is known as the *shape*. For example, *grid* has the shape (16, 20, 2, 2, 2, 2, 2).

A derived type may contain an array component. For example, the following type

```
type triplet
    real             :: u
    real, dimension(3)   :: du
    real, dimension(3,3) :: d2u
end type triplet
```

might be used to hold the value of a variable in three dimensions and the values of its first and second derivatives. If *t* is of type *triplet*, *t%du* and *t%d2u* are arrays of type *real*.

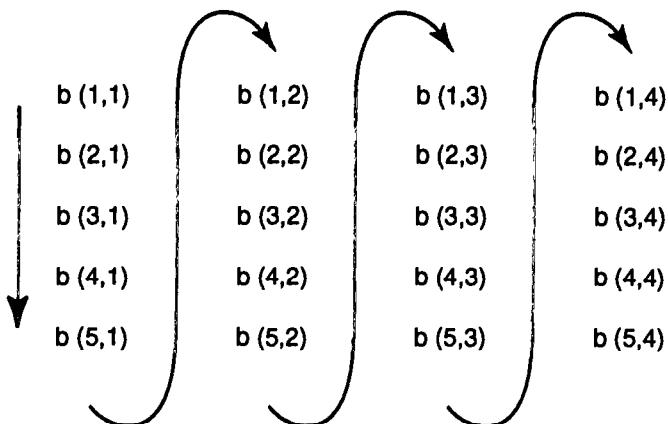
Some statements treat the elements of an array one-by-one in a special order which we call the *array element order*. It is obtained by counting most rapidly in the early dimensions. Thus, the elements of *grid* in array element order are

```
grid(-10, -20, 0, -1, 1, 1, 1)
grid( -9, -20, 0, -1, 1, 1, 1)
:
grid(  5,  -1, 1,  0, 2, 2, 2).
```

This is illustrated for an array of two dimensions in Figure 2.2. Most implementations actually store arrays in contiguous storage in array element order, but we emphasize that the standard does not require this.

We reference an individual element of an array by specifying, as in the examples above, its *subscript* values. In the examples we used integer constants, but in general each subscript may be formed of a *scalar integer expression*, that is, any arithmetic expression whose value is scalar and of type integer. Each subscript must be within the corresponding ranges defined in the array declaration and the number of subscripts must equal the rank. Examples are

Figure 2.2 The ordering of elements in the array $b(5,4)$.



```

a(1)
a(i*j)      ! i and j are of type integer
a(nint(x+3.)) ! x is of type real
t%d2u(i+1,j+2) ! t is of derived type triplet

```

where `nint` is an intrinsic function to convert a real value to the nearest integer (see Section 8.3.1). In addition subarrays, called *sections*, may be referenced by specifying a range for one or more subscripts. The following are examples of array sections:

```

a(i:j)          ! Rank-one array of size j-i+1
b(k, 1:n)       ! Rank-one array of size n
c(1:i, 1:j, k) ! Rank-two array with extents i and j

```

We describe array sections in more detail in Section 6.13. An array section is itself an array, but its individual elements must not be accessed through the section designator. Thus, $b(k, 1:n)(1)$ cannot be written; it must be expressed as $b(k, 1)$.

A further form of subscript is shown in

```
a(ipoint)      ! ipoint is an integer array
```

where `ipoint` is an array of indices, pointing to array elements. It may thus be seen that $a(ipoint)$, which identifies as many elements of a as `ipoint` has elements, is an example of another *array-valued object*, and `ipoint` is referred to as a *vector subscript*. This will be met in greater detail in Section 6.13.

It is often convenient to be able to define an array constant. In Fortran, a rank-one array may be constructed as a list of elements enclosed between the tokens (`/` and `/`). A simple example is

$$(/ 1, 2, 3, 5, 10 /)$$

which is an array of rank one and size five. To obtain a series of values, the individual values may be defined by an expression that depends on an integer variable having values in a range, with an optional stride. Thus, the constructor

$$(/1, 2, 3, 4, 5/)$$

can be written as

$$(/ (i, i = 1,5) /)$$

and

$$(/2, 4, 6, 8/)$$

as

$$(/ (i, i = 2,8,2) /)$$

and

$$(/ 1.1, 1.2, 1.3, 1.4, 1.5 /)$$

as

$$(/ (i*0.1, i=11,15) /)$$

An array constant of rank greater than one may be constructed by using the function `reshape` (see Section 8.13.3) to reshape a rank-one array constant.

A full description of array constructors is reserved for Section 6.16.

2.11 Character substrings

It is possible to build arrays of characters, just as it is possible to build arrays of any other type:

```
character, dimension(80) :: line
```

declares an array, called `line`, of 80 elements, each one character in length. Each character may be addressed by the usual reference, `line(i)` for example. In this case, however, a more appropriate declaration might be

```
character(len=80) :: line
```

which declares a scalar data object of 80 characters. These may be referenced individually or in groups using a *substring* notation

```
line(i:j) ! i and j are of type integer
```

which references all the characters from i to j in line . The colon is used to separate the two substring subscripts, which may be any scalar integer expressions. The colon is obligatory in substring references, so that referencing a single character requires $\text{line}(i:i)$. There are default values for the substring subscripts. If the lower one is omitted, the value 1 is assumed; if the upper one is omitted, a value corresponding to the character length is assumed. Thus,

```
line(:i)    is equivalent to line(1:i)
line(i:)    is equivalent to line(i:80)
line(:)     is equivalent to line or line(1:80)
```

If i is greater than j in $\text{line}(i:j)$, the value is a zero-sized string.

We may now combine the length declaration with the array declaration to build arrays of character objects of specified length, as in

```
character(len=80), dimension(60) :: page
```

which might be used to define storage for the characters of a whole page, with 60 elements of an array, each of length 80. To reference the line j on a page we may write $\text{page}(j)$, and to reference character i on that line we could combine the array subscript and character substring notations into

```
page(j)(i:i)
```

A substring of a character constant or of a structure component may also be formed:

```
'ABCDEFGHIJKLMNPQRSTUVWXYZ'(j:j)
you%name(1:2)
```

At this point we must note a limitation associated with character variables, namely that character variables must have a declared maximum length, making it impossible to manipulate character variables of variable length, unless they are defined appropriately as of a derived data type.⁴ Nevertheless, this data type is adequate for most character manipulation applications.

2.12 Objects and subobjects

We have seen that derived types may have components that are arrays, as in

```
type triplet
  real, dimension(3) :: vertex
end type triplet
```

and arrays may be of derived type as in the example

```
type(triplet), dimension(10) :: t
```

⁴But see Section 1.5.

A single structure (for example, `t(2)`) is always regarded as a scalar, but it may have a component (for example, `t(2)%vertex`) that is an array. Derived types may have components of other derived types.

An object referenced by an unqualified name (up to 31 alphanumeric characters) is called a *named object* and is not part of a bigger object. Its subobjects have *designators* that consist of the name of the object followed by one or more qualifiers (for example, `t(1:7)` and `t(1)%vertex`). Each successive qualifier specifies a part of the object specified by the name or designator that precedes it.

Because of these possibilities, the terms *array* and *variable* are now used with a more general meaning than in Fortran 77. The term ‘array’ is used for any object that is not scalar, including an array section or an array-valued component of a structure. The term ‘variable’ is used for any named object that is not specified to be a constant and for any part of such an object, including array elements, array sections, structure components, and substrings.

2.13 Pointers

In everyday language, nouns are often used in a way that makes their meaning precise only because of the context. ‘The chairman said that . . .’ will be understood precisely by the reader who knows that the context is the Fortran Committee developing Fortran 90 and that its chairman was then Jeanne Adams.

Similarly, in a computer program it can be very useful to be able to use a name that can be made to refer to different objects during execution of the program. One example is the multiplication of a vector by a sequence of square matrices. We might write code that calculates

$$y_i = \sum_{j=1}^n a_{ij} x_j, \quad i = 1, 2, \dots, n$$

from the vector x_j , $j = 1, 2, \dots, n$. In order to use this to calculate

BCz

we might first make x refer to z and A refer to C , thereby using our code to calculate $y = Cz$, then make x refer to y and A refer to B so that our code calculates the result vector we finally want.

An object that can be made to refer to other objects in this way is called a *pointer*, and must be declared with the pointer attribute, for example

```
real, pointer :: son
real, pointer, dimension(:) :: x, y
real, pointer, dimension(:, :) :: a
```

In the case of an array, only the rank (number of dimensions) is declared, and the bounds (and hence shape) are taken from that of the object to which it points. Given such a declaration, the compiler arranges storage for a descriptor that is

initially undefined but will later hold the address of the actual object (known as the *target*) and holds, if it is an array, its bounds and strides.

Besides pointing to existing variables, a pointer may be made explicitly to point at nothing:

`nullify (son, x, y, a)` ! Further details are in Section 6.5.4

or may be given fresh storage by an `allocate` statement such as

`allocate (son, x(10), y(-10:10), a(n, n))`

In the case of arrays, the lower and upper bounds are specified just as for the `dimension` attribute (Section 2.10) except that any scalar integer expression is permitted. Permitting such expressions remedies one of the major deficiencies of Fortran 77, namely that areas of only static storage may be defined, and we will discuss this use further in Section 6.5.

Components of derived types are permitted to have the `pointer` attribute. This enables a major application of pointers: the construction of linked lists. As a simple example, we might decide to hold a sparse vector as a chain of variables of the type shown in Figure 2.3, which allows us to access the entries one by one; given

`type(entry), pointer :: chain`

where `chain` is a scalar of this type and holds a chain that is of length two, its entries are `chain%index` and `chain%next%index`, and `chain%next%next` will have been nullified. Additional entries may be created when necessary by an appropriate `allocate` statement. We defer the details to Section 3.12.

Figure 2.3

```
type entry
    real           :: value
    integer        :: index
    type(entry), pointer :: next
end type entry
```

A subobject is not a pointer unless it has a final component selector for the name of a pointer component, for example, `chain%next`.

2.14 Summary

In this chapter, we have introduced the elements of the Fortran language. The character set has been listed, and the manner in which sequences of characters form literal constants and names explained. In this context, we have encountered the five intrinsic data types defined in Fortran, and seen how each data type has corresponding literal constants and named objects. We have seen how derived

types may be constructed from the intrinsic types. We have introduced one method by which arrays may be declared, and seen how their elements may be referenced by subscript expressions. The concepts of the array section, character substring, and pointer have been presented, and some important terms defined. In the following chapter we shall see how these elements may be combined into expressions and statements, Fortran's equivalents of 'phrases' and 'sentences'.

With respect to Fortran 77, there are many changes in this area: the larger character set; a new source form; the significance of blanks; the parameterization of the intrinsic types; the binary, octal, and hexadecimal constants; the ability to obtain a desired precision and range; quotes as well as apostrophes as character constant delimiters; longer names; derived data types; new array subscript notations; array constructors; and last, but not least, pointers. Together they represent a substantial improvement in the ease of use and power of the language.

2.15 Exercises

1. For each of the following assertions, state whether it is true, false or not determined, according to the Fortran collating sequences:

```
b is less than m
8 is less than 2
* is greater than T
$ is less than /
blank is greater than A
blank is less than 6
```

2. Which of the Fortran lines in Figure 2.4 are correctly written according to the requirements of the Fortran source form? Which ones contain commentary? Which lines are initial lines and which are continuation lines?

Figure 2.4

```
x = y
3 a = b+c ! add
word = 'string'
a = 1.0; b = 2.0
a = 15. ! initialize a; b = 22. ! and b
song = "Life is just&
      & a bowl of cherries"
chide = 'Waste not,
        want not!'
0 c(3:4) = 'up'
```

3. Classify the following literal constants according to the five intrinsic data types of Fortran. Which are not legal literal constants?

-43	'word'
4.39	1.9-4
0.0001e+20	'stuff & nonsense'
4_9	(0.,1.)
(1.e3,2)	'I can''t'
'(4.3e9, 6.2)'	.true._1
e5	'shouldn' 't'
1_2	"O.K."
z10	z'10'

4. Which of the following names are legal Fortran names?

name	name32
quotient	123
a182c3	no-go
stop!	burn_
no_go	long_name

5. What are the first, tenth, eleventh and last elements of the following arrays?

real, dimension(11)	:: a
real, dimension(0:11)	:: b
real, dimension(-11:0)	:: c
real, dimension(10,10)	:: d
real, dimension(5,9)	:: e
real, dimension(5,0:1,4)	:: f

Write an array constructor of eleven integer elements.

6. Given the array declaration

character(len=10), dimension(0:5,3) :: c

which of the following subobject designators are legal?

c(2,3)	c(4:3)(2,1)
c(6,2)	c(5,3)(9:9)
c(0,3)	c(2,1)(4:8)
c(4,3)(::)	c(3,2)(0:9)
c(5)(2:3)	c(5:6)
c(5,3)(9)	c(,)

7. Write derived type definitions appropriate for:

- a vehicle registration;
- a circle;
- a book (title, author, and number of pages).

Give an example of a derived type constant for each one.

8. Given the declaration for `t` in Section 2.12, which of the following objects and subobjects are arrays?

<code>t</code>	<code>t(4)%vertex(1)</code>
<code>t(10)</code>	<code>t(5:6)</code>
<code>t(1)%vertex</code>	<code>t(5:5)</code>

9. Write specifications for these entities:

- a) an integer variable inside the range -10^{20} to 10^{20} ;
- b) a real variable with a minimum of 12 decimal digits of precision and a range of 10^{-100} to 10^{100} ;
- c) a Kanji character variable on a processor that supports Kanji with `kind=2`.

3. Expressions and assignments

3.1 Introduction

We have seen in the previous chapter how we are able to build the ‘words’ of Fortran — the constants, keywords, and names — from the basic elements of the character set. In this chapter we shall discover how these entities may be further combined into ‘phrases’ or *expressions*, and how these, in turn, may be combined into ‘sentences’, or *statements*.

In an expression, we describe a computation that is to be carried out by the computer. The result of the computation may then be assigned to a variable. A sequence of assignments is the way in which we specify, step-by-step, the series of individual computations to be carried out, in order to arrive at the desired result. There are separate sets of rules for expressions and assignments, depending on whether the operands in question are numeric, logical, character, or derived in type, and whether they are scalars or arrays. There are also separate rules for pointer assignments. We shall discuss each set of rules in turn, including a description of the relational expressions which produce a result of type logical and are needed in control statements (see next chapter). To simplify the initial discussion, we commence by considering expressions and assignments that are intrinsically defined and involve neither arrays nor entities of derived data types.

An expression in Fortran is formed of operands and operators, combined in a way which follows the rules of Fortran syntax. A simple expression involving a *dyadic* (or binary) operator has the form

operand *operator* operand

an example being

$x+y$

and a unary or *monadic* operator has the form

operator operand

an example being

$-y$

The operands may be constants, variables, or functions (see Chapter 5), and an expression may itself be used as an operand. In this way, we can build up more complicated expressions such as

operand *operator* operand *operator* operand

where consecutive operands are separated by a single operator. Each operand must have a defined value and the result must be mathematically defined; for example, raising a negative real value to a real power is not permitted.

The rules of Fortran state that the parts of expressions without parentheses are evaluated successively from left to right for operators of equal precedence, with the exception of $\star\star$ (see Section 3.2). If it is necessary to evaluate part of an expression, or *subexpression*, before another, parentheses may be used to indicate which subexpression should be evaluated first. In

operand *operator* (operand *operator* operand)

the subexpression in parentheses will be evaluated, and the result used as an operand to the first operator.

If an expression or subexpression has no parentheses, the processor is permitted to evaluate an equivalent expression, that is an expression that always has the same value apart, possibly, from the effects of numerical round-off. For example, if *a*, *b*, and *c* are real variables, the expression

a/b/c

might be evaluated as

*a/(b*c)*

on a processor that can multiply much faster than it can divide. Usually, such changes are welcome to the programmer since the program runs faster, but when they are not (for instance because they would lead to more round-off) parentheses should be inserted because the processor is required to respect them.

If two operators immediately follow each other, as in

operand *operator* *operator* operand

the only possible interpretation is that the second operator is unary. Thus, there is a general rule that a binary operator must not follow immediately after another operator.

3.2 Scalar numeric expressions

A *numeric expression* is an expression whose operands are one of the three numeric types — integer, real, and complex — and whose operators are

- $\star\star$ exponentiation
- $*$ / multiplication, division
- $+$ - addition, subtraction

These operators are known as *numeric intrinsic* operators, and are listed here in their order of precedence. In the absence of parentheses, exponentiations will be carried out before multiplications and divisions, and these before additions and subtractions.

We note that the minus sign (-) and the plus sign (+) can be used as a unary operators, as in

`-tax`

Because it is not permitted in ordinary mathematical notation, a unary minus or plus must not follow immediately after another operator. When this is needed, as for x^{-y} , parentheses must be placed around the operator and its operand:

`x**(-y)`

The type and kind type parameter of the result of a unary operation are those of the operand.

The exception to the left-to-right rule noted in Section 3.1 concerns exponentiations. Whereas the expression

`-a+b+c`

will be evaluated from left to right as

`((-a)+b)+c`

the expression

`a**b**c`

will be evaluated as

`a**(b**c)`

For integer data, the result of any division will be truncated towards zero, that is to the integer value whose magnitude is equal to or just less than the magnitude of the exact result. Thus, the result of

`6/3` is 2
`8/3` is 2
`-8/3` is -2

This fact must always be borne in mind whenever integer divisions are written. Similarly, the result of

`2**3` is 8

whereas the result of

`2**(-3)` is $1/(2^{**3})$

which is zero.

The rules of Fortran allow a numeric expression to contain numeric operands of differing types or kind type parameters. This is known as a *mixed-mode expression*. Except when raising a real or complex value to an integer power, the object of the weaker (or simpler) of the two data types will be converted, or *coerced*, into the type of the stronger one. The result will also be that of the stronger type. If, for example, we write

$a*i$

when a is of type real and i is of type integer, then i will be converted to a real data type before the multiplication is performed, and the result of the computation will also be of type real. The rules are summarized for each possible combination for the operations $+$, $-$, $*$ and $/$ in Table 3.1, and for the operation $**$ in Table 3.2. The functions `real` and `cmplx` that they reference are defined in Section 8.3.1. In both Tables, I stands for integer, R for real, and C for complex.

Table 3.1. Type of result of $a .op. b$, where .op. is $+$, $-$, $*$ or $/$.

Type of a	Type of b	Value of a used	Value of b used	Type of result
I	I	a	b	I
I	R	<code>real(a,kind(b))</code>	b	R
I	C	<code>cmplx(a,0,kind(b))</code>	b	C
R	I	a	<code>real(b,kind(a))</code>	R
R	R	a	b	R
R	C	<code>cmplx(a,0,kind(b))</code>	b	C
C	I	a	<code>cmplx(b,0,kind(a))</code>	C
C	R	a	<code>cmplx(b,0,kind(a))</code>	C
C	C	a	b	C

If both operands are of type integer, the kind type parameter of the result is that of the operand with the greater decimal exponent range, or is processor dependent if the kinds differ but the decimal exponent ranges are the same. If both operands are of type real or complex, the kind type parameter of the result is that of the operand with the greater decimal precision, or is processor dependent if the kinds differ but the decimal precisions are the same. If one operand is of type integer and the other is of real or complex, the type parameter of the result is that of the real or complex operand.

In the case of raising a complex value to a complex power, the principal value¹ is taken.

¹The principal value of a^b is $\exp(b(\log|a| + i \arg a))$, with $-\pi < \arg a \leq \pi$.

Table 3.2. Type of result of $a^{**}b$.

Type of a	Type of b	Value of a used	Value of b used	Type of result
I	I	a	b	I
I	R	<code>real(a,kind(b))</code>	b	R
I	C	<code>cmplx(a,0,kind(b))</code>	b	C
R	I	a	b	R
R	R	a	b	R
R	C	<code>cmplx(a,0,kind(b))</code>	b	C
C	I	a	b	C
C	R	a	<code>cmplx(b,0,kind(a))</code>	C
C	C	a	b	C

3.3 Defined and undefined variables

In the course of the explanations in this and the following chapters, we shall often refer to a variable becoming *defined* or *undefined*. In the previous chapter, we showed how a scalar variable may be called into existence by a statement like

```
real :: speed
```

In this simple case, the variable `speed` has, at the beginning of the execution of the program, no defined value. It is undefined. No attempt must be made to reference its value since it has none. A common way in which it might become defined is for it to be assigned a value:

```
speed = 2.997
```

After the execution of such an *assignment statement* it has a value, and that value may be referenced, for instance in an expression:

```
speed*0.5
```

For a compound object, it is necessary for all its subobjects to be individually defined before the object as a whole is regarded as defined. Thus, an array is said to be defined only when each of its elements is defined, an object of a derived data type is defined only when each of its components is defined, and a character variable is defined only when each of its characters is defined.

A variable that is defined does not necessarily retain its state of definition throughout the execution of a program. As we shall see in Chapter 5, a variable that is local to a single subprogram usually becomes undefined when control is returned from that subprogram. In certain circumstances, it is even possible that a single array element becomes undefined: this causes the array considered as a whole to become undefined; a similar rule holds for entities of derived data type and for character variables.

A means to specify the initial value of a variable will be explained in Section 7.5.

In the case of a pointer, the pointer association status may be *undefined* (its initial state), *associated* with a target, or *disassociated*, which means that it is not associated with a target but has a definite status that may be tested by the function *associated* (Section 8.2). Even though a pointer is associated with a target, the target itself may be defined or undefined. A means to specify the initial status of disassociated is provided by Fortran 95 (see Section 7.5.3).

3.4 Scalar numeric assignment

The general form of a scalar numeric assignment is

$$\text{variable} = \text{expr}$$

where *variable* is a scalar numeric variable and *expr* is a scalar numeric expression. If *expr* is not of the same type or kind as *variable*, it will be converted to that type and kind before the assignment is carried out, according to the set of rules given in Table 3.3 (the function *int* is defined in Section 8.3.1).

Table 3.3. Numeric conversion for assignment statement *variable* = *expr*

Type of <i>variable</i>	<i>Value assigned</i>
integer	<i>int(expr, kind(variable))</i>
real	<i>real(expr, kind(variable))</i>
complex	<i>cmplx(expr, kind=kind(variable))</i>

We note that if the type of *variable* is integer but *expr* is not, then the assignment will result in a loss of precision unless *expr* happens to have an integral value. Similarly, assigning a real expression to a real variable of a kind with less precision will also cause a loss of precision to occur, and the assignment of a complex quantity to a non-complex variable involves the loss of the imaginary part. Thus, the values in *i* and *a* following the assignments

```
i = 7.3           ! i of type default integer
a = (4.01935, 2.12372) ! a of type default real
```

are 7 and 4.01935, respectively.

3.5 Scalar relational operators

It is possible in Fortran to test whether the value of one numeric expression bears a certain relation to that of another, and similarly for character expressions. The relational operators are

.lt. or <	less than
.le. or <=	less than or equal
.eq. or ==	equal
.ne. or /=	not equal
.gt. or >	greater than
.ge. or >=	greater than or equal

If either or both of the expressions are complex, only the operators == and /= (or .eq. and .ne.) are available.

The result of such a comparison is one of the default logical values .true. or .false., and we shall see in the next chapter how such tests are of great importance in controlling the flow of a program. Examples of relational expressions (for i and j of type integer, a and b of type real, and char1 of type default character) are

i < 0	integer relational expression
a < b	real relational expression
a+b > i-j	mixed-mode relational expression
char1 == 'Z'	character relational expression

In the third expression above, we note that the two components are of different numeric types. In this case, and whenever either or both of the two components consist of numeric expressions, the rules state that the components are to be evaluated separately, and converted to the type and kind of their sum before the comparison is made. Thus, a relational expression such as

a+b .le. i-j

will be evaluated by converting the result of (i-j) to type real.

For character comparisons, the kinds must be the same and the letters are compared from the left until a difference is found or the strings are found to be identical. If the lengths differ, the shorter one is regarded as being padded with blanks² on the right. Two zero-sized strings are considered to be identical.

No other form of mixed mode relational operator is intrinsically available, though such an operator may be defined (Section 3.8). The numeric operators take precedence over the relational operators.

3.6 Scalar logical expressions and assignments

Logical constants, variables, and functions may appear as operands in logical expressions. The logical operators, in decreasing order of precedence, are:

²Here and elsewhere, the blank padding character used for a non-default type is processor dependent.

unary operator:

.not. logical negation

binary operators:

.and.	logical intersection
.or.	logical union
.eqv. and .neqv.	logical equivalence and non-equivalence

If we assume a logical declaration of the form

```
logical i,j,k,l
```

then the following are valid logical expressions:

```
.not.j
j .and. k
i .or. l .and. .not.j
( .not.k .and. j .neqv. .not.l) .or. i
```

In the first expression we note the use of .not. as a unary operator. In the third expression, the rules of precedence imply that the subexpression l.and..not.j will be evaluated first, and the result combined with i. In the last expression, the two subexpressions .not.k.and.j and .not.l will be evaluated and compared for non-equivalence. The result of the comparison, .true. or .false., will be combined with i.

The kind type parameter of the result is that of the operand for .not., and for the others is that of the operands if they have the same kind or processor dependent otherwise.

We note that the .or. operator is an inclusive operator; the .neqv. operator provides an exclusive logical or (a.and..not.b.or..not.a.and.b).

The result of any logical expression is the value true or false, and this value may then be assigned to a logical variable such as element 3 of the logical array flag in the example

```
flag(3) = ( .not. k .eqv. l) .or. j
```

The kind type parameter values of the variable and expression need not be identical.

A logical variable may be set to a predetermined value by an assignment statement:

```
flag(1) = .true.
flag(2) = .false.
```

In the foregoing examples, all the operands and results were of type logical – no other data type is allowed to participate in an intrinsic logical operation or assignment.

The results of several relational expressions may be combined into a logical expression, and assigned, as in

```

real    :: a, b, x, y
logical :: cond
:
cond = a>b .or. x<0.0 .and. y>1.0

```

where we note the precedence of the relational operators over the logical operators. If the value of such a logical expression can be determined without evaluating a subexpression, a processor is permitted not to evaluate the subexpression. An example is

```
i<=10 .and. ary(i)==0
```

when *i* has the value 11. However, the programmer must not rely on such behaviour. For example, when *ary* has size 10, an out-of-bounds subscript might be referenced if the processor chooses to evaluate the right-hand subexpression before the left-hand one. We return to this topic in Section 5.10.1.

3.7 Scalar character expressions and assignments

The only intrinsic operator for character expressions is the concatenation operator `//`, which has the effect of combining two character operands into a single character result. For example, the result of concatenating the two character constants AB and CD, written as

```
'AB'//'CD'
```

is the character string ABCD. The operands must have the same kind parameter values, but may be character variables, constants, or functions. For instance, if *word1* and *word2* are both of default kind and length 4, and contain the character strings LOOP and HOLE respectively, the result of

```
word1(4:4)//word2(2:4)
```

is the string POLE.

The length of the result of a concatenation is the sum of the lengths of the operands. Thus, the length of the result of

```
word1//word2//'S'
```

is 9, which is the length of the string LOOPHOLES.

The result of a character expression may be assigned to a character variable of the same kind. Assuming the declarations

```

character(len=4) :: char1, char2
character(len=8) :: result

```

we may write

```

char1 = 'any '
char2 = 'book'
result = char1//char2

```

In this case, `result` will now contain the string `any book`. We note in these examples that the lengths of the left- and right-hand sides of the three assignments are in each case equal. If, however, the length of the result of the right-hand side is shorter than the length of the left-hand side, then the result is placed in the left-most part of the left-hand side and the rest is filled with blank characters. Thus, in

```
character(len=5) :: fill
fill(1:4) = 'AB'
```

`fill(1:4)` will have the value `ABbb` (where `b` stands for a blank character). The value of `fill(5:5)` remains undefined, that is, it contains no specific value and should not be used in an expression. As a consequence, `fill` is also undefined. On the other hand, when the left-hand side is shorter than the result of the right-hand side, the right-hand end of the result is truncated. The result of

```
character(len=5) :: trunc8
trunc8 = 'TRUNCATE'
```

is to place in `trunc8` the character string `TRUNC`. If a left-hand side is of zero length, no assignment takes place.

The left-hand and right-hand sides of an assignment may overlap. In such a case, it is always the old values that are used in the right-hand side expression. For example, the assignment

```
result(3:5) = result(1:3)
```

is valid and if `result` began with the value `ABCDEFGHI`, it would be left with the value `ABABCDFGH`.

Other means of manipulating characters and strings of characters, via intrinsic functions, are described in Sections 8.5 and 8.6.

3.8 Structure constructors and scalar defined operators

No operators for derived types are automatically available, but a structure may be constructed from expressions for its components, just as a constant structure may be constructed from constants (Section 2.9). The general form of a *structure constructor* is

type-name (*expr-list*)

where the *expr-list* specifies the values of the components. For example, given the type

```
type string
    integer          :: length
    character(len=10) :: value
end type string
```

and the variables

```
character(len=4) :: char1, char2
```

the following is a value of type string

```
string(8, char1//char2)
```

Each expression in *expr-list* corresponds to a component of the structure; if it is not a pointer component, the value is assigned to the component under the rules of intrinsic assignment; if it is a pointer component, the expression must be a valid target for it,³ as in a pointer assignment statement (Section 3.12).

When a programmer defines a derived type and wishes operators to be available, he or she must define the operators, too. For a binary operator this is done by writing a function, with two intent in arguments, that specifies how the result depends on the operands, and an interface block that associates the function with the operator token (functions, intent, and interface blocks will be explained fully in Chapter 5). For example, given the type

```
type interval
    real :: lower, upper
end type interval
```

that represents intervals of numbers between a lower and an upper bound, we may define addition by a module (Section 5.5) containing the procedure

```
function add_interval(a,b)
    type(interval)           :: add_interval
    type(interval), intent(in) :: a, b
    add_interval%lower = a%lower + b%lower ! Production code
    add_interval%upper = a%upper + b%upper ! would allow for
end function add_interval                         ! roundoff.
```

and the interface block (Section 5.18)

```
interface operator(+)
    module procedure add_interval
end interface
```

This function would be invoked in an expression such as

y + *z*

to perform this programmer-defined add operation for scalar variables *y* and *z* of type interval. A unary operator is defined by an interface block and a function with one intent in argument.

The operator token may be any of the tokens used for the intrinsic operators or may be a sequence of up to 31 letters enclosed in decimal points other than .true. or .false.. An example is

³In particular, it must not be a constant.

.SUM.

In this case, the header line of the interface block would be written as

interface operator(.sum.)

and the expression as

y.sum.z

If an intrinsic token is used, the number of arguments must be the same as for the intrinsic operation, the priority of the operation is as for the intrinsic operation, and a unary minus or plus must not follow immediately after another operator. Otherwise, it is of highest priority for defined unary operators and lowest priority for defined binary operators. The complete set of priorities is given in Table 3.4. Where another priority is required within an expression, parentheses must be used.

Table 3.4. Relative precedence of operators (in decreasing order)

Type of operation when intrinsic	Operator
—	monadic (unary) defined operator
Numeric	**
Numeric	* or /
Numeric	monadic + or -
Numeric	dyadic + or -
Character	//
Relational	.eq. .ne. .lt. .le. .gt. .ge. == /= < <= > >=
Logical	.not.
Logical	.and.
Logical	.or.
Logical	.eqv. or .neqv.
—	dyadic (binary) defined operator

Retaining the intrinsic priorities is helpful both to the readability of expressions and to the efficiency with which a compiler can interpret them. For example, if + is used for set union and * for set intersection, we can interpret the expression

i*j + k

for sets i, j, and k without difficulty.

If either of the intrinsic tokens .eq. and == is used, the definition applies to both tokens so that they are always equivalent. The same is true for the other equivalent pairs of relational operators.

Note that a defined unary operator not using an intrinsic token may follow immediately after another operator as in

```
y .sum. .inverse. x
```

Operators may be defined for any types of operands, except where there is an intrinsic operation for the operator and types. For example, we might wish to be able to add an interval number to an ordinary real, which can be done by adding the procedure

```
function add_interval_real(a,b)
    type(interval)           add_interval_real
    type(interval), intent(in) :: a
    real, intent(in)          :: b
    add_interval_real%lower = a%lower + b ! Production code would
    add_interval_real%upper = a%upper + b ! allow for roundoff.
end function add_interval_real
```

and changing the interface block to

```
interface operator(+)
    module procedure add_interval, add_interval_real
end interface
```

The result of a defined operation may have any type. The type of the result, as well as its value, must be specified by the function.

Note that an operation that is defined intrinsically cannot be redefined; thus in

```
real :: a, b, c
:
c = a + b
```

the meaning of the operation is always unambiguous.

3.9 Scalar defined assignments

Assignment of an expression of derived type to a variable of the same type is automatically available and takes place component by component. For example, if *a* is of the type *interval* defined at the start of Section 3.8, we may write

```
a = interval(0.0, 1.0)
```

(structure constructors were met in Section 3.8, too).

In other circumstances, however, we might wish to define a different action for an assignment involving an object of derived type, and indeed this is possible. An assignment may be redefined or another assignment may be defined by a subroutine with two arguments, the first having intent out or intent inout and corresponding to the variable and the second having intent in and corresponding

to the expression (subroutines will also be dealt with fully in Chapter 5). In the case of an assignment involving an object of derived type and an object of a different type, such a definition must be provided. For example, assignment of reals to intervals and vice versa might be defined by a module containing the subroutines

```
subroutine real_from_interval(a,b)
    real, intent(out)      :: a
    type(interval), intent(in) :: b
    a = (b%lower + b%upper)/2
end subroutine real_from_interval
```

and

```
subroutine interval_from_real(a,b)
    type(interval), intent(out) :: a
    real, intent(in)          :: b
    a%lower = b
    a%upper = b
end subroutine interval_from_real
```

and the interface block

```
interface assignment(=)
    module procedure real_from_interval, interval_from_real
end interface
```

Given this, we may write

```
type(interval) :: a
a = 0.0
```

A defined assignment must not redefine the meaning of an intrinsic assignment for intrinsic types, that is an assignment between two objects of numeric type, of logical type, or of character type with the same kind parameter, but may redefine the meaning of an intrinsic assignment for two objects of the same derived type. For instance, for an assignment between two variables of the type **string** (Section 3.8) that copies only the relevant part of the character component, we might write

```
subroutine assign_string (left, right)
    type(string), intent(out) :: left
    type(string), intent(in)  :: right
    left%length = right%length
    left%value(1:left%length) = right%value(1:right%length)
end subroutine assign_string
```

Intrinsic assignment for a derived-type object always involves intrinsic assignment for all its non-pointer components, even if a component is of a derived type for which assignment has been redefined.

3.10 Array expressions

So far in this chapter, we have assumed that all the entities in an expression are scalar. However, any of the unary intrinsic operations may also be applied to an array to produce another array of the same shape (identical rank and extents, see Section 2.10) and having each element value equal to that of the operation applied to the corresponding element of the operand. Similarly, binary intrinsic operations may be applied to a pair of arrays of the same shape to produce an array of that shape, with each element value equal to that of the operation applied to corresponding elements of the operands. One of the operands to a binary operation may be a scalar, in which case the result is as if the scalar had been broadcast to an array of the same shape as the array operand. Given the array declarations

```
real, dimension(10,20) :: a,b
real, dimension(5)      :: v
```

the following are examples of array expressions:

```
a/b          ! Array of shape (10,20), with elements a(i,j)/b(i,j)
v+1.        ! Array of shape (5), with elements v(i)+1.0
5/v+a(1:5,5) ! Array of shape (5), with elements 5/v(i)+a(i,5)
a.eq.b      ! Logical array of shape (10,20), with elements
             ! .true. if a(i,j).eq.b(i,j), and .false. otherwise
```

Two arrays of the same shape are said to be *conformable* and a scalar is conformable with any array.

Note that the correspondence is by position in the extent and not by subscript value. For example,

```
a(2:9,5:10) + b(1:8,15:20)
```

has element values

```
a(i+1,j+4) + b(i,j+14), i=1,2,...,8, j=1,2,...,6.
```

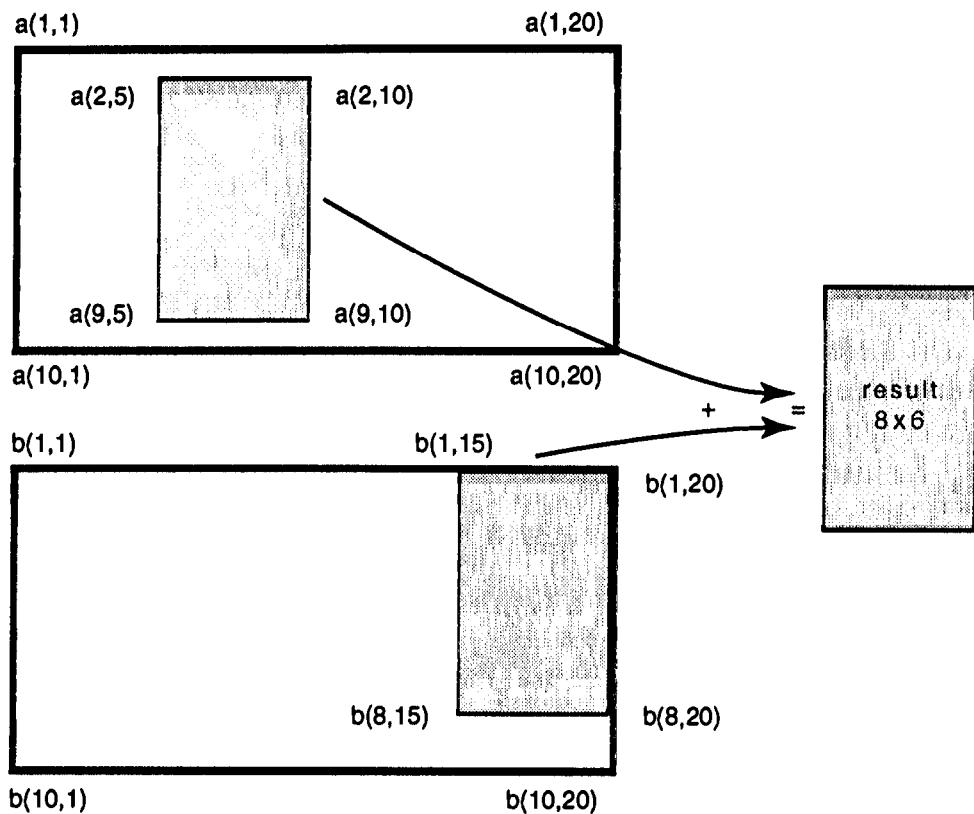
This may be represented pictorially as in Figure 3.1.

The order in which the scalar operations in any array expression are executed is not specified in the standard, thus enabling a compiler to arrange efficient execution on a vector or parallel computer.

Any scalar intrinsic operator may be applied in this way to arrays and array-scalar pairs. For derived operators, the programmer must define operators directly for array operands, for each rank or pair of ranks involved. For example, the type

```
type matrix
    real :: element
end type matrix
```

might be defined to have scalar operations that are identical to the operations for reals, but for arrays of ranks one and two the operator * defined to mean

Figure 3.1 The sum of two array sections.

matrix multiplication. The type `matrix` would therefore be suitable for matrix arithmetic, whereas `reals` are not suitable because multiplication for real arrays is done element by element. This is further discussed in Section 6.7.

3.11 Array assignment

By intrinsic assignment, an array expression may be assigned to an array variable of the same shape, which is interpreted as if each element of the expression were assigned to the corresponding element of the variable. For example, with the declarations of the beginning of the last section, the assignment

```
a = a + 1.0
```

replaces $a(i,j)$ by $a(i,j)+1.0$ for $i = 1, 2, \dots, 10$ and $j = 1, 2, \dots, 20$. Note that, as for expressions, the element correspondence is by position within the extent rather than by subscript value. This is illustrated by the example

```
a(1,11:15) = v      ! a(1,j+10) is assigned from
                      ! v(j), j=1,2,...,5
```

A scalar expression may be assigned to an array, in which case the scalar value is broadcast to all the array elements.

If the expression includes a reference to the array variable or to a part of it, the expression is interpreted as being fully evaluated before the assignment commences. For example, the statement

```
v(2:5) = v(1:4)
```

results in each element $v(i)$ for $i = 2, 3, 4, 5$ having the value that $v(i-1)$ had prior to the commencement of the assignment. This rule exactly parallels the rule for substrings that was explained in Section 3.7. The order in which the array elements are assigned is not specified by the standard, to allow optimizations.

Sets of numeric and mathematical intrinsic functions, whose results may be used as operands in scalar or array expressions and in assignments, are described in Sections 8.3 and 8.4.

For a defined assignment (Section 3.9), a separate subroutine must be provided for each combination of ranks for which it is required. Intrinsic assignment is overridden only for those combinations of ranks for which a corresponding defined assignment is accessible.

A form of array assignment expressed with the help of indices is provided by Fortran 95 (Section 6.9). Also, elemental defined assignments are available in Fortran 95 (Section 6.11).

3.12 Pointers in expressions and assignments

A pointer may appear as a variable in the expressions and assignments that we have considered so far in this chapter, provided it has a valid association with a target. The target is accessed without any need for an explicit dereferencing symbol. In particular, if two pointers appear on opposite sides of an assignment statement, data are copied from one target to the other target.

Sometimes the need arises for another sort of assignment. We may want the left-hand pointer to point to another target, rather than that its current target acquire fresh data. That is, we want the descriptor to be altered. This is called *pointer assignment* and takes place in a pointer assignment statement:

```
pointer => target
```

where *pointer* is the name of a pointer or the designator of a structure component that is a pointer, and *target* is usually a variable but may also be a reference to a pointer-valued function (see Section 5.10). For example, the statements

```
x => z
a => c
```

have variables as targets and are needed for the first matrix multiplication of Section 2.13, in order to make *x* refer to *z* and *a* to refer to *c*. In Fortran 95, the statement

```
x => null() ! Fortran 95 only
```

nullifies x. Pointer assignment also takes place for a pointer component of a structure when the structure appears on the left-hand side of an ordinary assignment. For example, suppose we have used the type entry of Section 2.13 to construct a chain of entries and wish to add a fresh entry at the front. If first points to the first entry and current is a scalar pointer of type entry, the statements

```
allocate (current)
current = entry(new_value, new_index, first)
first => current
```

allocate a new entry and link it into the top of the chain. The assignment statement has the effect

```
current%next => first
```

and establishes the link. The pointer assignment statement gives first the new entry as its target without altering the old first entry. An ordinary assignment would be incorrect because the target would be copied, destroying the old first entry, corresponding to the component assignments

```
first%value = current%value
first%index = current%index
first%next => current%next
```

In the case where the chain began with length two and consisted of

```
first :      (1.0, 10, associated)
first%next : (2.0, 15, null)
```

following the execution of the first set of statements it would have length 3 and consist of

```
first :      (4.0, 16, associated)
first%next : (1.0, 10, associated)
first%next%next : (2.0, 15, null)
```

If the *target* in a pointer assignment statement is a variable that is not itself a pointer or a subobject of a pointer, it must have the *target* attribute. For example, the statement

```
real, dimension(10), target :: y
```

declares y to have the *target* attribute. Any subobject of an object with the *target* attribute also has the *target* attribute. The *target* attribute is required for the purpose of code optimization by the compiler. It is very helpful to the compiler to know that a variable that is not a pointer or a target may not be accessed by a pointer.

The *target* in a pointer assignment statement may be a subobject of a pointer. For example, given the declaration

`character(len=80), dimension(:), pointer :: page`

and an appropriate association, the following are all permitted targets:

`page, page(10), page(2:4), page(2)(3:15)`

Note that it is sufficient for any part of the subobject to have the `pointer` attribute. For example, given the declaration

```
type(entry) :: node ! This has a pointer component next,  
! see Section 2.13.
```

and an appropriate association, `node%next%value` is a permitted target.

If the *target* in a pointer assignment statement is itself a pointer, then a straightforward copy of the descriptor takes place. If the pointer association status is undefined or disassociated, this state is copied.

If the *target* is a pointer or a subobject of a pointer, the new association is with that pointer's target and is not affected by any subsequent changes to its pointer association status. This is illustrated by the following example. The sequence

```
b => c    ! c has the target attribute  
a => b  
nullify (b)
```

will leave `a` still pointing to `c`.

The type, type parameters, and rank of the `pointer` and *target* in a pointer assignment statement must each be the same. If the `pointer` is an array, it takes its shape and bounds from the *target*. The bounds are as would be returned by the functions `lbound` and `ubound` (Section 8.12.2) for the *target*, which means that an array section or array expression is always taken to have the value 1 for a lower bound and the extent for the corresponding upper bound.

Fortran is unusual in not requiring a special character for a reference to a pointer target, but requiring one for distinguishing pointer assignment from ordinary assignment. The reason for this choice was the expectation that most engineering and scientific programs will refer to target data far more often than they change targets.

3.13 Summary

In this chapter, we have seen how scalar and array expressions of numeric, logical, character, and derived types may be formed, and how the corresponding assignments of the results may be made. The relational expressions and the use of pointers have also been presented. We now have the information required to write short sections of code forming a sequence of statements to be performed one after the other. In the following chapter we shall see how more complicated sequences, involving branching and iteration, may be built up.

Features described in this chapter which are new since Fortran 77 are the use of the alternative representations `<`, `<=`, `...` for the relational operators; the ability

of the two sides of a character assignment to overlap; structure constructors; defined operators and assignment; array expressions and assignment; and the use of pointers in expressions and assignment.

3.14 Exercises

1. If all the variables are numeric scalars, which of the following are valid numeric expressions?

$a+b$	$-c$
$a+-c$	$d+(-f)$
$(a+c)**(p+q)$	$(a+c)(p+q)$
$-(x+y)**i$	$4.((a-d)-(a+4.*x)+1)$

2. In the following expressions, add the parentheses which correspond to Fortran's rules of precedence (assuming $a, c-f$ are real scalars, $i-n$ are logical scalars, and b is a logical array), for example

$a+d**2/c$	becomes	$a+((d**2)/c)$
$c+4.*f$		
$4.*g-a+d/2.$		
$a**e**c**d$		
$a*e-c*d/a+e$		
$i .and. j .or. k$		
$.not. l .or. .not. i .and. m .neqv. n$		
$b(3).and.b(1).or.b(6).or..not.b(2)$		

3. What are the results of the following expressions?

$3+4/2$	$6/4/2$
$3.*4**2$	$3.**3/2$
$-1.**2$	$(-1.)**3$

4. A scalar character variable r has length 8. What are the contents of r after each of the following assignments?

```
r = 'ABCDEFGHI'
r = 'ABCD'//'01234'
r(:7) = 'ABCDEFGHI'
r(:6) = 'ABCD'
```

5. Which of the following logical expressions are valid if b is a logical array?

$.not.b(1).and.b(2)$	$.or.b(1)$
$b(1).or..not.b(4)$	$b(2).(and.b(3).or.b(4))$

6. If all the variables are real scalars, which of the following relational expressions are valid?

d .le. c	p .lt. t > 0
x-1 /= y	x+y < 3 .or. > 4.
d.lt.c.and.3.0	q.eq.r .and. s>t

7. Write expressions to compute:

- a) the perimeter of a square of side l ;
- b) the area of a triangle of base b and height h ;
- c) the volume of a sphere of radius r .

8. An item costs n cents. Write a declaration statement for suitable variables and assignment statements which compute the change to be given from a \$1 bill for any value of n from 1 to 99, using coins of denomination 1, 5, 10, and 25 cents.

9. Given the type declaration for interval in Section 3.8, the definitions of + given in Section 3.8, the definitions of assignment given in Section 3.9, and the declarations

```
type(interval) :: a,b,c,d
real             :: r
```

which of the following statements are valid?

```
a = b + c
c = b + 1.0
d = b + 1
r = b + c
a = r + 2
```

10. Given the type declarations

```
real, dimension(5,6) :: a, b
real, dimension(5)   :: c
```

which of the following statements are valid?

a = b	c = a(:,2) + b(5,:5)
a = c+1.0	c = a(2,:) + b(:,5)
a(:,3) = c	b(2:,3) = c + b(:,5,3)

4. Control constructs

4.1 Introduction

We have learnt in the previous chapter how assignment statements may be written, and how these may be ordered one after the other to form a sequence of code which is executed step-by-step. In most computations, however, this simple sequence of statements is by itself inadequate for the formulation of the problem. For instance, we may wish to follow one of two possible paths through a section of code, depending on whether a calculated value is positive or negative. We may wish to sum 1000 elements of an array, and to do this by writing 1000 additions and assignments is clearly tedious; the ability to iterate over a single addition is required instead. We may wish to pass control from one part of a program to another, or even stop processing altogether.

For all these purposes, we have available in Fortran various facilities to enable the logical flow through the program statements to be controlled. The facilities contained in Fortran correspond to those now widely regarded as being the most appropriate for a modern programming language. Their general form is that of a *block* construct, that is a construct which begins with an initial keyword statement, may have intermediate keyword statements, and ends with a matching terminal statement, and that may be entered only at the initial statement. Each sequence of statements between keywords is called a *block*. A block may be empty, though such cases are rare.

Block constructs may be *nested*, that is a block may contain another block construct. In such a case, the block must contain the whole of the inner construct. Execution of a block always begins with its first statement.

However, we begin by describing the simple go to statement.

4.2 The go to statement

In this section, we consider the most disputed statement in programming languages – the go to statement. It is generally accepted that it is difficult to understand a program which is interrupted by many branches, especially if there is a large number of backward branches – those returning control to a statement

preceding the branch itself. At the same time there are certain occasions, especially when dealing with error conditions, when go to statements are required in even the most advanced languages.

The form of the unconditional go to statement is

go to *label*

where *label* is a statement label. This statement label must be present on an *executable statement* (a statement which can be executed, as opposed to one of an informative nature, like a declaration). An example is

```
x = y+3.0
go to 4
3 x = x+2.0
4 z = x+y
```

in which we note that after execution of the first statement, a branch is taken to the last statement, labelled 4. This is a *branch target statement*. The statement labelled 3 is jumped over, and can be executed only if there is a branch to the label 3 somewhere else. If the statement following an unconditional go to is unlabelled it can never be reached and executed, creating *dead code*, normally a sign of incorrect coding.

A go to statement must never specify a branch into a block, though it may specify a branch

- from within a block to another statement in the block,
- to the terminal statement of its construct, or
- to a statement outside its construct.

4.3 The if statement and construct

The `if` statement and `if` construct provide a mechanism for branching depending on a condition. They are powerful tools, the `if` construct being a generalized form of the `if` statement.

4.3.1 The if statement

In the `if` statement, the value of a scalar logical expression is tested, and a single statement executed if its value is true. The general form is

`if (scalar-logical-expr) action-stmt`

where *scalar-logical-expr* is any scalar logical expression, and *action-stmt* is any executable statement other than one that marks the beginning or end of a block (for instance, `if`, `else if`, `else`, `end if`, see next subsection), another `if` statement, or an `end` statement (see Chapter 5). Examples are

```

if (flag) go to 6
if (x-y > 0.0) x = 0.0
if (cond .or. p<q .and. r<=1.0) s(i,j) = t(j,i)

```

The `if` statement is normally used either to perform a single assignment depending on a condition, or to branch depending on a condition. The *action-stmt* may not be labelled separately.

4.3.2 The `if` construct

The `if` construct allows either the execution of a sequence of statements (a block) to depend on a condition, or the execution of alternative sequences of statements (blocks) to depend on alternative conditions. The simplest of its three forms is

```

[name:] if (scalar-logical-expr) then
    block
end if [name]

```

where *scalar-logical-expr* is any scalar logical expression and *block* is any sequence of executable statements (except an `end` statement or an incomplete construct). The *block* is executed if *scalar-logical-expr* evaluates to the value true, and is not executed if it evaluates to the value false. The `if` construct may be optionally named: the first and last statements may bear the same name, which may be any valid and distinct Fortran name (see Section 5.15 for a discussion on the scope of names). The fact that the name is optional is indicated here by the square brackets, a convention that will be followed throughout the book.

We notice that the `if` construct is a compound statement, the beginning being marked by the `if...then`, and the end by the `end if`. An example is

```

swap: if (x < y) then
    temp = x
    x = y
    y = temp
end if swap

```

in which we notice also that the block inside the `if` construct is indented with respect to its beginning and end. This is not obligatory, but makes the logic easier to understand, especially in nested `if` constructs as we shall see at the end of this section.

In the second form of the `if` construct, an alternative block of statements is executable, for the case where the condition is false. The general form is

```

[name:] if (scalar-logical-expr) then
    block1
else [name]
    block2
end if [name]

```

in which the first block of statements (*block1*) is executed if the condition is true and the second block (*block2*), following the `else` statement, is executed if the condition is false. An example is

```
if (x < y) then
    x = -x
else
    y = -y
end if
```

in which the sign of *x* is changed if *x* is less than *y*, and the sign of *y* is changed if *x* is greater than or equal to *y*.

The third and most general type of `if` construct uses the `else if` statement to make a succession of tests, each of which has its associated block of statements. The tests are made one after the other until one is fulfilled, and the associated statements of the relevant `if` or `else if` block are executed. Control then passes to the end of the `if` construct. If no test is fulfilled, no block is executed, unless there is a final ‘catch-all’ `else` clause. The general form is shown in Figure 4.1. Here, and later in the book, we use the notation [] to indicate an optional item and []... to indicate an item that may occur any number of times (including zero). There can be any number (including zero) of `else if` statements, and zero or one `else` statements. An `else` or `else if` statement may be named only if the corresponding `if` and `end if` statements are named, and must be given the same name.

Figure 4.1

```
[name:] if (scalar-logical-expr) then
    block
    [else if (scalar-logical-expr) then [name]
        block]...
    [else [name]
        block]
end if [name]
```

The statements within an `if` construct may be labelled, but the labels must never be referenced in such a fashion as to pass control into the range of an `if` construct from outside it, to an `else if` or `else` statement, or into a block of the construct from outside the block. For example, the following `if` construct is illegal:

```
if (temp > 100.0) then
    go to 1                                ! illegal branch
    boil = .true.
    steam = .true.
else
1    boil = .false.
    liquid = .true.
end if
```

It is permitted to pass control to an end if statement from within its construct. execution of an end if statement has no effect.

It is permitted to nest if constructs within one another to an arbitrary depth, as shown to two levels in Figure 4.2, in which we see again the necessity to indent the code in order to be able to understand the logic easily. For even deeper nesting, naming is to be recommended. The constructs must be properly nested, that is each construct must be wholly contained in a block of the next outer construct.

Figure 4.2

```

if (i < 0) then
    if (j < 0) then
        x = 0.0
        y = 0.0
    else
        z = 0.0
    end if
else if (k < 0) then
    z = 1.0
else
    x = 1.0
    y = 1.0
end if

```

4.4 The case construct

Fortran provides another means of selecting one of several options, rather similar to that of the if construct. The principal differences between the two constructs are that, for the case construct, only *one* expression is evaluated for testing, and the evaluated expression may belong to no more than one of a series of pre-defined sets of values. The form of the case construct is shown by:

```

[name:] select case (expr)
    [case selector [name]
        block]...
end select [name]

```

As for the if construct, the leading and trailing statements must either both be unnamed or both bear the same name; an intermediate statement may be named only if the leading statement is named and bears the same name. The expression *expr* must be scalar and of type character, logical, or integer, and the specified values in each *selector* must be of this type. In the character case, the lengths are permitted to differ, but not the kinds. In the logical and integer cases, the kinds

may differ. The simplest form of *selector* is a scalar initialization expression¹ in parentheses, such as in the statement

```
case(1)
```

For character or integer *expr*, a range may be specified by a lower and an upper scalar initialization expression separated by a colon:

```
case (low:high)
```

Either *low* or *high*, but not both, may be absent; this is equivalent to specifying that the case is selected whenever *expr* evaluates to a value that is less than or equal to *high*, or greater than or equal to *low*, respectively. An example is shown in Figure 4.3.

Figure 4.3

```
select case (number)          ! number is of type integer
  case (: -1)                ! all values below 0
    n_sign = -1
  case (0)                   ! only 0
    n_sign = 0
  case (1:)                  ! all values above 0
    n_sign = 1
end select
```

The general form of *selector* is a list of non-overlapping values and ranges, all of the same type as *expr*, enclosed in parentheses, such as

```
case (1, 2, 7, 10:17, 23)
```

The form

```
case default
```

is equivalent to a list of all the possible values of *expr* that are not included in the other selectors of the construct. Though we recommend that the values be in order, as in this example, this is not required. Overlapping values are not permitted within one *selector*, nor between different ones in the same construct.

There may be only a single *case default selector* in a given *case* construct as shown in Figure 4.4. The *case default* clause does not necessarily have to be the last clause of the *case* construct.

Since the values of the selectors are not permitted to overlap, at most one selector may be satisfied; if none is satisfied, control passes to the next executable statement following the *end select* statement.

¹An initialization expression is a restricted form of constant expression (the restrictions being chosen for ease of implementation). The details are tedious and are deferred to Section 7.4. In this section, all examples employ the simplest form of initialization expression: the literal constant.

Figure 4.4

```

select case (ch)          ! ch of type character
  case ('c', 'd', 'r':)
    ch_type = .true.
  case ('i':'n')
    int_type = .true.
  case default
    real_type = .true.
end select

```

Like the **if** construct, case constructs may be nested inside one another. Branching to a statement in a **case** block is permitted only from another statement in the block, it is not permitted to branch to a **case** statement, and any branch to an **end select** statement must be from within the **case** construct which it terminates.

4.5 The do construct

Many problems in mathematics require, for their representation in a programming language, the ability to *iterate*. If we wish to sum the elements of an array **a** of length 10, we could write

```

sum = a(1)
sum = sum+a(2)
:
sum = sum+a(10)

```

which is clearly laborious. Fortran provides a facility known as the **do** construct which allows us to reduce these ten lines of code to

```

sum = 0.0
do i = 1,10 ! i is of type integer
  sum = sum+a(i)
end do

```

In this fragment of code we first set **sum** to zero, and then require that the statement between the **do** statement and the **end do** statement shall be executed ten times. For each iteration there is an associated value of an index, kept in **i**, which assumes the value 1 for the first iteration through the loop, 2 for the second, and so on up to 10. The variable **i** is a normal integer variable, but is subject to the rule that it must not be explicitly modified within the **do** construct.

The **do** statement has more general forms. If we wished to sum the fourth to ninth elements we would write

```
do i = 4, 9
```

thereby specifying the required first and last values of *i*. If, alternatively, we wished to sum all the odd elements, we would write

```
do i = 1, 9, 2
```

where the third of the three loop *parameters*, namely the 2, specifies that *i* is to be incremented in steps of 2, rather than by the default value of 1, which is assumed if no third parameter is given. In fact, we can go further still, as the parameters need not be constants at all, but integer expressions, as in

```
do i = j+4, m, -k(j)**2
```

in which the first value of *i* is *j*+4, and subsequent values are decremented by *k(j)**2* until the value of *m* is reached. Thus, do constructs may run ‘backwards’ as well as ‘forwards’. If any of the three parameters is a variable or is an expression that involves a variable, the value of the variable may be modified within the loop without affecting the number of iterations, as the *initial* values of the parameters are used for the control of the loop.

The general form of this type of bounded do construct control clause is

```
[name:] do [,] variable = expr1, expr2 [,expr3]
    block
    end do [name]
```

where *variable* is a named scalar integer variable, *expr1*, *expr2*, and *expr3* (*expr3* is optional but must be nonzero when present) are any valid scalar integer expressions, and *name* is the optional construct name. The do and end do statements must either both bear the same *name*, or both be unnamed.

The number of iterations of a do construct is given by the formula

$$\max((\text{expr2}-\text{expr1}+\text{expr3})/\text{expr3}, 0)$$

where *max* is a function which we shall meet in Section 8.3.2 and which returns either the value of the expression or zero, whichever is the larger. There is a consequence following from this definition, namely that if a loop begins with the statement

```
do i = 1, n
```

then its body will not be executed at all if the value of *n* on entering the loop is zero or less. This is an example of the *zero-trip loop*, and results from the application of the *max* function.

A very simple form of the do statement is the unbounded

```
[name:] do
```

which specifies an endless loop. In practice, a means to exit from an endless loop is required, and this is provided in the form of the *exit* statement:

```
exit [name]
```

where *name* is optional and is used to specify from which construct the exit should be taken in the case of nested constructs. Execution of an `exit` statement causes control to be transferred to the next executable statement after the `end do` statement to which it refers. If no name is specified, it terminates execution of the innermost `do` construct in which it is enclosed. As an example of this form of the `do`, suppose we have used the type `entry` of Section 2.13 to construct a chain of entries in a sparse vector, and we wish to find the entry with index 10, known to be present. If `first` points to the first entry, the code in Figure 4.5 is suitable.

Figure 4.5

```
type(entry), pointer :: first, current
:
current => first
do
    if (current%index == 10) exit
    current => current%next
end do
```

The `exit` statement is also useful in a bounded loop when all iterations are not always needed.

A related statement is the `cycle` statement

`cycle [name]`

which transfers control to the `end do` statement of the corresponding construct. Thus, if further iterations are still to be carried out, the next one is initiated.

The value of a `do` construct `index` (if present) is incremented at the end of every loop iteration for use in the subsequent iteration. As the value of this `index` is available outside the loop after its execution, we have three possible situations, each illustrated by the following loop:

```
do i = 1, n
:
if (i==j) exit
:
end do
l = i
```

The situations are:

- i) If, at execution time, `n` has the value zero or less, `i` is set to 1 but the loop is not executed, and control passes to the statement following the `end do` statement.
- ii) If `n` has a value which is greater than or equal to `j`, an exit will be taken at the `if` statement, and `l` will acquire the last value of `i`, which is of course `j`.

- iii) If the value of *n* is greater than zero but less than *j*, the loop will be executed *n* times, with the successive values of *i* being 1, 2, ... etc. up to *n*. When reaching the end of the loop for the *n*th time, *i* will be incremented a final time, acquiring the value *n*+1, which will then be assigned to 1.

We see how important it is to make careful use of loop indices outside the do block, especially when there is the possibility of the number of iterations taking on the boundary value of the maximum for the loop.

The do block, just mentioned, is the sequence of statements between the do statement and the end do statement. From anywhere outside a do block, it is prohibited to jump into the block or to its end do statement. The following sequence is thus illegal:

```
go to 2      ! illegal branch
:
do i = 1, n
:
2   a = b + c
:
end do
```

It is similarly illegal for the block of a do construct (or an if, case, or where construct, see Section 6.8), to be only partially contained in a block of another construct. The construct must be completely contained in the block. The following two sequences are thus legal:

```
if (scalar-logical-expr) then
  do i = 1, n
  :
  end do
else
  :
end if
```

and

```
do i = 1, n
  if (scalar-logical-expr) then
  :
  end if
end do
```

but this third sequence is not:

```
if (scalar-logical-expr) then
  do i = 1, 10
  :
end if ! illegal position of if construct termination
:
end do
```

Any number of do constructs may be nested provided that the range of each nested loop is completely contained within the range of another. We may thus write a matrix multiplication as shown in Figure 4.6.

Figure 4.6

```
do i = 1, n
    do j = 1, m
        a(i,j) = 0.0
        do l = 1, k
            a(i,j) = a(i,j)+b(i,l)*c(l,j)
        end do
    end do
end do
```

Another example is the summation loop in Figure 4.7.

Figure 4.7

```
do i = 1, n
    sum = 0.0
    do j = 1, i
        sum = sum+b(j,i)
    end do
    a(i) = sum
end do
```

A final form of the do construct makes use of a statement label to identify the end of the construct. In this case, the terminating statement may be either a labelled end do statement or a labelled continue ('do nothing') statement². The label is, in each case, the same as that on the do statement itself. Simple examples are

```
do 10 i = 1, n
:
10 end do
```

and

```
do 20 i = 1, j
    do 10 k = 1, l
    :
10     continue
20     continue
```

²The continue statement is not limited to being the last statement of a do construct; it may appear anywhere among the executable statements.

As shown in the second example, each loop must have a separate label. Additional, but redundant, do syntax is described in Section 11.3.2 (and Appendix C.2.2 and C.3.1). The full do construct syntax is given in Appendix B.

Finally, it should be noted that many short do-loops can be expressed alternatively in the form of array expressions and assignments. However, this is not always possible, and a particular danger to watch for is where one iteration of the loop depends upon a previous one. Thus, the loop

```
do i = 2, n
    a(i) = a(i-1) + b(i)
end do
```

cannot be replaced by the statement

```
a(2:n) = a(1:n-1) + b(2:n) ! Beware
```

4.6 Summary

In this chapter we have introduced the four main features by which the control in Fortran code may be programmed – the go to statement, the if statement and construct, the case construct and the do construct. The effective use of these features is the key to sound code. Of these features, the case construct is new to Fortran, and the do construct was formerly limited to the labelled form ending on a continue statement.

We have touched upon the concept of a *program unit* as being like the chapter of a book. Just as a book may have just one chapter, so a complete program may consist of just one program unit, which is known as a *main program*. In its simplest form it consists of a series of statements of the kinds we have been dealing with so far, and terminates with an end statement, which acts as a signal to the computer to stop processing the current program. In order to test whether a program unit of this type works correctly, we need to be able to output, to a terminal or printer, the values of the computed quantities. This topic will be fully explained in Chapter 9, and for the moment we need to know only that this can be achieved by a statement of the form

```
print *, ' var1 = ', var1, ' var2 = ', var2
```

which will output a line such as

```
var1 = 1.0  var2 = 2.0
```

Similarly, input data can be read by statements like

```
read *, val1, val2
```

Figure 4.8

```

! Print a conversion table of the Fahrenheit and Celsius
! temperature scales between specified limits.
!
real      :: celsius, fahrenheit
integer   :: low_temp, high_temp, temperature
character :: scale
!
read_loop: do
!
! Read scale and limits
    read *, scale, low_temp, high_temp
!
! Check for valid data
    if (scale /= 'C' .and. scale /= 'F') exit read_loop
!
! Loop over the limits
    do temperature = low_temp, high_temp
!
! Choose conversion formula
    select case (scale)
        case ('C')
            celsius = temperature
            fahrenheit = 9.0/5.0*celsius + 32.0
        case ('F')
            fahrenheit = temperature
            celsius = 5.0/9.0*(fahrenheit-32.0)
    end select
!
! Print table
    print *, celsius, ' degrees C correspond to', &
              fahrenheit, ' degrees F'
    end do
end do read_loop
!
! Termination
print *, ' End of valid data'
end
C 90 100
F 20 32
* 0 0

```

This is sufficient to allow us to write simple programs like that in Figure 4.8, which outputs the converted values of a temperature scale between specified limits. Valid inputs are shown at the end of the example.

4.7 Exercises

1. Write a program which

- a) defines an array to have 100 elements;
- b) assigns to the elements the values 1, 2, 3, ..., 100;
- c) reads two integer values in the range 1 to 100;
- d) reverses the order of the elements of the array in the range specified by the two values.

2. The first two terms of the Fibonacci series are both 1, and all subsequent terms are defined as the sum of the preceding two terms. Write a program which reads an integer value `limit` and which computes and prints the coefficients of the first `limit` terms of the series.

3. The coefficients of successive orders of the binomial expansion are shown in the normal Pascal triangle form as

$$\begin{array}{c} 1 \\ 1 \ 1 \\ 1 \ 2 \ 1 \\ 1 \ 3 \ 3 \ 1 \\ 1 \ 4 \ 6 \ 4 \ 1 \\ etc. \end{array}$$

Write a program which reads an integer value `limit` and prints the coefficients of the first `limit` lines of this Pascal triangle.

4. Define a character variable of length 80. Write a program which reads a value for this variable. Assuming that each character in the variable is alphabetic, write code which sorts them into alphabetic order, and prints out the frequency of occurrence of each letter.

5. Write a program to read an integer value `limit` and print the first `limit` prime numbers, by any method.

6. Write a program which reads a value `x`, and calculates and prints the corresponding value $x/(1.+x)$. The case $x=-1.$ should produce an error message and be followed by an attempt to read a new value of `x`.

7. Given a chain of entries of the type entry of Section 2.13, modify the code in Figure 4.5 (Section 4.5) so that it removes the entry with index 10, and makes the previous entry point to the following entry.

5. Program units and procedures

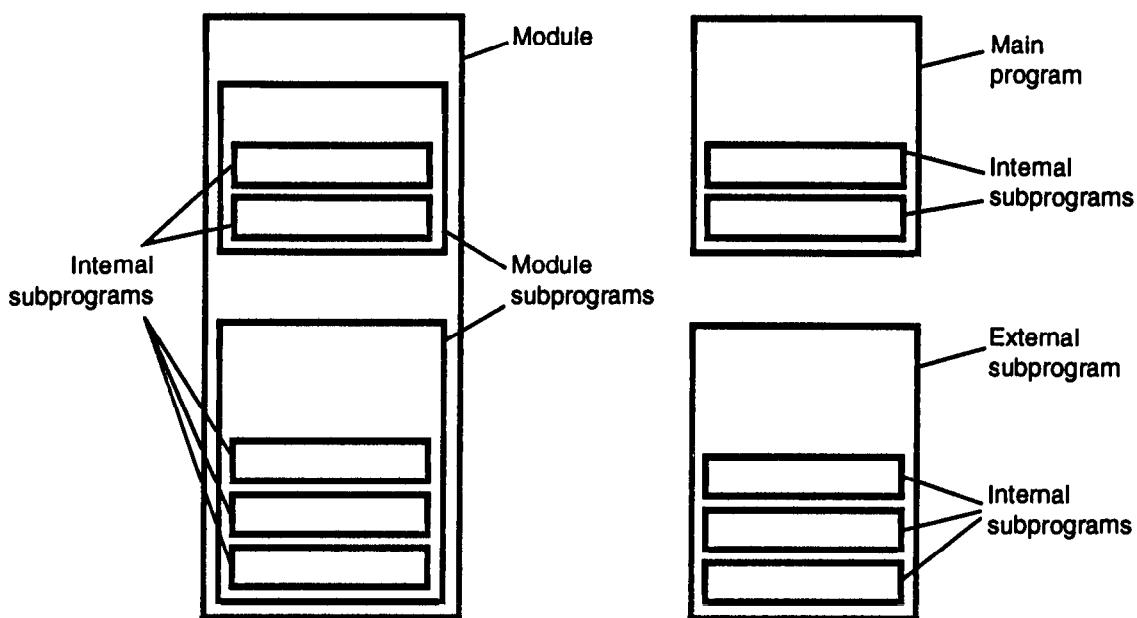
5.1 Introduction

As we saw in the previous chapter, it is possible to write a complete Fortran program as a single unit, but it is preferable to break the program down into manageable units. Each such *program unit* corresponds to a program task that can be readily understood and, ideally, can be written, compiled, and tested in isolation. We will discuss the three kinds of program unit, the main program, external subprogram, and module.

A complete program must, as a minimum, include one *main program*. This may contain statements of the kinds that we have met so far in examples, but normally its most important statements are invocations or *calls* to subsidiary programs known as *subprograms*. A subprogram defines a *function* or a *subroutine*¹. They differ in that a function returns a single object and usually does not alter the values of its arguments (so that it represents a function in the mathematical sense), whereas a subroutine usually performs a more complicated task, returning several results through its arguments and by other means. Functions and subroutines are known collectively as *procedures*.

There are various kinds of subprograms. A subprogram may be a program unit in its own right, in which case it is called an *external subprogram* and defines an *external procedure*. External procedures may also be defined by means other than Fortran (usually assembly language). A subprogram may be a member of a collection in a program unit called a *module*, in which case we call it a *module subprogram* and it defines a *module procedure*. A subprogram may be placed inside a module subprogram, an external subprogram, or a main program, in which case we call it an *internal subprogram* and it defines an *internal procedure*. Internal subprograms may not be nested, that is they may not contain further subprograms, and we expect them normally to be short sequences of code, say up to about twenty lines. We illustrate the nesting of subprograms in program units in Figure 5.1. If a program unit or subprogram contains a subprogram, it is called the *host* of that subprogram.

¹It is possible to write a subprogram that defines more than one function or more than one subroutine (see Section 11.2.6), but we do not recommend this practice.

Figure 5.1 Nesting of subprograms in program units.

Besides containing a collection of subprograms, a module may contain data definitions, derived type definitions, interface blocks (Section 5.11), and namelist groups (Section 7.15). This collection may be expected to provide facilities associated with some particular task, such as providing matrix arithmetic, a library facility, or a data base. It may sometimes be large.

In this chapter, we will describe program units and the statements that are associated with them. Within a complete program, they may appear in any order, but many compilers require a module to precede other program units that use it.

5.2 Main program

Every complete program must have one, and only one, main program. Optionally, it may contain calls to subprograms. A main program has the following form:

```
[program program-name]
  [specification-stmts]
  [executable-stmts]
[contains
  internal-subprograms]
end [program [program-name]]
```

The *program* statement is optional, but we recommend its use. The *program-name* may be any valid Fortran name such as `model`. The only non-optional statement is the *end* statement which has two purposes. It acts as a signal to the compiler that it has reached the end of the program unit and, when executed, it causes the complete program to stop. If it includes *program-name*, this must be the name on

the program statement. We recommend using the full form so that it is clear both to the reader and to the compiler exactly what is terminated by the end statement.

A main program without calls to subprograms is usually used only for short tests, as in

```
program test
    print *, 'Hello world!'
end program test
```

The specification statements define the environment for the executable statements. So far, we have met the type declaration statement (`integer`, `real`, `complex`, `logical`, `character`, and `type(type-name)`) that specifies the type and other properties of the entities that it lists, and the type definition block (bounded by `type type-name` and `end type` statements). We will meet other specification statements in this and the next two chapters.

The executable statements specify the actions that are to be performed. So far, we have met the assignment statement, the pointer assignment statement, the `go to` statement, the `if` statement and construct, the `do` and `case` constructs, and the `read` and `print` statements. We will meet other executable statements in this and later chapters. Execution of a program always commences with the first executable statement of the main program.

The `contains` statement flags the presence of one or more internal subprograms. We will describe internal subprograms in Section 5.6. If the execution of the last statement ahead of the `contains` statement does not result in a branch, control passes over the internal subprograms to the `end` statement and the program stops. The `end` statement may be labelled and may be the target of a branch from one of the executable statements. If such a branch is taken, again the program stops.

5.3 The stop statement

Another way to stop program execution is to execute a `stop` statement. This statement may be labelled, may be part of an `if` statement, and is an executable statement that may appear in the main program or any subprogram. A well-designed program normally returns control to the main program for program termination, so the `stop` statement should appear there. However, in applications where several `stop` statements appear in various places in a complete program, it is possible to distinguish which of the `stop` statements has caused the termination by adding to each one an *access code* consisting of a default character constant or a string of up to five digits whose leading zeros are not significant. This might be used by a given processor to indicate the origin of the `stop` in a message. Examples are

```
stop
stop 'Incomplete data. Program terminated.'
stop 12345
```

5.4 External subprograms

External subprograms are called from a main program or elsewhere, usually to perform a well-defined task within the framework of a complete program. Apart from the leading statement, they have a form that is very like that of a main program:

```
subroutine-stmt
  [specification-stmts]
  [executable-stmts]
[contains
  [internal-subprograms]]
end [subroutine [subroutine-name]]
```

or

```
function-stmt
  [specification-stmts]
  [executable-stmts]
[contains
  [internal-subprograms]]
end [function [function-name]]
```

The *contains* statement plays exactly the same role as within a main program (see Section 5.2). The effect of executing an *end* statement in a subprogram is to return control to the caller, rather than to stop execution. As for the *end* program statement, we recommend using the full form for the *end* statement so that it is clear both to the reader and to the compiler exactly what it terminates.

The simplest form of external subprogram defines a subroutine without any arguments and has a *subroutine-stmt* of the form

```
subroutine subroutine-name
```

Such a subprogram is useful when a program consists of a sequence of distinct phases, in which case the main program consists of a sequence of *call* statements that invoke the subroutines as in the example

```
program game      ! Main program to control a card game
  call shuffle   ! First shuffle the cards.
  call deal      ! Now deal them.
  call play       ! Play the game.
  call display    ! Display the result.
end program game ! Cease execution.
```

But how do we handle the flow of information between the subroutines? How does *play* know which cards *deal* has dealt? There are, in fact, two methods by which information may be passed. The first is via data held in a module (Section 5.5) and accessed by the subprograms, and the second is via arguments (Section 5.7) in the procedure calls.

5.5 Modules

The third type of program unit, the module, provides a means of packaging global data, derived types and their associated operations, interface blocks (Section 5.11), and namelist groups (Section 7.15). Everything associated with some task (such as interval arithmetic, see later in this section) may be collected into a module and accessed whenever it is needed. Those parts that are associated with the internal working and are of no interest to the user may be made ‘invisible’ to the user, which allows the internal design to be altered without the need to alter the program that uses it and prevents accidental alteration of internal data. We expect Fortran 90/95 libraries to consist of sets of modules.

The module has the form

```
module module-name
  [specification-stmts]
  [contains
    module-subprograms]
  end [module [module-name]]
```

As for the `end program`, `end subroutine`, and `end function` statements, we recommend using the full form for the `end` statement.

In its simplest form, the body consists only of data specifications. For example

```
module state
  integer, dimension(52) :: cards
end module state
```

might hold the state of play of the game of Section 5.4. It is accessed by the statement

```
use state
```

appearing at the beginnings of the main program `game` and subprograms `shuffle`, `deal`, `play`, and `display`. The array `cards` is set by `shuffle` to contain the integer values 1 to 52 in a random order, where each integer value corresponds to a pre-defined playing card. For instance, 1 might stand for the ace of clubs, 2 for the two of clubs, etc. up to 52 for the king of spades. The array `cards` is changed by the subroutines `deal` and `play`, and finally accessed by subroutine `display`.

A further example of global data in a module would be the definitions of the values of the kind type parameters that might be required throughout a program (Sections 2.6.1 and 2.6.2). They can be placed in a module and used wherever they are required. On a processor that supports all the kinds listed, an example might be:

```

module numeric_kinds
  ! named constants for 4, 2, and 1 byte integers:
  integer, parameter :: &
    i4b = selected_int_kind(9), &
    i2b = selected_int_kind(4), &
    i1b = selected_int_kind(2)
  ! and for single, double and quadruple precision reals:
  integer, parameter :: &
    sp = kind(1.0), &
    dp = selected_real_kind(2*precision(1.0_sp)), &
    qp = selected_real_kind(2*precision(1.0_dp))
end module numeric_kinds

```

A very useful role for modules is to contain definitions of types and their associated operators. For example, a module might contain the type `interval` of Section 3.8, as shown in Figure 5.2. Given this module, any program unit needing this type and its operators need only include the statement

```
use interval_arithmetic
```

at the head of its specification statements.

Figure 5.2

```

module interval_arithmetic
  type interval
    real :: lower, upper
  end type interval
  interface operator(+)
    module procedure add_intervals
  end interface
  :
  contains
    function add_intervals(a,b)
      type(interval)           :: add_intervals
      type(interval), intent(in) :: a, b
      add_intervals%lower = a%lower + b%lower
      add_intervals%upper = a%upper + b%upper
    end function add_intervals
    :
  end module interval_arithmetic

```

A module subprogram has exactly the same form as an external subprogram, except that `function` or `subroutine` *must* be present on the `end` statement, so there is no need for a separate description. It always has access to other entities of the module, including the ability to call other subprograms of the module, rather as if it contained a `use` statement for its module.

A module may contain use statements that access other modules. It must not access itself directly or indirectly through a chain of use statements, for example a accessing b and b accessing a. No ordering of modules is required by the standard, but normal practice is to require each module to precede its use. We recommend this practice, which will make it impossible for a module to access itself through other modules. It is required by many compilers.

It is possible within a module to specify that some of the entities are private to it and cannot be accessed from other program units. Also there are forms of the use statement that allow access to only part of a module and forms that allow renaming of the entities accessed. These features will be explained in Sections 7.6 and 7.10. For the present, we assume that the whole module is accessed without any renaming of the entities in it.

Besides data definitions, type definitions, subprograms, and interface blocks, a module may contain namelist groups (Section 7.15). The ability to make single definitions of interface blocks will be seen to be important in the context of constructing large libraries of reusable software.

5.6 Internal subprograms

We have seen that internal subprograms may be defined inside main programs and external subprograms, and within module subprograms. They have the form

```
subroutine-stmt
  [specification-stmts]
  [executable-stmts]
end subroutine [subroutine-name]
```

or

```
function-stmt
  [specification-stmts]
  [executable-stmts]
end function [function-name]
```

that is, the same form as a module subprogram, except that they may not contain further internal subprograms. Note that function or subroutine must be present on the end statement. An internal subprogram automatically has access to all the host's entities, including the ability to call its other internal subprograms. Internal subprograms must be preceded by a contains statement in the host.

In the rest of this chapter, we describe several properties of subprograms that apply to external, module, and internal subprograms. We therefore do not need to describe internal subprograms separately. An example is given in Figure 5.10 (Section 5.15).

5.7 Arguments of procedures

Procedure arguments provide an alternative means for two program units to access the same data. Returning to our card game example, instead of placing the array cards in a module, we might declare it in the main program and pass it as an actual argument to each subprogram, as shown in Figure 5.3.

Figure 5.3

```
program game      ! Main program to control a card game
    integer, dimension(52) :: cards
    call shuffle(cards)    ! First shuffle the cards.
    call deal(cards)      ! Now deal them.
    call play(cards)       ! Play the game.
    call display(cards)   ! Display the result.
end program game           ! Cease execution.
```

Each subroutine receives cards as a dummy argument. For instance, shuffle has the form shown in Figure 5.4.

Figure 5.4

```
subroutine shuffle(cards)
    ! Subroutine that places the values 1 to 52 in cards
    ! in random order.
    integer, dimension(52) :: cards
    ! Statements that fill cards
    :
end subroutine shuffle    ! Return to caller.
```

We can, of course, imagine a card game in which deal is going to deal only three cards to each of four players. In this case, it would be a waste of time for shuffle to prepare a deck of 52 cards when only the first 12 cards are needed. This can be achieved by requesting shuffle to limit itself to a number of cards that is transmitted in the calling sequence thus:

```
call shuffle(3*4, cards(1:12))
```

Inside shuffle, we would define the array to be of the given length and the algorithm to fill cards would be contained in a do construct with this number of iterations, as shown in Figure 5.5.

We have seen how it is possible to pass an array and a constant expression between two program units. An actual argument may be any variable or expression (or a procedure name, see Section 5.12). Each dummy argument of the called procedure must agree with the corresponding actual argument in type, type parameters, and shape (the requirements on character length and shape agreement

Figure 5.5

```

subroutine shuffle(ncards, cards)
    integer                               :: ncards, icard
    integer, dimension(ncards) :: cards
    do icard = 1, ncards
        :
        cards(icard) = ...
    end do
end subroutine shuffle

```

are relaxed in Chapter 12). However, the names do not have to be the same. For instance, if two decks had been needed, we might have written the code thus:

```

program game
    integer, dimension(52) :: acards, bcards
    call shuffle(acards)      ! First shuffle the a deck.
    call shuffle(bcards)      ! Next shuffle the b deck.
    :
end program game

```

The important point is that subprograms can be written independently of one another, the association of the dummy arguments with the actual arguments occurring each time the call is executed. We can imagine `shuffle` being used in other programs which use other names. In this manner, libraries of subprograms may be built up.

Being able to have different names for actual and dummy arguments provides a useful flexibility, but it should only be used when it is actually needed. When the same name can be used, the code is more readable.

As the type of an actual argument and its corresponding dummy argument must agree, care must be taken when using component selection within an actual argument. Thus, supposing the type definitions `point` and `triangle` of Figure 2.1 (Section 2.9) are available in a module `def`, we might write

```

use def
type(triangle) :: t
:
call sub(t%a)
:
contains
subroutine sub(p)
type(point) :: p

```

5.7.1 Pointer arguments

A dummy argument is permitted to have the attribute `pointer`. In this case, the actual argument must also have the attribute `pointer`. When the subprogram is invoked, the rank of the actual argument must match that of the dummy argument, and its pointer association status is passed to the dummy argument. On return, the actual argument normally takes its pointer association status from that of the dummy argument, but it becomes undefined if the dummy argument is associated with a target that becomes undefined when the return is executed (for example, if the target is a local variable that does not have the `save` attribute, Section 7.9). The `intent` attribute (Section 5.9) would be ambiguous in this context, since it might refer to the pointer association status alone or to both the pointer association status and the value of its target; it is not allowed to be specified.

In the case of a module or internal procedure, the compiler knows when the dummy argument is a pointer. In the case of an external or dummy procedure, the compiler assumes that the dummy argument is not a pointer unless it is told otherwise in an interface block (Section 5.11).

A pointer actual argument is also permitted to correspond to a non-pointer dummy argument. In this case, the pointer must have a target and the target is associated with the dummy argument, as in

```
real, pointer :: a(:,:)
:
allocate ( a(80,80) )
call find (a)
:
subroutine find (c)
real :: c(:,:)
```

5.7.2 Restrictions on actual arguments

There are two important restrictions on actual arguments, which are designed to allow the compiler to optimize on the assumption that the dummy arguments are distinct from each other and from other entities that are accessible within the procedure. For example, a compiler may arrange for an array to be copied to a local variable on entry, and copied back on return. While an actual argument is associated with a dummy argument:

- i) Action that affects the allocation status or pointer association status of the argument or any part of it (any pointer assignment, allocation, deallocation, or nullification) must be taken through the dummy argument. If this is done, then throughout the execution of the procedure, the argument may be referenced only through the dummy argument.
- ii) Action that affects the value of the argument or any part of it must be taken through the dummy argument unless

- a. the dummy argument has the `pointer` attribute,
- b. the part is all or part of a pointer subobject, or
- c. the dummy argument has the `target` attribute, the dummy argument does not have intent `in`, the dummy argument is scalar or an assumed-shape array, and the actual argument is a target other than an array section with a vector subscript.

If the value of the argument or any part of it is affected through a dummy argument for which neither a., b., or c. holds, then throughout the execution of the procedure, the argument may be referenced only through that dummy argument.

An example of i) is a pointer that is nullified (Section 6.5.4) while still associated with the dummy argument. As an example of ii), consider

```
call modify(a(1:5), a(3:9))
```

Here, `a(3:5)` may not be changed through either dummy argument since this would violate the rule for the other argument. However, `a(1:2)` may be changed through the first argument and `a(6:9)` may be changed through the second. Another example is an actual argument that is an object being accessed from a module; here, the same object must not be accessed from the module by the procedure and redefined. As a third example, suppose an internal procedure call associates a host variable `h` with a dummy argument `d`. If `d` is defined during the call, then at no time during the call may `h` be referenced directly.

5.7.3 Arguments with the target attribute

In most circumstances, an implementation is permitted to make a copy of an actual argument on entry to a procedure and copy it back on return. This may be desirable on efficiency grounds, particularly when the actual argument is not held in contiguous storage. In any case, if a dummy argument has neither the `target` nor `pointer` attribute, any pointers associated with the actual argument do not become associated with the corresponding dummy argument but remain associated with the actual argument.

However, copy in / copy out is not allowed when

- i) a dummy argument has the `target` attribute and is either scalar or is an assumed-shaped array, and
- ii) the actual argument is a target other than an array section with a vector subscript.

In this case, the dummy and actual arguments must have the same shape, any pointer associated with the actual argument becomes associated with the dummy argument on invocation, and any pointer associated with the dummy argument on return remains associated with the actual argument.

When a dummy argument has the `target` attribute, but the actual argument is not a target or is an array section with a vector subscript, any pointer associated with the dummy argument obviously becomes undefined on return.

In other cases where the dummy argument has the `target` attribute, whether copy in / copy out occurs is processor dependent. No reliance should be placed on the pointer associations with such an argument after the invocation.

5.8 The return statement

We saw in Section 5.2 that if the last executable statement in a main program is executed and does not cause a branch, the `end` statement is executed and the program stops. Similarly, if the last executable statement in a subprogram is executed and does not cause a branch, the `end` statement is executed and control returns to the point of invocation. Just as the `return` statement is an executable statement that provides an alternative means of stopping execution, so the `return` statement provides an alternative means of returning control from a subprogram. It has the form

```
return
```

Like the `stop` statement, this statement may be labelled, may be part of an `if` statement, and is an executable statement. It must not appear among the executable statements of a main program.

5.9 Argument intent

In Figure 5.5, the dummy argument `cards` was used to pass information out from `shuffle` and the dummy argument `ncards` was used to pass information in. A third possibility is for a dummy argument to be used for both. We can specify the intent on the type declaration statement for the argument, for example:

```
subroutine shuffle(ncards, cards)
    integer, intent(in) :: ncards
    integer, intent(out), dimension(ncards) :: cards
```

For input-output arguments, intent `inout` may be specified.

If a dummy argument is specified with intent `in`, it must not be redefined by the procedure, say by appearing on the left-hand side of an assignment or by being passed on as an actual argument to a procedure that redefines it. For the specification intent `inout`, the corresponding actual argument must be a variable because the expectation is that it will be redefined by the procedure. For the specification intent `out`, the corresponding actual argument must again be a variable; in this case, it becomes undefined on entry to the procedure because the intention is that it be used only to pass information out.

If a function specifies a defined operator (Section 3.8), the dummy arguments must have intent `in`. If a subroutine specifies defined assignment (Section 3.9),

the first argument must have intent out or inout, and the second argument must have intent in.

If a dummy argument has no intent, the actual argument may be a variable or an expression, but the actual argument must be a variable if the dummy argument is redefined. It has been traditional for Fortran compilers not to check this rule, since they usually compile each program unit separately. Breaching the rule can lead to program errors at execution time that are very difficult to find. We recommend that all dummy arguments be given a declared intent. Not only is this good documentation, but it allows compilers to make more checks at compile time.

If a dummy argument has the pointer attribute, its intent is not allowed to be specified. This is because of the ambiguity of whether the intent applies to the target data object or to the pointer association.

If a dummy argument is of a derived type with pointer components, its intent attribute refers to the pointer association status of those components. For example, if the intent is in, no pointer assignment, allocation, or deallocation is permitted. The intent attribute has no bearing on the values of the targets of the pointer components.

5.10 Functions

Functions are similar to subroutines in many respects, but they are invoked within an expression and return a value that is used within the expression. For example, the subprogram in Figure 5.6 returns the distance between two points in space and the statement

```
if (distance(a, c) > distance(b, c) ) then
```

invokes the function twice in the logical expression that it contains.

Figure 5.6

```
function distance(p, q)
    real :: distance
    real, intent(in), dimension(3) :: p, q
    distance = sqrt( (p(1)-q(1))**2 + (p(2)-q(2))**2 +      &
                     (p(3)-q(3))**2 )
    ! The intrinsic function sqrt is defined in Section 8.4.
end function distance
```

Note the type declaration for the function result. The result behaves just like a dummy argument with intent out. It is initially undefined, but once defined it may appear in an expression and it may be redefined. The type may also be defined on the function statement thus:

```
real function distance(p, q)
```

It is permissible to write functions that change the values of their arguments, modify values in modules, rely on saved local data (Section 7.9), or perform input-output operations. However, these are known as *side-effects* and conflict with good programming practice. Where they are needed, a subroutine should be used. It is reassuring to know that when a function is called, nothing else goes on ‘behind the scenes’, and it may be very helpful to an optimizing compiler, particularly for internal and module subprograms. A formal mechanism for avoiding side-effects is provided by Fortran 95, but we defer its description to Section 6.10.

A function result may be an array, in which case it must be declared as such. It may also be a pointer,² which is very useful when the size of the result depends on a calculation in the function itself. The result is initially undefined. Within the function, it must become associated or defined as disassociated. We expect the function reference usually to be such that a pointer assignment takes place for the result, that is, the reference occurs as the right-hand side of a pointer assignment (Section 3.12) or as a pointer component of a structure constructor. For example, the statements

```
use data_handler
real           :: x(100)
real, pointer :: y(:)
:
y => compact(x)
```

might be used to reference the pointer function

```
function compact(x) ! a procedure to remove duplicates from
                     ! the array x
  real, pointer :: compact(:)
  real          :: x(:)
  integer        :: n
  :             ! find the number of distinct values, n
  allocate(compact(n))
  :             ! copy the distinct values into compact
end function compact
```

in the module `data_handler`. The reference may also occur as a primary of an expression or as the right-hand side of an ordinary assignment, in which case the result must be associated with a target that is defined and the value of the target is used. We do not recommend this practice, however, since it is likely to lead to memory leakage, discussed at the end of Section 6.5.3.

The value returned by a non-pointer function must always be defined.

As well as being a scalar or array value of intrinsic type, a function result may also be a scalar or array value of a derived type, as we have seen already in Section 3.8. When the function is invoked, the function value must be used as a whole, that

²However, it is not possible for a pointer to have a function as its target. In other words, *dynamic binding*, or association of a pointer with a function at run time, is not available.

is, it is not permitted to be qualified by substring, array-subscript, array-section, or structure-component selection.

Although this is not very useful, a function is permitted to have an empty argument list. In this case, the brackets are obligatory both within the function statement and at every invocation.

5.10.1 Prohibited side-effects

In order to assist an optimizing compiler, the standard prohibits reliance on certain side-effects. It specifies that it is not necessary for a processor to evaluate all the operands of an expression, or to evaluate entirely each operand, if the value of the expression can be determined otherwise. For example, in evaluating

`x>y .or. l(z) ! x, y, and z are real; l is a logical function`

the function reference need not be made if x is greater than y . Since some processors will make the call and others will not, any variable (for example z) that is redefined by the function becomes undefined following such expression evaluation. Similarly, it is not necessary for a processor to evaluate any subscript or substring expressions for an array of zero size or character object of zero character length.

Another prohibition is that a function reference must not redefine the value of a variable that appears in the same statement or affect the value of another function reference in the same statement. For example, in

`d = max(distance(p,q), distance(q,r))`

`distance` is required not to redefine its arguments. This rule allows any expressions that are arguments of a single procedure call to be evaluated in any order. With respect to this rule, an `if` statement,

`if (expr) stmt`

is treated as the equivalent `if` construct

```
if (expr) then
    stmt
end if
```

and the same is true for the `where` statement (Section 6.8).

5.11 Explicit and implicit interfaces

A call to an internal subprogram must be from a statement within the same program unit. It may be assumed that the compiler will process the program unit as a whole and will therefore know all about any internal subprogram. In particular, it will know about its *interface*, that is whether it defines a function or

a subroutine, the names and properties of the arguments, and the properties of the result if it defines a function. This, for example, permits the compiler to check whether the actual and dummy arguments match in the way that they should. We say that the interface is *explicit*.

A call to a module subprogram must either be from another statement in the module or from a statement following a `use` statement for the module. In both cases, the compiler will know all about the subprogram, and again we say that the interface is explicit. Similarly, intrinsic procedures (Chapter 8) always have explicit interfaces.

When compiling a call to an external or dummy procedure (Section 5.12), the compiler normally does not have a mechanism to access its code. We say that the interface is *implicit*. To specify that a name is that of an external or dummy procedure, the `external` statement is available. It has the form

`external external-name-list`

and appears with other specification statements, after any `use` or `implicit` statements (Section 7.2) and before any executable statements. The type and type parameters of a function with an implicit interface are usually specified by a type declaration statement for the function name; an alternative is by the rules of implicit typing (Section 7.2) applied to the name, but this is not available in a module unless the function has the `private` attribute (see Section 7.6).

The `external` statement merely specifies that each *external-name* is the name of an external or dummy procedure. It does not specify the interface, which remains implicit. However, a mechanism is provided for the interface to be specified. It may be done through an interface block of the form

```
interface
  interface-body
end interface
```

Normally, the *interface-body* is an exact copy of the subprogram's header, the specifications of its arguments and function result, and its `end` statement. However,

- the names of the arguments may be changed;
- other specifications may be included (for example, for a local variable), but not internal procedures, data or format statements;
- the information may be given by a different combination of statements³; and
- in the case of an array argument or function result, the bounds may differ as long as the shape does not.

³A practice that is permitted by the standard, but which we do not recommend, is for a dummy argument to be declared implicitly as a procedure by invoking it in an executable statement. If the subprogram has such a dummy procedure, the interface will need an `external` statement for that dummy procedure.

An *interface-body* may be provided for a call to an external procedure defined by means other than Fortran (usually assembly language).

Naming a procedure in an *external* statement or giving it an interface body (doing both is not permitted) ensures that it is an external or dummy procedure. We strongly recommend the practice for external procedures, since otherwise the processor is permitted to interpret the name as that of an intrinsic procedure. It is needed for portability since processors are permitted to provide additional intrinsics. Naming a procedure in an *external* statement makes all versions of an intrinsic procedure having the same name unavailable. The same is true for giving it an interface body in the way described in the next section (but not when the interface is generic, Section 5.18).

The interface block is placed in a sequence of specification statements and this suffices to make the interface explicit. Perhaps the most convenient way to do this is to place the interface block among the specification statements of a module and then use the module. We imagine subprogram libraries being written as sets of external subprograms which are precompiled and whose interfaces are collected into modules. This keeps the modules of modest size. Note that if a procedure is accessible in a scoping unit, its interface is either explicit or implicit there. An external procedure may have an explicit interface in some scoping units and an implicit interface in others.

Interface blocks may also be used to allow procedures to be called as defined operators (Section 3.8), as defined assignments (Section 3.9), or under a single generic name. We therefore defer description of the full generality of the interface block until Section 5.18, where overloading is discussed.

An explicit interface is required to invoke a procedure with a pointer or target dummy argument or a pointer function result, and is required for several useful features that we will meet later in this and the next chapter. It is needed so that the processor can make the appropriate linkage. Even when not strictly required, it gives the compiler an opportunity to examine data dependencies and thereby improve optimization. Explicit interfaces are also desirable because of the additional security that they provide. It is straightforward to ensure that all interfaces are explicit and we recommend the practice.

5.12 Procedures as arguments

So far, we have taken the actual arguments of a procedure invocation to be variables and expressions, but another possibility is for them to be procedures. Let us consider the case of a library subprogram to perform function minimization. It needs to receive the user's function, just as the subroutine `shuffle` in Figure 5.5 needs to receive the required number of cards. The library code might look like the code in Figure 5.7. Notice the way the procedure argument is declared by an interface block playing a similar role to that of the type declaration statement for a data object. Although such an interface block is not required, we recommend its use.

Figure 5.7

```

real function minimum(a, b, func) ! Returns the minimum
    ! value of the function func(x) in the interval (a,b)
    real, intent(in) :: a, b
    interface
        real function func(x)
            real, intent(in) :: x
        end function func
    end interface
    real :: f,x
    :
    f = func(x) ! invocation of the user function.
    :
end function minimum

```

Just as the type and shape of actual and dummy data objects must agree, so must the properties of the actual and dummy procedures. The agreement is exactly as for a procedure and an interface body for that procedure (see Section 5.11). It would make no sense to specify an `intent` attribute (Section 5.9) for a dummy procedure, and this is not permitted.

On the user side, the code may look like that in Figure 5.8. Notice that the structure is rather like a sandwich: user-written code invokes the library code which in turn invokes user-written code. Again, we recommend the use of an interface block. As a minimum, the procedure name must be declared in an `external` statement.

Figure 5.8

```

program main
    real :: a, b, f
    interface
        real function fun(x)
            real, intent(in) :: x
        end function fun
    end interface
    f = minimum(1.0, 2.0, fun)
    :
end program main
real function fun(x)
    :
end function fun

```

The procedure that is passed must be an external or module procedure and its specific name must be passed when it also has a generic name (Section 5.18). Internal procedures are not permitted because it is anticipated that they may be implemented quite differently (for example, by in-line code), and because of the need to identify the depth of recursion when the host is recursive (Section 5.16) and the procedure involves host variables.

5.13 Keyword and optional arguments

In practical applications, argument lists can get long and many of the arguments may often not be needed. For example, a subroutine for constrained minimization might have the form

```
subroutine mincon(n, f, x, upper, lower, &
                  equalities, inequalities, convex, xstart)
```

On many calls, there may be no upper bounds, or no lower bounds, or no equalities, or no inequalities, or it may not be known whether the function is convex, or a sensible starting point may not be known. All the corresponding dummy arguments may be declared optional (see also Section 7.8). For instance, the bounds might be declared by the statement

```
real, optional, dimension(n) :: upper,lower
```

If the first four arguments are the only wanted ones, we may use the statement

```
call mincon(n, f, x, upper)
```

but usually the wanted arguments are scattered. In this case, we may follow a (possibly empty) ordinary positional argument list for leading arguments by a keyword argument list, as in the statement

```
call mincon(n, f, x, equalities=q, xstart=x0)
```

The keywords are the dummy argument names and there must be no further positional arguments after the first keyword argument.

This example also illustrates the merits of both positional and keyword arguments as far as readability is concerned. A small number of leading positional arguments (for example, n, f, x) are easily linked in the reader's mind to the corresponding dummy arguments. Beyond this, the keywords are very helpful to the reader in making these links. We recommend their use for long argument lists even when there are no gaps caused by optional arguments that are not present.

A non-optional argument must appear exactly once, either in the positional list or in the keyword list. An optional argument may appear at most once, either in the positional list or in the keyword list. An argument must not appear in both lists.

The called subprogram needs some way to detect whether an argument is present so that it can take appropriate action when it is not. This is provided by the intrinsic function present (see Section 8.2). For example

```
present(xstart)
```

returns the value `.true.` if the current call has provided a starting point and `.false.` otherwise. When it is absent, the subprogram might use a random number generator to provide a starting point.

A slight complication occurs if an optional dummy argument is used within the subprogram as an actual argument in a procedure invocation. For example, our minimization subroutine might start by calling a subroutine that handles the corresponding equality problem by the call

```
call mineq(n, f, x, equalities, convex, xstart)
```

In such a case, an absent optional argument is also regarded as absent in the second-level subprogram. For instance, when `convex` is absent in the call of `mincon`, it is regarded as absent in `mineq` too. Such absent arguments may be propagated through any number of calls, provided the dummy argument is optional in each case. An absent argument further supplied as an actual argument must be specified as a whole, and not as a subobject. Furthermore, an absent pointer is not permitted to be associated with a non-pointer dummy argument (the target is doubly absent).

Since the compiler will not be able to make the appropriate associations unless it knows the keywords (dummy argument names), the interface must be explicit (Section 5.11) if any of the dummy arguments are optional or keyword arguments are in use. Note that an interface block may be provided for an external procedure to make the interface explicit. In all cases where an interface block is provided, it is the names of the dummy arguments in the block that are used to resolve the associations.

5.14 Scope of labels

Execution of the main program or a subprogram always starts at its first executable statement and any branching always takes place from one of its executable statements to another. Indeed, each subprogram has its own independent set of labels. This includes the case of a host subprogram with several internal subprograms. The same label may be used in the host and the internal subprograms without ambiguity.

This is our first encounter with *scope*. The scope of a label is a main program or a subprogram, excluding any internal subprograms that it contains. The label may be used unambiguously anywhere among the executable statements of its scope. Notice that the host end statement may be labelled and be a branch target from a host statement, that is the internal subprograms leave a hole in the scope of the host (see Figure 5.9).

5.15 Scope of names

In the case of a named entity, there is a similar set of statements within which the name may always be used to refer to the entity. Here, type definitions and interface blocks as well as subprograms can knock holes in scopes. This leads us to regard each program unit as consisting of a set of non-overlapping scoping units. A *scoping unit* is one of the following:

- a derived-type definition,
- a procedure interface body, excluding any derived-type definitions and interface bodies contained within it, or
- a program unit or subprogram, excluding derived-type definitions, interface bodies, and subprograms contained within it.

An example containing five scoping units is shown in Figure 5.9.

Figure 5.9

```
module scope1          ! scope 1
  :
contains             ! scope 1
  subroutine scope2   ! scope 2
    type scope3       ! scope 3
      :
    end type scope3 ! scope 3
    interface         ! scope 2
      :
    end interface     ! scope 2
    :
contains             ! scope 2
  function scope5(...) ! scope 5
    :
  end function scope5 ! scope 5
end subroutine scope2 ! scope 2
end module scope1    ! scope 1
```

Once an entity has been declared in a scoping unit, its name may be used to refer to it in that scoping unit. An entity declared in another scoping unit is always a different entity even if it has the same name and exactly the same properties⁴. Each is known as a *local* entity. This is very helpful to the programmer, who does not have to be concerned about the possibility of accidental name clashes. Note that this is true for derived types, too. Even if two derived types have the same

⁴Apart from the effect of storage association, which is not discussed until Chapter 11 and whose use we strongly discourage.

name and the same components, entities declared with them are treated as being of different types⁵.

A *use* statement of the form

```
use module-name
```

is regarded as a re-declaration of all the module entities inside the local scoping unit, with exactly the same names and properties. The module entities are said to be accessible by *use association*. Names of entities in the module may not be used to declare local entities (but see Section 7.10 for a description of further facilities provided by the *use* statement when greater flexibility is required).

In the case of a derived-type definition, a module subprogram, or an internal subprogram, the name of an entity in the host (including an entity accessed by *use association*) is similarly treated as being automatically re-declared with the same properties, provided no entity with this name is declared locally, is a local dummy argument or function result, or is accessed by *use association*. The host entity is said to be accessible by *host association*. For example, in the subroutine *inner* of Figure 5.10, *x* is accessible by *host association*, but *y* is a separate local variable and the *y* of the host is inaccessible. We note that *inner* calls another internal procedure that is a function, *f*; it must not contain a type specification for that function, as the interface is already explicit. Such a specification would, in fact, declare a different, *external* function of that name. The same remark applies to a module procedure calling a function in the same module.

Figure 5.10

```
subroutine outer
    real :: x, y
    :
contains
    subroutine inner
        real :: y
        y = f(x) + 1.
        :
    end subroutine inner
    function f(z)
        real :: f
        real, intent(in) :: z
        :
    end function f
end subroutine outer
```

Note that the host does not have access to the local entities of any subroutine that it contains.

⁵Apart from storage association effects (Chapter 11)

Host association does not extend to interface blocks. This allows an interface body to be constructed mechanically from the specification statements of an external procedure. Note, however, that if a derived type needed for the interface is accessed from a module, the interface block constructed from the procedure cannot be placed in the module that defines the type since a module is not permitted to access itself. For example, the following is not permitted:

```
module m
  type t
    integer :: i, j, k
  end type t
  interface g
    subroutine s(a)
      use m          ! Illegal module access.
      type(t) :: a
    end subroutine s
  end interface
end module m
```

Within a scoping unit, each named data object, procedure, derived type, named construct, and namelist group (Section 7.15) must have a distinct name, with the one exception of generic names of procedures (to be described in Section 5.18). Note that this means that any appearance of the name of an intrinsic procedure in another rôle makes the intrinsic procedure inaccessible by its name (the renaming facility described in Section 7.10 allows an intrinsic procedure to be accessed from a module and renamed). Within a type definition, each component of the type, each intrinsic procedure referenced, and each derived type or named constant accessed by host association, must have a distinct name. Apart from these rules, names may be re-used. For instance, a name may be used for the components of two types, or the arguments of two procedures referenced with keyword calls.

The names of program units and external procedures are *global*, that is available anywhere in a complete program. Each must be distinct from the others and from any of the local entities of the program unit.

At the other extreme, the do variable of an implied-do in a data statement (Section 7.5.2) or an array constructor (Section 6.16) has a scope that is just the implied-do. It is different from any other entity with the same name.

5.16 Direct recursion

Normally, a subprogram may not invoke itself, either directly or indirectly through a sequence of other invocations. However, if the leading statement is prefixed recursive, this is allowed. Where the subprogram is a function that calls itself directly in this fashion, the function name cannot be used for the function result and another name is needed. This is done by adding a further clause to the

function statement as in Figure 5.11, which illustrates the use of a recursive function to calculate $n! = n(n - 1)\dots(1)$.

Figure 5.11

```
recursive function factorial(n) result(res)
    integer, intent(in) :: n
    integer             :: res
    if(n==1) then
        res = 1
    else
        res = n*factorial(n-1) ! Beware - few computers check for
        end if                  ! integer overflow.
    end function factorial
```

The type of the function (and its result) may be specified on the function statement, either before or after the token recursive:

integer recursive function factorial(n) result(res)

or

recursive integer function factorial(n) result(res)

or in a type declaration statement for the result name (as in Figure 5.11). In fact, the result name, rather than the function name, must be used in any specification statement. In the executable statements, a reference to the function name is a recursive invocation of the function and the result name must be used for the result variable. If there is no result clause, the function name is used for the result, and is not available for a recursive function call.

The result clause may also be used in a non-recursive function.

Just as in Figure 5.11, any recursive procedure that calls itself directly must contain a conditional test that terminates the sequence of calls at some point, otherwise it will call itself indefinitely.

Each time a recursive procedure is invoked, a fresh set of local data objects is created, which ceases to exist on return. They consist of all data objects declared in its specification statements or declared implicitly (see Section 7.2), but excepting those with the data or save attribute (see Sections 7.5 and 7.9) and any dummy arguments. The interface is explicit within the procedure.

5.17 Indirect recursion

A procedure may also be invoked by indirect recursion, that is, it may call itself through calls to other procedures. To illustrate that this may be useful, suppose we wish to perform a two-dimensional integration but have only the procedure for one-dimensional integration shown in Figure 5.12.

Figure 5.12

```

recursive function integrate(f, bounds)
    ! Integrate f(x) from bounds(1) to bounds(2)
    real :: integrate
    interface
        function f(x)
            real           :: f
            real, intent(in) :: x
        end function f
    end interface
    real, dimension(2), intent(in) :: bounds
    :
end function integrate

```

For example, suppose that it is desired to integrate a function f of x and y over a rectangle. We might write a Fortran function in a module to receive the value of x as an argument and the value of y from the module itself by host association, as shown in Figure 5.13. We can then integrate over x for a particular value of

Figure 5.13

```

module func
    real           :: yval
    real, dimension(2) :: xbounds, ybounds
contains
    function f(xval)
        real           :: f
        real, intent(in) :: xval
        r = ...      ! Expression involving xval and yval
    end function f
end module func

```

y , as shown in Figure 5.14, where `integrate` might be as shown in Figure 5.12. We may now integrate over the whole rectangle thus

```
volume = integrate(fy, ybounds)
```

Note that `integrate` calls `fy`, which in turn calls `integrate`.

5.18 Overloading and generic interfaces

We saw in Section 5.11 how to use a simple interface block to provide an explicit interface to an external or dummy procedure. Another use is for overloading, that is being able to call several procedures by the same generic name. Here

Figure 5.14

```
function fy(y)
  use func
  real :: fy
  real, intent(in) :: y
  yval = y
  r = integrate(f, xbounds)
end function fy
```

the interface block contains several interface bodies and the `interface` statement specifies the generic name. For example,

```
interface gamma
  function sgamma(x)
    real (selected_real_kind( 6 )) :: sgamma
    real (selected_real_kind( 6 )), intent(in) :: x
  end function sgamma
  function dgamma(x)
    real (selected_real_kind(12)) :: dgamma
    real (selected_real_kind(12)), intent(in) :: x
  end function dgamma
end interface
```

permits both the functions `sgamma` and `dgamma` to be invoked using the generic name `gamma`.

A specific name for a procedure may be the same as its generic name. For example, the procedure `sgamma` could be renamed `gamma` without invalidating the interface block.

Furthermore, a generic name may be the same as another accessible generic name. In such a case, all the procedures that have this generic name may be invoked through it. This capability is important, since a module may need to extend the intrinsic functions such as `sin` to a new type such as `interval` (Section 3.8).

If it is desired to overload a module procedure, the interface is already explicit so it is inappropriate to specify an interface body. Instead, the statement `module procedure procedure-name-list` is included in the interface block in order to name the module procedures for overloading: if the functions `sgamma` and `dgamma` above were defined in a module, the interface block becomes

```
interface gamma
  module procedure sgamma, dgamma
end interface
```

It is probably most convenient to place such a block in the module itself.

Fortran 95 allows any generic specification on an `interface` statement to be repeated on the corresponding `end interface` statement, for example,

```
end interface gamma           ! Fortran 95 only
```

As for other end statements, we recommend use of this fuller form.

Another form of overloading occurs when an interface block specifies a defined operation (Section 3.8) or a defined assignment (Section 3.9) to *extend* an intrinsic operation or assignment. The scope of the defined operation or assignment is the scoping unit that contains the interface block, but it may be accessed elsewhere by use or host association. If an intrinsic operator is extended, the number of arguments must be consistent with the intrinsic form (for example, it is not possible to define a unary *).

The general form of the interface block is

```
interface [generic-spec]
  [interface-body]...
  [module procedure procedure-name-list]...
    ! In Fortran 95, interface bodies and
    ! module procedure statements may appear in any order.
end interface [generic-spec] ! Only in Fortran 95 is
                           ! generic-spec allowed here
```

where *generic-spec* is

generic-name, *operator(defined-operator)*, or *assignment(=)*.

A module procedure statement is permitted only when a *generic-spec* is present, and all the procedures must be accessible module procedures (as shown in the complete module in Figure 5.16 below). No procedure name may be given a particular *generic-spec* more than once in the interface blocks within a scoping unit. An interface body must be provided for an external or dummy procedure.

If operator is specified on the interface statement, all the procedures in the block must be functions with one or two non-optional arguments having intent in⁶. If assignment is specified, all the procedures must be subroutines with two non-optional arguments, the first having intent out or inout and the second intent in. In order that invocations are always unambiguous, if two procedures have the same generic operator and the same number of arguments or both define assignment, one must have a dummy argument that corresponds by position in the argument list to a dummy argument of the other that has a different type, different kind type parameter, or different rank.

All procedures that have a given generic name must be subroutines or all must be functions, including the intrinsic ones when an intrinsic procedure is extended. Any two non-intrinsic procedures with the same generic name must have arguments that differ sufficiently for any invocation to be unambiguous. The rule is that either

⁶Since intent must not be specified for a pointer dummy argument (Section 5.7.1), this implies that if an operand of derived data type also has the pointer attribute, it is the value of its target that is passed to the function defining the operator, and not the pointer itself. The pointer status is inaccessible within the function.

- i) one of them has more non-optional dummy arguments of a particular data type, kind type parameter, and rank than the other has dummy arguments (including optional dummy arguments) of that data type, kind type parameter, and rank; or
- ii) at least one of them must have a non-optional dummy argument that both
 - corresponds by position in the argument list to a dummy argument that is not present in the other, is present with a different type or kind type parameter, or is present with a different rank, and
 - corresponds by name to a dummy argument that is not present in the other, is present with a different type or kind type parameter, or is present with a different rank.

For case (ii), both rules are needed in order to cater for both keyword and positional dummy argument lists. For instance, the interface in Figure 5.15 is invalid because the two functions are always distinguishable in a positional call, but not on a keyword call such as `f(i=int, x=posn)`. If a generic invocation is ambiguous between a non-intrinsic and an intrinsic procedure, the non-intrinsic procedure is invoked.

Figure 5.15

```
! Example of a broken overloading rule
interface f
  function fxi(x,i)
    real :: fxi
    real, intent(in) :: x
    integer :: i
  end function fxi
  function fix(i,x)
    real :: fix
    real, intent(in) :: x
    integer :: i
  end function fix
end interface
```

Note that the presence or absence of the pointer attribute is insufficient to ensure an unambiguous invocation since a pointer actual argument may be associated with a non-pointer dummy argument, see Section 5.7.1.

There are many scientific applications in which it is useful to keep a check on the sorts of quantities involved in a calculation. For instance, in dimensional analysis, whereas it might be sensible to divide length by time to obtain velocity, it is not sensible to add time to velocity. There is no intrinsic way to do this, but we conclude this section with an outline example, Figures 5.16 & 5.17, of how it might be achieved using derived types.

Figure 5.16

```

module sorts
    type time
        real :: seconds
    end type time
    type velocity
        real :: metres_per_second
    end type velocity
    type length
        real :: metres
    end type length
    type length_squared
        real :: metres_squared
    end type length_squared
    interface operator(/)
        module procedure length_by_time
    end interface
    interface operator(+)
        module procedure time_plus_time
    end interface
    interface sqrt
        module procedure sqrt_metres_squared
    end interface
contains
    function length_by_time(s, t)
        type(length), intent(in) :: s
        type(time), intent(in)   :: t
        type(velocity)           :: length_by_time
        length_by_time%metres_per_second = s%metres / t%seconds
    end function length_by_time
    function time_plus_time(t1, t2)
        type(time), intent(in)   :: t1, t2
        type(time)               :: time_plus_time
        time_plus_time%seconds = t1%seconds + t2%seconds
    end function time_plus_time
    function sqrt_metres_squared(l2)
        type(length_squared), intent(in) :: l2
        type(length)                  :: sqrt_metres_squared
        sqrt_metres_squared%metres = sqrt(l2%metres_squared)
    end function sqrt_metres_squared
end module sorts

```

Figure 5.17

```

program test
    use sorts
    type(length)      :: s = length(10.0), 1
    type(length_squared) :: s2 = length_squared(10.0)
    type(velocity)     :: v
    type(time)         :: t = time(3.0)
    v = s / t
! Note: v = s + t   or   v = s * t  would be illegal
    t = t + time(1.0)
    l = sqrt(s2)
    print *, v, t, l
end program test

```

Note that definitions for operations between like entities are also required, as shown by `time_plus_time`. Similarly, any intrinsic function that might be required, here `sqrt`, must be overloaded appropriately. Of course, this can be avoided if the components of the variables are referenced directly, as in

`t%seconds = t%seconds + 1.0`

5.19 Assumed character length

A character dummy argument may be declared with an asterisk for the value of the length type parameter, in which case it automatically takes the value from the actual argument. For example, a subroutine to sort the elements of a character array might be written thus

```

subroutine sort(n,chars)
    integer, intent(in)                      :: n
    character(len=*), dimension(n), intent(in) :: chars
    :
end subroutine sort

```

If the length of the associated actual argument is needed within the procedure, the intrinsic function `len` (Section 8.6) may be invoked, as in Figure 5.18.

An asterisk must not be used for a kind type parameter value. This is because a change of character length is analogous to a change of an array size and can easily be accommodated in the object code, whereas a change of kind probably requires a different machine instruction for every operation involving the dummy argument. A different version of the procedure would need to be generated for each possible kind value of each argument. The overloading feature (previous section) gives the programmer an equivalent functionality with explicit control over which versions are generated.

Figure 5.18

```

integer function count (letter, string)
    character (1), intent(in) :: letter
    character (*), intent(in) :: string
!     Count the number of occurrences of letter in string
    count = 0
    do i = 1, len(string)
        if (string(i:i) == letter) count = count + 1
    end do
end function count

```

5.20 The subroutine and function statements

We finish this chapter by giving the full syntax of the Fortran 90 subroutine and function statements, which have so far been explained through examples. It is

[recursive] &
subroutine *subroutine-name* [([*dummy-argument-list*])]

and

[*prefix*] function *function-name* ([*dummy-argument-list*]) &
[*result(result-name)*]

where *prefix* is

type [recursive]

or

recursive [*type*]

(for details of *type* see Section 7.13).

Each feature has been explained separately and the meanings are the same in the combinations allowed by the syntax. The syntax has been extended in Fortran 95 to allow pure and elemental procedures to be specified (Sections 6.10 and 6.11).

5.21 Summary

A program consists of a sequence of program units. It must contain exactly one main program but may contain any number of modules and external subprograms. We have described each kind of program unit. Modules contain data definitions, type definitions, namelist groups, interface blocks, and module subprograms, all of which may be accessed in other program units with the *use* statement. The program units may be in any order, but many compilers require modules to precede their use.

Subprograms define procedures, which may be functions or subroutines. They may also be defined intrinsically (Chapter 8) and external procedures may be defined by means other than Fortran. We have explained how information is passed between program units and to procedures through argument lists and through the use of modules. Procedures may be called recursively provided they are correspondingly specified.

The interface to a procedure may be explicit or implicit. If it is explicit, keyword calls may be made, and the procedure may have optional arguments. Interface blocks permit procedures to be invoked as operations or assignments, or by a generic name. The character lengths of dummy arguments may be assumed.

We have also explained about the scope of labels and Fortran names, and introduced the concept of a scoping unit.

Many of the features are new since Fortran 77: the internal subprogram, modules, the interface block, optional and keyword arguments, argument intent, pointer dummy arguments and function results, recursion, and overloading. These are powerful additions to the language, particularly in the construction of large programs and libraries.

5.22 Exercises

1. A subroutine receives as arguments an array of values, x , and the number of elements in x , n . If the mean and variance of the values in x are estimated by

$$\text{mean} = \frac{1}{n} \sum_{i=1}^n x(i)$$

and

$$\text{variance} = \frac{1}{n-1} \sum_{i=1}^n (x(i) - \text{mean})^2$$

write a subroutine which returns these calculated values as arguments. The subroutine should check for invalid values of n (≤ 1).

2. A subroutine `matrix_mult` multiplies together two matrices A and B , whose dimensions are $i \times j$ and $j \times k$, respectively, returning the result in a matrix C dimensioned $i \times k$. Write `matrix_mult`, given that each element of C is defined by

$$C(m, n) = \sum_{\ell=1}^j (A(m, \ell) \times B(\ell, n))$$

The matrices should appear as arguments to `matrix_mult`.

3. the subroutine `random_number` (Section 8.16.3) returns a random number in the range 0.0 to 1.0, that is

```
call random_number(r) ! 0 ≤ r < 1
```

Using this function, write the subroutine `shuffle` of Figure 5.4.

4. A character string consists of a sequence of letters. Write a function to return that letter of the string which occurs earliest in the alphabet, for example, the result of applying the function to 'DGUMVETLOIC' is 'C'.
5. Write an internal procedure to calculate the volume of a cylinder of radius r and length ℓ , $\pi r^2 \ell$, using as the value of π the result of $\text{acos}(-1.0)$, and reference it in a host procedure.
6. Choosing a simple card game of your own choice, and using the random number procedure (Section 8.16.3), write subroutines `deal` and `play` of Section 5.4, using data in a module to communicate between them.
7. Objects of the intrinsic type `character` are of a fixed length. Write a module containing a definition of a variable length character string type, of maximum length 80, and also the procedures necessary to:
 - i) assign a character variable to a string;
 - ii) assign a string to a character variable;
 - iii) return the length of a string;
 - iv) concatenate two strings.

6. Array features

6.1 Introduction

In an era when many computers have the hardware capability for efficient processing of array operands, it is self-evident that a numerically based language such as Fortran should have matching notational facilities. Such facilities provide not only a notational convenience for the programmer, but provide an opportunity to extend the power of the language. However, new optimization techniques are required, for instance the ability to recognize that two or more consecutive array statements may, in some cases, be processed in a single loop at the object code level. These techniques are being progressively introduced.¹

Arrays were introduced in Sections 2.10 to 2.13, their use in simple expressions and in assignments was explained in Sections 3.10 and 3.11, and they were used as procedure arguments in Chapter 5. These descriptions were deliberately restricted because Fortran contains a very full set of array features whose complete description would have unbalanced those chapters. The purpose of this chapter is to describe the array features in detail, but without anticipating the descriptions of the array intrinsic procedures of Chapter 8; the rich set of intrinsic procedures should be regarded as an integral part of the array features.

6.2 Zero-sized arrays

It might be thought that an array would always have at least one element. However, such a requirement would force programs to contain extra code to deal with certain natural situations. For example, the code in Figure 6.1 solves a lower-triangular set of linear equations. When i has the value n , the sections have size zero, which is just what is required.

Fortran allows arrays to have zero size in all contexts. Whenever a lower bound exceeds the corresponding upper bound, the array has size zero.

There are few special rules for zero-sized arrays because they follow the usual rules, though some care may be needed in their interpretation. For example, two zero-sized arrays of the same rank may have different shapes. One might have shape $(0,2)$ and the other $(0,3)$ or $(2,0)$. Such arrays of differing shape are not

¹A fuller discussion of this topic can be found in *Optimizing Supercompilers for Supercomputers*, M. Wolfe (Pitman, 1989).

Figure 6.1

```
do i = 1,n
    x(i) = b(i) / a(i, i)
    b(i+1:n) = b(i+1:n) - a(i+1:n, i) * x(i)
end do
```

conformable and therefore may not be used together as the operands of a binary operation. However, an array is always conformable with a scalar so the statement

zero-sized-array = scalar

is valid and the scalar is ‘broadcast to all the array elements’, making this a ‘do nothing’ statement.

A zero-sized array is regarded as being defined always, because it has no values that can be undefined.

6.3 Assumed-shape arrays

Outside Chapter 11, we require that the shapes of actual and dummy arguments agree, and so far we have achieved this by passing the extents of the array arguments as additional arguments. However, it is possible to require that the shape of the dummy array be taken automatically to be that of the corresponding actual array argument. Such an array is said to be an *assumed-shape* array. When the shape is declared by the dimension clause, each dimension has the form

[lower-bound] :

where *lower-bound* is an integer expression that may depend on module data or the other arguments (see Section 7.14 for the exact rules). If *lower-bound* is omitted, the default value is 1. Note that it is the shape that is passed, and not the upper and lower bounds. For example, if the actual array is *a*, declared thus:

real, dimension(0:10, 0:20) :: a

and the dummy array is *da*, declared thus:

real, dimension(:, :) :: da

then *a(i,j)* corresponds to *da(i+1,j+1)*; to get the natural correspondence, the lower bound must be declared:

real, dimension(0:, 0:) :: da

In order that the compiler knows that additional information is to be supplied, the interface must be explicit (Section 5.11) at the point of call. A dummy array with the pointer attribute is not regarded as an assumed-shape array because its shape is not necessarily assumed.

6.4 Automatic objects

A procedure with dummy arguments that are arrays whose size varies from call to call may also need local arrays whose size varies. A simple example is the array work in the subroutine to interchange two arrays that is shown in Figure 6.2.

Figure 6.2

```
subroutine swap(a, b)
    real, dimension(:, ), intent(inout) :: a, b
    real, dimension(size(a))           :: work
        ! size provides the size of an array,
        ! and is defined in Section 8.12.2.
    work = a
    a = b
    b = work
end subroutine swap
```

Arrays whose extents vary in this way are called *automatic arrays*, and are examples of *automatic data objects*. These are data objects whose declarations depend on the value of non-constant expressions, and are not dummy arguments. Implementations are likely to bring them into existence when the procedure is called and destroy them on return, maintaining them on a stack². The non-constant expressions are limited to be specification expressions (Section 7.14).

The other way that automatic objects arise is through varying character length. The variable word2 in

```
subroutine example(word1)
    character(len = *), intent(inout) :: word1
    character(len = len(word1))      :: word2
```

is an example. If a function result has varying character length, the interface must be explicit at the point of call because the compiler needs to know this, as shown in Figure 6.3.

An array bound or the character length of an automatic object is fixed for the duration of each execution of the procedure and does not vary if the value of the specification expression varies or becomes undefined.

Some small restrictions on the use of automatic data objects appear in Sections 7.5, 7.9, and 7.15.

²A stack is a memory management mechanism whereby fresh storage is established and old storage is discarded on a ‘last in, first out’ basis within contiguous memory.

Figure 6.3

```

program loren
    character (len = *), parameter :: a = 'just a simple test'
    print *, double(a)
contains
    function double(a)
        character (len = *), intent(in) :: a
        character (len = 2*len(a))      :: double
        double = a//a
    end function double
end program loren

```

6.5 Heap storage

There is an underlying assumption in Fortran that the processor supplies a mechanism for managing heap³ storage. The statements described in this section are the user interface to that mechanism.

6.5.1 Allocatable arrays

Sometimes an array is required to be of a size that is known only after some data have been read or some calculations performed. An array with the pointer attribute might be used for this purpose, but this is really not appropriate if the other properties of pointers are not needed. Instead, an array that is not a dummy argument or function result may be given the allocatable attribute by a statement such as

```
real, dimension(:, :, ), allocatable :: a
```

Such an array is called *allocatable*. Its rank is specified when it is declared, but the bounds are undefined until an allocate statement such as

```
allocate(a(n, 0:n+1))      ! n of type integer
```

has been executed for it. Its initial allocation status is ‘not currently allocated’ and it becomes allocated following successful execution of an allocate statement.

An important example is shown in Figure 6.4. The array *work* is placed in a module and is allocated at the beginning of the main program to a size that depends on input data. The array is then available throughout program execution in any subprogram that has a use statement for *work_array*.

When an allocatable array *a* is no longer needed, it may be deallocated by execution of the statement

³A heap is a memory management mechanism whereby fresh storage may be established and old storage may be discarded in any order. Mechanisms to deal with the progressive fragmentation of the memory are usually required.

Figure 6.4

```

module work_array
    integer :: n
    real, dimension(:,:,:,:), allocatable :: work
end module work_array
program main
    use work_array
    read *, n
    allocate(work(n, 2*n, 3*n))
    :

```

deallocate (a)

following which the array is ‘not currently allocated’. The `deallocate` statement is described in more detail in Section 6.5.3.

If it is required to make any change to the bounds of an allocatable array, the array must be deallocated and then allocated afresh. Allocating an allocatable array that is already allocated, or deallocating an allocatable array that is not currently allocated, is an error.

If a variable-sized array component of a structure is required, unfortunately, an array pointer must be used (see Section 6.14). The prohibition on allocatable arrays here was made to keep the feature simple, but this is now recognized as a mistake that will be corrected in Fortran 2000 (see Sections 1.5 and 13.4).

In Fortran 90, an allocatable array that does not have the `save` attribute (Section 7.9) may have a third allocation state: undefined. Since an undefined allocatable array may not be referenced in any way, not even an enquiry about its status using the `allocated` intrinsic function, we recommend avoiding this state. It occurs on return from a subprogram if the array is local to the subprogram or local to a module that is currently accessed only by the subprogram, and the array is allocated. To avoid this situation, such an allocatable array must be explicitly deallocated before such a return.

In Fortran 95, the undefined allocation status cannot occur. On return from a subprogram, an allocated allocatable array without the `save` attribute is automatically deallocated if it is local to the subprogram, and it is processor dependent as to whether it remains allocated or is deallocated if it is local to a module and is accessed only by the subprogram. This automatic deallocation not only avoids inadvertent memory leakage, but prevents the very undesirable undefined allocation status.

6.5.2 The `allocate` statement

We mentioned in Section 2.13 that the `allocate` statement can also be used to give fresh storage for a pointer target directly. A pointer becomes associated

(Section 3.3) following successful execution of the statement. The general form of the `allocate` statement is

```
allocate( allocation-list [,stat=stat] )
```

where *allocation-list* is a list of allocations of the form

```
allocate-object [( array-bounds-list )]
```

each *array-bound* has the form

```
[lower-bound:] upper-bound
```

and *stat* is a scalar integer variable that must not be part of an object being allocated.

If the `stat=` specifier is present, *stat* is given either the value zero after a successful allocation or a positive value after an unsuccessful allocation (for example, if insufficient storage is available). After an unsuccessful execution, each array that was not successfully allocated retains its previous allocation or pointer association status. If `stat=` is absent and the allocation is unsuccessful, program execution stops.

Each *allocate-object* is an allocatable array or a pointer. It may have zero character length and in the case of a pointer may be a structure component.

Each *lower-bound* and each *upper-bound* is a scalar integer expression. The default value for the lower bound is 1. The number of *array-bounds* in a list must equal the rank of the *allocate-object*. They determine the array bounds, which do not alter if the value of a variable in one of the expressions changes subsequently. An array may be allocated to be of size zero.

The bounds of all the arrays being allocated are regarded as undefined during the execution of the `allocate` statement, so none of the expressions that specify the bounds may depend on any of the bounds. For example,

```
allocate (a(size(b)), b(size(a))) ! illegal
```

or even

```
allocate (a(n), b(size(a))) ! illegal
```

is not permitted, but

```
allocate (a(n))
allocate (b(size(a)))
```

is valid. This restriction allows the processor to perform the allocations in a single `allocate` statement in any order.

In contrast to the case with an allocatable array, a pointer may be allocated a new target even if it is currently associated with a target. In this case, the previous association is broken. If the previous target was created by allocation, it becomes inaccessible unless another pointer is associated with it. We expect linked lists

normally to be created by using a single pointer in an `allocate` statement for each node of the list, using pointer components of the allocated object at the node to hold the links from the node. We illustrate this by the addition of an extra nonzero element to the sparse vector held as a chain of entries of the type

```
type entry
    real           :: value
    integer        :: index
    type(entry), pointer :: next
end type entry
```

of Section 2.13. The code in Figure 6.5 adds the new entry at the front of the chain. Note the importance of the last statement being a pointer assignment: the assignment

```
first = current
```

would overwrite the old leading entry by the new one.

Figure 6.5

```
type(entry), pointer :: first, current
real    :: fill
integer :: fill_index
:
allocate (current)
current = entry (fill, fill_index, first)
first => current
```

6.5.3 The `deallocate` statement

When an allocatable array or pointer target is no longer needed, its storage may be recovered by using the `deallocate` statement. Its general form is

```
deallocate ( allocate-object-list [,stat=stat] )
```

where each *allocate-object* is an allocatable array that is allocated or a pointer that is associated with the whole of a target that was allocated through a pointer in an `allocate` statement. Here *stat* is a scalar integer variable that must not be deallocated by the statement nor depend on an object that is deallocated by the statement. If *stat=* is present, *stat* is given either the value zero after a successful execution or a positive value after an unsuccessful execution (for example, if a pointer is disassociated). After an unsuccessful execution, each array that was not successfully deallocated retains its previous allocation or pointer association status. If *stat=* is absent and the deallocation is unsuccessful, program execution stops.

A pointer becomes disassociated (Section 3.3) following successful execution of the statement. If there is more than one object in the list, there must be no dependencies among them, to allow the processor to deallocate the objects one by one in any order.

A danger in using the `deallocate` statement is that storage may be deallocated while pointers are still associated with the targets it held. Such pointers are left ‘dangling’ in an undefined state, and must not be reused until they are again associated with an actual target.

In order to avoid an accumulation of unused and unusable storage, all explicitly allocated storage should be explicitly deallocated when it is no longer required (although, as noted at the end of Section 6.5.1, in Fortran 95, for allocatable arrays, there are circumstances in which this is automatic). This explicit management is required in order to avoid a potentially significant overhead on the part of the processor in handling arbitrarily complex allocation and reference patterns.

Note also that the standard does not specify whether the processor recovers storage allocated through a pointer but no longer accessible through this or any other pointer. This might be important where, for example, a pointer function is referenced within an expression — the programmer cannot rely on the compiler to arrange for deallocation. To ensure that there is no memory leakage, it is necessary to use functions on the right-hand side of pointer assignments, as in the example `compact` in Section 5.10, or as pointer component values in structure constructors, and to deallocate the pointer (`y` in Section 5.10) when it is no longer needed (but see also Section 13.3).

6.5.4 The `nullify` statement

A pointer may be explicitly disassociated from its target by executing a `nullify` statement. Its general form is

`nullify(pointer-object-list)`

There must be no dependencies among the objects, in order to allow the processor to nullify the objects one by one in any order. The statement is also useful for giving the disassociated status to an undefined pointer. An advantage of nullifying pointers rather than leaving them undefined is that they may then be tested by the intrinsic function `associated` (Section 8.2). For example, the end of the chain of Figure 6.5 will be flagged as a disassociated pointer if the statement

`nullify(first)`

is executed initially to create a zero-length chain. Because often there are other ways to access a target (for example, through another pointer), the `nullify` statement does not deallocate the targets. If deallocation is also required, a `deallocate` statement should be executed instead.

6.6 Elemental operations and assignments

We saw in Section 3.10 that an intrinsic operator can be applied to conformable operands, to produce an array result whose element values are the values of the operation applied to the corresponding elements of the operands. Such an operation is called *elemental*.

It is not essential to use operator notation to obtain this effect. Many of the intrinsic procedures (Chapter 8) are elemental and have scalar dummy arguments that may be called with array actual arguments provided all the array arguments have the same shape. For a function, the shape of the result is the shape of the array arguments. For example, we may find the square roots of all the elements of a real array thus:

```
a = sqrt(a)
```

For a subroutine, if any argument is array-valued, all the arguments with intent out or inout must be arrays. If a procedure that references an elemental function has an optional array-valued dummy argument that is absent, that dummy argument must not be used in the elemental reference unless another array of the same rank is associated with an non-optional argument of the elemental procedure (to ensure that the rank does not vary from call to call).

Similarly, an intrinsic assignment may be used to assign a scalar to all the elements of an array, or to assign each element of an array to the corresponding element of an array of the same shape (Section 3.11). Such an assignment is also called *elemental*.

If a similar effect is desired for a defined operator, a function must be provided for each rank or pair of ranks for which it is needed (but this is not necessary in Fortran 95, see Section 6.11). For example, the module in Figure 6.6 provides summation for scalars and rank-one arrays of intervals (Section 3.8). We leave it as an exercise for the reader to add definitions for mixing scalars and rank-one arrays.

Similarly, elemental versions of defined assignments must be provided explicitly (but, again, this is not necessary in Fortran 95, see Section 6.11).

6.7 Array-valued functions

We mentioned in Section 5.10 that a function may have an array-valued result, and have used this language feature in Figure 6.6 where the interpretation is obvious.

In order that the compiler should know the shape of the result, the interface must be explicit (Section 5.11) whenever such a function is referenced. The shape is specified within the function definition by the dimension attribute for the function name. Unless the function result is a pointer, the bounds must be explicit expressions and they are evaluated on entry to the function. For another example, see the declaration of the function result in Figure 6.7.

An array-valued function is not necessarily elemental. For example, at the end of Section 3.10 we considered the type

Figure 6.6

```

module interval_addition
  type interval
    real :: lower, upper
  end type interval
  interface operator(+)
    module procedure add00, add11
  end interface
contains
  function add00 (a, b)
    type (interval)           :: add00
    type (interval), intent(in) :: a, b
    add00%lower = a%lower + b%lower ! Production code would
    add00%upper = a%upper + b%upper ! allow for roundoff.
  end function add00
  function add11 (a, b)
    type (interval), dimension(:), intent(in)      :: a
    type (interval), dimension(size(a))            :: add11
    type (interval), dimension(size(a)), intent(in) :: b
    add11%lower = a%lower + b%lower ! Production code would
    add11%upper = a%upper + b%upper ! allow for roundoff.
  end function add11
end module interval_addition

```

```

type matrix
  real :: element
end type matrix

```

Its scalar and rank-one operations might be as for reals, but for multiplying a rank-two array by a rank-one array, we might use the module function shown in Figure 6.7 to provide matrix by vector multiplication.

6.8 The where statement and construct

It is often desired to perform an array operation only for certain elements, say those whose values are positive. The `where` statement provides this facility. A simple example is

```
where ( a > 0.0 ) a = 1.0/a      ! a is a real array
```

which reciprocates the positive elements of `a` and leaves the rest unaltered. The general form is

```
where (logical-array-expr) array-variable = expr
```

Figure 6.7

```

function mult(a, b)
!
    type(matrix), dimension(:, :)      :: a
    type(matrix), dimension(size(a, 2)) :: b
        ! size is defined in Section 8.12
    type(matrix), dimension(size(a, 1)) :: mult
    integer                           :: j, n
!
    mult = 0.0      ! A defined assignment from a real
                    ! scalar to a rank-one matrix.
    n = size(a, 1)
    do j = 1, size(a, 2)
        mult = mult + a(1:n, j) * b(j)
            ! Uses defined operations for addition of
            ! two rank-one matrices and multiplication
            ! of a rank-one matrix by a scalar matrix.
    end do
end function mult

```

The logical array expression *logical-array-expr* must have the same shape as *array-variable*. It is evaluated first and then just those elements of *expr* that correspond to elements of *logical-array-expr* that have the value true are evaluated and are assigned to the corresponding elements of *array-variable*. All other elements of *array-variable* are left unaltered. In Fortran 90, the assignment must not be a defined assignment (this restriction is relaxed in Fortran 95, see Section 6.8.1).

A single logical array expression may be used for a sequence of array assignments all of the same shape. The general form of this construct is

```

where (logical-array-expr)
    array-assignments
end where

```

The logical array expression *logical-array-expr* is first evaluated and then each array assignment is performed in turn, under the control of this mask. If any of these assignments affect entities in *logical-array-expr*, it is always the value obtained when the where statement is executed that is used as the mask.

Finally, the where construct may take the form

```
where (logical-array-expr)
      array-assignments
elsewhere
      array-assignments
end where
```

Here, the assignments in the first block of assignments are performed in turn under the control of *logical-array-expr* and then the assignments in the second block are performed in turn under the control of *.not. logical-array-expr*. Again, if any of these assignments affect entities in *logical-array-expr*, it is always the value obtained when the where statement is executed that is used as the mask. No array assignment in a where construct may be a branch target statement.

A simple example of a where construct is

```
where (pressure <= 1.0)
      pressure = pressure + inc_pressure
      temp = temp + 5.0
elsewhere
      raining = .true.
end where
```

where *pressure*, *inc_pressure*, *temp*, and *raining* are arrays of the same shape.

If a where statement or construct masks an elemental function reference, the function is called only for the wanted elements. For example,

```
where ( a > 0 ) a = log(a) ! log is defined in Section 8.4
```

would not lead to erroneous calls of *log* for negative arguments.

This masking applies to all elemental function references except any that are within an argument of a non-elemental function reference. The masking does not extend to array arguments of such a function. In general, such arguments have a different shape so that masking would not be possible, but the rule applies in such a case as

```
where (a > 0) a = a/sum(log(a)) ! sum is defined in Section 8.11
```

Here the logarithms of each of the elements of *a* are summed, and the statement will fail if they are not all positive.

If a non-elemental function reference or an array constructor is masked, it is fully evaluated before the masking is applied.

6.8.1 Some where construct extensions (Fortran 95 only)

In Fortran 95, it is permitted to mask not only the where statement of the where construct (Section 6.8), but also any elsewhere statement that it contains. The masking expressions involved must be of the same shape. A where construct may

contain any number of masked elsewhere statements but at most one elsewhere statement without a mask, and that must be the final one. In addition, where constructs may be nested within one another; the masking expressions of the nested constructs must be of the same shape, as must be the array variables on the left-hand sides of the assignments.

A where assignment statement is permitted to be a defined assignment, provided that it is elemental (Section 6.11).

Finally, a where construct may be named in the same way as other constructs. These extensions allow sequences like those in Figure 6.8.

Figure 6.8

```

assign_1: where (cond_1)      ! Fortran 95
          :
          ! masked by cond_1
      elsewhere (cond_2)
          :
          ! masked by
          :
          ! cond_2.and..not.cond_1
assign_2:   where (cond_4)
          :
          ! masked by
          :
          ! cond_2.and..not.cond_1.and.cond_4
      elsewhere
          :
          ! masked by
          :
          ! cond_2.and..not.cond_1.and..not.cond_4
      end where assign_2
      :
      elsewhere (cond_3) assign_1
          :
          ! masked by
          :
          ! cond_3.and..not.cond_1.and.not.cond_2
      elsewhere assign_1
          :
          ! masked by
          :
          ! not.cond_1.and..not.cond_2.and..not.cond_3
      end where assign_1

```

All the statements of a where construct are executed one by one in sequence, including the where and elsewhere statements. The logical array expressions in the where and elsewhere statements are evaluated once and control of subsequent assignments is not affected by changes to the values of these expressions. Throughout a where construct there is a control mask and a pending mask which change after the evaluation of each where, elsewhere, and end where statement, as illustrated in Figure 6.8.

6.9 The forall statement and construct (Fortran 95 only)

When a do construct such as

```
do i = 1, n
    a(i, i) = x(i)      ! a is rank-2 and x rank-1
end do
```

is executed, the processor is required to perform each successive iteration in order and one after the other. This represents a potentially severe impediment to optimization on a parallel processor so, for this purpose, Fortran 95 has the **forall** statement. The above loop can be written as

```
forall(i = 1:n) a(i, i) = x(i)      ! Fortran 95
```

which specifies that the individual assignments may be carried out in any order, and even simultaneously. The **forall** statement may be considered to be an array assignment expressed with the help of indices. In this particular example, we note also that this operation could not otherwise be represented as a simple array assignment. Other examples of the **forall** statement are

```
! Fortran 95
forall(i = 1:n, j = 1:m)           a(i, j) = i + j
forall(i = 1:n, j = 1:n, y(i, j) /= 0.) x(j, i) = 1.0/y(i, j)
```

where, in the second statement, we note the masking condition — the assignment is not carried out for zero elements of *y*.

The **forall** construct also exists. It allows several assignment statements to be executed in order. The **forall** equivalent of the array assignments

```
a(2:n-1, 2:n-1) = a(2:n-1, 1:n-2) + a(2:n-1, 3:n)  &
                  + a(1:n-2, 2:n-1) + a(3:n, 2:n-1)
b(2:n-1, 2:n-1) = a(2:n-1, 2:n-1)
```

is

```
forall(i = 2:n-1, j = 2:n-1)      ! Fortran 95
    a(i, j) = a(i, j-1) + a(i, j+1) + a(i-1, j) + a(i+1, j)
    b(i, j) = a(i, j)
end forall
```

This sets each internal element of *a* equal to the sum of its four nearest neighbours and copies the result to *b*. The **forall** version is more readable. Note that each assignment in a **forall** is like an array assignment; the effect is as if all the expressions were evaluated in any order, held in temporary storage, then all the assignments performed in any order. The first statement must fully complete before the second can begin.

A **forall** statement or construct may contain pointer assignments. An example is

```

type element
    character(32), pointer :: name
end type element
type(element)      :: chart(200)
character(32), target :: names(200)
:
           ! define names
forall(i =1:200)          ! Fortran 95
    chart(i)%name => names(i)
end forall

```

Note that there is no array syntax for performing, as in this example, an array of pointer assignments.

As with all constructs, `forall` constructs may be nested. The sequence

```

forall (i = 1:n-1)          ! Fortran 95
    forall (j = i+1:n)
        a(i, j) = a(j, i)      ! a is a rank-2 array
    end forall
end forall

```

assigns the transpose of the lower triangle of `a` to the upper triangle of `a`.

A `forall` construct can include a `where` statement or construct. Each statement of a `where` construct is executed in sequence. An example with a `where` statement is

```

forall (i = 1:n)          ! Fortran 95
    where ( a(i, :) == 0) a(i, :) = i
        b(i, :) = i / a(i, :)
    end forall

```

Here, each zero element of `a` is replaced by the value of the row index and, following this complete operation, the elements of the rows of `b` are assigned the reciprocals of the corresponding elements of `a` multiplied by the corresponding row index.

The complete syntax of the `forall` construct is

```

[name:] forall(index = lower:upper [:stride] & ! Fortran 95
    [, index = lower:upper [:stride]]... [,scalar-logical-expr] )
        [body]
    end forall [name]

```

where *index* is a named integer scalar variable. Its scope is that of the construct; that is, other variables may have the name but are separate and not accessible in the `forall`. The *index* may not be redefined within the construct. Within a nested construct, each *index* must have a distinct name. The expressions *lower*, *upper*, and *stride* (*stride* is optional but must be nonzero when present) are scalar integer expressions and form a sequence of values as for a section subscript (Section 6.13); they may not reference any *index* of the same statement but may reference

an *index* of an outer `forall`. Once these expressions have been evaluated, the *scalar-logical-expr*, if present, is evaluated for each combination of index values. Those for which it has the value `.true.` are active in each statement of the construct. The *name* is the optional construct name; if present, it must appear on both the `forall` and the `end forall` statements. The blank between the keywords `end` and `forall` is optional.

The *body* itself consists of one or more: assignment statements, pointer assignment statements, where statements or constructs, and further `forall` statements or constructs. The subobject on the left-hand side of each assignment in the *body* should reference each *index* of the constructs it is contained in as part of the identification of the subobject, whether it be a non-pointer variable or a pointer object.⁴ None of the statements in the *body* may be a branch target, for instance for a `go to` statement.

In the case of a defined assignment statement, the subroutine that is invoked must not reference any variable that becomes defined by the statement, nor any pointer object that becomes associated.

A `forall` construct whose body is a single assignment or pointer assignment statement may be written as a single `forall` statement.

Procedures may be referenced within the scope of a `forall`, both in the logical scalar expression that forms the optional mask or, directly or indirectly (for instance as a defined operation or assignment), in the body of the construct. *All such procedures must be pure* (see Section 6.10)

As in assignments to array sections (Section 6.13), it is not allowed to make a many-to-one assignment. The construct

```
forall (i = 1:10)           ! Fortran 95
    a(index(i)) = b(i)      ! a, b and index are arrays
end forall
```

is valid if and only if `index(1:10)` contains no repeated values. Similarly, it is not permitted to associate more than one target with the same pointer.

6.10 Pure procedures (Fortran 95 only)

In the description of functions in Section 5.10, we noted the fact that, although it is permissible to write functions with side-effects, this is regarded as undesirable. In fact, used within `forall` statements or constructs (Section 6.9), the possibility that a function or subroutine reference might have side-effects is a severe impediment to optimization on a parallel processor – the order of execution of the assignments could affect the results. In order to control this situation, it is possible for the

⁴This is not actually a requirement, but any missing *index* would need to be restricted to a single value to satisfy the requirements of the final paragraph of this section. For example, the statement

```
forall (i = i1:i2, j = j1:j2) a(j) = a(j) + b(i, j)
```

is valid only if `i1` and `i2` have the same value.

programmer to assert that a procedure has no side-effects by adding the **pure** keyword to the subroutine or function statement. In practical terms, this is an assertion that the procedure

- i) if a function, does not alter any dummy argument;
- ii) does not alter any part of a variable accessed by host or use association;
- iii) contains no local variable with the **save** attribute;
- iv) performs no operation on an external file (Chapters 9 and 10); and
- v) contains no **stop** statement.

To ensure that these requirements are met and that a compiler can easily check that this is so, there are the following further rules:

- i) any dummy argument that is a procedure and any procedure referenced must be pure and have an explicit interface;
- ii) the intent of a dummy argument must be declared unless it is a procedure or a pointer, and this intent must be **in** in the case of a function;
- iii) any procedure internal to a pure procedure must be pure; and
- iv) a variable that is accessed by host or use association or is an intent in dummy argument or any part of such a variable must not be the target of a pointer assignment statement; if it is of derived type with a pointer component, it must not be the right-hand side of an assignment; and it must not be associated as an actual argument with a dummy argument that is a pointer or has intent **out** or **inout**.

This last rule ensures that a local pointer cannot cause a side effect but unfortunately prevents benign uses such as aliasing (Section 6.15) for use within an expression.

The function in Figure 5.6 (Section 5.10) is pure, and this could be specified explicitly:

```
pure function distance(p, q)      ! Fortran 95
```

An external or dummy procedure that is used as a pure procedure must have an interface block that specifies it as pure. However, the procedure may be used in other contexts without the use of an interface block or with an interface block that does not specify it as pure. For example, this allows library procedures to be specified as pure without limiting them to be used as such.

The main reason for allowing pure subroutines is to be able to use a defined assignment in a **forall** statement or construct and so, unlike pure functions, they may have dummy arguments that have intent **out** or **inout** or the pointer attribute. Their existence also gives the possibility of making subroutine calls from within pure functions.

All the intrinsic functions (Chapter 8) are pure, and can thus be referenced freely within pure procedures. In addition, the elemental intrinsic subroutine `mvbits` (Section 8.8.3) is pure.

The `pure` attribute is given automatically to any procedure that has the `elemental` attribute (next section).

The complete set of options for the *prefix* of a function statement (Section 5.20) is

prefix-spec [*prefix-spec*] ... ! Fortran 95

where *prefix-spec* is `type`, `recursive`, `pure`, or `elemental`. A *prefix-spec* must not be repeated. A subroutine statement is permitted a similar prefix, except of course that `type` must not be present.

6.11 Elemental procedures (Fortran 95 only)

We have met already the notion of elemental intrinsic procedures (Section 6.6 and, later, Chapter 8) — those with scalar dummy arguments that may be called with array actual arguments provided that the array arguments have the same shape (that is, provided all the arguments are conformable). For a function, the shape of the result is the shape of the array arguments. Fortran 95 extends this to non-intrinsic procedures. This requires the `elemental` prefix on the function or subroutine statement. For example, we could make the function `add_intervals` of Section 3.8 elemental, as shown in Figure 6.9. This is enormously useful to the programmer who can get the same effect in Fortran 90 only by writing 22 versions, for ranks 0-0, 0-1, 1-0, 1-1, 0-2, 2-0, 2-2, ... 0-7, 7-0, 7-7, and is an aid to optimization on parallel processors.

Figure 6.9

```
elemental function add_intervals(a,b)      ! Fortran 95
    type(interval)           :: add_intervals
    type(interval), intent(in) :: a, b
    add_intervals%lower = a%lower + b%lower ! Production code
    add_intervals%upper = a%upper + b%upper ! would allow for
end function add_intervals                ! roundoff.
```

A procedure is not permitted to be both elemental and recursive.

An elemental procedure must satisfy all the requirements of a pure procedure (previous section); in fact, it automatically has the `pure` attribute. In addition, all dummy arguments and function results must be scalar variables without the `pointer` attribute. A dummy argument or its subobject may be used in a specification expression only as an argument to the intrinsic functions `bit_size`, `kind`, `len` or numeric inquiry functions of Section 8.7.2. An example is

```

elemental real function f(a)      ! Fortran 95
    real, intent(in)                      :: a
    real(selected_real_kind(precision(a)*2)) :: work
    :
end function f

```

This restriction prevents character functions yielding an array result with elements of varying character lengths and permits implementations to create array-valued versions that employ ordinary arrays internally. A simple example that would break the rule is

```

elemental function c(n)          ! Fortran 95
    character (len=n)   :: c      ! Invalid
    integer, intent(in) :: n
    real                 :: work(n) ! Invalid
    :
end function c

```

If this were allowed, a rank-one version would need to hold `work` as a ragged-edge array of rank two.

An interface block for an external or dummy procedure is required if the procedure itself is non-intrinsic and elemental. The interface must specify it as elemental. This is because the compiler may use a different calling mechanism in order to accommodate the array case efficiently. It contrasts with the case of pure procedures, where more freedom is permitted (see previous section).

For an elemental subroutine, if any argument is array valued, all the arguments with intent `inout` or `out` must be arrays. For example, we can make the subroutine `swap` of Figure 6.2 (Section 6.4) perform its task on arrays of any shape or size, as shown in Figure 6.10. Calling `swap` with an array and a scalar argument is obviously erroneous and is not permitted.

Figure 6.10

```

elemental subroutine swap(a, b)      ! Fortran 95
    real, intent(inout) :: a, b
    real                :: work
    work = a
    a = b
    b = work
end subroutine swap

```

If a generic procedure reference (Section 5.18) is consistent with both an elemental and a non-elemental procedure, the non-elemental procedure is invoked. For example, we might write versions of `add_intervals` (Figure 6.9) for arrays of rank one and rely on the elemental function for other ranks. In general, one must expect the elemental version to execute more slowly for a specific rank than the corresponding non-elemental version.

We note that an elemental procedure may not be used as an actual argument.

6.12 Array elements

In Section 2.10, we restricted the description of array elements to simple cases. In general, an array element is a scalar of the form

part-ref [%*part-ref*] ...

where *part-ref* is

part-name[(*subscript-list*)]

The last *part-ref* must have a *subscript-list*. The number of subscripts in each list must be equal to the rank of the array or array component, and each subscript must be a scalar integer expression whose value is within the bounds of its dimension of the array or array component. To illustrate this, take the type

```
type triplet
    real :: u
    real, dimension(3) :: du
    real, dimension(3,3) :: d2u
end type triplet
```

which was considered in Section 2.10. An array may be declared of this type:

```
type(triplet), dimension(10,20,30) :: tar
```

and

```
tar(n,2,n*n) ! n of type integer
```

is an array element. It is a scalar of type triplet and

```
tar(n, 2, n*n)%du
```

is a real array with

```
tar(n, 2, n*n)%du(2)
```

as one of its elements.

If an array element is of type character, it may be followed by a substring reference:

(*substring-range*)

for example,

```
page (k*k) (i+1:j-5) ! i, j, k of type integer.
```

By convention, such an object is called a substring rather than an array element.

Notice that it is the array *part-name* that the subscript list qualifies. It is not permitted to apply such a subscript list to an array designator unless the designator terminates with an array *part-name*. An array section, a function reference, or an array expression in parentheses must not be qualified by a subscript list.

6.13 Array subobjects

Array sections were introduced in Section 2.10 and provide a convenient way to access a regular subarray such as a row or a column of a rank-two array:

```
a(i, 1:n) ! Elements 1 to n of row i
a(1:m, j) ! Elements 1 to m of column j
```

For simplicity of description, we did not explain that one or both bounds may be omitted when the corresponding bound of the array itself is wanted, and that a stride other than one may be specified:

```
a(i, :) ! The whole of row i
a(i, 1:n:3) ! Elements 1, 4, ... of row i
```

Another form of section subscript is a rank-one integer expression. All the elements of the expression must be defined with values that lie within the bounds of the parent array's subscript. For example,

```
v( (/ 1, 7, 3, 2 /) )
```

is a section with elements $v(1)$, $v(7)$, $v(3)$, and $v(2)$, in this order. Such a subscript is called a *vector subscript*. If there are any repetitions in the values of the elements of a vector subscript, the section is called a *many-one section* because more than one element of the section is mapped onto a single array element. For example

```
v( (/ 1, 7, 3, 7 /) )
```

has elements 2 and 4 mapped onto $v(7)$. A many-one section must not appear on the left of an assignment statement because there would be several possible values for a single element. For instance, the statement

```
v( (/ 1, 7, 3, 7 /) ) = (/ 1, 2, 3, 4 /) ! Illegal
```

is not allowed because the values 2 and 4 cannot both be stored in $v(7)$. The extent is zero if the vector subscript has zero size.

When an array section with a vector subscript is an actual argument, it is regarded as an expression and the corresponding dummy argument must not be defined or redefined and must not have intent out or inout. We expect compilers to make a copy as a temporary regular array on entry but to perform no copy back on return. Also, an array section with a vector subscript is not permitted to be a pointer target, since allowing them would seriously complicate the mechanism that compilers would otherwise have to establish for pointers. For similar reasons, such an array section is not permitted to be an internal file (Section 9.6).

In addition to the regular and irregular subscripting patterns just described, the intrinsic circular shift function `cshift` (Section 8.13.5) provides a mechanism that manipulates array sections in a ‘wrap-round’ fashion. This is useful in handling the boundaries of certain types of periodic grid problems, although it is subject to

similar restrictions to those on vector subscripts. If an array $v(5)$ has the value $[1,2,3,4,5]$, then $cshift(v, 2)$ has the value $[3,4,5,1,2]$.

The general form of a subobject is

$part\text{-}ref[%part\text{-}ref] \dots [(substring\text{-}range)]$

where $part\text{-}ref$ now has the form

$part\text{-}name [(section\text{-}subscript\text{-}list)]$

where the number of section subscripts in each list must be equal to the rank of the array or array component. Each *section-subscript* is either a *subscript* (Section 6.12), a rank-one integer expression (vector subscript), or a *subscript-triplet* of the form

$[lower] : [upper] [: stride]$

where *lower*, *upper*, and *stride* are scalar integer expressions. If *lower* is omitted, the default value is the lower bound for this subscript of the array. If *upper* is omitted, the default value is the upper bound for this subscript of the array. If *stride* is omitted, the default value is one. The stride may be negative so that it is possible to take, for example, the elements of a row in reverse order by specifying a section such as

$a(i, 10:1:-1)$

The extent is zero if $stride > 0$ and $lower > upper$, or if $stride < 0$ and $lower < upper$. The value of *stride* must not be zero.

Normally, we expect the values of both *lower* and *upper* to be within the bounds of the corresponding array subscript. However, all that is required is that each value actually used to select an element is within the bounds. Thus,

$a(1, 2:11:2)$

is legal even if the upper bound of the second dimension of a is only 10.

The *subscript-triplet* specifies a sequence of subscript values,

$lower, lower + stride, lower + 2*stride, \dots$

going as far as possible without going beyond *upper* (above it when $stride > 0$ or below it when $stride < 0$). The length of the sequence for the i -th *subscript-triplet* determines the i -th extent of the array that is formed.

The rank of a *part-ref* with a *section-subscript-list* is the number of vector subscripts and subscript triplets that it contains. So far in this section, all the examples have been of rank one; by contrast, the ordinary array element

$a(1,7)$

is an example of a *part-ref* of rank zero, and the section

$a(:,1:7)$

is an example of a *part-ref* of rank two. The rank of a *part-ref* without a *section-subscript-list* is the rank of the object or component. A *part-ref* may be an array; for example,

`tar%du(2)`

for the array `tar` of Section 6.12 is an array section with elements `tar(1)%du(2)`, `tar(2)%du(2)`, `tar(3)%du(2)`, Being able to form sections in this way from arrays of derived type, as well as by selecting sets of elements, is a very useful feature of the language. A more prosaic example, given the specification

`type(person), dimension(1:50) :: my_group`

for the type `person` of Section 2.9, is the subobject `my_group%id` which is an integer array section of size 50.

Unfortunately, it is not permissible for more than one *part-ref* to be an array; for example, it is not permitted to write

`tar%du ! Illegal`

for the array `tar` of Section 6.12. The reason for this is that if `tar%du` were considered to be an array, its element (1,2,3,4) would correspond to

`tar(2,3,4)%du(1)`

which would be too confusing a notation.

The *part-ref* with nonzero rank determines the rank and shape of the subobject. If any of its extents is zero, the subobject itself has size zero. It is called an array section if the final *part-ref* has a *section-subscript-list* or another *part-ref* has a nonzero rank.

A *substring-range* may be present only if the last *part-ref* is of type character and is either a scalar or has a *section-subscript-list*. By convention, the resulting object is called a section rather than a substring. It is formed from the unqualified section by taking the specified substring of each element. Note that, if `c` is a rank-one character array,

`c(i:j)`

is the section formed from elements `i` to `j`; if substrings of all the array elements are wanted, we may write the section

`c(:)(k:1)`

An array section that ends with a component name is also called a *structure component*. Note that if the component is scalar, the section cannot be qualified by a trailing subscript list or section subscript list. Thus, using the example of Section 6.12,

`tar%u`

is such an array section and

```
tar(1, 2, 3)%u
```

is a component of a valid element of `tar`. The form

```
tar%u(1, 2, 3) ! not permitted
```

is not allowed.

Additionally, a *part-name* to the right of a *part-ref* with nonzero rank must not have the `pointer` attribute. This is because such an object would represent an array of pointers and require a very different implementation mechanism from that needed for an ordinary array. For example, consider the array

```
type(entry), dimension(n) :: rows ! n of type integer
```

for the type `entry` defined near the end of Section 6.5.2. If we were allowed to write the object `rows%next`, it would be interpreted as another array of size `n` and type `entry`, but its elements are likely to be stored without any regular pattern (each having been separately given storage by an `allocate` statement) and indeed some will be null if any of the pointers are disassociated. Note that there is no problem over accessing individual pointers such as `rows(i)%next`.

6.14 Arrays of pointers

Although arrays of pointers as such are not allowed in Fortran, the equivalent effect can be achieved by creating a type containing a pointer component. For example, a lower-triangular matrix may be held by using a pointer for each row. Consider the type

```
type row
    real, dimension(:, ), pointer :: r
end type row
```

and the arrays

```
type(row), dimension(n) :: s, t ! n of type integer
```

Storage for the rows can be allocated thus

```
do i = 1, n ! i of type integer.
    allocate (t(i)%r(1:i)) ! Allocate row i of length i.
end do
```

The array assignment

```
s = t
```

would then be equivalent to the pointer assignments

```
s(i)%r => t(i)%r
```

for all the components.

A type containing just a pointer component is useful also when constructing a linked list that is more complicated than the chain described in Section 2.13. For instance, if a variable number of links are needed at each entry, the recursive type entry of Figure 2.3 might be expanded to the pair of types:

```
type ptr
    type(entry), pointer :: point
end type ptr
type entry
    real             :: value
    integer          :: index
    type(ptr), pointer :: children(:)
end type entry
```

After appropriate allocations and pointer associations, it is then possible to refer to the index of child j of node as

```
node%children(j)%point%index
```

This extra level of indirection is necessary because the individual elements of children do not, themselves, have the pointer attribute – this is a property only of the whole array. For example, we can take two existing nodes, say a and b, each of which is a tree root, and make a big tree thus

```
tree%children(1)%point => a
tree%children(2)%point => b
```

which would not be possible with the original type entry.

6.15 Pointers as aliases

If an array section without vector subscripts, such as

```
table(m:n, p:q)
```

is wanted frequently while the integer variables m, n, p, and q do not change their values, it is convenient to be able to refer to the section as a named array such as

```
window
```

Such a facility is provided in Fortran by pointers and the pointer assignment statement. Here window would be declared thus

```
real, dimension(:, :), pointer :: window
```

and associated with table, which must of course have the target or pointer attribute, by the execution of the statement

```
window => table(m:n, p:q)
```

If, later on, the size of `window` needs to be changed, all that is needed is another pointer assignment statement. Note, however, that the subscript bounds for `window` in this example are $(1:n-m+1, 1:q-p+1)$ since they are as provided by the functions `lbound` and `ubound` (Section 8.12.2).

The facility provides a mechanism for subscripting or sectioning arrays such as

`tar%u`

where `tar` is an array and `u` is a scalar component, discussed in Section 6.13. Here we may perform the pointer association

`taru => tar%u`

if `taru` is a rank-three pointer of the appropriate type. Subscripting as in

`taru(1, 2, 3)`

is then permissible. Here the subscript bounds for `taru` will be those of `tar`.

6.16 Array constructors

The syntax that we introduced in Section 2.10 for array constants may be used to construct more general rank-one arrays. The general form of an *array-constructor* is

`(/ array-constructor-value-list /)`

where each *array-constructor-value* is one of *expr* or *constructor-implied-do*. The array thus constructed is of rank one with its sequence of elements formed from the sequence of scalar expressions and elements of the array expressions in array element order. A *constructor-implied-do* has the form

`(array-constructor-value-list, variable = expr1, expr2 [,expr3])`

where *variable* is a named integer scalar variable, and *expr1*, *expr2*, and *expr3* are scalar integer expressions. Its interpretation is as if the *array-constructor-value-list* had been written

`max ((expr2 - expr1 + expr3)/expr3, 0)`

times, with *variable* replaced by *expr1*, *expr1+expr3*, ..., as for the do construct (Section 4.5). A simple example is

`(/ (i,i=1,10) /)`

which is equal to

`(/ 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 /)`

Note that the syntax permits nesting of one *constructor-implied-do* inside another, as in the example

```
(/ ((i,i=1,3), j=1,3) /)
```

which is equal to

```
(/ 1, 2, 3, 1, 2, 3, 1, 2, 3 /)
```

and the nesting of structure constructors within array constructors (and vice versa), for instance, for the type in Section 6.7,

```
(/ (matrix(0.0), i = 1, 100) /)
```

The sequence may be empty, in which case a zero-sized array is constructed. The scope of the *variable* is the *constructor-implied-do*. Other statements, or even other parts of the array constructor, may refer to another variable having the same name. The value of the other variable is unaffected by execution of the array constructor and is available except within the *constructor-implied-do*.

The type and type parameters of an array constructor are those of the first *expr*, and each *expr* must have the same type and type parameters. If every *expr*, *expr1*, *expr2*, and *expr3* is a constant expression, the array constructor is a constant expression.

An array of rank greater than one may be constructed from an array constructor by using the intrinsic function `reshape` (Section 8.13.3). For example,

```
reshape( source = (/ 1,2,3,4,5,6 /), shape = (/ 2,3 /) )
```

has the value

1	3	5
2	4	6

6.17 Mask arrays

Logical arrays are needed for masking in `where` statements and constructs (Section 6.8), and they play a similar role in many of the array intrinsic functions (Chapter 8). Often, such arrays are large, and there may be a worthwhile storage gain from using non-default logical types, if available. For example, some processors may use bytes to store elements of `logical(kind=1)` arrays, and bits to store elements of `logical(kind=0)` arrays. Unfortunately, there is no *portable* facility to specify such arrays, since there is no intrinsic function comparable to `selected_int_kind` and `selected_real_kind`.

Logical arrays are formed implicitly in certain expressions, usually as compiler-generated temporary variables. In

```
where (a > 0.0) a = 2.0 * a
```

or

```
if (any(a > 0.0)) then ! any is described in Section 8.11.1.
```

the expression `a > 0.0` is a logical array. In such a case, an optimizing compiler can be expected to choose a suitable kind type parameter for the temporary array.

6.18 Summary

We have explained that arrays may have zero size and that no special rules are needed for them. A dummy array may assume its shape from the corresponding actual argument. Storage for an array may be allocated automatically on entry to a procedure and automatically deallocated on return, or the allocation may be controlled in detail by the program. Functions may be array-valued either through the mechanism of an elemental reference that performs the same calculation for each array element (in Fortran 90, for intrinsic functions only), or through the truly array-valued function. Array assignments may be masked through the use of the where statement and construct. Structure components may be arrays if the parent is an array or the component is an array, but not both. A subarray may either be formulated directly as an array section, or indirectly by using pointer assignment to associate it with a pointer. An array may be constructed from a sequence of expressions. A logical array may be used as a mask.

Basically, the whole of the contents of this chapter represents features new since Fortran 77, and is a hallmark of Fortran 90/95. The intrinsic functions are an important part of the array features and will be described in Chapter 8.

We conclude this chapter with a complete program, Figures 6.12 & 6.13, that illustrates the use of array expressions, array assignments, allocatable arrays, automatic arrays, and array sections. The module `linear` contains a subroutine for solving a set of linear equations, and this is called from a main program that prompts the user for the problem and then solves it.

Figure 6.12

```

module linear
    integer, parameter, public :: kind=selected_real_kind(10)
    public :: solve

contains
    subroutine solve(a, piv_tol, b, ok)
        ! arguments
        real(kind), intent(inout), dimension(:, :) :: a
            ! The matrix a.
        real(kind), intent(in) :: piv_tol
            ! Smallest acceptable pivot.
        real(kind), intent(inout), dimension(:) :: b
            ! The right-hand side vector on
            ! entry. Overwritten by the solution.
        logical, intent(out)      :: ok
            ! True after a successful entry
            ! and false otherwise.

        ! Local variables
        integer :: i      ! Row index.
        integer :: j      ! Column index.
        integer :: n      ! Matrix order.
        real(kind), dimension(size(b)) :: row
            ! Automatic array needed for workspace;
            ! size is described in Section 8.12.2.
        real(kind) :: element ! Workspace variable.

        n = size(b)
        ok = size(a, 1) == n .and. size(a, 2) == n
        if (.not.ok) then
            return
        end if

        do j = 1, n
            ! Update elements in column j.
            do i = 1, j - 1
                a(i+1:n, j) = a(i+1:n, j) - a(i,j) * a(i+1:n, i)
            end do

            ! Find pivot and check its size (using maxval just to
            ! obtain a scalar).
            i = maxval(maxloc(abs(a(j:n, j)))) + j - 1
                ! maxval and maxloc are in Sections 8.11.1 and 8.14.
            if (abs(a(i, j)) < piv_tol) then
                ok = .false.
                return
            end if
        end do
    end subroutine solve
end module linear

```

Figure 6.13

```

! If necessary, apply row interchange
  if (i/=j) then
    row = a(j, :); a(j, :) = a(i, :); a(i, :) = row
    element = b(j); b(j) = b(i); b(i) = element
  end if

! Compute elements j+1 : n of j-th column.
  a(j+1:n, j) = a(j+1:n, j)/a(j, j)
end do

! Forward substitution
do i = 1, n-1
  b(i+1:n) = b(i+1:n) - b(i)*a(i+1:n, i)
end do

! Back-substitution
do j = n, 1, -1
  b(j) = b(j)/a(j, j)
  b(1:j-1) = b(1:j-1) - b(j)*a(1:j-1, j)
end do
end subroutine solve
end module linear

program main
  use linear
  integer :: i, n
  real(kind), allocatable :: a(:, :), b(:)
  logical :: ok

  print *, ' Matrix order?'
  read *, n
  allocate ( a(n, n), b(n) )
  do i = 1, n
    write(*,'(a, i2, a)') ' Elements of row ', i, ' of a?'
    ! Edit descriptors are described in Section 9.13
    read *, a(i,:)
    write(*,'(a, i2, a)') ' Component ', i, ' of b?'
    read *, b(i)
  end do

  call solve(a, maxval(abs(a))*1.0e-10, b, ok)
  if (ok) then
    write(*, '(/,a,/,5f12.4)') ' Solution is', b
  else
    print *, ' The matrix is singular'
  end if
end program main

```

6.19 Exercises

1. Given the array declaration

```
real, dimension(50,20) :: a
```

write array sections representing

- i) the first row of a;
- ii) the last column of a;
- iii) every second element in each row and column;
- iv) as for (iii) in reverse order in both dimensions;
- v) a zero-sized array.

2. Write a where statement to double the value of all the positive elements of an array z.

3. Write an array declaration for an array j which is to be completely defined by the statement

```
j = (/ (3, 5, i=1,5), 5,5,5, (i, i = 5,3,-1 ) /)
```

4. Classify the following arrays:

```
subroutine example(n, a, b)
    real, dimension(n, 10) :: w
    real                  :: a(:), b(0:)
    real, pointer          :: d(:, :)
```

5. Write a declaration and a pointer assignment statement suitable to reference as an array all the third elements of component du in the elements of the array tar having all three subscript values even (Section 6.12).

6. Given the array declarations

```
integer, dimension(100, 100), target :: l, m, n
integer, dimension(:, :, ), pointer   :: ll, mm, nn
```

rewrite the statements

```
l(j:k+1, j-1:k) = l(j:k+1, j-1:k) + l(j:k+1, j-1:k)
l(j:k+1, j-1:k) = m(j:k+1, j-1:k) + n(j:k+1, j-1:k) + n(j:k+1, j:k+1)
```

as they could appear following execution of the statements

```
ll => l(j:k+1, j-1:k)
mm => m(j:k+1, j-1:k)
nn => n(j:k+1, j-1:k)
```

7. Complete Exercise 1 of Chapter 4 using array syntax instead of do constructs.

8. Write a module to maintain a data structure consisting of a linked list of integers, with the ability to add and delete members of the list, efficiently.

9. Write a module that contains the example in Figure 6.7 (Section 6.7) as a module procedure and supports the defined operations and assignments that it contains.

7. Specification statements

7.1 Introduction

In the preceding chapters we have learnt the elements of the Fortran language, how they may be combined into expressions and assignments, how we may control the logic flow of a program, how to divide a program into manageable parts, and have considered how arrays may be processed. We have seen that this knowledge is sufficient to write programs, when combined with a rudimentary print statement and with the end statement.

Already in Chapters 2 to 6, we met some specification statements when declaring the type and other properties of data objects, but to ease the reader's task we did not always explain all the available options. In this chapter we fill this gap. To begin with, however, it is necessary to recall the place of specification statements in a programming language. A program is processed by a computer in (usually) three stages. In the first stage, *compilation*, the source code (text) of the program is read and processed by a program known as a *compiler* which analyses it, and generates a file containing *object code*. Each program unit of the complete program is usually processed separately. The object code is a translation of the source code into a form which can be understood by the computer hardware, and contains the precise instructions as to what operations the computer is to perform. In the second stage of processing, the object code is placed in the relevant part of the computer's storage system by a program often known as a loader which prepares it for the next stage; during this second stage, the separate program units are linked to one another, that is joined to form a complete executable program. The third stage consists of the *execution*, whereby the coded instructions are performed and the results of the computations made available.

During the first stage, the compiler requires information about the entities involved. This information is provided at the beginning of each program unit or subprogram by specification statements. The description of most of these is the subject of this chapter. The specification statements associated with procedure interfaces, including interface blocks and the interface statement and also the external statement, were explained in Chapter 5. The intrinsic statement is explained in Chapter 8. The statements connected with storage association (common, equivalence, and sequence) are deferred to Chapter 11.

7.2 Implicit typing

Many programming languages require that all typed entities have their types specified explicitly. Any data entity that is encountered in an executable statement without its type having been declared will cause the compiler to indicate an error. This, and a prohibition on mixing types, is known as *strong typing*. In the case of Fortran, an entity appearing in the code without having been explicitly typed is normally *implicitly* typed, being assigned a type according to its initial letter. The default in a program unit or an interface block is that entities whose names begin with one of the letters i,j,...,n are of type default integer, and variables beginning with the letters a,b,...,h or o,p,...,z are of type default real. This absence of strong typing can lead to program errors; for instance, if a variable name is misspelt, the misspelt name will give rise to a separate variable. For this reason, we recommend that implicit typing be avoided.

Implicit typing does not apply to an entity accessed by use or host association because its type is the same as in the module or the host.

If a different rule for implicit typing is desired in a given scoping unit, the `implicit` statement may be employed. For no implicit typing whatsoever, the statement

```
implicit none
```

is available (our recommendation), and for changing the mapping between the letters and the types, statements such as

```
implicit integer (a-h)
implicit real(selected_real_kind(10)) (r,s)
implicit type(entry) (u,x-z)
```

are available. The letters are specified as a list in which a set of adjacent letters in the alphabet may be abbreviated, as in a-h. No letter may appear twice in the implicit statements of a scoping unit and if there is an `implicit none` statement, there must be no other implicit statement in the scoping unit. For a letter not included in the implicit statements, the mapping between the letter and a type is the default mapping.

In the case of a scoping unit other than a program unit or an interface block, for example a module subprogram, the default mapping for each letter in an inner scoping unit is the mapping for the letter in the immediate host. If the host contains an `implicit none` statement, the default mapping is null and the effect may be that implicit typing is available for some letters, because of an additional implicit statement in the inner scope, but not for all of them. The mapping may be to a derived type even when that type is not otherwise accessible in the inner scoping unit because of a declaration there of another type with the same name.

Figure 7.1 provides a comprehensive illustration of the rules of implicit typing.

Figure 7.1

```

module example_mod
    implicit none
    :
    interface
        function fun(i)      ! i is implicitly
            integer :: fun   ! declared integer.
        end function fun
    end interface
contains
    function jfun(j)      ! All data entities must
        integer :: jfun, j ! be declared explicitly.
        :
    end function jfun
end module example_mod
subroutine sub
    implicit complex (c)
    c = (3.0,2.0)          ! c is implicitly declared complex.
    :
contains
    subroutine sub1
        implicit integer (a,c)
        c = (0.0,0.0) ! c is host associated and of type complex
        z = 1.0       ! z is implicitly declared real.
        a = 2         ! a is implicitly declared integer.
        cc = 1.0      ! cc is implicitly declared integer.
        :
    end subroutine sub1
    subroutine sub2
        z = 2.0       ! z is implicitly declared real and is
                      ! different from the variable z in sub1.
        :
    end subroutine sub2
    subroutine sub3
        use example_mod      ! Access the integer function fun.
        q = fun(k)           ! q is implicitly declared real and
                            ! k is implicitly declared integer.
        :
    end subroutine sub3
end subroutine sub

```

The general form of the `implicit` statement is

```
implicit none
```

or

```
implicit type (letter-spec-list) [,type (letter-spec-list)] ...
```

where `type` specifies the type and type parameters (Section 7.13) and each `letter-spec` is `letter [- letter]`.

The `implicit` statement may be used for a derived type. For example, given access to the type

```
type posn
    real :: x, y
    integer :: z
end type posn
```

and given the statement

```
implicit type(posn) (a,b), integer (c-z)
```

variables beginning with the letters `a` and `b` are implicitly typed `posn` and variables beginning with the letters `c,d,...,z` are implicitly typed `integer`.

An `implicit none` statement may be preceded within a scoping unit only by `use` (and `format`) statements, and other implicit statements may be preceded only by `use`, `parameter`, and `format` statements. We recommend that all `implicit` statements be at the start of the specifications, immediately following any `use` statements.

7.3 Declaring entities of differing shapes

So far, we have used separate type declaration statements such as

```
integer :: a, b
integer, dimension(10) :: c, d
integer, dimension(8,7) :: e
```

to declare several entities of the same type but differing shapes. In fact, Fortran permits the convenience of using a single statement. Whether or not there is a `dimension` attribute present, arrays may be declared by placing the shape information after the name of the array:

```
integer :: a, b, c(10), d(10), e(8, 7)
```

If the `dimension` attribute is present, it provides a default shape for the entities that are not followed by their own shape information, and is ignored for those that are:

```
integer, dimension(10) :: c, d, e(8, 7)
```

7.4 Named constants and constant expressions

Inside a program, we often need to define a constant or set of constants. For instance, in a program requiring repeated use of the speed of light, we might use a real variable *c* that is given its value by the statement

```
c = 2.99792458
```

A danger in this practice is that the value of *c* may be overwritten inadvertently, for instance because another programmer re-uses *c* as a variable to contain a different quantity, failing to notice that the name is already in use.

Another situation which can arise is that the program contains specifications such as

```
real :: x(10), y(10), z(10)
integer :: mesh(10, 10), ipoint(100)
```

where all the dimensions are 10 or 10². Such specifications may be used extensively, and 10 may even appear as an explicit constant, say as a parameter in a do-construct which processes these arrays:

```
do i = 1, 10
```

Later, it may be realised that the value 20 rather than 10 is required, and the new value must be substituted everywhere the old one occurs, an error-prone undertaking.

Yet another case was met in Section 2.6, where named constants were needed for kind type parameter values.

In order to deal with all of these situations, Fortran contains what are known as *named constants*. These may never appear on the left-hand side of an assignment statement, but may be used in expressions in any way in which a literal constant may be used. A type declaration statement may be used to specify such a constant:

```
real, parameter :: c = 2.99792458
```

The value is protected, as *c* is now the name of a constant and may not be used as a variable name in the same scoping unit. Similarly, we may write

```
integer, parameter :: length = 10
real :: x(length), y(length), z(length)
integer :: mesh(length, length), ipoint(length**2)
:
do i = 1, length
```

which has the clear advantage that in order to change the value of 10 to 20 only a single line need be modified, and the new value is then correctly propagated.

In this example, the expression *length**2* appeared in one of the array bound specifications. This is a particular example of a constant expression. A *constant expression* is an expression in which each operation is intrinsic, and each primary is

- i) a constant or a subobject of a constant,
- ii) an array constructor whose expressions (including bounds and strides) have primaries that are constant expressions,
- iii) a structure constructor whose components are constant expressions,
- iv) an elemental intrinsic function reference whose arguments are constant expressions,
- v) a transformational intrinsic function reference whose arguments are constant expressions,
- vi) a reference to an inquiry function (Section 8.1.2) other than present, associated, or allocated, where each argument is either a constant expression or a variable whose type parameters or bounds inquired about are neither assumed, defined by an expression that is not constant, defined by an allocate statement, nor defined by a pointer assignment,
- vii) an implied-do variable whose bounds and strides are constant expressions,
or
- viii) a constant expression enclosed in parentheses,

and where each subscript, section subscript, and substring bound is a constant expression. In Fortran 95, v) includes null.

Because the values of named constants are expected to be evaluated at compile time, the expressions permitted for their definition are restricted in their form. An *initialization expression* is a constant expression in which

- i) the exponentiation operator must have an integer power,
- ii) an elemental intrinsic function must have arguments and results of type integer or character, and
- iii) of the transformational functions, only repeat, reshape, selected_int_kind, selected_real_kind, transfer, and trim are permitted.

If an initialization expression invokes an inquiry function for a type parameter or an array bound of an object, the type parameter or array bound must be specified in a prior specification statement or to the left in the same specification statement.

In the definition of a named constant we may use any initialization expression, and the constant becomes defined with the value of the expression according to the rules of intrinsic assignment. This is illustrated by the example:

```
integer, parameter :: length=10, long=selected_real_kind(12)
real, parameter :: lsq = length**2
```

Note from this example that it is possible in one statement to define several named constants, in this case two, separated by commas.

A named constant may be an array, as in the case

```
real, dimension(3), parameter :: field = (/ 0.0, 10.0, 20.0 /)
```

For an array of rank greater than one, the reshape function described in Section 8.13.3 must be applied. A named constant may be of derived type, as in the case

```
type(posn), parameter :: a = posn(1.0,2.0,0)
```

for the type defined at the end of Section 7.2. Note that a subobject of a constant need not necessarily have a constant value. For example, if *i* is an integer variable, *field(i)* may have the value 0.0, 10.0, or 20.0. Note also that a constant may not be a pointer, allocatable array, dummy argument, or function result, since these are always variables.

Any named constant used in an initialization expression must either be accessed from the host, be accessed from a module, be declared in a preceding statement, or be declared to the left of its use in the same statement. An example using a constant expression including a named constant that is defined in the same statement is

```
integer, parameter :: apple = 3, pear = apple**2
```

Finally, there is an important point concerning the definition of a scalar named constant of type character. Its length may be specified as an asterisk and taken directly from its value, which obviates the need to count the length of a character string, and makes modifications to its definition much easier. An example of this is

```
character(len=*), parameter :: string = 'No need to count'
```

Unfortunately, there *is* a need to count when a character array is defined using an array constructor, since all the elements must be of the same length:

```
character(len=7), parameter, dimension(2) :: &
c=('/Metcalf', 'Reid   ')
```

would not be correct if the three blanks in 'Reid ' were removed.

The parameter attribute is an important means whereby constants may be protected from overwriting, and programs modified in a safe way. It should be used for these purposes on every possible occasion.

7.5 Initial values for variables

7.5.1 Initialization in type declaration statements

A variable may be assigned an initial value in a type declaration statement, simply by following the name of the variable by an initialization expression (Section 7.4), as in the examples:

```
real :: a = 0.0
real, dimension(3) :: b = (/ 0.0, 1.2, 4.5 /)
```

The initial value is defined by the value of the corresponding expression according to the rules of intrinsic assignment. The variable automatically acquires the `save` attribute (Section 7.9). It must not be a dummy argument, a pointer, an allocatable array, an automatic object, or a function result.

7.5.2 The data statement

An alternative way to specify an initial value for a variable is by the `data` statement. It has the general form

```
data object-list /value-list/ [[,] object-list /value-list/] ...
```

where *object-list* is a list of variables and *implied-do loops*; and *value-list* is a list of scalar constants and structure constructors. A simple example is

```
real :: a, b, c
integer :: i, j, k
data a,b,c/1.,2.,3./, i,j,k/1,2,3/
```

in which a variable *a* acquires the initial value 1., *b* the value 2., etc.

If any part of a variable is initialized in this way, the variable automatically acquires the `save` attribute. The variable must not be a dummy argument, an allocatable array, an automatic object, or a function result. It may be a pointer only in Fortran 95, and the corresponding value must be `null()`.

After any array or array section in *object-list* has been expanded into a sequence of scalar elements in array element order, there must be as many constants in each *value-list* as scalar elements in the corresponding *object-list*. Each scalar element is assigned the corresponding scalar constant.

Constants which repeat may be written once and combined with a scalar integer *repeat count* which may be a named or literal constant:

```
data i,j,k/3*0/
```

The value of the repeat count must be positive or zero. As an example consider the statement

```
data r(1:length)/length*0./
```

where *r* is a real array and *length* is a named constant which might take the value zero.

Arrays may be initialized in three different ways: as a whole, by element, or by an implied-do loop. These three ways are shown below for an array declared by

```
real :: a(5, 5)
```

Firstly, for the whole array, the statement

```
data a/25*1.0/
```

sets each element of a to 1.0.

Secondly, individual elements and sections of a may be initialized, as in

```
data a(1,1), a(3,1), a(1,2), a(3,3) /2*1.0, 2*2.0/
data a(2:5,4) /4*1.0/
```

in each of which only the four specified elements and the section are initialized. Each array subscript must be an initialization expression, as must any character substring subscript.

When the elements to be selected fall into a pattern which can be represented by do-loop indices, it is possible to write data statements a third way, like

```
data ((a(i,j), i=1,5,2), j=1,5) /15*0./
```

The general form of an implied-do loop is

$$(dlist, do-var = expr, expr[, expr])$$

where *dlist* is a list of array elements, scalar structure components, and implied-do loops, *do-var* is a named integer scalar variable, and each *expr* is a scalar integer expression. It is interpreted as for a do construct (Section 4.5) except that the do variable has the scope of the implied-do as in an array constructor (Section 6.16). A variable in an *expr* must be a *do-var* of an outer implied-do:

```
integer :: j, k
integer, parameter :: l=5, 12=((l+1)/2)**2
real :: a(l,l)
data ((a(j,k), k=1,j), j=1,1,2) / 12 * 1.0 /
```

This example sets to 1.0 the first element of the first row of a, the first three elements of the third row, and all the elements of the last row, as shown in Figure 7.2.

Figure 7.2 Result of an implied-do loop in a data statement.

1.0
.
1.0	1.0	1.0	.	.
.
1.0	1.0	1.0	1.0	1.0

The only variables permitted in subscript expressions in data statements are do indices of the same or an outer level loop, and all operations must be intrinsic.

An object of derived type may appear in a data statement. In this case, the corresponding value must be a structure constructor having an initialization expression for each component. Using the type definition of posn in Section 7.2, we can write

```
type(posn) :: position1, position2
data position1 /posn(2., 3., 0)/, position2%z /4/
```

In the examples given so far, the types and type parameters of the constants in a *value-list* have always been the same as the type of the variables in the *object-list*. This need not be the case, but they must be compatible for intrinsic assignment since the entity is initialized following the rules for intrinsic assignment. It is thus possible to write statements such as

```
data q/1/, i/3.1/, b/(0.,1.)/
```

(where b and q are real and i is integer). Integer values may be binary, octal, or hexadecimal constants (Section 2.6.1).

Each variable must either have been typed in a previous type declaration statement in the scoping unit, or its type is that associated with the first letter of its name according to the implicit typing rules of the scoping unit. In the case of implicit typing, the appearance of the name of the variable in a subsequent type declaration statement in the scoping unit must confirm the type and type parameters. Similarly, any array variable must have previously been declared as such.

No variable or part of a variable may be initialized more than once in a scoping unit.

We recommend using the type declaration statement rather than the data statement, but the data statement *must* be employed when only part of a variable is to be initialized.

7.5.3 Pointer initialization and the function null (Fortran 95 only)

In Fortran 90, the initial status of a pointer is always undefined. This is a most undesirable status since such a pointer cannot even be tested by the intrinsic function associated (Section 8.2). Fortran 95 allows pointers to be given the initial status of disassociated in a type declaration statement such as

```
real, pointer, dimension(:) :: vector => null() ! Fortran 95
```

or a data statement

```
real, pointer, dimension(:) :: vector
data vector/ null() / ! Fortran 95
```

This, of course, implies the save attribute, which applies to the pointer association status. The pointer must not be a dummy argument or function result.

Our recommendation is that all pointers be so initialized to reduce the risk of bizarre effects from the accidental use of undefined pointers. This is an aid too in writing code that avoids memory leaks.

The function null is a new intrinsic function (Section 8.15), whose simple form null(), as used in the above example, is almost always suitable since the attributes are immediately apparent from the context. For example, given the type entry of Section 6.5.2, the structure constructor

```
entry (0.0, 0, null()) ! Fortran 95
```

is available. Also, for a pointer vector, the statement

```
vector => null() ! Fortran 95
```

is equivalent to

```
nullify(vector)
```

The form with the argument is needed when `null` is an actual argument in a reference to a generic procedure and the type, type parameter, or rank is needed to resolve the reference (Section 5.18).

As in Fortran 90, there is no mechanism to initialize a pointer as associated.

7.5.4 Default initialization of components (Fortran 95 only)

Means are available in Fortran 95 to specify that any object of a derived type is given a default initial value for a component. The value must be specified when the component is declared as part of the type definition (Section 2.9). If the component is not a pointer, this is done in the usual way (Section 7.5.1) with the equal sign followed by an initialization expression and the rules of intrinsic assignment apply (including specifying a scalar value for all the elements of an array component). If the component is a pointer, the only initialization allowed is the pointer assignment symbol followed by `null()`.

Initialization does not have to apply to all components of a given derived type. An example for the type defined in Section 6.5.2 is

```
type entry
    real :: value = 2.0
    integer :: index
    type(entry), pointer :: next => null() ! Fortran 95
end type entry
```

Given an array declaration such as

```
type(entry), dimension(100) :: matrix
```

subobjects such as `matrix(3)%value` will have the initial value 2.0, and the reference `associated(matrix(3)%next)` will return the value false.

For an object of a nested derived type, the initializations associated with components at all levels are recognized. For example, given the specifications

```
type node
    integer :: counter
    type(entry) :: element
end type node
type (node) :: n
```

the component `n%element%value` will have the initial value 2.0.

Unlike explicit initialization in a type declaration or data statement, default initialization does not imply that the objects have the `save` attribute. However, an object of such a type that is declared in a module is required to have the `save` attribute unless it is a pointer or an allocatable array. This is because of the difficulty that some implementations would have with determining when a non-saved object would need to be re-initialized.

Objects may still be explicitly initialized in a type declaration statement, as in

```
type(entry), dimension(100) :: matrix=entry(huge(0.0), &
                                         huge(0),null()) ! Fortran 95
```

in which case the default initialization is ignored. Similarly, default initialization may be overridden in a nested type definition such as

```
type node
    integer      :: counter
    type(entry) :: element=entry(0.0, 0 , null()) ! Fortran 95
end type node
```

However, no part of a non-pointer object with default initialization is permitted in a data statement (subsection 7.5.2).

As well as applying to the initial values of static data, default initialization also applies to any data that is dynamically created during program execution. This includes allocation with the `allocate` statement. For example, the statement

```
allocate (matrix(1)%next)
```

creates a partially initialized object of type `entry`. It also applies to automatic objects and to dummy arguments with intent `out`. It applies even if the type definition is `private` or the components are `private`.

7.6 The public and private attributes

Modules (Section 5.5) permit specifications to be ‘packaged’ into a form that allows them to be accessed elsewhere in the program. So far, we have assumed that all the entities in the module are to be accessible, that is have the `public` attribute, but sometimes it is desirable to limit the access. For example, several procedures in a module may need access to a work array containing the results of calculations that they have performed. If access is limited to only the procedures of the module, there is no possibility of an accidental corruption of these data by another procedure and design changes can be made within the module without affecting the rest of the program. In cases where entities are not to be accessible outside their own module, they may be given the `private` attribute.

These two attributes may be specified with the `public` and `private` attributes on type declaration statements in the module, as in

```
real, public    :: x, y, z
integer, private :: u, v, w
```

or in **public** and **private** statements, as in

```
public :: x, y, z, operator(.add.)
private :: u, v, w, assignment(=), operator(*)
```

which have the general forms

```
public [ [ :: ] access-id-list]
private [ [ :: ] access-id-list]
```

where *access-id* is a name or a *generic-spec* (Section 5.18).

Note that if a procedure has a generic identifier, the accessibility of its specific name is independent of the accessibility of its generic identifier. One may be **public** while the other is **private**, which means that it is accessible only by its specific name or only by its generic identifier.

If a **public** or **private** statement has no list of entities, it confirms or resets the default. Thus the statement

```
public
```

confirms **public** as the default value, and the statement

```
private
```

sets the default value for the module to **private** accessibility. For example,

```
private
public :: means
```

gives the entity **means** the **public** attribute whilst all others are **private**. There may be at most one accessibility statement without a list in a scoping unit.

The entities that may be specified by name in **public** or **private** lists are named variables, procedures (including generic procedures), derived types, named constants, and namelist groups. Thus, to make a generic procedure name accessible but the corresponding specific names inaccessible, we might write

```
module example
  private specific_int, specific_real
  interface generic_name
    module procedure specific_int, specific_real
  end interface
contains
  subroutine specific_int(i)
  :
  subroutine specific_real(a)
  :
end module example
```

An entity with a type must not have the `public` attribute if its type is declared with the `private` attribute (because there is virtually nothing one can do with such an entity without access to its type). As we shall see in Section 7.10, the `public` and `private` attributes may be redefined for an entity accessed by use association but, here, we refer to the original declaration in such a context. This restriction is not needed when such a type is given the `private` attribute in another module that uses the first, since a subsequent use statement referencing an object of that type may be accompanied by an additional use statement for the original module that defines the type.

For similar reasons, if a module procedure has a dummy argument or function result of a type declared with the `private` attribute, the procedure must be given the attribute `private` and must not have a generic identifier that is `public`.

The use of the `private` statement for components of derived types in the context of defining an entity's access within a module will be described in Section 7.11.

The `public` and `private` attributes may appear only in the specifications of a module.

7.7 The pointer, target, and allocatable statements

For the sake of regularity in the language, there are statements for specifying the `pointer`, `target`, and `allocatable` attributes of entities. They take the forms:

```
pointer [::] object-name[(array-spec)]  
           [,object-name [(array-spec)]]...  
target [::] object-name[(array-spec)]  
           [,object-name [(array-spec)]]...
```

and

```
allocatable [::] array-name[(array-spec)]  
           [,array-name [(array-spec)]]...
```

as in

```
real      ::a, son, y  
allocatable :: a(:,:)  
pointer    :: son  
target     :: a, y(10)
```

We believe that it is much clearer to specify these attributes on the type declaration statements, and therefore do not use these forms.

7.8 The intent and optional statements

The `intent` attribute (Section 5.9) for a dummy argument that is not a dummy procedure or pointer may be specified in a type declaration statement or in an `intent` statement of the form

`intent(inout) [::] dummy-argument-name-list`

where *inout* is *in*, *out*, or *inout*. Examples are

```
subroutine solve (a, b, c, x, y, z)
    real :: a, b, c, x, y, z
    intent(in) :: a, b, c
    intent(out) :: x, y, z
```

The optional attribute (Section 5.13) for a dummy argument may be specified in a type declaration statement or in an optional statement of the form

`optional [::] dummy-argument-name-list`

An example is

```
optional :: a, b, c
```

The optional attribute is the only attribute which may be specified for a dummy argument that is a procedure.

Note that the intent and optional attributes may be specified only for dummy arguments.

7.9 The save attribute

Let us suppose that we wish to retain the value of a local variable in a subprogram, for example to count the number of times the subprogram is entered. We might write a section of code as in Figure 7.3. In this example, the local variables, *a* and *counter*, are initialized to zero, and it is assumed that their current values are available each time the subroutine is called. This is not necessarily the case. Fortran allows the computer system being used to ‘forget’ a new value, the variable becoming undefined on each return unless it has the save attribute. In Figure 7.3, it is sufficient to change the declaration of *a* to

```
real, save :: a
```

to be sure that its value is always retained between calls. This may be done for *counter*, too, but is not necessary as all variables with initial values acquire the save attribute automatically (Section 7.5).

A similar situation arises with the use of variables in modules (Section 5.5). On return from a subprogram that accesses a variable in a module, the variable becomes undefined unless the main program accesses the module, another subprogram in execution accesses the module, or the variable has the save attribute.

If a variable that becomes undefined has a pointer associated with it, the pointer’s association status becomes undefined.

The save attribute must not be specified for a dummy argument, a function result, or an automatic object (Section 6.4). It may be specified for a pointer, in which case the pointer association status is saved. It may be specified for an

Figure 7.3

```

subroutine any(x)
    real    :: a, x
    integer :: counter = 0 ! Initialize the counter
    :
    counter = counter + 1
    if (counter==1) then
        a = 0.0
    else
        a = a + x
    end if
    :

```

allocatable array, in which case the allocation status and value are saved. A saved variable in a recursive subprogram is shared by all instances of the subprogram.

An alternative to specifying the `save` attribute on a type declaration statement is the `save` statement:

`save [::] variable-name-list]`

A `save` statement with no list is equivalent to a list containing all possible names, and in this case the scoping unit must contain no other `save` statements and no `save` attributes in type declaration statements. Our recommendation is against this form of `save`. If a programmer tries to give the `save` attribute explicitly to an automatic object, a diagnostic will result. On the other hand, he or she might think that `save` without a list would do this too, and not get the behaviour intended. Also, there is a loss of efficiency associated with `save` on some processors, so it is best to restrict it to those objects for which it is really needed.

The `save` statement or `save` attribute may appear in the declaration statements in a main program but has no effect.

7.10 The `use` statement

In Section 5.5, we introduced the `use` statement in its simplest form

`use module-name`

which provides access to all the public named data objects, derived types, interface blocks, procedures, generic identifiers, and namelist groups in the module named. Any `use` statements must precede other specification statements in a scoping unit. The only attribute of an accessed entity that may be specified afresh is `public` or `private` (and this only in a module), but the entity may be included in one or more namelist groups (Section 7.15).

If access is needed to two or more modules that have been written independently, the same name may be used in more than one module. This is the main

reason for permitting accessed entities to be renamed by the *use* statement. Renaming is also available to resolve a name clash between a local entity and an entity accessed from a module, though our preference is to use a text editor or other tool to change the local name. With renaming, the *use* statement has the form

use module-name, rename-list

where each *rename* has the form

local-name => use-name

and refers to a public entity in the module that is to be accessed by a different local name.

As an example,

```
use stats_lib, sprod => prod
use maths_lib
```

makes all the public entities in both *stats_lib* and *maths_lib* accessible. If *maths_lib* contains an entity called *prod*, it is accessible by its own name while the entity *prod* of *stats_lib* is accessible as *sprod*.

Renaming is not needed if there is a name clash between two entities that are not required. A name clash is permitted if there is no reference to the name in the scoping unit.

A name clash is also permissible for a generic name that is required. Here, all generic interfaces accessed by the name are treated as a single concatenated interface block. This is true also for defined operators and assignments, where no renaming facility is available. In all these cases, any two procedures having the same generic identifier must differ as explained in Section 5.18. We imagine that this will usually be exactly what is needed. For example, we might access modules for interval arithmetic and matrix arithmetic, both needing the functions *sqrt*, *sin*, etc., the operators *+*, *-*, etc., and assignment, but for different types.

For cases where only a subset of the names of a module is needed, the only option is available, having the form

use module-name, only : [only-list]

where each *only* has the form

access-id

or

[local-name =>] use-name

where each *access-id* is a public entity in the module, and is either a *use-name* or a *generic-spec* (Section 5.18). This provides access to an entity in a module only if the entity is public and is specified as a *use-name* or *access-id*. Where a *use-name* is preceded by a *local-name*, the entity is known locally by the *local-name*. An example of such a statement is

```
use stats_lib, only : sprod => prod, mult
```

which provides access to `prod` by the local name `sprod` and to `mult` by its own name.

We would recommend that only one `use` statement for a given module be placed in a scoping unit, but more are allowed. If there is a `use` statement without an `only` qualifier, all public entities in the module are accessible and the *rename-lists* and *only-lists* are interpreted as if concatenated into a single *rename-list* (with the form `use-name` in an `only` list being treated as the rename `use-name => use-name`). If all the statements have the `only` qualification, only those entities named in one or more of the *only-lists* are accessible, that is all the *only-lists* are interpreted as if concatenated into a single *only-list*.

The form

```
use module-name, only :
```

might appear redundant. It is provided for the situation where a scoping unit calls a set of procedures that communicate with each other through shared data in a module. It ensures that the data are available throughout the execution of the scoping unit.

An `only` list will be rather clumsy if almost all of a module is wanted. The effect of an ‘except’ clause can be obtained by renaming unwanted entities. For example, if a large program (such as one written in Fortran 77) contains many external procedures, a good practice is to collect interface blocks for them all into a module that is referenced in each program unit for complete mutual checking. In an external procedure, we might then write:

```
use all_interfaces, except_this_one => name
```

to avoid having two explicit interfaces for itself (where `all_interfaces` is the module name and `name` is the procedure name).

When a module contains `use` statements, the entities accessed are treated as entities in the module. They may be given the `private` or `public` attribute explicitly or through the default rule in effect in the module.

An entity may be accessed by more than one local name. This is illustrated in Figure 7.4, where module `b` accesses `s` of module `a` by the local name `bs`; if a subprogram such as `c` accesses both `a` and `b`, it will access `s` by both its original name and by the name `bs`. Figure 7.4 also illustrates that an entity may be accessed by the same name by more than one route (see variable `t`).

A more direct way for an entity to be accessed by more than one local name is for it to appear more than once as a *use-name*. This is not a practice that we recommend.

Of course, all the local names of entities accessed from modules must differ from each other and from names of local entities. If a local entity is accidentally given the same name as an accessible entity from a module, this will be noticed at compile time if the local entity is declared explicitly (since no accessed entity may give any attribute locally, other than `private` or `public`, and that only in a

Figure 7.4

```

module a
    real :: s, t
    :
end module a
module b
    use a, bs => s
    :
end module b
subroutine c
    use a
    use b
    :
end subroutine c

```

module). However, if the local entity is intended to be implicitly typed (Section 7.2) and appears in no specification statements, then each appearance of the name will be taken, incorrectly, as a reference to the accessed variable. To avoid this, we recommend the use of

implicit none

in a scoping unit containing one or more use statements. For greater safety, the only option may be employed on a use statement to ensure that all accesses are intentional.

7.11 Derived-type definitions

When derived types were introduced in Section 2.9, some simple example definitions were given, but the full generality was not included. An example illustrating more features is

```

type, public :: lock
    private
    integer, pointer :: key(:)
    logical         :: state
end type lock

```

The general form (apart from redundant features, see Sections 11.2 and C.1.3) is

```

type [[,access]:: ] type-name
    [ private ]
    component-def-stmt
    [component-def-stmt] ...
end type [ type-name ]

```

Each *component-def-stmt* has the form

type [[,*component-attr-list*] ::]*component-decl-list*

where *type* specifies the type and type parameters (Section 7.13), each *component-attr* is either **pointer** or **dimension**(*bounds-list*), and each *component-decl* is

component-name [(*bounds-list*)][**char-len*]

or (Fortran 95 only)

component-name [(*bounds-list*)][**char-len*] [*comp-int*]

The meaning of **char-len* is explained in Section 7.13. If the *type* is a derived type and the **pointer** attribute is not specified, the type must be previously defined in the host scoping unit or accessible there by use or host association. If the **pointer** attribute is specified, the type may also be the one being defined (for example, the type entry of Section 2.13), or one defined elsewhere in the scoping unit.

A *type-name* must not be the same as the name of any intrinsic type or a derived type accessed from a module.

The bounds of an array component are declared by a *bounds-list* where each *bounds* is

:

for a pointer component (see example in Section 6.14) or

[*lower-bound*:] *upper-bound*

for a non-pointer component, and *lower-bound* and *upper-bound* are constant expressions that are restricted to specification expressions (Section 7.14). Similarly, the character length of a component of type character must be a constant specification expression. If there is a *bounds-list* attached to the *component-name*, this defines the bounds. If a **dimension** attribute is present in the statement, its *bounds-list* applies to any component in the statement without its own *bounds-list*.

Only if the host scoping unit is a module may the **access** qualifier or **private** statement appear. The **access** qualifier on a type statement may be **public** or **private** and specifies the accessibility of the type. If it is **private**, then the type name, the structure constructor for the type, any entity of the type, and any procedure with a dummy argument or function result of the type are all inaccessible outside the host module. The accessibility may also be specified in a **private** or **public** statement in the host. In the absence of both of these, the type takes the default accessibility of the host module. If a **private** statement appears for a type with **public** accessibility, the components of the type are inaccessible in any scoping unit accessing the host module, so that neither component selection nor structure construction are available there. Also, if any component is of a derived type that is **private**, the type being defined must be **private** or have **private** components.

We can thus distinguish three levels of access:

- i) all **public**, where the type and all its components are accessible;
- ii) a **public** type with **private** components, where the type is accessible but its components are hidden;
- iii) all **private**, where both the type and its components are used only within the host module, and are hidden to an accessing procedure.

Case ii) has, where appropriate, the advantage of enabling changes to be made to the type without in any way affecting the code in the accessing procedure. Case iii) offers this advantage and has the additional merit of not cluttering the name space of the accessing procedure. The use of **private** accessibility for the components or for the whole type is thus recommended whenever possible.

We note that even if two derived-type definitions are identical in every respect except their names, that entities of those two types are *not* equivalent and are regarded as being of different types. Even if the names, too, are identical, the types are different (unless they have the **sequence** attribute, a feature that we do not recommend and whose description is left to Section 11.2.1). If a type is needed in more than one program unit, the definition should be placed in a module and accessed by a **use** statement wherever it is needed. Having a single definition is far less prone to errors.

7.12 The type declaration statement

We have already met many simple examples of the declarations of named entities by **integer**, **real**, **complex**, **logical**, **character**, and **type(*type-name*)** statements. The general form is

type [[, *attribute*]... ::] *entity-list*

where *type* specifies the type and type parameters (Section 7.13), *attribute* is one of the following

parameter	dimension (<i>bounds-list</i>)
public	intent (<i>inout</i>)
private	optional
pointer	save
target	external
allocatable	intrinsic

and each *entity* is

object-name [(*bounds-list*)] [**char-len*] [=initialization-expr]

or

function-name [**char-len*]

or (Fortran 95 only)

pointer-name [(*bounds-list*)] [**char-len*] [=⇒*null()*]

The meaning of **char-len* is explained in Section 7.13; a *bounds-list* specifies the rank and possibly bounds of array-valued entities.

No attribute may appear more than once in a given type declaration statement. The double colon :: need not appear in the simple case without any *attributes* and without any =*initialization-expr*; for example

```
real a, b, c(10)
```

If the statement specifies a parameter attribute, =*initialization-expr* must appear.

If a pointer attribute is specified, the target, intent, external, and intrinsic attributes must not be specified. The target and parameter attributes may not be specified for the same entity, and the pointer and allocatable attributes may not be specified for the same array. If the target attribute is specified, neither the external nor the intrinsic attribute may also be specified.

If an object is specified with the intent or parameter attribute, this is shared by all its subobjects. The pointer attribute is not shared in this manner, but note that a derived-data type component may itself be a pointer. However, the target attribute is shared by all its subobjects, except for any that are pointer components.

The allocatable, parameter, or save attribute must not be specified for a dummy argument or function result.

The intent and optional attributes may be specified only for dummy arguments.

For a function result, specifying the external attribute is an alternative to the external statement (Section 5.11) for declaring the function to be external, and specifying the intrinsic attribute is an alternative to the intrinsic statement (Section 8.1.3) for declaring the function to be intrinsic. These two attributes are mutually exclusive.

Each of the attributes may also be specified in statements (such as save) that list entities having the attribute. This leads to the possibility of an attribute being specified explicitly more than once for a given entity, but this is not permitted. Our recommendation is to avoid such statements because it is much clearer to have all the attributes for an entity collected in one place.

7.13 Type and type parameter specification

We have used *type* to represent one of the following

```
integer [( [kind=] kind-value)]
real [( [kind=] kind-value)]
complex [( [kind=] kind-value)]
character [(actual-parameter-list)]
logical [( [kind=] kind-value) ]
type ( type-name )
```

in the function statement (Section 5.20), the implicit statement (Section 7.2), the component definition statement (Section 7.11), and the type declaration statement (Section 7.12). A *kind-value* must be an initialization expression (Section 7.4) and must have a value that is valid on the processor being used.

For character, each *actual-parameter* has the form

`[len=] len-value`

or

`[kind=] kind-value`

and provides a value for one of the parameters. It is permissible to omit *kind=* from a kind *actual-parameter* only when *len=* is omitted and *len-value* is both present and comes first, just as for an actual argument list (Section 5.13). Neither parameter may be specified more than once.

For a scalar named constant or for a dummy argument of a subprogram, a *len-value* may be specified as an asterisk, in which case the value is assumed from that of the constant itself or the associated actual argument. In both cases, the *len* intrinsic function (Section 8.6.1) is available if the actual length is required directly, for instance as a do construct iteration count. A combined example is

```
character(len=len(char_arg)) function line(char_arg)
    character(len=*) :: char_arg
    character(len=*), parameter :: char_const = 'page'
    if ( len(char_arg) < len(char_const) ) then
        :

```

A *len-value* that is not an asterisk must be a specification expression (Section 7.14). Negative values declare character entities to be of zero length.

In addition, it is possible to attach an alternative form of *len-value* to individual entities in a type declaration statement using the syntax *entity*char-len*, where *char-len* is either (*len-value*) or *len* and *len* is a scalar integer literal constant which specifies a length for the entity. The constant *len* must not have a kind type parameter specified for it. An illustration of this form is

```
character(len=8) :: word(4), point*1, text(20)*4
```

here, *word*, *point* and *text* have character length 8, 1, and 4, respectively. Similarly, the alternative form may be used for individual components in a component definition statement.

7.14 Specification expressions

Non-constant scalar integer expressions may be used to specify the array bounds (examples in Section 6.4) and character lengths of data objects in a subprogram, and of function results. Such an expression may depend only on data values that are defined on entry to the subprogram. Any variable referenced must not have

its type and type parameters specified later in the same sequence of specification statements, unless they are those implied by the implicit typing rules.

Array constructors and derived-type constructors are permitted. The expression may reference an inquiry function for an array bound or for a type parameter of an entity which either is accessed by use or host association, or is specified earlier in the same specification sequence, but not later in the sequence¹. An element of an array specified in the same specification sequence can be referenced only if the bounds of the array are specified earlier in the sequence². Such an expression is called a *specification expression*.

An array whose bounds are declared using specification expressions is called an *explicit-shape array*.

A variety of possibilities are shown in Figure 7.5.

Figure 7.5

```
subroutine sample(arr, value, string)
  use definitions ! Contains the real a
  real, dimension(:,:), intent(out) :: arr ! Assumed-shape array
  integer, intent(in)           :: value
  character(len=*), intent(in)  :: string ! Assumed length
  real, dimension(ubound(arr, 1)+5) :: x      ! Automatic array
  character(len=value+len(string)) :: cc     ! Automatic object
  integer, parameter :: pa2 =   &
                      selected_real_kind(2*precision(a))
  real(kind=pa2) :: z    ! Precision of z is at least twice
                        ! the precision of a
  :
```

The bounds and character lengths are not affected by any redefinitions or undefinitions of variables in the expressions during execution of the procedure.

7.14.1 Specification expression restrictions (Fortran 90 only)

In Fortran 90, references to non-intrinsic procedures are not permitted and intrinsic function references are limited to:

- an elemental function reference for which the arguments and result are of type integer or character,

¹This avoids such a case as

```
character (len=len(a)) :: fun
character (len=len(fun)) :: a
```

²This avoids such a case as

```
integer, parameter, dimension (j(1):j(1)+1) :: i = (/0,1/)
integer, parameter, dimension (i(1):i(1)+1) :: j = (/1,2/)
```

- a reference to `repeat`, `trim`, `transfer`, or `reshape` for which the arguments are of type `integer` or `character`,
- a reference to `selected_int_kind` or `selected_real_kind`,
- a reference to an inquiry function other than `present`, `associated`, or `allocated`, provided the quantity inquired about does not depend on an allocation or on a pointer assignment.

7.14.2 Specification functions (Fortran 95 only)

In Fortran 95, any of the intrinsic functions defined by the standard may be used in a specification expression. In addition, a non-intrinsic pure function may be used provided that such a function is neither an internal function nor recursive, it does not have a dummy procedure argument, and the interface is explicit. Functions that fulfil these conditions are termed *specification functions*. The arguments of a specification function when used in a specification expression are subject to the same restrictions as those on specification expressions themselves, except that they do not necessarily have to be scalar.

As the interfaces of specification functions must be explicit yet they cannot be internal functions,³ such functions are probably most conveniently written as module procedures.

This feature will be a great convenience for specification expressions that cannot be written as simple expressions. Here is an example,

```
function solve (a, ...           ! Fortran 95
    use matrix_ops
    type(matrix), intent(in) :: a
    :
    real                   :: work(wszie(a))
    :
```

where `matrix` is a type defined in the module `matrix_ops` and intended to hold a sparse matrix and its LU factorization:

```
type matrix      ! Fortran 95
    integer :: n ! Matrix order.
    integer :: nz ! Number of nonzero entries.
    logical :: new = .true. ! Whether this is a new,
                           ! unfactorized matrix.
    :
end type matrix
```

and `wszie` is a module procedure that calculates the required size of the array `work`:

³This prevents them enquiring, via host association, about objects being specified in the set of statements in which the specification function itself is referenced.

```

pure integer function wsize(a) ! Fortran 95
  type(matrix), intent(in) :: a
  wsize = 2*a%n + 2
  if(a%new) wsize = a%nz + wsize
end function wsize

```

7.15 The namelist statement

It is sometimes convenient to gather a set of variables into a single group, in order to facilitate input/output (I/O) operations on the group as a whole. The actual use of such groups is explained in Section 9.10. The method by which a group is declared is via the *namelist* statement which in its simple form has the syntax

namelist *namelist-spec*

where *namelist-spec* is

/namelist-group-name/ *variable-name-list*

The *namelist-group-name* is the name given to the group for subsequent use in the I/O statements. A variable named in the list must not be a dummy array with a non-constant bound, a variable with non-constant character length, an automatic object, an allocatable array, a pointer, or have a component at any depth of component selection that is a pointer or is inaccessible. An example is

```

real :: carpet, tv, brushes(10)
namelist /household_items/ carpet, tv, brushes

```

It is possible to declare several namelist groups in one statement, with the syntax

namelist *namelist-spec* [[,] *namelist-spec*] ...

as in the example

```
namelist /list1/ a, b, c /list2/ x, y, z
```

It is possible to continue a list within the same scoping unit by repeating the namelist name on more than one statement. Thus,

```

namelist /list/ a, b, c
namelist /list/ d, e, f

```

has the same effect as a single statement containing all the variable names in the same order. A namelist group object may belong to more than one namelist group.

If the type, type parameters, or shape of a namelist variable is specified in a specification statement in the same scoping unit, the specification statement must either appear before the *namelist* statement, or be a type declaration statement that confirms the implicit typing rule in force in the scoping unit for the initial letter of the variable. Also, if the namelist group has the *public* attribute, no variable in the list may have the *private* attribute or have private components.

Figure 7.6

```

module sort          ! To sort postal addresses by zip code.
  implicit none
  private
  public :: selection_sort
  integer, parameter :: string_length = 30
  type, public :: address
    character(len = string_length) :: name, street, town, &
                                      state*2
    .
    integer                         :: zip_code
  end type address
contains
  recursive subroutine selection_sort (array_arg)
    type (address), dimension (:), intent (inout)      &
                                              :: array_arg
    integer                                         :: current_size
    integer, dimension (1)                         :: big
    ! Result of maxloc (Section 8.14) is array valued
    current_size = size (array_arg)
    if (current_size > 0) then
      big = maxloc (array_arg(:)%zip_code)
      call swap (big(1), current_size)
      call selection_sort (array_arg(1: current_size - 1))
    end if
contains
  subroutine swap (i, j)
    integer, intent (in) :: i, j
    type (address)      :: temp
    temp = array_arg(i)
    array_arg(i) = array_arg(j)
    array_arg(j) = temp
  end subroutine swap
end subroutine selection_sort
end module sort

```

Figure 7.7

```

program zippy
    use sort
    implicit none
    integer, parameter :: array_size = 100
    type (address), dimension (array_size) :: data_array
    integer :: i, n
    do i = 1, array_size
        read (*, '(/a/a/a/a2,i8)', end=10) data_array(i)
            ! For end= see Section 9.7;
        write (*, '(/a/a/a/a2,i8)') data_array(i)
    end do
        ! for editing see Section 9.13.
10 n = i - 1
    call selection_sort (data_array(1: n))
    write(*, '(/a')' ) 'after sorting:'
    do i = 1, n
        write (*, '(/a/a/a/a2,i8)' ) data_array(i)
    end do
end program zippy

```

7.16 Summary

In this chapter most of the specification statements of Fortran have been described. The following concepts have been introduced: implicit typing and its attendant dangers, named constants, constant expressions, data initialization, control of the accessibility of entities in modules, saving data between procedure calls, selective access of entities in a module, renaming entities accessed from a module, specification expressions that may be used when specifying data objects and function results, and the formation of variables into namelist groups. We have also explained alternative ways of specifying attributes.

The features described here that are new since Fortran 77 are `implicit none`; initialization and specification expressions; a much extended type declaration statement; `data` statement extended to include derived types, subobjects, and binary, octal, and hexadecimal constants; new attributes and statements: `public`, `private`, `pointer`, `allocatable`, `target`, `intent`, and `optional`; and the `use` and `namelist` statements.

We conclude this chapter with a complete program, Figures 7.6 and 7.7, that uses a module to sort US-style addresses (name, street, town, and state with a numerical zip code) by order of zip code. It illustrates the interplay between many of the features described so far, but note that it is not a production code since the sort routine is not very efficient and the full range of US addresses is not handled. Suitable test data are:

**Prof. James Bush,
206 Church St. SE,
Minneapolis,
MN 55455**

**J. E. Dougal,
Rice University,
Houston,
TX 77251**

**Jack Finch,
104 Ayres Hall,
Knoxville,
TN 37996**

7.17 Exercises

1. Write suitable type statements for the following quantities:

- i) an array to hold the number of counts in each of the 100 bins of a histogram numbered from 1 to 100;
- ii) an array to hold the temperature to two significant decimal places at points, on a sheet of iron, equally spaced at 1cm intervals on a rectangular grid 20cm square, with points in each corner (the melting point of iron is 1530° C);
- iii) an array to describe the state of 20 on/off switches;
- iv) an array to contain the information destined for a printed page of 44 lines each of 70 letters or digits.

2. Explain the difference between the following pair of declarations

`real :: i = 3.1`

and

`real, parameter :: i = 3.1`

What is the value of `i` in each case?

3. Write type declaration statements which initialize:

- i) all the elements of an integer array of length 100 to the value zero.
- ii) all the odd elements of the same array to 0 and the even elements to 1.
- iii) the elements of a real 10×10 square array to 1.0 .
- iv) a character string to the digits 0 to 9.

4. In the following module, identify all the scoping units and list the mappings for implicit typing for all the letters in all of them:

```

module mod
    implicit character(10, 2) (a-b)
    :
contains
    subroutine outer
        implicit none
        :
contains
    subroutine inner(fun)
        implicit complex (z)
        interface
            function fun(x)
                implicit real (f, x)
                :
            end function fun
        end interface
    end subroutine inner
end subroutine outer
end module mod

```

5.

- i) Write a type declaration statement that declares and initializes a variable of derived type `person` (Section 2.9).
- ii) Either
 - a. write a type declaration statement that declares and initializes a variable of type `entry` (Section 2.13), or
 - b. write a type declaration statement for such a variable and a `data` statement to initialize its non-pointer components.

6. Which of the following are initialization expressions:

- i) `kind(x)`, for `x` of type `real`
- ii) `selected_real_kind(6, 20)`
- iii) `1.7**2`
- iv) `1.7**2.0`
- v) `(1.7, 2.3)**(-2)`
- vi) `(/ (7*i, i=1, 10) /)`
- vii) `person("Reid", 25*2.0, 22**2)`
- viii) `entry(1.7, 1, null_pointer)`

8. Intrinsic procedures

8.1 Introduction

In a language that has a clear orientation towards scientific applications there is an obvious requirement for the most frequently required mathematical functions to be provided as part of the language itself, rather than expecting each user to code them afresh. When provided with the compiler, they are normally coded to be very efficient and will have been well tested over the complete range of values that they accept. It is difficult to compete with the high standard of code provided by the vendors.

The efficiency of the intrinsic procedures when handling arrays is likely to be particularly marked because a single call may cause a large number of individual operations to be performed, during the execution of which advantage may be taken of the specific nature of the hardware.

Another feature of a substantial number of the intrinsic procedures is that they extend the power of the language by providing access to facilities that are not otherwise available in the language. Examples are inquiry functions for the presence of an optional argument, the parts of a floating-point number, and the length of a character string.

There are over a hundred intrinsic procedures in all, a particularly rich set. They fall into distinct groups, which we describe in turn. A list in alphabetical order, with one-line descriptions, is given in Appendix A. Some processors may offer additional intrinsic procedures. Note that a program containing references to such procedures is portable only to other processors that provide those same procedures. In fact, it does not conform to the standard unless the access is through use association.

8.1.1 Keyword calls

The procedures may be called with keyword actual arguments, using the dummy argument names as keywords. This facility is not very useful for those with a single non-optional argument, but is useful for those with several optional arguments. For example

```
call date_and_time (date=d)
```

returns the date in the scalar character variable `d`. The rules for positional and keyword argument lists were explained in Section 5.13. In this chapter, the dummy arguments that are optional are indicated with square brackets. We have taken some ‘poetic licence’ with this notation, which might suggest to the reader that the positional form is permitted following an absent argument (this is not the case).

8.1.2 Categories of intrinsic procedures

There are four categories of intrinsic procedures:

- i) *Elemental procedures* are specified for scalar arguments, but may also be applied to conforming array arguments. In order that the rank always be known at compile time, at least one of the array arguments must correspond to a non-optional argument of the elemental procedure. In the case of an elemental function, each element of the result, if any, is as would have been obtained by applying the function to corresponding elements of each of the array arguments. In the case of an elemental subroutine with an array argument, each argument of intent out or inout must be an array, and each element is as would have resulted from applying the subroutine to corresponding elements of each of the array arguments.
- ii) *Inquiry functions* return properties of their principal arguments that do not depend on their values; indeed, for variables, their values may be undefined.
- iii) *Transformational functions* are functions that are neither elemental nor inquiry; they usually have array arguments and an array result whose elements depend on many of the elements of the arguments.
- iv) *Non-elemental subroutines*.

8.1.3 The intrinsic statement

A name may be specified to be that of an intrinsic procedure in an ***intrinsic*** statement, which has the general form

`intrinsic [:] intrinsic-name-list ! ::` in Fortran 95 only

where *intrinsic-name-list* is a list of intrinsic procedure names. A name must not appear more than once in the ***intrinsic*** statements of a scoping unit and must not appear in an external statement there (but may appear as a generic name on an interface block if an intrinsic procedure is being extended, see Section 5.18). We believe that it is good programming practice to include such a statement in every scoping unit that contains references to intrinsic procedures, because this makes the use clear to the reader. We particularly recommend it when referencing intrinsic procedures that are not defined by the standard, for then a clear diagnostic message should be produced if the program is ported to a processor that does not support the extra intrinsic procedures.

8.1.4 Argument intents

The functions do not change the values of their arguments. In fact, the non-pointer arguments all have the intent in. For the subroutines, the intents vary from case to case (see the descriptions given later in the chapter).

8.2 Inquiry functions for any type

The following are inquiry functions whose arguments may be of any type:

associated (pointer [,target]), when target is absent, returns the value true if the pointer pointer is associated with a target and false otherwise. The pointer association status of pointer must not be undefined. If target is present, it must have the same type, type parameters, and rank as pointer. The value is true if pointer is associated with target, and false otherwise. In the array case, true is returned only if the shapes are identical and corresponding array elements, in array element order, are associated with each other. If the character length or array size is zero, false is returned. A different bound, as in the case of associated(p,a) following the pointer assignment $p \Rightarrow a(:)$ when $\text{lbound}(a) = 0$, is insufficient to cause false to be returned. The argument target may itself be a pointer, in which case its target is compared with the target of pointer; the pointer association status of target must not be undefined and if either pointer or target is disassociated, the result is false .

present (a) may be called in a subprogram that has an optional dummy argument a or accesses such a dummy argument from its host. It returns the value true if the corresponding actual argument is present in the current call to it, and false otherwise. If an absent dummy argument is used as an actual argument in a call of another subprogram, it is regarded as also absent in the called subprogram.

There is an inquiry function whose argument may be of any intrinsic type:

kind (x) has type default integer and value equal to the kind type parameter value of x.

8.3 Elemental numeric functions

There are 17 elemental functions for performing simple numerical tasks, many of which perform type conversions for some or all permitted types of arguments.

8.3.1 Elemental functions that may convert

If kind is present in the following elemental functions, it must be a scalar integer initialization expression and provide a kind type parameter that is supported on the processor.

abs (a) returns the absolute value of an argument of type integer, real, or complex. The result is of type integer if a is of type integer and otherwise it is real. It has the same kind type parameter as a.

aimag (z) returns the imaginary part of the complex value z. The type is real and the kind type parameter is that of z.

aint (a [,kind]) truncates a real value a towards zero to produce a real that is a whole number. The value of the kind type parameter is the value of the argument kind if it is present, or that of a otherwise.

anint (a [,kind]) returns a real whose value is the nearest whole number to the real value a. The value of the kind type parameter is the value of the argument kind, if it is present, or that of a otherwise.

ceiling (a [,kind]) returns the least integer greater than or equal to its real argument. The optional argument kind is available in **Fortran 95 only**. If kind is present, the value of the kind type parameter of the result is the value of kind, otherwise it is that of the default integer type.

cmplx (x [,y] [,kind]) converts x or (x, y) to complex type with the value of the kind type parameter being the value of the argument kind if it is present or that of default complex otherwise. If y is absent, x may be of type integer, real, or complex. If y is present, it must be of type integer or real and x must be of type integer or real.

floor (a [,kind]) returns the greatest integer less than or equal to its real argument. The optional argument kind is available in **Fortran 95 only**. If kind is present, the value of the kind type parameter of the result is the value of kind, otherwise it is that of the default integer type.

int (a [,kind]) converts to integer type with the value of the kind type parameter being the value of the argument kind, if it is present, or that of the default integer otherwise. The argument a may be

- integer, in which case **int (a)=a**,
- real, in which case the value is truncated towards zero, or
- complex, in which case the real part is truncated towards zero.

nint (a [,kind]) returns the integer value that is nearest to the real a. If kind is present, the value of the kind type parameter of the result is the value of kind, otherwise it is that of the default integer type.

`real (a [,kind])` converts to real type with the value of the kind type parameter being that of kind if it is present. If kind is absent, the kind type parameter is that of default real when a is of type integer or real, and is that of a when a is type complex. The argument a may be of type integer, real, or complex. If it is complex, the imaginary part is ignored.

8.3.2 Elemental functions that do not convert

The following are elemental functions whose result is of type and kind type parameter that are those of the first or only argument. For those having more than one argument, all arguments must have the same type and kind type parameter.

`conjg (z)` returns the conjugate of the complex value z.

`dim (x, y)` returns $\max(x-y, 0.)$ for arguments that are both integer or both real.

`max (a1, a2 [,a3,...])` returns the maximum of two or more integer or real values.

`min (a1, a2 [,a3,...])` returns the minimum of two or more integer or real values.

`mod (a, p)` returns the remainder of a modulo p, that is $a - \text{int}(a/p)*p$. If p=0, the result is processor dependent. a and p must be both integer or both real.

`modulo (a, p)` returns a modulo p when a and p are both integer or both real, that is $a - \text{floor}(a/p)*p$ in the real case, and $a - \text{floor}(a \div p)*p$ in the integer case, where \div represents ordinary mathematical division. If p=0, the result is processor dependent.

`sign (a, b)` returns the absolute value of a times the sign of b. The arguments a and b must be both integer or both real. If b is zero, its sign is taken as positive. In Fortran 95 only, however, if b is real with the value zero and the processor can distinguish between a negative and a positive real zero, the result has the sign of b (see also Section 8.7.1).

8.4 Elemental mathematical functions

The following are elemental functions that evaluate elementary mathematical functions. The type and kind type parameter of the result are those of the first argument, which is usually the only argument.

`acos (x)` returns the arc cosine (inverse cosine) function value for real values x such that $|x| \leq 1$, expressed in radians in the range $0 \leq \text{acos}(x) \leq \pi$.

`asin (x)` returns the arc sine (inverse sine) function value for real values x such that $|x| \leq 1$, expressed in radians in the range $-\frac{\pi}{2} \leq \text{asin}(x) \leq \frac{\pi}{2}$.

`atan (x)` returns the arc tangent (inverse tangent) function value for real x , expressed in radians in the range $-\frac{\pi}{2} \leq \text{atan}(x) \leq \frac{\pi}{2}$.

`atan2 (y, x)` returns the arc tangent (inverse tangent) function value for pairs of reals, x and y , of the same type and type parameter. The result is the principal value of the argument of the complex number (x, y) , expressed in radians in the range $-\pi < \text{atan2}(y, x) \leq \pi$. The values of x and y must not both be zero.

`cos (x)` returns the cosine function value for an argument of type real or complex that is treated as a value in radians.

`cosh (x)` returns the hyperbolic cosine function value for a real argument x .

`exp (x)` returns the exponential function value for a real or complex argument x .

`log (x)` returns the natural logarithm function for a real or complex argument x .

In the real case, x must be positive. In the complex case, x must not be zero, and the imaginary part w of the result lies in the range $-\pi < w \leq \pi$.

`log10 (x)` returns the common (base 10) logarithm of a real argument whose value must be positive.

`sin (x)` returns the sine function value for a real or complex argument that is treated as a value in radians.

`sinh (x)` returns the hyperbolic sine function value for a real argument.

`sqrt (x)` returns the square root function value for a real or complex argument x . If x is real, its value must be not be negative. In the complex case, the real part of the result is not negative, and when it is zero the imaginary part of the result is not negative.

`tan (x)` returns the tangent function value for a real argument that is treated as a value in radians.

`tanh (x)` returns the hyperbolic tangent function value for a real argument.

8.5 Elemental character and logical functions

8.5.1 Character-integer conversions

The following are elemental functions for conversions from a single character to an integer, and vice-versa.

`achar (i)` is of type default character with length one and returns the character in the position in the ASCII collating sequence that is specified by the integer i . i must be in the range $0 \leq i \leq 127$, otherwise the result is processor dependent.

`char (i[,kind])` is of type character and length one, with a kind type parameter value that of the value of `kind` if present, or default otherwise. It returns the character in position `i` in the processor collating sequence associated with the relevant kind parameter. The value of `i` must be in the range $0 \leq i \leq n-1$, where `n` is the number of characters in the processor's collating sequence. If `kind` is present, it must be a scalar integer initialization expression and provide a kind type parameter that is supported on the processor.

`iachar (c)` is of type default integer and returns the position in the ASCII collating sequence of the default character `c`. If `c` is not in the sequence, the result is processor dependent.

`ichar (c)` is of type default integer and returns the position of the character `c` in the processor collating sequence associated with the kind parameter of `c`.

8.5.2 Lexical comparison functions

The following elemental functions accept default character strings as arguments, make a lexical comparison based on the ASCII collating sequence, and return a default logical result. If the strings have different lengths, the shorter one is padded on the right with blanks.

`lge (string_a, string_b)` returns the value true if `string_a` follows `string_b` in the ASCII collating sequence or is equal to it, and the value false otherwise.

`lgt (string_a, string_b)` returns the value true if `string_a` follows `string_b` in the ASCII collating sequence, and the value false otherwise.

`lle (string_a, string_b)` returns the value true if `string_b` follows `string_a` in the ASCII collating sequence or is equal to it, and the value false otherwise.

`llt (string_a, string_b)` returns the value true if `string_b` follows `string_a` in the ASCII collating sequence, and false otherwise.

8.5.3 String-handling elemental functions

The following are elemental functions that manipulate strings. The arguments `string`, `substring`, and `set` are always of type character, and where two are present have the same kind type parameter. The kind type parameter value of the result is that of `string`.

`adjustl (string)` adjusts left to return a string of the same length by removing all leading blanks and inserting the same number of trailing blanks.

`adjustr (string)` adjusts right to return a string of the same length by removing all trailing blanks and inserting the same number of leading blanks.

`index (string, substring [,back])` has type default integer and returns the starting position of `substring` as a substring of `string`, or zero if it does not occur as a substring. If `back` is absent or present with value false, the starting position of the first such substring is returned; the value 1 is returned if `substring` has zero length. If `back` is present with value true, the starting position of the last such substring is returned; the value `len(string)+1` is returned if `substring` has zero length.

`len_trim (string)` returns a default integer whose value is the length of `string` without trailing blank characters.

`scan (string, set [,back])` returns a default integer whose value is the position of a character of `string` that is in `set`, or zero if there is no such character. If the logical `back` is absent or present with value false, the position of the leftmost such character is returned. If `back` is present with value true, the position of the rightmost such character is returned.

`verify (string, set [,back])` returns the default integer value 0 if each character in `string` appears in `set`, or the position of a character of `string` that is not in `set`. If the logical `back` is absent or present with value false, the position of the left-most such character is returned. If `back` is present with value true, the position of the rightmost such character is returned.

8.5.4 Logical conversion

The following elemental function converts from a logical value with one kind type parameter to another.

`logical (1 [,kind])` returns a logical value equal to the value of the logical 1. The value of the kind type parameter of the result is the value of `kind` if it is present or that of default logical otherwise. If `kind` is present, it must be a scalar integer initialization expression and provide a kind type parameter that is supported on the processor.

8.6 Non-elemental string-handling functions

8.6.1 String-handling inquiry function

`len (string)` is an inquiry function that returns a scalar default integer holding the number of characters in `string` if it is scalar, or in an element of `string` if it is array valued. The value of `string` need not be defined.

8.6.2 String-handling transformational functions

There are two functions that cannot be elemental because the length type parameter of the result depends on the value of an argument.

`repeat (string, ncopies)` forms the string consisting of the concatenation of `ncopies` copies of `string`, where `ncopies` is of type integer and its value must not be negative. Both arguments must be scalar.

`trim (string)` returns `string` with all trailing blanks removed. The argument `string` must be scalar.

8.7 Numeric inquiry and manipulation functions

8.7.1 Models for integer and real data

The numeric inquiry and manipulation functions are defined in terms of a model set of integers and a model set of reals for each kind of integer and real data type implemented. For each kind of integer, it is the set

$$i = s \times \sum_{k=1}^q w_k \times r^{k-1}$$

where s is ± 1 , q is a positive integer, r is an integer exceeding one (usually 2), and each w_k is an integer in the range $0 \leq w_k < r$. For each kind of real, it is the set

$$x = 0$$

and

$$x = s \times b^e \times \sum_{k=1}^p f_k \times b^{-k}$$

where s is ± 1 , p and b are integers exceeding one, e is an integer in a range $e_{\min} \leq e \leq e_{\max}$, and each f_k is an integer in the range $0 \leq f_k < b$ except that f_1 is also nonzero.

Values of the parameters in these models are chosen for the processor so as best to fit the hardware with the proviso that all model numbers are representable. Note that it is quite likely that there are some machine numbers that lie outside the model. For example, many computers represent the integer $-r^q$, and the IEEE standard for Binary Floating-point Arithmetic (IEEE 754-1985 or IEC 60559:1989) contains reals with $f_1 = 0$ (called denormalized numbers) and register numbers with increased precision and range.

In Section 2.6, we noted that the value of a signed zero is regarded as being the same as that of an unsigned zero. However, many processors distinguish at the hardware level between a negative real zero value and a positive real zero value, and the IEEE standard makes use of this where possible. For example, when the exact result of an operation is nonzero but the rounding produces a zero, the sign is retained.

In Fortran 95, the two zeros are still treated identically in all relational operations, as input arguments to all intrinsic functions (except `sign`), or as the scalar expression in the arithmetic `if`-statement (Appendix C.2.1). However, the function `sign` (Section 8.3.2) has been generalized such that the sign of the second

argument may be taken into account even if its value is zero. On a processor that has IEEE arithmetic, the value of `sign(2.0, -0.0)` is -2.0. Also, a Fortran 95 processor is required to represent all negative numbers on output, including zero, with a minus sign.

8.7.2 Numeric inquiry functions

There are nine inquiry functions that return values from the models associated with their arguments. Each has a single argument that may be scalar or array-valued and each returns a scalar result. The value of the argument need not be defined.

`digits (x)`, for real or integer x , returns the default integer whose value is the number of significant digits in the model that includes x , that is p or q .

`epsilon (x)`, for real x , returns a real result with the same type parameter as x that is almost negligible compared with the value one in the model that includes x , that is b^{1-p} .

`huge (x)`, for real or integer x , returns the largest value in the model that includes x . It has the type and type parameter of x . The value is

$$(1 - b^{-p})b^{e_{\max}}$$

or

$$r^{q-1}$$

`maxexponent (x)`, for real x , returns the default integer e_{\max} , the maximum exponent in the model that includes x .

`minexponent (x)`, for real x , returns the default integer e_{\min} , the minimum exponent in the model that includes x .

`precision (x)`, for real or complex x , returns a default integer holding the equivalent decimal precision in the model representing real numbers with the same type parameter value as x . The value is

$$\text{int}((p - 1) * \log10(b)) + k,$$

where k is 1 if b is an integral power of 10 and 0 otherwise.

`radix (x)`, for real or integer x , returns the default integer that is the base in the model that includes x , that is b or r .

`range (x)`, for integer, real, or complex x , returns a default integer holding the equivalent decimal exponent range in the models representing integer or real numbers with the same type parameter value as x . The value is `int(log10(huge))` for integers and

```
int(min(log10(huge), -log10(tiny)))
```

for reals, where *huge* and *tiny* are the largest and smallest positive numbers in the models.

tiny (x), for real *x*, returns the smallest positive number

$$b^{e_{\min}-1}$$

in the model that includes *x*. It has the type and type parameter of *x*.

8.7.3 Elemental functions to manipulate reals

There are seven elemental functions whose first or only argument is of type real and that return values related to the components of the model values associated with the actual value of the argument.

exponent (x) returns the default integer whose value is the exponent part *e* of *x* when represented as a model number. If *x*=0, the result has value zero.

fraction (x) returns a real with the same type parameter as *x* whose value is the fractional part of *x* when represented as a model number, that is $x b^{-e}$.

nearest (x, s) returns a real with the same type parameter as *x* whose value is the nearest different machine number in the direction given by the sign of the real *s*. The value of *s* must not be zero.

rrspacing (x) returns a real with the same type parameter as *x* whose value is the reciprocal of the relative spacing of model numbers near *x*, that is $|x b^{-e}|b^p$.

scale (x, i) returns a real with the same type parameter as *x*, whose value is $x b^i$, where *b* is the base in the model for *x*, and *i* is of type integer.

set_exponent (x, i) returns a real with the same type parameter as *x*, whose fractional part is the fractional part of the model representation of *x* and whose exponent part is *i*, that is $x b^{i-e}$.

spacing (x) returns a real with the same type parameter as *x* whose value is the absolute spacing of model numbers near *x*. It is b^{e-p} if *x* is nonzero and this result is within range; otherwise, it is **tiny(x)**.

8.7.4 Transformational functions for kind values

There are two functions that return the least kind type parameter value that will meet a given numeric requirement. They have scalar arguments and results, so are classified as transformational.

`selected_int_kind (r)` returns the default integer scalar that is the kind type parameter value for an integer data type able to represent all integer values n in the range $-10^r < n < 10^r$, where r is a scalar integer. If more than one is available, a kind with least decimal exponent range is chosen (and least kind value if several have least decimal exponent range). If no corresponding kind is available, the result is -1.

`selected_real_kind ([p][, r])` returns the default integer scalar that is the kind type parameter value for a real data type with decimal precision (as returned by the function `precision`) at least p , and decimal exponent range (as returned by the function `range`) at least r . If more than one is available, a kind with the least decimal precision is chosen (and least kind value if several have least decimal precision). Both p and r are scalar integers; at least one of them must be present. If no corresponding kind value is available, the result is -1 if sufficient precision is unavailable, -2 if sufficient exponent range is unavailable, and -3 if both are unavailable.

8.8 Bit manipulation procedures

There are eleven procedures for manipulating bits held within integers. They are based on those in the US Military Standard MIL-STD 1753. They differ only in that here they are elemental, where appropriate, whereas the original procedures accepted only scalar arguments.

These intrinsics are based on a model in which an integer holds s bits w_k , $k = 0, 1, \dots, s - 1$, in a sequence from right to left, based on the non-negative value

$$\sum_{k=0}^{s-1} w_k \times 2^k$$

This model is valid only in the context of these intrinsics. It is identical to the model for integers in Section 8.7.1 when r is an integral power of 2 and $w_{s-1} = 0$, but when $w_{s-1} = 1$ the models do not correspond, and the value expressed as an integer may vary from processor to processor.

8.8.1 Inquiry function

`bit_size (i)` returns the number of bits in the model for bits within an integer of the same type parameter as i . The result is a scalar integer having the same type parameter as i .

8.8.2 Elemental functions

`btest (i, pos)` returns the default logical value true if bit pos of the integer i has value 1 and false otherwise. pos must be an integer with value in the range $0 \leq pos < \text{bit_size}(i)$.

iand (i, j) returns the logical and of all the bits in i and corresponding bits in j, according to the truth table

i	1	1	0	0
j	1	0	1	0
iand(i, j)	1	0	0	0

The arguments i and j must have the same type parameter value, which is the type parameter value of the result.

ibclr (i, pos) returns an integer, with the same type parameter as i, and value equal to that of i except that bit pos is cleared to 0. The argument pos must be an integer with value in the range $0 \leq pos < \text{bit_size}(i)$.

ibits (i, pos, len) returns an integer, with the same type parameter as i, and value equal to the len bits of i starting at bit pos right adjusted and all other bits zero. The arguments pos and len must be integers with non-negative values such that $pos+len \leq \text{bit_size}(i)$.

ibset (i, pos) returns an integer, with the same type parameter as i, and value equal to that of i except that bit pos is set to 1. The argument pos must be an integer with value in the range $0 \leq pos < \text{bit_size}(i)$.

ieor (i, j) returns the logical exclusive or of all the bits in i and corresponding bits in j, according to the truth table

i	1	1	0	0
j	1	0	1	0
ieor(i, j)	0	1	1	0

The arguments i and j must have the same type parameter value, which is the type parameter value of the result.

ior (i, j) returns the logical inclusive or of all the bits in i and corresponding bits in j, according to the truth table

i	1	1	0	0
j	1	0	1	0
ior(i, j)	1	1	1	0

The arguments i and j must have the same type parameter value, which is the type parameter value of the result.

ishft (i, shift) returns an integer, with the same type parameter as i, and value equal to that of i except that the bits are shifted shift places to the left (-shift places to the right if shift is negative). Zeros are shifted in from the other end. The argument shift must be an integer with value satisfying the inequality $|shift| \leq \text{bit_size}(i)$.

`ishftc (i, shift [, size])` returns an integer, with the same type parameter as `i`, and value equal to that of `i` except that the `size` rightmost bits (or all the bits if `size` is absent) are shifted circularly `shift` places to the left (`-shift` places to the right if `shift` is negative). The argument `shift` must be an integer with absolute value not exceeding the value of `size` (or `bit_size(i)` if `size` is absent).

`not (i)` returns the logical complement of all the bits in `i`, according to the truth table

<code>i</code>	0	1
<code>not(i)</code>	1	0

8.8.3 Elemental subroutine

`call mvbits (from, frompos, len, to, topos)` copies the sequence of bits in `from` that starts at position `frompos` and has length `len` to `to`, starting at position `topos`. The other bits of `to` are not altered. The arguments `from`, `frompos`, `len`, and `topos` are all integers with intent `in`, and they must have values that satisfy the inequalities: $\text{frompos} + \text{len} \leq \text{bit_size}(\text{from})$, $\text{len} \geq 0$, $\text{frompos} \geq 0$, $\text{topos} + \text{len} \leq \text{bit_size}(\text{to})$, and $\text{topos} \geq 0$. The argument `to` is an integer with intent `inout`; it must have the same kind type parameter as `from`. The same variable may be specified for `from` and `to`.

8.9 Transfer function

The transfer function allows data of one type to be transferred to another without the physical representation being altered. This would be useful, for example, in writing a data storage and retrieval system. The system itself could be written for one type, default integer say, and other types handled by transfers to and from that type, for example:

```
integer :: store
character(len=4) :: word ! To be stored and retrieved
:
store = transfer(word, store) ! Before storage
:
word = transfer(store, word) ! After retrieval
:
```

`transfer (source, mold [,size])` returns a result of type and type parameters those of `mold`. When `size` is absent, the result is scalar if `mold` is scalar, and it is of rank one and size just sufficient to hold all of `source` if `mold` is array-valued. When `size` is present, the result is of rank one and size `size`. If the physical representation of the result is as long as or longer than that

of source, the result contains source as its leading part and the rest is undefined; otherwise the result is the leading part of source. As the rank of the result can depend on whether or not size is specified, the corresponding actual argument must not itself be an optional dummy argument.

8.10 Vector and matrix multiplication functions

There are two transformational functions that perform vector and matrix multiplications. They each have two arguments that are both of numeric type (integer, real, or complex) or both of logical type. The result is of the same type and type parameter as for the multiply or and operation between two such scalars. The functions sum and any, used in the definitions, are defined in Section 8.11.1.

`dot_product (vector_a, vector_b)` requires two arguments each of rank one and the same size. If `vector_a` is of type integer or type real, it returns `sum(vector_a * vector_b)`; if `vector_a` is of type complex, it returns `sum(conjg(vector_a) * vector_b)`; and if `vector_a` is of type logical, it returns `any(vector_a .and. vector_b)`.

`matmul (matrix_a, matrix_b)` performs matrix multiplication. For numeric arguments, three cases are possible:

- i) `matrix_a` has shape (n, m) and `matrix_b` has shape (m, k) . The result has shape (n, k) and element (i, j) has the value
`sum(matrix_a(i, :) * matrix_b(:, j))`.
- ii) `matrix_a` has shape (m) and `matrix_b` has shape (m, k) . The result has shape (k) and element (j) has the value
`sum(matrix_a * matrix_b(:, j))`.
- iii) `matrix_a` has shape (n, m) and `matrix_b` has shape (m) . The result has shape (n) and element (i) has the value
`sum(matrix_a(i, :) * matrix_b)`.

For logical arguments, the shapes are as for numeric arguments and the values are determined by replacing ‘sum’ and ‘*’ in the above expressions by ‘any’ and ‘.and.’.

8.11 Transformational functions that reduce arrays

There are seven transformational functions that perform operations on arrays such as summing their elements.

8.11.1 Single argument case

In their simplest form, these functions have a single array argument and return a scalar result. All except count have a result of the same type and type parameter

as the argument. The mask array `mask`, used as an argument in `any`, `all`, `count`, and optionally in others, is described also in Section 6.17.

`all (mask)` returns the value true if all elements of the logical array `mask` are true or `mask` has size zero, and otherwise returns the value false.

`any (mask)` returns the value true if any of the elements of the logical array `mask` is true, and returns the value false if no elements are true or if `mask` has size zero.

`count (mask)` returns the default integer value that is the number of elements of the logical array `mask` that have the value true.

`maxval (array)` returns the maximum value of an element of an integer or real array. If `array` has size zero, it returns the negative value of largest magnitude supported by the processor.

`minval (array)` returns the minimum value of an element of an integer or real array. If `array` has size zero, it returns the largest positive value supported by the processor.

`product (array)` returns the product of the elements of an integer, real, or complex array. It returns the value one if `array` has size zero.

`sum (array)` returns the sum of the elements of an integer, real, or complex array. It returns the value zero if `array` has size zero.

8.11.2 Optional argument `dim`

All these functions have an optional second argument `dim` that is a scalar integer. If this is present, the operation is applied to all rank-one sections that span right through dimension `dim` to produce an array of rank reduced by one and extents equal to the extents in the other dimensions. For example, if `a` is a real array of shape (4,5,6), `sum(a, dim=2)` is a real array of shape (4,6) and element (*i*, *j*) has value `sum(a(i,:,:,j))`.

As the rank of the result depends on whether `dim` is specified, the corresponding actual argument must not itself be an optional dummy argument.

8.11.3 Optional argument `mask`

The functions `maxval`, `minval`, `product`, and `sum` have a third optional argument, a logical array `mask`. If this is present, it must have the same shape as the first argument and the operation is applied to the elements corresponding to true elements of `mask`; for example, `sum(a, mask = a>0)` sums the positive elements of the array `a`. The argument `mask` affects only the value of the function and does not affect the evaluation of arguments that are array expressions. In **Fortran 95** only, `mask` is permitted as the second positional argument when `dim` is absent.

8.12 Array inquiry functions

There are five functions for inquiries about the bounds, shape, size and allocation status of an array of any type. Because the result depends only the array properties, the value of the array need not be defined.

8.12.1 Allocation status

`allocated (array)` returns, when the allocatable array `array` is currently allocated, the value true; otherwise it returns the value false . If the allocation status of `array` is undefined, the result is undefined.

8.12.2 Bounds, shape, and size

The following functions enquire about the bounds of an array. In the case of an allocatable array, it must be allocated; and in the case of a pointer, it must be associated with a target. An array section or an array expression is taken to have lower bounds 1 and upper bounds equal to the extents (like an assumed-shape array with no specified lower bounds).

`lbound (array [,dim])`, when `dim` is absent, returns a rank-one default integer array holding the lower bounds. When `dim` is present, it must be a scalar integer and the result is a scalar default integer holding the lower bound in dimension `dim`. As the rank of the result depends on whether `dim` is specified, the corresponding actual argument must not itself be an optional dummy argument.

`shape (source)` returns a rank-one default integer array holding the shape of the array or scalar `source`. In the case of a scalar, the result has size zero.

`size (array [,dim])` returns a scalar default integer that is the size of the array array or extent along dimension `dim` if the scalar integer `dim` is present.

`ubound (array [,dim])` is similar to `lbound` except that it returns upper bounds.

8.13 Array construction and manipulation functions

There are eight functions that construct or manipulate arrays of any type.

8.13.1 The merge elemental function

`merge (tsource, fsource, mask)` is an elemental function. The argument `tsource` may have any type and `fsource` must have the same type and type parameters. The argument `mask` must be of type logical. The result is `tsource` if `mask` is true and `fsource` otherwise.

The principal application of `merge` is when the three arguments are arrays having the same shape, in which case `tsource` and `fsource` are merged under the control of `mask`. Note, however, that `tsource` or `fsource` may be scalar in which case the elemental rules effectively broadcast it to an array of the correct shape.

8.13.2 Packing and unpacking arrays

The transformational function `pack` packs into a rank-one array those elements of an array that are selected by a logical array of conforming shape, and the transformational function `unpack` performs the reverse operation. The elements are taken in array element order.

`pack (array, mask [,vector])`, when `vector` is absent, returns a rank-one array containing the elements of `array` corresponding to true elements of `mask` in array element order; `mask` may be scalar with value true, in which case all elements are selected. If `vector` is present, it must be a rank-one array of the same type and type parameters as `array` and size at least equal to the number t of selected elements; the result has size equal to the size n of `vector`; if $t < n$, elements i of the result for $i > t$ are the corresponding elements of `vector`.

`unpack (vector, mask, field)` returns an array of the type and type parameters of `vector` and shape of `mask`. The argument `mask` must be a logical array and `vector` must be a rank-one array of size at least the number of true elements of `mask`. `field` must be of the same type and type parameters as `vector` and must either be scalar or be of the same shape as `mask`. The element of the result corresponding to the i th true element of `mask`, in array element order, is the i th element of `vector`; all others are equal to the corresponding elements of `field` if it is an array or to `field` if it is a scalar.

8.13.3 Reshaping an array

The transformational function `reshape` allows the shape of an array to be changed, with possible permutation of the subscripts.

`reshape (source, shape [,pad] [,order])` returns an array with shape given by the rank-one integer array `shape`, and type and type parameters those of the array `source`. The size of `shape` must be constant, and its elements must not be negative. If `pad` is present, it must be an array of the same type and type parameters as `source`. If `pad` is absent or of size zero, the size of the result must not exceed the size of `source`. If `order` is absent, the elements of the result, in array element order, are the elements of `source` in array element order followed by copies of `pad` in array element order. If `order` is present, it must be a rank-one integer array with a value that is a permutation of $(1, 2, \dots, n)$; the elements $r(s_1, \dots, s_n)$ of the result, taken in subscript order for the array having elements $r(s_{\text{order}(1)}, \dots, s_{\text{order}(n)})$, are

those of source in array element order followed by copies of pad in array element order. For example, if order has the value (/3,1,2/), the elements $r(1,1,1)$, $r(1,1,2)$, ..., $r(1,1,k)$, $r(2,1,1)$, $r(2,1,2)$, ... correspond to the elements of source and pad in array element order.

8.13.4 Transformational function for replication

`spread (source, dim, ncopies)` returns an array of type and type parameters those of source and of rank increased by one. The argument `source` may be scalar or array-valued. The arguments `dim` and `ncopies` are integer scalars. The result contains $\max(ncopies, 0)$ copies of `source`, and element (r_1, \dots, r_{n+1}) of the result is `source(s1, \dots, sn)` where (s_1, \dots, s_n) is (r_1, \dots, r_{n+1}) with subscript `dim` omitted (or `source` itself if it is scalar).

8.13.5 Array shifting functions

`cshift (array, shift [,dim])` returns an array of the same type, type parameters, and shape as `array`. The argument `shift` is of type integer and must be scalar if `array` is of rank one. If `shift` is scalar, the result is obtained by shifting every rank-one section that extends across dimension `dim` circularly `shift` times. The argument `dim` is an integer scalar and, if it is omitted, it is as if it were present with the value 1. The direction of the shift depends on the sign of `shift`, being to the left for a positive value and to the right for a negative value. Thus, for the case with `shift=1` and `array` of rank one and size m , the element i of the result is `array(i+1)`, where $i = 1, 2, \dots, m-1$, and element m is `array(1)`. If `shift` is an array, it must have the same shape as that of `array` with dimension `dim` omitted, and it supplies a separate value for each shift. For example, if `array` is of rank three and shape (k, l, m) and `dim` has the value 2, `shift` must be of shape (k, m) and supplies a shift for each of the $k \times m$ rank-one sections in the second dimension of `array`.

`eoshift (array, shift [,boundary] [,dim])` is identical to `cshift` except that an end-off shift is performed and boundary values are inserted into the gaps so created. The argument `boundary` may be omitted when `array` has intrinsic type, in which case the value zero is inserted for the integer, real, and complex cases; false in the logical case; and blanks in the character case. If `boundary` is present, it must have the same type and type parameters as `array`; it may be scalar and supply all needed values or it may be an array whose shape is that of `array` with dimension `dim` omitted and supply a separate value for each shift.

8.13.6 Matrix transpose

The `transpose` function performs a matrix transpose for any array of rank two.

`transpose (matrix)` returns an array of the same type and type parameters as the rank-two array `matrix`. Element (i, j) of the result is `matrix(j, i)`.

8.14 Transformational functions for geometric location

There are two transformational functions that find the locations of the maximum and minimum values of an integer or real array.

`maxloc (array [,mask])` returns a rank-one default integer array of size equal to the rank of `array`. Its value is the sequence of subscripts of an element of maximum value (among those corresponding to true values of the conforming logical array `mask` if it is present), as though all the declared lower bounds of `array` were 1. If there is more than one such element, the first in array element order is taken.

`maxloc (array, dim [,mask])` is available in **Fortran 95 only**. It returns a default integer array of shape equal to the that of `array` with dimension `dim` omitted, where `dim` is a scalar integer with value in the range $1 \leq \text{dim} \leq \text{rank}(\text{array})$. The value of each element of the result is the position of the first element of maximum value in the corresponding rank-one section spanning dimension `dim`, among those elements corresponding to true values of the conforming logical array `mask` when it is present.

`minloc (array [,mask])` is identical to `maxloc (array [,mask])` except that the position of an element of minimum value is obtained.

`minloc (array, dim [,mask])` (available in **Fortran 95 only**) is identical to `maxloc (array, dim [,mask])` except that positions of elements of minimum value are obtained.

8.15 Transformational function for pointer disassociation (Fortran 95)

In Fortran 95, the function `null` is available to give the disassociated status to pointer entities.

`null ([mold])` returns a disassociated pointer. The argument `mold` is a pointer of any type and may have any association status, including undefined. The type, type parameter, and rank of the result are those of `mold` if it is present and otherwise are those of the object with which it is associated.

8.16 Non-elemental intrinsic subroutines

There are also in Fortran non-elemental intrinsic subroutines, which were chosen to be subroutines rather than functions because of the need to return information through the arguments.

8.16.1 Real-time clock

There are two subroutines that return information from the real-time clock, the first based on the ISO standard IS 8601 (Representation of dates and times). It is assumed that there is a basic system clock that is incremented by one for each clock count until a maximum `count_max` is reached and on the next count is set to zero. Default values are returned on systems without a clock. All the arguments have intent out.

`call date_and_time ([date] [,time] [,zone] [,values])` returns the following (with default values blank or `-huge(0)`, as appropriate, when there is no clock):

`date` is a scalar character variable holding the date in the form *ccyyymmdd*, corresponding to century, year, month, and day.

`time` is a scalar character variable holding the time in the form *hhmmss.sss*, corresponding to hours, minutes, seconds, and milliseconds.

`zone` is a scalar character variable that is set to the difference between local time and Coordinated Universal Time (UTC, also known as Greenwich Mean Time) in the form *Shmm*, corresponding to sign, hours, and minutes. For example, a processor in New York in winter would return the value `-0500`.

`values` is a rank-one default integer array of size at least 8 holding the sequence of values: the year, the month of the year, the day of the month, the time difference in minutes with respect to UTC, the hour of the day, the minutes of the hour, the seconds of the minute, and the milliseconds of the second.

`call system_clock ([count][,count_rate][,count_max])` returns the following:

`count` is a scalar default integer holding a processor-dependent value based on the current value of the processor clock, or `-huge(0)` if there is no clock. On the first call, the processor may set an initial value that may be zero.

`count_rate` is a scalar default integer holding the number of clock counts per second, or zero if there is no clock.

`count_max` is a scalar default integer holding the maximum value that `count` may take, or zero if there is no clock.

8.16.2 CPU time (Fortran 95 only)

In Fortran 95, there is a non-elemental intrinsic subroutine that returns the processor time.

`call cpu_time (time)` returns the following:

`time` is a scalar real that is assigned a processor-dependent approximation to the processor time in seconds, or a processor-dependent negative value if there is no clock.

The exact definition of time is left imprecise because of the variability in what different processors are able to provide. The primary purpose is to compare different algorithms on the same computer or discover which parts of a calculation on a computer are the most expensive.

The start time is left imprecise because the purpose is to time sections of code, as in the example

```
real :: t1, t2
:
call cpu_time(t1)    ! Fortran 95
:                   ! Code to be timed.
call cpu_time(t2)
write (*,*) 'Time taken by code was ', t2-t1, ' seconds'
```

8.16.3 Random numbers

A sequence of pseudorandom numbers is generated from a seed that is held as a rank-one array of integers. The subroutine `random_number` returns the pseudorandom numbers and the subroutine `random_seed` allows an inquiry to be made about the size or value of the seed array, and the seed to be reset. The subroutines provide a portable interface to a processor-dependent sequence.

`call random_number (harvest)` returns a pseudorandom number from the uniform distribution over the range $0 \leq x < 1$ or an array of such numbers. `harvest` has intent `out`, may be a scalar or an array, and must be of type `real`.

`call random_seed ([size] [put] [get])` has the following arguments:

`size` has intent `out` and is a scalar default integer that the processor sets to the size n of the seed array.

`put` has intent `in` and is a default integer array of rank one and size n that is used by the processor to reset the seed. A processor may set the same seed value for more than one value of `put`.

`get` has intent `out` and is a default integer array of rank one and size n that the processor sets to the current value of the seed.

No more than one argument may be specified; if no argument is specified, the seed is set to a processor-dependent value.

8.17 Summary

In this chapter, we introduced the four categories of intrinsic procedures, explained the `intrinsic` statement, and gave detailed descriptions of all the procedures. The procedures of Sections 8.2, 8.6.2, and 8.7 to 8.16 are all new since Fortran 77. Within Sections 8.3 to 8.5 the procedures `ceiling`, `floor`, `modulo`, `achar`, `iachar`, `adjustl`, `adjustr`, `len_trim`, `scan`, `verify`, and `logical` are new; the remaining functions were present in Fortran 77, have been generalized to handle all kind type parameters, have become elemental, and several have been given additional optional arguments. The function `len` has become an inquiry function.

Of the many new intrinsic procedures, some have names that might also be names of external functions in existing Fortran 77 programs. Appendix B15 of the Fortran 77 standard recommended that external procedures be identified as such by using the `external` statement. For any external procedure with a name contained in the following list, it is essential to provide an interface body or to use the `external` statement.

achar	all	any	btest	count	cshift
digits	floor	huge	iachar	iand	ibclr
ibits	ibset	ieor	ior	ishft	ishftc
kind	lbound	matmul	maxloc	maxval	merge
minloc	minval	modulo	mvbits	not	null
pack	radix	range	repeat	scale	scan
shape	size	spread	sum	tiny	trim
ubound	unpack	verify			

Note: `null` is Fortran 95 only.

8.18 Exercises

1. Write a program to calculate the real roots or pairs of complex-conjugate roots of the quadratic equation $ax^2 + bx + c = 0$ for any real values of a , b , and c . The program should read these three values and print the results. Use should be made of the appropriate intrinsic functions.
2. Repeat Exercise 1 of Chapter 5, avoiding the use of do constructs.
3. Given the rules explained in Sections 3.12 and 8.2, what are the values printed by the following program?

```
program main
    real, target :: a(3:10)
    real, pointer :: p1(:), p2(:)
    p1 => a(3:9:2)
    p2 => a(9:3:-2)
    print *, associated(p1, p2)
    print *, associated(p1, p2(4:1:-1))
end program main
```

4. In the following program, two pointer assignments, one to an array the other to an array section, are followed by a subroutine call. Bearing in mind the rules given in Sections 3.12, 6.3, and 8.12.2, what values does the program print?

```
program main
    real, target :: a(5:10)
    real, pointer :: p1(:), p2(:)
    p1 => a
    p2 => a(:)
    print *, lbound (a), lbound (a(:))
    print *, lbound (p1), lbound (p2)
    call what (a, a(:))
contains
    subroutine what (x, y)
        real, intent (in) :: x(:), y(:)
        print *, lbound (x), lbound (y)
    end subroutine what
end program main
```

9. Data transfer

9.1 Introduction

Fortran has, in comparison with most other high-level programming languages, a particularly rich set of facilities for input/output (I/O). The Fortran 77 standard brought with it important new features including direct-access files, internal files, execution-time format specification, list-directed input/output, file inquiry, and some new edit descriptors. By contrast, the only significant new features in the latest standards are non-advancing I/O, `namelist`, and some new edit descriptors. In addition, there are a number of detailed changes to support new facilities in other areas.

Input/output is an area of Fortran into which not all programmers need to delve very deeply. For most small-scale programs it is sufficient to know how to read a few data records containing input variables, and how to transmit to a terminal or printer the results of a calculation. In large-scale data processing, on the other hand, the programs often have to deal with huge streams of data to and from many disc, tape, and cartridge files; in these cases it is essential that great attention be paid to the way in which the I/O is designed and coded, as otherwise both the execution time and the real time spent in the program can suffer dramatically. The term *file* is used for a collection of data on one of these devices and a file is always organized into a sequence of *records*.

This chapter begins by discussing the various forms of formatted I/O, that is I/O which deals with records that do not use the internal number representation of the computer, but rather a character string which can be displayed for visual inspection by the human eye. It is also the form usually needed for transmitting data between different kinds of computers. The so-called *edit descriptors*, which are used to control the translation between the internal number representation and the external format, are then explained. Finally, the topics of unformatted (or binary) I/O and direct-access files are covered.

9.2 Number conversion

The ways in which numbers are stored internally by a computer are the concern of neither the Fortran standard nor this book. However, if we wish to output values – to display them on a terminal or to print them – then their internal representations

must be converted into a character string which can be read in a normal way. For instance, the contents of a given computer word may be (in hexadecimal) `be1d7dbf` and correspond to the value `-0.000450`. For our particular purpose, we may wish to display this quantity as `-.000450`, or as `-4.5E-04`, or rounded to one significant digit as `-5e-04`. The conversion from the internal representation to the external form is carried out according to the information specified by an edit descriptor contained in a *format specification*. These will both be dealt with fully later in this chapter; for the moment, it is sufficient to give a few examples. For instance, to print an integer value in a field of 10 characters width, we would use the edit descriptor `i 10`, where `i` stands for integer conversion, and 10 specifies the width of the output field. To print a real quantity in a field of 10 characters, five of which are reserved for the fractional part of the number, we specify `f10.5`. The edit descriptor `f` stands for floating-point (real) conversion, 10 is the total width of the output field and 5 is the width of the fractional part of the field. If the number given above were to be converted according to this edit descriptor, it would appear as `bb-0.00045`, where `b` represents a blank. To print a character variable in a field of 10 characters, we would specify `a10`, where `a` stands for alphanumeric conversion.

A format specification consists of a list of edit descriptors enclosed in parentheses, and can be coded either as a default character expression, for instance

```
'(i10, f10.3, a10)'
```

or as a separate format statement, referenced by a statement label, for example

```
10 format(i10, f10.3, a10)
```

To print the scalar variables `j`, `b`, and `c`, of types integer, real, and character respectively, we may then write either

```
print '(i10, f10.3, a10)', j,b,c
```

or

```
print 10, j,b,c
10 format(i10, f10.3, a10)
```

The first form is normally used when there is only a single reference in a scoping unit to a given format specification, the second when there are several or when the format is complicated. The part of the statement designating the quantities to be printed is known as the *output list* and forms the subject of the following section.

9.3 I/O lists

The quantities to be read or written by a program are specified in an I/O list. For output, they may be expressions but for input must be variables. In both cases, list items may be implied-do lists of quantities. Examples are shown in Figure 9.1, where we note the use of a *repeat count* in front of those edit descriptors that

are required repeatedly. A repeat count must be a positive integer literal constant and not have a kind type parameter. Function references are permitted in an I/O list, provided they do not themselves cause further I/O to occur.

Figure 9.1

```
integer :: i
real, dimension(10) :: a
character(len=20) :: word
print '(i10)', i
print '(10f10.3)', a
print '(3f10.3)', a(1),a(2),a(3)
print '(a10)', word(5:14)
print '(5f10.3)', (a(i), i=1,9,2)
print '(2f10.3)', a(1)*a(2)+i, sqrt(a(3))
```

In all these examples, except the last one, the expressions consist of single variables and would be equally valid in input statements using the `read` statement, for example

```
read '(i10)', i
```

Such statements may be used to read values which are then assigned to the variables in the input list.

If an array appears as an item, it is treated as if the elements were specified in array element order. For example, the third of the `print` statements in Figure 9.1 could have been written

```
print '(3f10.3)', a(1:3)
```

However, no element of the array may appear more than once in an input item. Thus, the case in Figure 9.2 is not allowed.

Figure 9.2

```
integer :: j(10), k(3)
:
k = (/ 1, 2, 1 /)
read '(3i10)', j(k)      ! Illegal because j(1) appears twice
```

If an allocatable array appears as an item, it must be currently allocated.

Any pointers in an I/O list must be associated with a target, and transfer takes place between the file and the targets.

An item of derived type is treated as if the components were specified in the same order as in the type declaration. This rule is applied repeatedly for components of derived type, so that it is as if we specified the list of items of

intrinsic type that constitute its ultimate components. For example, if *p* and *t* are of the types point and triangle of Figure 2.1, the statement

```
read '(8f10.5)', p, t
```

has the same effect as the statement

```
read '(8f10.5)', p%x, p%y, t%a%x, t%a%y, t%b%x, &
      t%b%y, t%c%x, t%c%y
```

Each ultimate component must be accessible (not, for example, be a private component of a public type).

An object in an I/O list is not permitted to be of a derived type that has a pointer component at any level of component selection. One reason for this restriction is because of the problems associated with recursive data structures. For example, supposing *chain* is a data object of the type entry of Figure 2.3 (in Section 2.13) and is set up to hold a chain of length three, then it has as its ultimate components *chain*%*index*, *chain*%*next*%*index*, *chain*%*next*%*next*%*index*, and *chain*%*next*%*next*%*next*, the last of which is a disassociated pointer. Another reason is the intention to add defined edit descriptors for data structures to Fortran 2000. Programmers will be able to write procedures that are called as part of the I/O processing. Such a procedure will be much better able to handle structures whose size and composition vary dynamically, the usual case for pointer components.

An I/O list may include an implied-do list, as illustrated by the fifth print statement in Figure 9.1. The general form is

(*do-object-list*, *do-var* = *expr*, *expr* [, *expr*])

where each *do-object* is a variable (for input), an expression (for output), or is itself an implied-do list; *do-var* is a named scalar integer variable; and each *expr* is a scalar integer expression. The loop initialization and execution is the same as for a (possibly nested) set of do constructs (Section 4.5). In an input list, a variable that is an item in a *do-object-list* must not be a *do-var* of any implied-do list in which it is contained, nor be associated¹ with such a *do-var*. In an input or output list, no *do-var* may be a *do-var* of any implied-do list in which it is contained or be associated with such a *do-var*.

Note that a zero-sized array, or an implied-do list with a zero iteration count, may occur as an item in an I/O list. Such an item corresponds to no actual data transfer.

9.4 Format definition

In the print and read statements of the previous section, the format specification was given each time in the form of a character constant immediately following the keyword. In fact, there are three ways in which a format specification may be given. They are:

¹Such an illegal association could be established by pointer association.

- i) As a statement label referring to a `format` statement containing the relevant specification between parentheses:

```
print 100, q
:
100 format(f10.3)
```

The `format` statement must appear in the same scoping unit, before the `contains` statement if it has one. It is customary either to place each `format` statement immediately after the first statement which references it, or to group them all together just before the `contains` or `end` statement. It is also customary to have a separate sequence of numbers for the statement labels used for `format` statements. A given `format` statement may be used by any number of formatted I/O statements, whether for input or for output.

- ii) As a default character expression whose value commences with a `format` specification in parentheses:

```
print '(f10.3)', q
```

or

```
character(len=*), parameter :: form='(f10.3)'
:
print form, q
```

or

```
character :: carray(7)=(/ '(', 'f', '1', '0', '.', '3', ')' /)
:
print carray, q ! Elements of an array expression
                  ! are concatenated.
```

or

```
character(4) :: carr1(10)
character(3) :: carr2(10)
integer       :: i, j
:
carr1(10) = '(f10'
carr2(3) = '.3)'
:
i = 10
j = 3
:
print carr1(i)//carr2(j), q
```

From these examples it may be seen that it is possible to program formats in a flexible way, and particularly that it is possible to use arrays, expressions and also substrings in a way which allows a given format to be built up dynamically at execution-time from various components. Any character data which might follow the trailing right parenthesis are ignored and may be undefined. In the case of an array, its elements are concatenated in array element order. However, on input *no* component of the format specification may appear also in the input list, or be associated with it. This is because the standard requires that the whole format specification be established *before* any I/O takes place. Further, no redefinition or undefinition of any characters of the format is permitted during the execution of the I/O statement.

- iii) As an asterisk. This is a type of I/O known as *list-directed* I/O, in which the format is defined by the computer system at the moment the statement is executed, depending on both the type and magnitude of the entities involved. This facility is particularly useful for the input and output of small quantities of values, especially in temporary code which is used for test purposes, and which is removed from the final version of the program:

```
print *, 'Square-root of q = ', sqrt(q)
```

This example outputs a character constant describing the expression which is to be output, followed by the value of the expression under investigation. On the terminal screen, this might appear as

```
Square-root of q = 4.392246
```

the exact format being dependent on the computer system used. Character strings in this form of output are normally undelimited, as if an a edit descriptor were in use, but an option in the open statement (Section 10.3) may be used to require that they be delimited by apostrophes or quotation marks. Except for adjacent undelimited strings, values are separated by spaces or commas. Logical variables are represented as T for true and F for false. The processor may represent a sequence of *r* identical values *c* by the form *r * c*. Further details of list-directed input/output are deferred until Section 9.9.

Blank characters may precede the left parenthesis of a format specification, and may appear at any point within a format specification with no effect on the interpretation, except within a character string edit descriptor (Section 9.13.4).

9.5 Unit numbers

Input/output operations are used to transfer data between the variables of an executing program, as stored in the computer, and an external medium. There are

many types of external media: the terminal, printer, disc drive, and CD are perhaps the most familiar. Whatever the device, a Fortran program regards each one from which it reads or to which it writes as a *unit*, and each unit, with two exceptions, has associated with it a *unit number*. This number must not be negative and is often in the range 1 to 99. Thus we might associate with a disc drive from which we are reading the unit number 10, and to a hard disc drive to which we are writing the unit number 11. All program units of an executable program that refer to a particular unit number are referencing the same file.

There are two I/O statements, print and a variant of read, that do not reference any unit number; these are the statements that we have used so far in examples, for the sake of simplicity. A read statement without a unit number will normally expect to read from the terminal, unless the program is working in batch (non-interactive) mode in which case there will be a disc file with a reserved name from which it reads. A print statement will normally expect to output to the terminal, unless the program is in batch mode in which case another disc file with a reserved name will be used. Such files are usually suitable for subsequent output on a physical output device. The system may implicitly associate unit numbers to these default units.

Apart from these two special cases, all I/O statements must refer explicitly to a unit in order to identify the device to which or from which data are to be transferred. The unit may be given in one of three forms. These are shown in the following examples which use another form of the read containing a unit specifier, *u*, and format specifier, *fmt*, in parentheses and separated by a comma, where *fmt* is a format specification as described in the previous section:

```
read (u, fmt) list
```

The three forms of *u* are:

- i) As a scalar integer expression that gives the unit number:

```
read (4, '(f10.3)') q
read (nunit, '(f10.3)') q
read (4*i+j, 100) a
```

where the value may be any nonnegative integer allowed by the system for this purpose.

- ii) As an asterisk:

```
read (*, '(f10.3)') q
```

where the asterisk implies the standard input unit designated by the system, the same as that used for read without a unit number.

- iii) As a default character variable identifying an *internal file* (see next section).

9.6 Internal files

Internal files allow format conversion between various representations to be carried out by the program in a storage area defined within the program itself. There are two particularly useful applications, one to read data whose format is not properly known in advance, and the other to prepare output lists containing mixed character and numerical data, all of which has to be prepared in character form, perhaps to be displayed as a caption on a graphics display. The character data must be of default kind. The first application will now be described; the second will be dealt with in Section 9.8.

Imagine that we have to read a string of 30 digits, which might correspond to 30 one-digit integers, 15 two-digit integers or 10 three-digit integers. The information as to which type of data is involved is given by the value of an additional digit, which has the value 1, 2, or 3, depending on the number of digits each integer contains. An internal file provides us with a mechanism whereby the 30 digits can be read into a character buffer area. The value of the final digit can be tested separately, and 30, 15, or 10 values read from the internal file, depending on this value. The basic code to achieve this might read as follows (no error recovery or data validation is included, for simplicity):

```
integer      :: ival(30), key, i
character(30):: buffer
character(6) :: form(3) = (/ '(30i1)', '(15i2)', '(10i3)' /)
read (*, '(a30,i1)')      buffer, key
read (buffer, form (key)) (ival(i), i=1,30/key)
```

Here, `ival` is an array which will receive the values, `buffer` a character variable of a length sufficient to contain the 30 input digits, and `form` a character array containing the three possible formats to which the input data might correspond. The first `read` statement reads 30 digits into `buffer` as character data, and a final digit into the integer variable `key`. The second `read` statement reads the data from `buffer` into `ival`, using the appropriate conversion as specified by the edit descriptor selected by `key`. The number of variables read from `buffer` to `ival` is defined by the implied-do loop, whose second specifier is an integer expression depending also on `key`. After execution of this code, `ival` will contain `30/key` values, their number and exact format not having been known in advance.

If an internal file is a scalar, it has a single record whose length is that of the scalar. If it is an array, its elements, in array element order, are treated as successive records of the file and each has length that of an array element. It may not be an array section with a vector subscript.

A record becomes defined when it is written. The number of characters sent must not exceed the length of the record. It may be less, in which case the rest of the record is padded with blanks. For list-directed output (Section 9.4), character constants are not delimited. A record may be read only if it is defined (which need not only be by an output statement). Records are padded with blanks, if necessary.

An internal file is always positioned at the beginning of its first record prior to data transfer (the array section notation may be used to start elsewhere in an array). Of course, if an internal file is an allocatable array or pointer, it must be allocated or associated with a target. Also, no item in the input/output list may be in the file or associated with the file.

An internal file must be of default character type and non-default character items are not permitted in input/output lists. It may be used for list-directed I/O (Section 9.9), but not for namelist I/O (Section 9.10).

9.7 Formatted input

In the previous sections we have given complete descriptions of the ways that formats and units may be specified, using simplified forms of the read and print statements as examples. There are, in fact, two forms of the formatted read statement. Without a unit, it has the form

```
read fmt [,list]
```

and with a unit it may take the form

```
read ([unit=]u, [fmt=]fmt [,iostat=ios] &
      [, err=error-label] [,end=end-label]) [list]
```

where *u* and *fmt* are the unit and format specifiers described in Sections 9.4 and 9.5; iostat=, err=, and end= are optional specifiers which allow a user to specify how a read statement shall recover from various exceptional conditions; and *list* is a list of variables and implied-do lists of variables. The keyword items may be specified in any order, although it is usual to keep the unit number and format specification as the first two. The unit number must be first if it does not have its keyword. If the format does not have its keyword, it must be second, following the unit number without its keyword. Note that this parallels the rules for keyword calls of procedures, except that the positional list is limited to two items.

For simplicity of exposition, we have so far limited ourselves to formats that correspond to a single record in the file, but we will meet later in this chapter cases that lead to the input of a part of a record or of several successive records.

The meanings of the optional specifiers are as follows. If the iostat= is specified, then *ios* must be a scalar integer variable of default kind which, after execution of the read statement, has a negative value if an end-of-record condition is encountered during non-advancing input (Section 9.12), a different negative value if an endfile condition was detected on the input device (Section 10.2.3), a positive value if an error was detected (for instance a parity error), or the value zero otherwise. The actual values assigned to *ios* in the event of an exception occurring are not defined by the standard, only the signs.

If the end= is specified, then *end-label* must be a statement label of a statement in the same scoping unit, to which control will be transferred in the event of the end of the file being reached.

If the `err=` is specified, then *error-label* is a statement label in the same scoping unit, to which control will be transferred in the event of any other exception occurring. The labels *error-label* and *end-label* may be the same. If they are not specified and an exception occurs, execution will stop, unless `iostat` is specified. An example of a read statement with its associated error recovery is given in Figure 9.3, in which `error` and `last_file` are subroutines to deal with the exceptions. They will normally be system dependent.

Figure 9.3

```

read (nunit, '(3f10.3)', iostat=ios, err=110, end=120) a,b,c
!
! Successful read - continue execution.
:
:
!
! Error condition - take appropriate action.
110 call error (ios)
go to 999
!
! End-of-file condition - test whether more
! files follow.
120 call last_file
:
999 end

```

If an error or end-of-file condition occurs on input, the statement terminates and all list items and any implied-do variables become undefined. If an end-of-file condition occurs for an external file, the file is positioned following the `endfile` record (Section 10.2.3); if there is otherwise an error condition, the file position is indeterminate. An end-of-file condition occurs also if an attempt is made to read beyond the end of an internal file.

It is a good practice to include some sort of error recovery in all `read` statements which are included permanently in a program. On the other hand, input for test purposes is normally sufficiently well handled by the simple form of `read` without unit number, and without error recovery.

9.8 Formatted output

There are two types of formatted output statements, the `print` statement which has appeared in many of the examples so far in this chapter, and the `write` statement whose syntax is similar to that of the `read` statement:

`print fmt [,list]`

and

```
write ([unit=]u, [fmt=]fmt [,iostat=iostat]
      [,err=error-label] ) [list]
```

where all the components have the same meanings as described for the `read` statement (Section 9.7). An asterisk for `u` specifies the standard output unit, as used by `print`. If an error condition occurs on output, execution of the statement terminates, any implied-do variables become undefined, and the file position becomes indeterminate.

An example of a `write` statement is

```
write (nout, '(10f10.3)', iostat=iostat, err=110) a
```

An example using an internal file is given in Figure 9.4, which builds a character string from numeric and character components. The final character string might be passed to another subroutine for output, for instance as a caption on a graphics display.

Figure 9.4

```
integer :: day
real :: cash
character(len=50) :: line
:
! write into line
write (line,'(a, i2, a, f8.2, a)') &
  'Takings for day ', day, ' are ', cash, ' dollars'
```

In this example, we declare a character variable that is long enough to contain the text to be transferred to it. (The `write` statement contains a format specification with a edit descriptors without a field width. These assume a field width corresponding to the actual length of the character strings to be converted.) After execution of the `write` statement, `line` might contain the character string

Takings for day 3 are 4329.15 dollars

and this could be used as a string for further processing.

The number of characters written to `line` must not exceed its length.

9.9 List-directed I/O

In Section 9.4, the list-directed output facility using an asterisk as format specifier was introduced. We assumed that the list was short enough to fit into a single record, but for long lists the processor is free to output several records. Character constants may be split between records, and complex constants that are as long as, or longer than, a record may be split after the comma that separates the two parts. Apart from these cases, a value always lies within a single record. For the sake of carriage control (which is described in Section 9.11), the first character of each

record is blank unless a delimited character constant is being continued. Note that when an undelimited character constant is continued, the first character of the continuation record is blank. The only blanks permitted in a numeric constant are within a split complex constant after the comma.

This facility is equally useful for input, especially of small quantities of test data. On the input record, the various constants may appear in any of their usual forms, just as if they were being read under the usual edit descriptors, as defined in Section 9.13. Exceptions are that complex values must be enclosed in parentheses, character constants may be delimited, a blank must not occur except in a delimited character constant or in a complex constant before or after a numeric field, blanks are never interpreted as zeros, and the optional characters which are allowed in a logical constant (those following t or f, see Section 9.13.2) must include neither a comma nor a slash.

Character constants that are enclosed in apostrophes or quotation marks may be spread over as many records as necessary to contain them, except that a doubled quotation mark or apostrophe must not be split between records. Delimiters may be omitted for a default character constant if

- it is of nonzero length;
- the constant does not contain a blank, comma, or slash;
- it is contained in one record;
- the first character is neither a quotation mark nor an apostrophe; and
- the leading characters are not numeric followed by an asterisk.

In this case, the constant is terminated when a blank, comma, slash, or end of record is encountered, and apostrophes or quotation marks appearing within the constant must not be doubled.

Whenever a character value has a different length from the corresponding list item, the value is truncated or padded on the right with blanks, as in the character assignment statement.

It is possible to use a repeat count for a given constant, for example $6*10$ to specify six occurrences of the integer value 10.

The (optionally repeated) constants are separated in the input by *separators*. A separator is one of the following, appearing other than in a character constant:

- a comma, optionally preceded and optionally followed by one or more contiguous blanks,
- a slash (/), optionally preceded and optionally followed by one or more contiguous blanks, or
- one or more contiguous blanks between two non-blank values or following the last non-blank value.

An end of record not within a character constant is regarded as a blank and, therefore, forms part of a separator. A blank embedded in a complex constant or delimited character constant is not a separator. An input record may be terminated by a slash separator, in which case all the following values in the record are ignored, and the input statement terminates.

If there are no values between two successive separators, or between the beginning of the first record and the first separator, this is taken to represent a *null value* and the corresponding item in the input list is left unchanged, defined or undefined as the case may be. A null value must not be used for the real or imaginary part of a complex constant, but a single null value may be used for the whole complex value. A series of null values may be represented by a repeat count without a constant: ,*n**,. When a slash separator is encountered, null values are given to any remaining list items.

An example of this form of the read statement is:

```
integer          :: i
real            :: a
complex         :: field(2)
logical          :: flag
character (len=12) :: title
character (len=4)  :: word
:
read *, i, a, field, flag, title, word
```

If this reads the input record

```
10b6.4b(1.,0.)b(2.,0.)btbtest/
```

(in which *b* stands for a blank, and blanks are used as separators), then *i*, *a*, *field*, *flag*, and *title* will acquire the values 10, 6.4, (1.,0.) and (2.,0.), .true. and test respectively, while *word* remains unchanged. For the input records

```
10,.64e1,2*,.true.
'histogramb10'/val1
```

(in which commas are used as separators), the variables *i*, *a*, *flag*, and *title* will acquire the values 10, 6.4, .true., and histogramb10 respectively. The variable *field* and *word* remain unchanged, and the input string val1 is ignored as it follows a slash. (Note the apostrophes, which are required as the string contains a blank. Without delimiters, this string would appear to be a string followed by the integer value 10.) Because of this slash, the read statement does not continue with the next record and the list is thus not fully satisfied.

9.10 Namelist I/O

It can be useful, especially for program testing, to input or output an annotated list of values. The values required are specified in a namelist group (Section 7.15),

and the I/O is performed by a `read` or `write` statement that does not have an I/O list, and in which either

- the format is replaced by a namelist-group name as the second positional parameter, or
- the `fmt=` specifier is replaced by a `nml=` specifier with that name.

When reading, only those objects which are specified in the input record and which do not have a null value become defined. All other list items remain in their existing state of definition or undefined. It is possible to define the value of an array element or section without affecting the other portions of the array. When writing, all the items in the group are written to the file specified. This form of I/O is not available for internal files.

The value for a scalar object or list of values for an array is preceded in the records by the name or designator and an equals sign which may optionally be preceded or followed by blanks. The form of the list of values and null values in the input and output records is as that for list-directed I/O (Section 9.9), except that character constants must *always* be delimited in input records and logical constants must not contain an equals sign. A `namelist` input statement terminates on the appearance of a slash in the list outside a character constant. A simple example is

```
integer :: no_of_eggs, litres_of_milk, kilos_of_butter
namelist/food/no_of_eggs, litres_of_milk, kilos_of_butter
read (5, nml=food)
```

to read the record

```
&food litres_of_milk=5, no_of_eggs=12 /
```

where we note that the order of the two values given is not the same as their order in the `namelist` group — the orders need not necessarily match. The value of `kilos_of_butter` remains unchanged. The first non-blank item in the record is an ampersand followed without an intervening blank by the group name. The slash is obligatory as a terminator. On output, a similar annotated list of values is produced, starting with the name of the group and ending with a slash. Here the order is that of the `namelist` group. Thus, the statements

```
integer :: number, list(10)
namelist/out/number, list
write (6, nml=out)
```

might produce the record

```
&OUT NUMBER=1, LIST=14, 9*0 /
```

On output, the names are always in upper case.

Where a subobject designator appears in an input record, all substring expressions, subscripts, and strides must be scalar integer literal constants without

specified kind parameters. All group names, object names, and component names are interpreted without regard to case. Blanks may precede or follow the name or designator, but must not appear within it.

If the object is scalar and of intrinsic type, the equals sign must be followed by one value. If it is of derived type or is an array, the equals sign must be followed by a list of values of intrinsic type corresponding to the replacement of each derived-type value by its ultimate components and each array by its elements in array element order.

The list of values must not be too long, but it may be too short, in which case trailing null values are regarded as having been appended. If an object is of type character, the corresponding item must be of the same kind.

Zero-sized objects must not appear in a namelist input record. In any multiple occurrence of an object in a sequence of input records, the final value is taken.

9.10.1 Comments in namelist input (Fortran 95 only)

In Fortran 95, input records for namelist input may bear a comment following an object name/value separator other than a slash. This allows programmers to document the structure of a namelist input file line-by-line. The comment is in the usual format for comments. Taking the input record of Section 9.10, it may be documented thus:

```
&food litres_of_milk=5, ! Fortran 95
no_of_eggs=12 /
```

A comment line, with ! as the first non-blank character in an input record, is also permitted, but may not occur in a character context.

9.11 Carriage control

Fortran's formatted output statements were originally designed for line-printers, with their concept of lines and pages of output. On such a device, the first character of each output record must be of default kind. It is not printed but interpreted as a *carriage control character*. If it is a blank, no action is taken, and it is good practice to insert a blank as the first character of each record, either explicitly as ' ' or using the t2 edit descriptor (described in Section 9.13.5), in order to avoid inadvertent generation of spurious carriage control characters. This can happen when the first character in an output record is non-blank, and might occur, for instance, when printing integer values with the format '(i5)'. Here all output values between -999 and 9999 will have a blank in the first position, but all others will generate a character there which may be used mistakenly for carriage control.

The carriage control characters defined by the standard are:

- b* to start a new line
- +* to remain on the same line (overprint)
- 0* to skip a line
- 1* to advance to the beginning of the next page

As a precaution, the first character of each record produced by list-directed and `namelist` output is a blank, unless it is the continuation of a delimited character constant.

In this context, we note that execution of a `print` statement does not imply that any printing will actually occur, and nor does execution of a `write` statement imply that printing will not occur.

9.12 Non-advancing I/O

So far we have considered each `read` or `write` statement to perform the input or output of a complete record. There are, however, many applications, especially in screen management, where this would become an irksome restriction. What is required is the ability to read and write without always advancing the file position to ahead of the next record. This facility is provided by *non-advancing I/O*. To gain access to this facility, the optional `advance=` specifier must appear in the `read` or `write` statement and be associated with a scalar default character expression *advance* which evaluates, after suppression of any trailing blanks and conversion of any upper-case letters to lower case, to the value `no`. The only other allowed value is `yes` which is the default value if the specifier is absent; in this case normal (advancing) I/O occurs.

The following optional specifiers are available for a non-advancing read statement:

eor=eor-label
size=size

where *eor-label* is a statement label in the same scoping unit and *size* is a default integer scalar variable. The *eor-label* may be the same as an *end-label* or *error-label* of the `read` statement.

An advancing I/O statement always repositions the file after the last record accessed, but a non-advancing I/O statement performs no such repositioning and may therefore leave the file positioned within a record. If a non-advancing input statement attempts to transfer data from beyond the end of the *current* record, an end-of-record condition occurs. The `iostat` variable, if present, will acquire a different negative value to the one indicating an end-of-file condition; and, if the `eor=` specifier is present, control is transferred to the statement specified by its associated *eor-label*. In order to provide a means of controlling this process, the `size=` specifier, when present, sets *size* to the number of characters actually read. A full example is thus

```

character(len=3) :: key
integer           :: unit, size
read (unit, '(a3)', advance='no', size=size, eor=66) key
:
! key is not in one record
66 key(size+1:) = ''
:

```

As for error and end-of-file conditions, the program terminates when an end-of-record condition occurs if neither `eor=` nor `iostat=` is specified.

If encountering an end-of-record on reading results in the input list not being satisfied, the `pad=` specifier described in Section 10.3 will determine whether any padding with blank characters occurs. Blanks inserted as padding are not included in the `size=` count.

It is possible to perform normal and non-advancing I/O on the same record or file. For instance, a non-advancing read might read the first few characters of a record and a normal read the remainder.

A particular application of this facility is to write a prompt to a terminal screen and to read from the next character position on the screen without an intervening line-feed:

```

write (*, '(a)', advance='no') 'enter next prime number:'
read  (*, '(i10)') prime_number

```

Non-advancing I/O may be performed only on an external file, and may not be used for namelist or list-directed I/O. Note that, as for advancing input/output, several records may be processed by a single statement.

9.13 Edit descriptors

In the description of the possible forms of a format specification in Section 9.4, a few examples of the edit descriptors were given. As mentioned there, edit descriptors give a precise specification of how values are to be converted into a character string on an output device or internal file, or converted from a character string on an input device or internal file to internal representations.

With certain exceptions noted in the following text, edit descriptors in a list are separated by commas, and only in the case where an input/output list is empty or specifies only zero-sized arrays may there be no edit descriptor at all in the format specification.

On a processor that supports upper- and lower-case letters, edit descriptors are interpreted without regard to case. This is also true for numerical and logical input fields; an example is 89AB as a hexadecimal input value.

9.13.1 Repeat counts

Edit descriptors fall into three classes: *data*, *control*, and *character-string*. The data edit descriptors may be preceded by a repeat count (a nonzero unsigned default integer literal constant), as in the example

`10f12.3`

Of the remaining edit descriptors, only the slash edit descriptor (Section 9.13.5) may have an associated repeat count. A repeat count may be applied to a group of edit descriptors, enclosed in parentheses:

`print '(4(i5,f8.2))', (i(j), a(j), j=1,4)`

(for integer `i` and real `a`). This is equivalent to writing

`print '(i5,f8.2,i5,f8.2,i5,f8.2,i5,f8.2)', (i(j), a(j), j=1,4)`

Repeat counts such as this may be nested:

`print '(2(2i5,2f8.2))', i(1),i(2),a(1),a(2),i(3),i(4),a(3),a(4)`

If a format specification without components in parentheses is used with an I/O list that contains more elements than the number of edit descriptors, taking account of repeat counts, then a new record will begin, and the format specification repeated. Further records begin in the same way until the list is exhausted. To print an array of 100 integer elements, 10 elements to a line, the following statement might be used:

`print '(10i8)', (i(j), j=1,100)`

Similarly, when reading from an input file, new records would be read until the list is satisfied, a new record being taken from the input file each time the specification is repeated *even if the individual records contain more input data than specified by the format specification*. These superfluous data would be ignored. For example, reading the two records (`b` again stands for a blank)

```
bbb10bbb15bbb20
bbb25bbb30bbb35
```

under control of the read statement

`read '(2i5)', i,j,k,l`

would result in the four integer variables `i`, `j`, `k` and `l` acquiring the values 10, 15, 25 and 30, respectively.

If a format contains components in parentheses, as in

`'(2i5, 3(i2,2(i1,i3)), 2(2f8.2,i2))'`

whenever the format is exhausted, a new record is taken and format control reverts to the repeat factor preceding the left parenthesis corresponding to the last-but-one right parenthesis, here `2(2f8.2,i2)`, or to the parenthesis itself if it has no repeat factor. This we call *reversion*.

9.13.2 Data edit descriptors

Values of all the intrinsic data types may be converted by the g edit descriptor. However, for reasons of clarity, it is described last.

Integer values may be converted by means of the i edit descriptor. This comes in a basic form, $i\ w$, where w is a nonzero unsigned default integer literal constant that defines the width of the field. The integer value will be read from or written to this field, adjusted to its right-hand side. If we again designate a blank position by b then the value -99 printed under control of the edit descriptor i5 will appear as $bb-99$, the sign counting as one position in the field.

For output, an alternative form of this edit descriptor allows the number of digits that are to be printed to be specified exactly, even if some are leading zeros. The form $i\ w.m$ specifies the width of the field, w , and that at least m digits are to be output, where m is an unsigned default integer literal constant. The value 99 printed under control of the edit descriptor i5.3 would appear as $bb099$. The value of m is even permitted to be zero, and the field will be then filled with blanks if the value printed is 0. On input, $i\ w.m$ is interpreted in exactly the same way as $i\ w$.

For the i and all other numeric edit descriptors, if the output field is too narrow to contain the number to be output, it is filled with asterisks.

Integer values may also be converted by the bw, bw.m, ow, ow.m, zw, and zw.m edit descriptors. These are similar to the i form, but are intended for integers represented in the binary, octal, and hexadecimal number systems, respectively (Section 2.6.1). The external form does not contain the leading letter (b, o, or z) or the delimiters.

Real values may be converted by either e, en, es, or f edit descriptors. The f descriptor we have met in earlier examples. Its general form is fw.d, where w and d are unsigned default integer literal constants which define, respectively, the field width and the number of digits to appear after the decimal point in the output field. The decimal point counts as one position in the field. On input, if the input string has a decimal point, the value of d is ignored. Reading the input string b9.3729b with the edit descriptor f8.3 would cause the value 9.3729 to be transferred. All the digits are used, but roundoff may be inevitable because of the actual physical storage reserved for the value on the computer being used.

There are, in addition, two other forms of input string that are acceptable to the f edit descriptor. The first is an optionally signed string of digits without a decimal point. In this case, the d rightmost digits will be taken to be the fractional part of the value. Thus b-14629 read under control of the edit descriptor f7.2 will transfer the value -146.29. The second form is the standard default real form of literal constant, as defined in Section 2.6.2, and the variant in which the exponent is signed and e is omitted. In this case, the d part of the descriptor is again ignored. Thus the value 14.629e-2 (or 14.629-2), under control of the edit descriptor f9.1, will transfer the value 0.14629. The exponent letter may also be written in upper case.

Values are rounded on output following the normal rules of arithmetic. Thus, the value 10.9336, when output under control of the edit descriptor f8.3, will appear as *bb10.934*, and under the control of f4.0 as *b11*.

The e edit descriptor has two forms, *ew.d* and *ew.dee*, and is more appropriate for numbers with a magnitude below about 0.01, or above 1000. The rules for these two forms for input are identical to those for the *fw.d* edit descriptor. For output with the *ew.d* form of the descriptor, a different character string will be transferred, containing a significand with absolute value less than 1 and an exponent field of four characters that consists of either E followed by a sign and two digits or of a sign and three digits. Thus, for $1.234 * 10^{23}$ converted by the edit descriptor e10.4, the string *b.1234E+24* or *b.1234+024* will be transferred. The form containing the exponent letter E is not used if the magnitude of the exponent exceeds 99. For instance, e10.4 would cause the value $1.234 * 10^{-150}$ to be transferred as *b.1234-149*. Some processors print a zero before the decimal point.

In the second form of the e edit descriptor, *ew.dee*, *e* is an unsigned, nonzero default integer literal constant that determines the number of digits to appear in the exponent field. This form is obligatory for exponents whose magnitude is greater than 999. Thus the value $1.234 * 10^{1234}$ with the edit descriptor e12.4e4 is transferred as the string *b.1234E+1235*. An increasing number of computers are able to deal with these very large exponent ranges. It can also be used if only one exponent digit is desired. For example, the value 1.211 with the edit descriptor e9.3e1 is transferred as the string *b0.121E+1*.

The en (*engineering*) edit descriptor is identical to the e edit descriptor except that on output the decimal exponent is divisible by three, a nonzero significand is greater than or equal to 1 and less than 1000, and the scale factor (Section 9.13.5) has no effect. Thus, the value 0.0217 transferred under an en9.2 edit descriptor would appear as 21.70E-03 or 21.70-003.

The es (*scientific*) edit descriptor is identical to the e edit descriptor, except that on output the absolute value of a nonzero significand is greater than or equal to 1 and less than 10 and the scale factor (Section 9.13.5) has no effect. Thus, the value 0.0217 transferred under an es9.2 edit descriptor would appear as 2.17E-02 or 2.17-002.

Complex values may be edited under control of pairs of f, e, en, or es edit descriptors. The two descriptors do not need to be identical. The complex value (0.1,100.) converted under control of f6.1,e8.1 would appear as *bbb0.1b0.1E+03*. The two descriptors may be separated by character string and control edit descriptors (to be described in Sections 9.13.4 and 9.13.5).

Logical values may be edited using the *lw* edit descriptor. This defines a field of width *w* which on input consists of optional blanks, optionally followed by a decimal point, followed by t or f (or T or F), optionally followed by additional characters. Thus a field defined by 17 permits the strings .true. and .false. to be input. The characters t or f will be transferred as the values true or false respectively. On output, the character T or F will appear in the right-most position in the output field.

Character values may be edited using the a edit descriptor in one of its two forms, either a or aw. In the first of the two forms, the width of the input or output field is determined by the actual width of the item in the I/O list, measured in number of characters of whatever kind. Thus, a character variable of length 10, containing the value STATEMENTS, when written under control of the a edit descriptor would appear in a field 10 characters wide, and the non-default character variable of length 4 containing the value 国際標準 would appear in a field 4 characters wide. If, however, the first variable were converted under an a11 edit descriptor, it would be printed with a leading blank, bSTATEMENTS. Under control of a8, the eight left-most characters only would be written: STATEMEN.

Conversely, with the same variable on input, an a11 edit descriptor would cause the 10 right-most characters in the 11 character-wide input field to be transferred: bSTATEMENTS would be transferred as STATEMENTS. The a8 edit descriptor would cause the eight characters in the field to be transferred to the eight left-most positions in the variable, and the remaining two would be filled with blanks: STATEMEN would be transferred as STATEMENbb.

All characters transferred under the control of an a or aw edit descriptor have the kind of the I/O list item, and we note that this edit descriptor is the *only* one which can be used to transmit non-default characters to or from a record. In the non-default case, the blank padding character is processor dependent.

The gw.d and gw.dee (*general*) edit descriptor may be used for any intrinsic data type. When used for real or complex types, it is identical to the e edit descriptor except that an output value with magnitude n in the range

$$0.1 - 0.5 \times 10^{-d-1} \leq n < 10^d - 0.5$$

or zero when d = 0 are converted as if by an f edit descriptor, and followed by the same number of blanks as the e edit descriptor would have used for the exponent part. The equivalent f edit descriptor is fw'.d', where w' = w - 4 for gw.d or w-e-2 for gw.dee, and d' = d - k when n lies in the range

$$10^{k-1}(1 - 0.5 \times 10^{-d}) \leq n < 10^k(1 - 0.5 \times 10^{-d})$$

for k = 0, 1, ..., d and d' = d - 1 when n = 0 and d > 0. This form is useful for printing values whose magnitudes are not well known in advance, and where an f conversion is preferred where possible, and an e otherwise.

When the g edit descriptor is used for integer, logical, or character types, it follows the rules of the iw, lw, and aw edit descriptors, respectively.

Finally, values of *derived types* are edited by the appropriate sequence of edit descriptors corresponding to the intrinsic types of the ultimate components of the derived type. An example is:

```
type string
    integer          :: length
    character(len=20) :: word
end type string
type(string) :: text
read(*, '(i2, a)') text
```

9.13.3 Minimal field width editing (Fortran 95 only)

In order to allow output records to contain as little unused space as possible, the i, f, b, o, and z edit descriptors (Section 9.13.2) may specify, in Fortran 95, a field width of zero, as in i0 or f0.3. This does not denote a zero-width field, but a field that is of the minimum width necessary to contain the output value in question. The programmer does not need to worry that a field with too narrow a width will cause output values to overflow and contain only asterisks.

9.13.4 Character string edit descriptor

A *default character* literal constant without a specified kind parameter can be transferred to an output file by embedding it in the format specification itself, as in the example

```
print "(' This is a format statement')"
```

The string will appear each time the statement is executed. In this descriptor, case is significant. Character string edit descriptors must not be used on input.

9.13.5 Control edit descriptors

It is sometimes necessary to give other instructions to an I/O device than just the width of fields and how the contents of these fields are to be interpreted. For instance, it may be that one wishes to position fields at certain columns or to start a new record without issuing a new write command. For this type of purpose, the control edit descriptors provide a means of informing the processor which action has to be taken. Some of these edit descriptors contain information that is used as it is processed; others are like switches, which change the conditions under which I/O takes place from the point where they are encountered, until the end of the processing of the I/O statement containing them (including reversions, Section 9.13.1). These latter descriptors we shall deal with first.

Control edit descriptors setting conditions

Embedded blanks in numeric input fields are treated in one of two ways, either as zero, or as null characters that are squeezed out by moving the other characters in the input field to the right, and adding leading blanks to the field (unless the field is totally blank, in which case it is interpreted as zero). The default is given by the blank= specifier (Section 10.3) currently in effect for the unit or is null for an internal file. Whatever the default may then be for a file, it may be overridden during a given format conversion by the bn (blanks null) and bz (blanks zero) edit descriptors. Let us suppose that the mode is that blanks are treated as zeros. The input string bb1b4 converted by the edit descriptor i5 would transfer the value 104. The same string converted by bn, i5 would give 14. A bn or bz edit descriptor

switches the mode for the rest of that format specification, or until another bn or bz edit descriptor is met. The bn and bz edit descriptors have no effect on output.

Negative numerical values are always written with *leading signs* on output. For positive quantities other than exponents, whether the signs are written depends on the processor. The ss (sign suppress) edit descriptor suppresses leading plus signs, that is the value 99 printed by i5 is *bbb99* and 1.4 is printed by e10.2 as *bb0.14E+01*. To switch on plus sign printing, the sp (sign print) edit descriptors may be used: the same numbers written by sp,i5,e10.2 become *bb+99* and *b+0.14E+01*. The s edit descriptor restores the option to the processor. An ss, sp, or s will remain in force for the remainder of the format specification, unless another ss, sp, or s edit descriptor is met. These edit descriptors provide complete control over sign printing, and are useful for producing coded outputs which have to be compared automatically, on two different computers.

Scale factors apply to the input of real quantities under the e, f, en, es, and g edit descriptors, and are a means of scaling the input values. Their form is *kp*, where *k* is a default integer literal constant specifying the scale factor. The value is zero at the beginning of execution of the statement. The effect is that any quantity which does not have an exponent field will be reduced by a factor 10^k . Quantities with an exponent are not affected.

The scale factor *kp* also affects output with e, f or g editing, but has no effect with en or es editing. Under control of an f edit descriptor, the quantity will be multiplied by a factor 10^k . Thus, the number 10.39 output by an f6.0 edit descriptor following the scale factor 2p will appear as *b1039..* With the e edit descriptor, and with g where the e style editing is taken, the quantity is transferred with the exponent reduced by *k*, and the significand multiplied by 10^k . Thus $0.31 * 10^3$, written after a 2p edit descriptor under control of e9.2, will appear as *31.00E+01*. This gives a better control over the output style of real quantities which otherwise would have no significant digits before the decimal point.

The comma between a scale factor and an immediately following f, e, en, es, or g edit descriptor may be omitted, but we do not recommend that practice since it suggests that the scale factor applies only to the next edit descriptor, whereas in fact it applies throughout the format until another scale factor is encountered.

Control edit descriptors for immediate processing

Tabulation in an input or output field can be achieved using the edit descriptors tn, trn (and nx), and tln, where *n* is a positive default integer literal constant. These state, respectively, that the next part of the I/O should begin at position *n* in the current record (where the *left tab limit* is position 1), or at *n* positions to the right of the current position, or at *n* positions to the left of the current position (the left tab limit if the current position is less than or equal to *n*). Let us suppose that, following an advancing read, we read an input record *bb9876* with the following statement:

```
read (*, '(t3, i4, t14, i1, i2)') i, j, k
```

The format specification will move a notional pointer firstly to position 3, whence *i* will be read. The variable *i* will acquire the value 9876, and the notional pointer is then at position 7. The edit descriptor *t14* moves it left four positions, back to position 3. The quantities *j* and *k* are then read, and they acquire the values 9 and 87, respectively. These edit descriptors cause replacement on output, or multiple reading of the same items in a record on input. On output, any gaps ahead of the last character actually written are filled with spaces. If any character that is skipped by one of the descriptors is of other than default type, the positioning is processor dependent.

If the current record is the first one processed by the I/O statement and follows non-advancing I/O that left the file positioned within a record, the next character is the left tab limit; otherwise, the first character of the record is the left tab limit.

The *nx* edit descriptor is equivalent to the *trn* edit descriptor. It is often used to place spaces in an output record. For example, to start an output record with a blank by this method, one writes

```
fmt= '(1x,....)'
```

Spaces such as this can precede a data edit descriptor, but *1x,i5* is not, for instance, exactly equivalent to *i6* on output, as any value requiring the full six positions in the field will not have them available in the former case.

The *t* and *x* edit descriptors never cause replacement of a character already in an output record, but merely cause a change in the position within the record such that such a replacement might be caused by a subsequent edit descriptor.

New records may be started at any point in a format specification by means of the slash (/) edit descriptor. This edit descriptor, although described here, may in fact have repeat counts; to skip, say, three records one can write either */,/,/* or *3/*. On input, a new record will be started each time a / is encountered, even if the contents of the current record have not all been transferred. Reading the two records

```
bbb99bbb10
bb100bbb11
```

with the statement

```
read '(bz,i5,i3,/i5,i3,i2)', i, j, k, l, m
```

will cause the values 99, 0, 100, 0 and 11 to be transferred to the five integer variables, respectively. This edit descriptor does not need to be separated by a comma from a preceding edit descriptor, unless it has a repeat count; it does not ever need to be separated by a comma from a succeeding edit descriptor.

The result of writing with a format containing a sequence of, say, four slashes, as represented by

```
print '(i5,4/,i5)', i, j
```

is to separate the two values by three blank records (the last slash starts the record containing *j*); if *i* and *j* have the values 99 and 100, they would appear as

```
bbb99
b
b
b
bb100
```

A slash edit descriptor written to an internal file will cause the following values to be written to the next element of the character array specified for the file. Each such element corresponds to a record, and the number of characters written to a record must not exceed its length.

Colon editing is a means of terminating format control if there are no further items in an I/O list. In particular, it is useful for preventing further output of character strings used for annotation if the output list is exhausted. Consider the following output statement, for an array $l(3)$:

```
print'("11 =", i5, :, "12 =", i5, :, "13 =", i5)', &
      (l(i), i=1, n)
```

If n has the value 3, then three values are printed. If n has the value 1 then, without the colons, the following output string would be printed:

```
11 = 59 12 =
```

The colon, however, stops the processing of the format, so that the annotation for the absent second value is not printed. This edit descriptor need not be separated from a neighbour by a comma. It has no effect if there are further items in the I/O list.

9.14 Unformatted I/O

The whole of this chapter has so far dealt with formatted I/O. The internal representation of a value may differ from the external form, which is always a character string contained in an input or output record. The use of formatted I/O involves an overhead for the conversion between the two forms, and often a roundoff error too. There is also the disadvantage that the external representation usually occupies more space on a storage medium than the internal representation. These three actual or potential drawbacks are all absent when unformatted I/O is used. In this form, the internal representation of a value is written exactly as it stands to the storage medium, and can be read back directly with neither roundoff nor conversion overhead. Here, a value of derived type is treated as a whole and is not equivalent to a list of its ultimate components. This is another reason for the rule (Section 9.3) that it must not have a pointer component at any level of component selection.

This type of I/O should be used in all cases where the records are generated by a program on one computer, to be read back on the same computer or another computer using the same internal number representations. Only when this is not the case, or when the data have to be visualized in one form or another, should

formatted I/O be used. The records of a file must all be formatted or all be unformatted (apart from the `endfile` record).

Unformatted I/O has the incidental advantage of being simpler to program since no complicated format specifications are required. The forms of the `read` and `write` statements are the same as for formatted I/O, but without any `fmt=` or `nm1=` specifier:

```
read(4) q
write(nout, iostat=ios, err=110) a
```

Non-advancing I/O is not available (in fact, an `advance=` specifier is not allowed).

Each `read` or `write` statement transfers exactly one record. The file must be an external file. The number of values specified by the input list of a `read` statement must not exceed the number of values available in the current record.

On output to a file connected for sequential access, a record of sufficient length is created. On input, the type and type parameters of each entity in the list must agree with those of the value in the record, except that two reals may correspond to one complex when all three have the same kind parameter.

9.15 Direct-access files

The only type of file organization that we have so far dealt with is the sequential file, which has a beginning and an end, and which contains a sequence of records, one after the other. Fortran permits another type of file organization known as *direct access* (or sometimes as random access or indexed). All the records have the same length, each record is identified by an index number, and it is possible to write, read, or re-write any specified record without regard to position. (In a sequential file, only the last record may be rewritten without losing other records; in general, records in sequential files cannot be replaced.) The records are either all formatted or all unformatted.

By default, any file used by a Fortran program is a sequential file, unless declared to be direct access. This declaration has to be made using the `access='direct'` and `rec1=rl` specifiers of the `open` statement, which is described in the next chapter, (rl is the length of a record in the file). Once this declaration has been made, reading and writing, whether formatted or unformatted, proceeds as described for sequential files, except for the addition of a `rec=i` specifier to the `read` and `write` statements, where i is a scalar integer expression whose value is the index number of the record concerned. An `end=` specifier is not permitted. Usually, a data transfer statement for a direct-access file accesses a single record, but during formatted I/O any slash edit descriptor increases the record number by one and causes processing to continue at the beginning of this record. A sequence of statements to write, read, and replace a given record is given in Figure 9.5.

The file must be an external file and `namelist` formatting, list-directed formatting, and non-advancing I/O are all unavailable.

Figure 9.5

```

integer, parameter :: nunit=2, len=100
integer          :: i, length
real            :: a(len), b(len+1:2*len)
:
inquire (iolength=length) a           ! See Section 10.5
open (nunit, access='direct', recl=length)
                                         ! See Section 10.3
:
! Write array B to direct-access file in record 14
write (nunit, rec=14) b
:
!
! Read the array back into array a
read (nunit, rec=14) a
:
do i = 1, len/2
    a(i) = i
end do
!
! Replace modified record
write (nunit, rec=14) a

```

Direct-access files are particularly useful for applications which involve lots of hopping around inside a file, or where records need to be replaced, for instance in data base applications. A weakness is that the length of all the records must be the same, though on formatted output, the record is padded with blanks if necessary. For unformatted output, if the record is not filled, the remainder is undefined.

This simple and powerful facility allows much clearer control logic to be written than is the case for a sequential file which is repeatedly read, backspaced, or rewound. Only when direct-access files become large may problems of long access times become evident on some computer systems, and this point should always be investigated before heavy investments are made in programming large direct-access file applications.

Some computer systems allow the same file to be regarded as sequential or direct access according to the specification in the open statement or its default. The standard, therefore, regards this as a property of the connection rather than of the file. In this case, the order of records, even for sequential I/O, is that determined by the direct-access record numbering.

9.16 Execution of a data transfer statement

So far, we have used simple illustrations of data transfer statements without dependencies. However, some forms of dependency are permitted and can be very useful. For example, the statement

```
read (*, *) n, a(1:n) ! n is an integer
```

allows the length of an array section to be part of the data.

With dependencies in mind, the order in which operations are executed is important. It is as follows:

- i) identify the unit;
- ii) establish the format (if any);
- iii) position the file ready for the transfer (if required);
- iv) transfer data between the file and the I/O list or namelist;
- v) position the file following the transfer (if required);
- vi) cause the iostat and size variables (if present) to become defined.

The order of transfer of namelist input is that in the input records. Otherwise, the order is that of the I/O list or namelist. Each input item is processed in turn, and may affect later subobjects and implied-do indices. All expressions within an I/O list item are determined at the beginning of processing of the item. If an entity is specified more than once during execution of a namelist input statement, the later value overwrites the earlier value. Any zero-sized array or zero-length implied-do list is ignored.

When an input item is an array, no element of the array is permitted to affect the value of an expression within the item. For example, the cases shown in Figure 9.6 are not permitted. This prevents dependencies occurring within the item itself.

Figure 9.6

```
integer :: j(10)
:
read *, j(j) ! Not permitted
read *, j(j(1):j(10)) ! Not permitted
```

In the case of an internal file, an I/O item must not be in the file or associated with it. Nor may an input item contain or be associated with any portion of the established format.

Finally, a function reference must not appear in an expression anywhere in an I/O statement if it causes another I/O statement to be executed.

9.17 Summary

This chapter has begun the description of Fortran's extensive I/O facilities. It has covered the formatted I/O statements, and their associated format specifications, and then turned to unformatted I/O and direct-access files.

The syntax of the `read` and `write` statements has been introduced gradually. The full syntax is

`read (control-list) [input-list]`

and

`write (control-list) [output-list]`

where *control-list* contains one or more of the following:

```
[unit=] u,
[fmt=] fmt,
[nml=] nml-name,
rec= i,
iostat= ios,
err= error-label,
end= end-label,
advance= advance,
size= size,
eor= eor-label.
```

A *control-list* must include a unit specifier and must not include any specifier more than once. The `iostat` and `size` variables must not be associated with each other (for instance be identical), nor with any entity being transferred, nor with any *do-var* of an implied-do list of the same statement. If either of these variables is an array element, the subscript value must not be affected by the data transfer, implied-do processing, or the evaluation of any other specifier in the statement.

There are many detailed changes with respect to Fortran 77, often to support new features in other parts of the language, such as derived types. Other new features are `namelist`, non-advancing I/O, the `b`, `o`, `z`, `en` and `es` edit descriptors, and the generalization of the `g` edit descriptor. In Fortran 95, minimal field width editing is new.

9.18 Exercises

1. Write suitable `print` statements to print the name and contents of each of the following arrays:

- a) `real :: grid d(10,10)`, 10 elements to a line (assuming the values are between 1.0 and 100.0);
- b) `integer :: list(50)`, the odd elements only;

- c) character(len=10) :: titles(20), two elements to a line;
 - d) real :: power(10), five elements to a line in engineering notation;
 - e) logical :: flags(10), on one line;
 - f) complex :: plane(5), on one line.
2. Write statements to output the state of a game of tic-tac-toe (noughts-and-crosses) to a unit designated by the variable `unit`.
3. Write a program which reads an input record of up to 132 characters into an internal file and classifies it as a Fortran comment line with no statement, an initial line without a statement label, an initial line with a statement label, a continuation line, or a line containing multiple statements.
4. Write separate list-directed input statements to fill each of the arrays of Exercise 1. For each statement write a sample first input record.
5. Write the function `get_char`, to read single characters from a formatted, sequential file, ignoring any record structure.

10. Operations on external files

10.1 Introduction

So far we have discussed the topic of external files in a rather superficial way. In the examples of the various I/O statements in the previous chapter, an implicit assumption has always been made that the specified file was actually available, and that records could be written to it and read from it. For sequential files, the file control statements described in the next section further assume that it can be positioned. In fact, these assumptions are not necessarily valid. In order to define explicitly and to test the status of external files, three file status statements are provided: `open`, `close`, and `inquire`. Before beginning their description, however, two new definitions are required.

A computer system contains, among other components, a CPU and a storage system. Modern storage systems are usually based on some form of disc, which is used to store files for long or short periods of time. The execution of a computer program is, by comparison, a transient event. A file may exist for years, whereas programs run for only seconds or minutes. In Fortran terminology, a file is said to *exist* not in the sense we have just used, but in the restricted sense that it exists as a file *to which the program might have access*. In other words, if the program is prohibited from using the file because of a password protection system, or because some necessary action has not been taken in the job control language which is controlling the execution of the program, the file ‘does not exist’.

A file which exists for a running program may be empty and may or may not be *connected* to that program. The file is connected if it is associated with a unit number known to the program. Such connection is usually made by executing an `open` statement for the file, but many computer systems will *pre-connect* certain files which any program may be expected to use, such as terminal input and output. Thus we see that a file may exist but not be connected. It may also be connected but not exist. This can happen for a pre-connected new file. The file will only come into existence (be *created*) if some other action is taken on the file: executing an `open`, `write`, `print`, or `endfile` statement. A unit must not be connected to more than one file at once, and a file must not be connected to more than one unit at once.

There are a number of other points to note with respect to files:

- The set of allowed names for a file is processor dependent.

- Both sequential and direct access may be available for some files, but normally a file is limited to one or the other.
- A file never contains both formatted and unformatted records.

Finally, we note that no statement described in this chapter applies to internal files.

10.2 File positioning statements

When reading or writing an external file that is connected for sequential access, whether formatted or unformatted, it is sometimes necessary to perform other control functions on the file in addition to input and output. In particular, one may wish to alter the current position, which may be within a record, between records, ahead of the first record (at the *initial point*), or after the last record (at its *terminal point*). The following three statements are provided for these purposes.

10.2.1 The backspace statement

It can happen in a program that a series of records is being written and that, for some reason, the last record written should be replaced by a new one, that is be overwritten. Similarly, when reading records, it may be necessary to reread the last record read, or to check-read a record which has just been written. For this purpose, Fortran provides the `backspace` statement, which has the syntax

`backspace u`

or

`backspace ([unit=]u [,iostat=ios] [,err=error-label])`

where u is a scalar integer expression whose value is the unit number, and the other optional specifiers have the same meaning as for a `read` statement. Again, keyword specifiers may be in any order, but the unit specifier must come first as a positional specifier.

The action of this statement is to position the file before the current record if it is positioned within a record, or before the preceding record if it is positioned between records. An attempt to `backspace` when already positioned at the beginning of a file results in no change in the file's position. If the file is positioned after an `endfile` record (Section 10.2.3), it becomes positioned before that record. It is not possible to `backspace` a file that does not exist, nor to `backspace` over a record written by a list-directed or namelist output statement (Sections 9.9 and 9.10). A series of `backspace` statements will `backspace` over the corresponding number of records. This statement is often very costly in computer resources and should be used as little as possible.

10.2.2 The rewind statement

In an analogous fashion to rereading, rewriting, or check-reading a record, a similar operation may be carried out on a complete file. For this purpose the `rewind` statement,

`rewind u`

or

`rewind ([unit=]u [,iostat=ios] [,err=error-label])`

may be used to reposition a file, whose unit number is specified by the scalar integer expression *u*. Again, keyword specifiers may be in any order, but the unit specifier must come first as a positional specifier. If the file is already at its beginning, there is no change in its position. The statement is permitted for a file that does not exist, and has no effect.

10.2.3 The endfile statement

The end of a file connected for sequential access is normally marked by a special record which is identified as such by the computer hardware, and computer systems ensure that all files written by a program are correctly terminated by such an *endfile record*. In doubtful situations, or when a subsequent program step will reread the file, it is possible to write an endfile record explicitly using the `endfile` statement:

`endfile u`

or

`endfile ([unit=]u [,iostat=ios] [,err=error-label])`

where *u*, once again, is a scalar integer expression specifying the unit number. Again, keyword specifiers may be in any order, but the unit specifier must come first as a positional specifier. The file is then positioned after the endfile record. This endfile record, if subsequently read by a program, must be handled using the `end=end-label` specifier of the `read` statement, otherwise program execution will normally terminate. Prior to data transfer, a file must not be positioned after an endfile record, but it is possible to backspace or rewind across an endfile record, which allows further data transfer to occur. An endfile record is written automatically whenever either a backspace or rewind operation follows a write operation as the next operation on the unit, or the file is closed by execution of a `close` statement (Section 10.4), by an `open` statement for the same unit (Section 10.3), or by normal program termination.

If the file may also be connected for direct access, only the records ahead of the endfile record are considered to have been written and only these may be read during a subsequent direct-access connection.

Note that if a file is connected to a unit but does not exist for the program, it will be made to exist by executing an `endfile` statement on the unit.

10.2.4 Data transfer statements

Execution of a data transfer statement (`read`, `write`, or `print`) also affects the file position. If it is between records, it is moved to the start of the next record. Data transfer then takes place, which usually moves the position. No further movement occurs for non-advancing access. For advancing access, the position finally moves to follow the last record transferred.

10.3 The open statement

The `open` statement is used to connect an external file to a unit, create a file that is preconnected, create a file and connect it to a unit, or change certain properties of a connection. The syntax is

```
open ([unit=]u [,olist])
```

where *u* is a scalar integer expression specifying the external file unit number, and *olist* is a list of optional specifiers. If the unit is specified with `unit=`, it may appear in *olist*. A specifier must not appear more than once. In the specifiers, all entities are scalar and all characters are of default kind. In character expressions, any trailing blanks are ignored and, except for `file=`, any upper-case letters are converted to lower case. The specifiers are

`iostat= ios`, where *ios* is a default integer variable which is set to zero if the statement is correctly executed, and to a positive value otherwise.

`err= error-label`, where *error-label* is the label of a statement in the same scoping unit to which control will be transferred in the event of an error occurring during execution of the statement.

`file= fn`, where *fn* is a character expression that provides the name of the file. If this specifier is omitted and the unit is not connected to a file, the `status=` specifier must be specified with the value `scratch` and the file connected to the unit will then depend on the computer system. Whether the interpretation is case sensitive varies from system to system.

`status= st`, where *st* is a character expression that provides the value `old`, `new`, `replace`, `scratch`, or `unknown`. The `file=` specifier must be present if `new` or `replace` is specified or if `old` is specified and the unit is not connected; the `file=` specifier must not be present if `scratch` is specified. If `old` is specified, the file must already exist; if `new` is specified, the file must not already exist, but will be brought into existence by the action of the `open` statement. The status of the file then becomes `old`. If `replace` is specified and the file does not already exist, the file is created; if the file does exist, the file is deleted, and a new file is created with the same name. In each case the status is changed to `old`. If the value `scratch` is specified, the file is created and becomes connected, but it cannot be kept after completion of

the program or execution of a `close` statement (Section 10.4). If `unknown` is specified, the status of the file is system dependent. This is the default value of the specifier, if it is omitted.

`access= acc`, where `acc` is a character expression that provides one of the values `sequential` or `direct`. For a file which already exists, this value must be an allowed value. If the file does not already exist, it will be brought into existence with the appropriate access method. If this specifier is omitted, the value `sequential` will be assumed.

`form= fm`, where `fm` is a character expression that provides the value `formatted` or `unformatted`, and determines whether the file is to be connected for formatted or unformatted I/O. For a file which already exists, the value must be an allowed value. If the file does not already exist, it will be brought into existence with an allowed set of forms that includes the specified form. If this specifier is omitted, the default is `formatted` for sequential access and `unformatted` for direct-access connection.

`recl= rl`, where `rl` is an integer expression whose value must be positive. For a direct-access file, it specifies the length of the records, and is obligatory. For a sequential file, it specifies the maximum length of a record, and is optional with a default value that is processor dependent. For formatted files, the length is the number of characters for records that contain only default characters; for unformatted files it is system dependent but the `inquire` statement (Section 10.5) may be used to find the length of an I/O list. In either case, for a file which already exists, the value specified must be allowed for that file. If the file does not already exist, the file will be brought into existence with an allowed set of record lengths that includes the specified value.

`blank= bl`, where `bl` is a character expression that provides the value `null` or `zero`. This connection must be for formatted I/O. This specifier sets the default for the interpretation of blanks in numeric input fields, as discussed in the description of the `bn` and `bz` edit descriptors (Section 9.13.5). If the value is `null`, such blanks will be ignored (except that a completely blank field is interpreted as zero). If the value is `zero`, such blanks will be interpreted as zeros. If the specifier is omitted, the default is `null`.

`position= pos`, where `pos` is a character expression that provides the value `asis`, `rewind`, or `append`. The access method must be `sequential`, and if the specifier is omitted the default value `asis` will be assumed. A new file is positioned at its initial point. If `asis` is specified and the file exists and is already connected, the file is opened without changing its position; if `rewind` is specified the file is positioned at its initial point; if `append` is specified and the file exists, it is positioned ahead of the `endfile` record if it has one (and otherwise at its terminal point). For a file which exists but

is not connected, the effect of the `asis` specifier on the file's position is unspecified.

`action= act`, where `act` is a character expression that provides the value `read`, `write`, or `readwrite`. If `read` is specified, the `write`, `print` and `endfile` statements must not be used for this connection; if `write` is specified, the `read` statement must not be used (and `backspace` and `position='append'` may fail on some systems); if `readwrite` is specified, there is no restriction. If the specifier is omitted, the default value is processor dependent.

`delim= del` where `del` is a character expression that provides the value `quote`, `apostrophe`, or `none`. If `apostrophe` or `quote` is specified, the corresponding character will be used to delimit character constants written with list-directed or `namelist` formatting, and it will be doubled where it appears within such a character constant; also, non-default character values will be preceded by kind values. No delimiting character is used if `none` is specified, nor does any doubling take place. The default value if the specifier is omitted is `none`. This specifier may appear only for formatted files.

`pad= pad`, where `pad` is a character expression that provides the value `yes` or `no`. If `yes` is specified, a formatted input record will be regarded as padded out with blanks whenever an input list and the associated format specify more data than appear in the record. (If `no` is specified, the length of the input record must not be less than that specified by the input list and the associated format, except in the presence of an `advance='no'` specifier and either an `eor=` or an `iostat=` specification.) The default value if the specifier is omitted is `yes`. For non-default characters, the blank padding character is processor dependent.

An example of an open statement is

```
open (2, iostat=ios, err=99, file='cities', &
      status='new', access='direct', recl=100)
```

which brings into existence a new, direct-access, unformatted file named `cities`, whose records have length 100. The file is connected to unit number 2. Failure to execute the statement correctly will cause control to be passed to the statement labelled 99, where the value of `ios` may be tested.

The open statements in a program are best collected together in one place, so that any changes which might have to be made to them when transporting the program from one system to another can be carried out without having to search for them. Regardless of where they appear, the connection may be referenced in any program unit of the program.

The purpose of the open statement is to connect a file to a unit. If the unit is, however, already connected to a file then the action may be different. If the `file=` specifier is omitted, the default is the name of the connected file. If the file in question does not exist, but is pre-connected to the unit, then all the properties

specified by the `open` statement become part of the connection. If the file is already connected to the unit, then of the existing attributes only the `blank=`, `delim=`, `pad=`, `err=`, and `iostat=` specifiers may have values different from those already in effect. If the unit is already connected to another file, the effect of the `open` statement includes the action of a prior `close` statement on the unit (without a `status=` specifier, see next section).

A file already connected to one unit must not be specified for connection to another unit.

In general, by repeated execution of the `open` statement on the same unit, it is possible to process in sequence an arbitrarily high number of files, whether they exist or not, as long as the restrictions just noted are observed.

10.4 The `close` statement

The purpose of the `close` statement is to disconnect a file from a unit. Its form is

```
close ([unit=]u [,iostat=ios] [,err=error-label] [,status=st])
```

where *u*, *ios*, and *error-label* have the same meanings as described in the previous section for the `open` statement. Again, keyword specifiers may be in any order, but the unit specifier must come first as a positional specifier.

The function of the `status=` specifier is to determine what will happen to the file once it is disconnected. The value of *st*, which is a scalar default character expression, may be either `keep` or `delete`, ignoring any trailing blanks and converting any upper-case letters to lower case. If the value is `keep`, a file that exists continues to exist after execution of the `close` statement, and may later be connected again to a unit. If the value is `delete`, the file no longer exists after execution of the statement. In either case, the unit is free to be connected again to a file. The `close` statement may appear anywhere in the program, and if executed for a non-existing or unconnected unit, acts as a ‘do nothing’ statement. The value `keep` must not be specified for files with the status `scratch`.

If the `status=` specifier is omitted, its default value is `keep` unless the file has status `scratch`, in which case the default value is `delete`. On normal termination of execution, all connected units are closed, as if `close` statements with omitted `status=` specifiers were executed.

An example of a `close` statement is

```
close (2, iostat=ios, err=99, status='delete')
```

10.5 The `inquire` statement

The status of a file can be defined by the operating system prior to execution of the program, or by the program itself during execution, either by an `open` statement or by some action on a pre-connected file which brings it into existence. At any time during the execution of a program it is possible to inquire about the status and

attributes of a file using the `inquire` statement. Using a variant of this statement, it is similarly possible to determine the status of a unit, for instance whether the unit number exists for that system (that is, whether it is an allowed unit number), whether the unit number has a file connected to it and, if so, which attributes that file has. Another variant permits an inquiry about the length of an output list when used to write an unformatted record.

Some of the attributes that may be determined by use of the `inquire` statement are dependent on others. For instance, if a file is not connected to a unit, it is not meaningful to inquire about the form being used for that file. If this is nevertheless attempted, the relevant specifier is undefined.

The three variants are known as `inquire by file`, `inquire by unit`, and `inquire by output list`. In the description of the `inquire` statement which follows, the first two variants will be described together. Their forms are

`inquire ([unit=]u, ilist)`

for `inquire by unit`, where `u` is a scalar integer expression specifying an external unit, and

`inquire (file=f1n, ilist)`

for `inquire by file`, where `f1n` is a scalar character expression whose value, ignoring any trailing blanks, provides the name of the file concerned. Whether the interpretation is case sensitive is system dependent. If the unit or file is specified by keyword, it may appear in `ilist`. A specifier must not occur more than once in the list of optional specifiers, `ilist`. All assignments occur following the usual rules, and all values of type character, apart from that for the `name=` specifier, are in upper case. The specifiers, in which all variables are scalar and of default kind, are

`iostat= ios` and `err= error-label`, have the meanings described for them in the `open` statement in Section 10.3. The `iostat=` variable is the only one which is defined if an error condition occurs during the execution of the statement.

`exist= ex`, where `ex` is a logical variable. The value true is assigned to `ex` if the file (or unit) exists, and false otherwise.

`opened= open`, where `open` is a logical variable. The value true is assigned to `open` if the file (or unit) is connected to a unit (or file), and false otherwise.

`number= num`, where `num` is an integer variable that is assigned the value of the unit number connected to the file, or -1 if no unit is connected to the file.

`named= nmd` and `name= nam`, where `nmd` is a logical variable that is assigned the value true if the file has a name, and false otherwise. If the file has a name, the character variable `nam` will be assigned the name. This value is not necessarily the same as that given in the `file` specifier, if used, but may be qualified in some way. However, in all cases it is a name which is valid

for use in a subsequent open statement, and so the `inquire` can be used to determine the actual name of a file before connecting it. Whether the file name is case sensitive is system dependent.

`access= acc`, where `acc` is a character variable that is assigned one of the values SEQUENTIAL or DIRECT depending on the access method for a file that is connected, and UNDEFINED if there is no connection.

`sequential= seq` and `direct= dir`, where `seq` and `dir` are character variables that are assigned the value YES, NO, or UNKNOWN, depending on whether the file may be opened for sequential or direct access respectively, or whether this cannot be determined.

`form= frm`, where `frm` is a character variable that is assigned one of the values FORMATTED or UNFORMATTED, depending on the form for which the file is actually connected, and UNDEFINED if there is no connection.

`formatted= fmt` and `unformatted= unf`, where `fmt` and `unf` are character variables that are assigned the value YES, NO, or UNKNOWN, depending on whether the file may be opened for formatted or unformatted access, respectively, or whether this cannot be determined.

`recl= rec`, where `rec` is an integer variable that is assigned the value of the record length of a file connected for direct access, or the maximum record length allowed for a file connected for sequential access. The length is the number of characters for formatted records containing only characters of default type, and system dependent otherwise. If there is no connection, `rec` becomes undefined.

`nextrec= nr`, where `nr` is an integer variable that is assigned the value of the number of the last record read or written, plus one. If no record has been yet read or written, it is assigned the value 1. If the file is not connected for direct access or if the position is indeterminate because of a previous error, `nr` becomes undefined.

`blank= bl`, where `bl` is a character variable that is assigned the value NULL or ZERO, depending on whether the blanks in numeric fields are by default to be interpreted as null fields or zeros, respectively, and UNDEFINED if there is either no connection, or if the connection is not for formatted I/O.

`position= pos`, where `pos` is a character variable that is assigned the value REWIND, APPEND, or ASIS, as specified in the corresponding open statement, if the file has not been repositioned since it was opened. If there is no connection, or if the file is connected for direct access, the value is UNDEFINED. If the file has been repositioned since the connection was established, the value is processor dependent (but must not be REWIND or APPEND unless that corresponds to the true position).

action= *act*, where *act* is a character variable that is assigned the value READ, WRITE, or READWRITE, according to the connection. If there is no connection, the value assigned is UNDEFINED.

read= *rd*, where *rd* is a character variable that is assigned the value YES, NO or UNKNOWN according to whether read is allowed, not allowed, or is undetermined for the file.

write= *wr*, where *wr* is a character variable that is assigned the value YES, NO or UNKNOWN according to whether write is allowed, not allowed, or is undetermined for the file.

readwrite= *rw*, where *rw* is a character variable that is assigned the value YES, NO or UNKNOWN according to whether read/write is allowed, not allowed, or is undetermined for the file.

delim= *del*, where *del* is a character variable that is assigned the value QUOTE, APOSTROPHE, or NONE, as specified by the corresponding open statement (or by default). If there is no connection, or if the file is not connected for formatted I/O, the value assigned is UNDEFINED.

pad= *pad*, where *pad* is a character variable that is assigned the value YES if so specified by the corresponding open statement (or by default), and otherwise NO.

A variable that is a specifier in an inquire statement or is associated with one must not appear in another specifier in the same statement.

The third variant of the inquire statement, inquire by I/O list, has the form

```
inquire (iolength=length) olist
```

where *length* is a scalar integer variable of default kind and is used to determine the length of an unformatted output list in processor-dependent units, and might be used to establish whether, for instance, an output list is too long for the record length given in the recl= specifier of an open statement, or be used as the value of the length to be supplied to a recl= specifier, (see Figure 9.5 in Section 9.15).

An example of the inquire statement, for the file opened as an example of the open statement in Section 10.3, is

```
logical :: ex, op
character (len=11) :: nam, acc, seq, frm
integer :: irec, nr
inquire (2, err=99, exist=ex, opened=op, name=nam, access=acc, &
sequential=seq, form=frm, recl=irec, nextrec=nr)
```

After successful execution of this statement, the variables provided will have been assigned the following values:

```

ex      .true.
op      .true.
nam    citiesbbbb
acc    DIRECTbbbb
seq    NObbbbbbbb
frm    UNFORMATTED
irec   100
nr     1

```

(assuming no intervening read or write operations).

The three I/O status statements just described are perhaps the most indigestible of all Fortran statements. They provide, however, a powerful and portable facility for the dynamic allocation and deallocation of files, completely under program control, which is far in advance of that found in any other programming language suitable for scientific applications.

10.6 Summary

This chapter has completed the description of the input/output features begun in the previous chapter, and together they provide a complete reference to all the facilities available. The features new since Fortran 77 are `inquire` by I/O list and the additional specifiers for the `open` and `inquire` statements: `position`, `action`, `delim`, `pad`, `read`, `write`, and `readwrite`. There have also been detailed changes to accommodate other features of the language.

10.7 Exercises

1. A direct-access file is to contain a list of names and initials, to each of which there corresponds a telephone number. Write a program which opens a sequential file and a direct-access file, and copies the list from the sequential file to the direct-access file, closing it for use in another program.

Write a second program which reads an input record containing either a name or a telephone number (from a terminal if possible), and prints out the corresponding entry (or entries) in the direct-access file if present, and an error message otherwise. Remember that names are as diverse as Wu, O'Hara and Trevington-Smythe, and that it is insulting for a computer program to corrupt or abbreviate people's names. The format of the telephone numbers should correspond to your local numbers, but the actual format used should be readily modifiable to another.

11. Other features

11.1 Introduction

This chapter describes features that are redundant within Fortran 90 and whose use we deprecate. They might become obsolescent in a future revision, but this is a decision that can be made only within the standardization process. We note again that this decision to group certain features into a final chapter and to deprecate their use is ours alone, and does not have the actual or implied approval of either WG5 or J3.

Our deprecated features fall into three groups:

- those linked to storage association;
- those introduced into Fortran 90 because of strong public pressure, but for which there are better ways to achieve the same effects; and
- those which are made redundant by newer features.

Each description mentions how the feature concerned may be effectively replaced by a newer feature or features.

11.2 Storage association

11.2.1 Storage units

Storage units are the fixed units of physical storage allocated to certain data. There is a storage unit called *numeric* for any non-pointer scalar of the default real, default integer, and default logical types, and a storage unit called *character* for any non-pointer scalar of type default character and character length 1. Non-pointer scalars of type default complex or double precision real (Section 11.4.1) occupy two contiguous numeric storage units. Non-pointer scalars of type default character length *len* occupy *len* contiguous character storage units.

As well as numeric and character storage units, there are a large number of *unspecified* storage units. A non-pointer scalar object of type non-default integer, real other than default or double precision, non-default logical, non-default complex, or non-default character of any particular length occupies a single unspecified storage unit that is different for each case. An object with the

pointer attribute has an unspecified storage unit, different from that of any non-pointer object and different for each combination of type, type parameters, and rank. The standard makes no statement about the relative sizes of all these storage units and permits storage association to take place only between objects with the same category of storage unit.

An array of intrinsic type occupies a sequence of storage units, one for each element, in array element order.

Objects of derived type have no storage association, each occupying an unspecified storage unit that is different in each case, except where a given type contains a sequence statement making it a *sequence type*:

```
type storage
  sequence
    integer i           ! First numeric storage unit;
    real a(0:999)       ! subsequent 1000 numeric storage units.
  end type storage
```

Should any other derived types appear in such a definition, they too must be sequence types. A scalar of sequence type occupies a storage sequence that consists of the concatenation of the storage sequences of its components. An array of sequence type occupies a storage sequence that consists of the concatenation of the storage sequences of its elements.

A sequence type whose ultimate components are non-pointers of type default integer, default real, double precision real, default complex and default logical has *numeric storage association*. Similarly, a sequence type whose ultimate components are non-pointers of type default character has *character storage association*.

A derived type with the sequence attribute may have private components:

```
type storage
  private
  sequence
    integer i
    real a(0:999)
  end type storage
```

The private and sequence statements may be interchanged but must be the second and third statements of the type definition.

Two type definitions in different scoping units define the same data type if they have the same name¹, both have the sequence attribute, and they have components that are not private and agree in order, name, and attributes. However, such a practice is prone to error and offers no advantage over having a single definition in a module and accessed by use association.

¹If one or both types have been accessed by use association and renamed, it is the original names that must agree.

11.2.2 The equivalence statement

The equivalence statement specifies that a given storage area may be shared by two or more objects. For instance

```
real aa, angle, alpha, a(3)
equivalence (aa, angle), (alpha, a(1))
```

allows aa and angle to be used interchangeably in the program text, as both names now refer to the same storage location. similarly, alpha and a(1) may be used interchangeably.

It is possible to equivalence arrays together. In

```
real a(3,3), b(3,3), col1(3), col2(3), col3(3)
equivalence (col1, a, b), (col2, a(1,2)), (col3, a(1,3))
```

the two arrays a and b are equivalenced, and the columns of a (and hence of b) are equivalenced to the arrays col1, etc. We note in this example that more than two entities may be equivalenced together, even in a single declaration.

It is possible to equivalence variables of the same intrinsic type and kind type parameter or of the same derived type having the sequence attribute. It is also possible to equivalence variables of different types if both have numeric storage association or both have character storage association (see Section 11.2.1). Default character variables need not have the same length, as in

```
character(len=4) a
character(len=3) b(2)
equivalence (a, b(1)(3:))
```

where the character variable a is equivalenced to the last four characters of the six characters of the character array b. Zero character length is not permitted. An example for different types is

```
integer i(100)
real x(100)
equivalence (i, x)
```

where the arrays i and x are equivalenced. This might be used, for instance, to save storage space if i is used in one part of a program unit and x separately in another part. This is a highly dangerous practice, as considerable confusion can arise when one storage area contains variables of two or more data types, and program changes may be made very difficult if the two uses of the one area are to be kept distinct.

Types with default initialization (Fortran 95 only) are permitted, provided each initialized component has the same type, type parameters, and value in any pair of equivalenced objects.

All the various combinations of types that may be equivalenced have been described. No other is allowed. Also, apart from double precision real and the default numeric types, equivalencing objects that have different kind type parameters is not allowed. The general form of the statement is

equivalence (object, object-list) [, (object, object-list)] ...

where each *object* is a variable name, array element, or substring. An object must be a variable and must not be a dummy argument, a function result, a pointer, an object with a pointer component at any level of component selection, an allocatable array, an automatic object, a function, a structure component, or a subobject of such an object. Each array subscript and character substring range must be an initialization expression. The interpretation of an array name is identical to that of its first element. An equivalence object must not have the target attribute.

The objects in an equivalence set are said to be *storage associated*. Those of nonzero length share the same first storage unit. Those of zero length are associated with each other and with the first storage unit of those of nonzero length. equivalence statements may cause other parts of the objects to be associated, but not such that different subobjects of the same object share storage. For example

```
real a(2), b
equivalence (a(1), b), (a(2), b) ! Prohibited.
```

is not permitted. Also, objects declared in different scoping units must not be equivalenced. For example

```
use my_module, only : xx
real bb
equivalence(xx, bb) ! Prohibited.
```

is not permitted.

The various uses to which the equivalence was put are replaced by automatic arrays, allocatable arrays, and pointers (reuse of storage, Sections 6.4 and 6.5), pointers as aliases (storage mapping, Section 6.15), and the transfer function (mapping of one data type onto another, Section 8.9).

11.2.3 The common block

We have seen in Chapter 5 how two program units are able to communicate by passing variables, or values of expressions between them via argument lists or by using modules. It is also possible to define areas of storage known as common blocks. Each has a storage sequence and may be either named or unnamed, as shown by the simplified syntax of the common specification statement,

```
common [/ [cname] /] vlist
```

in which *cname* is an optional name, and *vlist* is a list of variable names, each optionally followed by an array bounds specification. An unnamed common block is known as a *blank* common block. Examples of each are

```
common /hands/ nshuff, nplay, nhand, cards(52)
```

and

```
common // buffer(10000)
```

in which the named common block hands defines a data area containing the quantities which might be required by the subroutines of a card playing program, and the blank common defines a large data area which might be used by different routines as a buffer area.

The name of a common block has global scope and must differ from that of any other global entity (external procedure, program unit, or common block). It may, however, be the same as that of a local entity other than a named constant or intrinsic procedure.

No object in a common block may have the parameter attribute or be a dummy argument, an automatic object, an allocatable array, or a function. An array may have its bounds declared either in the common statement or in a type declaration or dimension statement. If it is a non-pointer array, the bounds must be declared explicitly and with constant specification expressions. If it is a pointer array, however, the bounds may not be declared in the common statement itself. An object of derived type must have the sequence attribute and (Fortran 95 only) the type must not have default initialization.

In order for a subroutine to access the variables in the data area, it is sufficient to insert the common definition in each scoping unit which requires access to one or more of the entities in the list. In this fashion, the variables nshuff, nplay, nhand and cards are made available to the those scoping units. No variable may appear more than once in all the common blocks in a scoping unit.

Usually, a common block contains identical variable names in all its appearances, but this is not necessary. In fact, the shared data area may be partitioned in quite different ways in different routines, using different variable names. They are said to be storage associated. It is thus possible for one subroutine to contain a declaration

```
common /coords/ x, y, z, i(10)
```

and another to contain a declaration

```
common /coords/ i, j, a(11)
```

This means that a reference to i(1) in the first routine is equivalent to a reference to a(2) in the second. Through multiple references via use or host association, this can even happen in a single routine. This manner of coding is both untidy and dangerous, and every effort should be made to ensure that all declarations of a given common block declaration are identical in every respect. In particular, the presence or absence of the target attribute is required to be consistent, since otherwise a compiler would have to assume that everything in common has the target attribute in case it has it in another program unit.

A further practice that is permitted but which we do not recommend is to mix different storage units in the same common block. When this is done, each position in the storage sequence must always be occupied by a storage unit of the same category.

The total number of storage units must be the same in each occurrence of a named common block, but blank common is allowed to vary in size and the longest definition will apply for the complete program.

Yet another practice to be avoided is to use the full syntax of the common statement,

```
common [/ [cname] /] vlist [[,]/[cname]/vlist] ...
```

which allows several common blocks to be defined in one statement, and a single common block to be declared in parts. A combined example is

```
common /pts/x,y,z /matrix/a(10,10),b(5,5) /pts/i,j,k
```

which is equivalent to

```
common /pts/ x, y, z, i, j, k  
common /matrix/ a(10,10), b(5,5)
```

which is certainly a more understandable declaration of two shared data areas. The only need for the piece-wise declaration of one block is when the limit of 39 continuation lines is otherwise too low.

The common statement may be combined with the equivalence statement, as in the example

```
real a(10), b  
equivalence (a,b)  
common /change/ b
```

In this case, a is regarded as part of the common block, and its length is extended appropriately. Such an equivalence must not cause data in two different common blocks to become storage associated, it must not cause an extension of the common block except at its tail, and two different objects or subobjects in the same common block must not become storage associated. In Fortran 95, it must not cause an object of a type with default initialization to become associated with an object in a common block.

A common block may be declared in a module, and its variables accessed by use association. Variable names in a common block in a module may be declared to have the private attribute, but this does not prevent associated variables being declared elsewhere through other common statements.

An individual variable in a common block may not be given the save attribute, but the whole block may. If a common block has the save attribute in any scoping unit other than the main program, it must have the save attribute in all such scoping units. The general form of the save statement is

```
save [::] saved-entity-list]
```

where *saved-entity* is *variable-name* or *common-block-name*. A simple example is

```
save /change/
```

Blank common always has the save attribute.

Data in a common block without the save attribute become undefined on return from a subprogram unless the block is also declared in the main program or in another subprogram that is in execution.

Use of modules (section 5.5) obviates the need for common blocks.

11.2.4 The block data program unit

Non-pointer variables in named common blocks may be initialized in data statements, but such statements must be collected into a special type of program unit, known as a block data program unit. It must have the form

```
block data [block-data-name]
    [specification-stmt] ...
end [block data [block-data-name]]
```

where each *specification-stmt* is an implicit, use, type declaration (including double precision), intrinsic, pointer, target, common, dimension, data, equivalence, parameter, or save statement or derived-type definition. A type declaration statement must not specify the allocatable, external, intent, optional, private, or public attributes. An example is

```
block data
    common /axes/ i,j,k
    data i,j,k /1,2,3/
end block data
```

in which the variables in the common block axes are defined for use in any other scoping unit which accesses them.

It is possible to collect many common blocks and their corresponding data statements together in one block data program unit. However, it may be a better practice to have several different block data program units, each containing common blocks which have some logical association with one another. To allow for this eventuality, block data program units may be named in order to be able to distinguish them. A complete program may contain any number of block data program units, but only one of them may be unnamed. A common block must not appear in more than one block data program unit. It is not possible to initialize blank common.

The name of a block data program unit may appear in an external statement. When a processor is loading program units from a library, it may need such a statement in order to load the block data program unit.

Use of modules (Section 5.5) obviates the need for block data.

11.2.5 Shape and character length disagreement

In Fortran 77, it was often convenient, when passing an array, not to have to specify the size of the dummy array. For this case, the *assumed-size* array declaration is available, where the last *bounds* in the *bounds-list* is

`[lower-bound:] *`

and the other bounds (if any) must be declared explicitly. Such an array must not be a function result.

Since an assumed-size array has no bounds in its last dimension, it does not have a shape and, therefore, must not be used as a whole array in an executable statement, except as an argument to a procedure that does not require its shape. However, if an array section is formed with an explicit upper bound in the last dimension, this has a shape and may be used as a whole array.

An object of one size or rank may be passed to an explicit-shape or assumed-size dummy argument array that is of another size or rank, except when the dummy argument has the target attribute and the actual argument is a target other than an array section with a vector subscript. If an array element is passed to an array, the actual argument is regarded as an array with elements that are formed from the parent array from the given array element onwards, in array element order. Figure 11.1 illustrates this. Here only the last 49 elements of *a* are available to *sub*, as the first array element of *a* which is passed to *sub* is *a*(52). Within *sub*, this element is referenced as *b*(1).

Figure 11.1

```
real a(100)
:
call sub (a(52), 49)
:
subroutine sub(b,n)
:
real b(n)
:
```

In the same example, it would also be perfectly legitimate for the declaration of *b* to be written as

`real b(7, 7)`

and for the last 49 elements of *a* to be addressed as though they were ordered as a 7×7 array. The converse is also true. An array dimensioned 10×10 in a calling subroutine may be dimensioned as a singly-dimensioned array of size 100 in the called subroutine. Within *sub*, it is illegal to address *b*(50) in any way, as that would be beyond the declared length of *a* in the calling routine. In all cases, the association is by storage sequence, in array element order.

In the case of default character type, agreement of character length is not required. For a scalar dummy argument of character length *len*, the actual argument may have a greater character length and its leftmost *len* characters are associated with the dummy argument. For example, if `chasub` has a single dummy argument of character length 1,

```
call chasub(word(3:4))
```

is a valid `call` statement. For an array dummy argument, the restriction is on the total number of characters in the array. An array element or array element substring is regarded as a sequence of characters from its first character to the last character of the array. For an assumed-size array, the size is the number of characters in the sequence divided by the character length of the dummy argument.

Shape or character length disagreement of course cannot occur when the dummy argument is assumed-shape (by definition the shape is assumed from the actual argument). It can occur for explicit-shape and assumed-size arrays. Implementations are likely to receive explicit-shape and assumed-size arrays in contiguous storage, but permit any uniform spacing of the elements of an assumed-shape array. They will need to make a copy of any array argument that is not stored contiguously (for example, the section `a(1:10:2)`), unless the dummy argument is assumed shape. To avoid unnecessary copies of this kind, a scalar actual argument is permitted to be associated with an array only if the actual argument is an element of an array that is not an assumed-shaped array, an array pointer, a dummy argument with the `target` attribute, or is a subobject of such an element.

When a procedure is invoked through a generic name, as a defined operation, or as a defined assignment, rank agreement between the actual and the dummy arguments is required. Note also that only a scalar dummy argument may be associated with a scalar actual argument.

Assumed-shape arrays (Section 6.3) supplant this feature.

11.2.6 The entry statement

A subprogram usually defines a single procedure, and the first statement to be executed is the first executable statement after the header statement. In some cases it is useful to be able to define several procedures in one subprogram, particularly when wishing to share access to some saved local variables or to a section of code. This is possible for external and module subprograms (but not for internal subprograms) by means of the `entry` statement. This is a statement that has the form

```
entry entry-name [([dummy-argument-list])] [result(result-name)]]
```

and may appear anywhere between the header line and contains (or end if it has no `contains`) statement of a subprogram, except within a construct. The `entry`

statement provides a procedure with an associated dummy argument list, exactly as does the subroutine or function statement, and these arguments may be different from those given on the subroutine or function statement. Execution commences with the first executable statement following the entry statement.

In the case of a function, each entry defines another function, whose characteristics (that is, shape, type, type parameters, and whether a pointer) are given by specifications for the *result-name* (or *entry-name* if there is no result clause). If the characteristics are the same as for the main entry, a single variable is used for both results; otherwise, they must not be pointers, must be scalar, and must both be one of the default integer, default real, double precision real (Section 11.4.1), or default complex types, and they are treated as equivalenced. The result clause plays exactly the same rôle as for the main entry.

Each entry is regarded as defining another procedure, with its own name. The name of an entry has the same scope as the name of the subprogram. It must not be the name of a dummy argument of any of the procedures defined by the subprogram. An entry statement is not permitted in an interface block; there must be another body for each entry whose interface is wanted, using a subroutine or function statement, rather than an entry statement.

An entry is called in exactly the same manner as a subroutine or function, depending on whether it appears in a subroutine subprogram or a function subprogram. An example is given in Figure 11.2 which shows a search function with two entry points. We note that `looku` and `looks` are synonymous within the function, so that it is immaterial which value is set before the return.

None of the procedures defined by a subprogram is permitted to reference itself, unless the keyword recursive is present on the subroutine or function statement. For a function, such a reference must be indirect unless there is a result clause on the function or entry statement. If a procedure may be referenced directly in the subprogram that defines it, the interface is explicit in the subprogram.

The name of an entry dummy argument that appears in an executable statement preceding the entry statement in the subprogram must also appear in a function, subroutine, or entry statement that precedes the executable statement. Also, if a dummy argument is used to define the array size or character length of an object, the object must not be referenced unless the argument is present in the procedure reference that is active.

During the execution of one of the procedures defined by a subprogram, a reference to a dummy argument is permitted only if it is a dummy argument of the procedure referenced.

The entry statement is made unnecessary by the use of modules (Section 5.5), with each procedure defined by an entry becoming a module procedure. Its presence has substantially complicated the standard because the reader has to remember that a subprogram may define several procedures.

Figure 11.2

```

function looku(list, member)
integer looku, list(:), member, looks
!
!      To locate member in an array list.
!      If list is unsorted, entry looku is used;
!      if list is sorted, entry looks is used.
!
!      list is unsorted
do looku = 1, size(list)
    if list(looku) .eq. member) go to 9
end do
go to 3
!
!      entry for sorted list
entry looks(list, member)
!
do looku = 1, size(list)
    if (list(looku) .ge. member) go to 2
end do
go to 3
!
!      is member at position looku?
2 if (list(looku) .eq. member) go to 9
!
!      member not in list
3 looku = 0
!
9 end function looku

```

11.3 New redundant features

11.3.1 The include line

It is sometimes useful to be able to include source text from somewhere else into the source stream presented to the compiler. This facility is possible using an **include** line:

include *char-literal-constant*

where *char-literal-constant* must not have a kind parameter that is a named constant. This line is not a Fortran statement and must appear as a single source line where a statement may occur. It will be replaced by material in a processor-dependent way determined by the character string *char-literal-constant*. The included text may itself contain **include** lines, which are similarly replaced. An

include line must not reference itself, directly or indirectly. When an include line is resolved, the first included line must not be a continuation line and the last line must not be continued. An include line may have a trailing comment, but may not be labelled nor, when expanded, may it contain incomplete statements.

The include line was available as an extension to many Fortran 77 systems and was often used to ensure that every occurrence of global data in common was identical. In Fortran 90, the same effect is better achieved by placing global data in a module (Section 5.5). This cannot lead to accidental declarations of local variables in each procedure.

11.3.2 The do while form of loop control

In Section 4.5, a form of the do construct was described that may be written as

```
do
  if (scalar-logical-expr) exit
  :
end do
```

An alternative, but redundant, form of this is its representation using a do while statement:

```
do [label] [,] while (.not.scalar-logical-expr)
```

We prefer the form that uses the exit statement because this can be placed anywhere in the loop, whereas the do while statement always performs its test at the loop start. If the *scalar-logical-expr* becomes false in the middle of the loop, the rest of the loop is still executed. Potential optimization penalties that the use of the do while entails are fully described in Chapter 10 of *Optimizing Supercompilers for Supercomputers*, M. Wolfe (Pitman, 1989).

11.4 Old redundant features

11.4.1 Double precision real

Another *type* that may be used in a type declaration, function, implicit, or component declaration statement is double precision which specifies double precision real. The precision is greater than that of default real.

Literal constants written with the exponent letter d (or D) are of type double precision real by default; no kind parameter may be specified if this exponent letter is used. Thus, 1d0 is of type double precision real. If dp is an integer named constant with the value kind(1d0), double precision is synonymous with real(kind=dp).

There is a d (or D) edit descriptor that was originally intended for double precision quantities but, in Fortran 90, it is identical to the e edit descriptor except that the output form may have a D instead of an E as its exponent letter. A

double precision real literal constant, with exponent letter d, is acceptable on input whenever any other real literal constant is acceptable.

There are two elemental intrinsic functions which were not described in Chapter 8 because they have result of type double precision real:

`dble (a)` for a of type integer, real, or complex returns the double precision real value `real(a, kind(0d0))`.

`dprod (x, y)` returns the product `x*y` for x and y of type default real as a double precision real result.

The double precision real data type has been replaced by the real type of kind `kind(0.d0)`.

11.4.2 The dimension and parameter statements

To declare entities, we normally use type specifications. However, if all the entities involved are arrays, they may be declared *without* type specifications in a dimension statement:

```
dimension i(10), b(50,50), c(n,m) ! n and m are dummy scalar
                                         ! integer arguments or
                                         ! named constants.
```

The general form is

```
dimension [::] array-name(array-spec) [,array-name(array-spec)] ...
```

Here, the type may either be specified in a type declaration statement such as

```
integer i
```

that does not specify the dimension information, or be specified implicitly. Our view is that neither of these is sound practice: the type declaration statement looks like a declaration of a scalar and we explained in Section 7.2 that we regard implicit typing as dangerous. Therefore, the use of the dimension statement is not recommended.

An alternative way to specify a named constant is by the parameter statement. It has the general form

```
parameter ( named-constant-definition-list )
```

where each *named-constant-definition* is

```
constant-name = initialization-expr
```

Each constant named must either have been typed in a previous type declaration statement in the scoping unit, or take its type from the first letter of its name according to the implicit typing rule of the scoping unit. In the case of implicit typing, the appearance of the named constant in a subsequent type declaration

statement in the scoping unit must confirm the type and type parameters, and there must not be an `implicit` statement for the letter subsequently in the scoping unit. Similarly, the shape must have been specified previously or be scalar. Each named constant in the list is defined with the value of the corresponding expression according to the rules of intrinsic assignment.

An example using implicit typing and a constant expression including a named constant that is defined in the same statement is

```
implicit integer (a, p)
parameter (apple = 3, pear = apple**2)
```

For the same reasons as for dimension, we recommend avoiding the parameter statement.

11.4.3 Specific names of intrinsic procedures

There are a number of intrinsic functions that may have arguments that are all of one type and type parameters or all of another. For instance, we may write

```
a = sqrt(b)
```

and the appropriate square-root function will be invoked, depending on whether the variable `b` is real or complex and on its type parameters. In this case, the name `sqrt` is known as a *generic name*, meaning that the appropriate function is supplied, depending on the type and type parameters of the actual arguments of the function, and that a single name may be used for what are, probably, different specific functions.

Some of the intrinsic functions have *specific names* and are specified by the standard. They are listed in Tables 11.1 and 11.2. In the Tables, ‘Character’ stands for default character, ‘Integer’ stands for default integer, ‘Real’ stands for default real, ‘Double’ stands for double precision real, and ‘Complex’ stands for default complex. Those in Tables 11.2 may be passed as actual arguments to a subprogram, provided they are specified in an `intrinsic` statement (Section 8.1.3).

All the procedures that we described in Chapter 8 are regarded as generic, even where there is only one version.

Table 11.1. Specific intrinsic functions not available as actual arguments

Description	Generic Form	Specific Name	Argument Type	Function Type
Conversion to integer	<code>int(a)</code>	<code>int</code>	Real	Integer
		<code>ifix</code>	Real	Integer
		<code>idint</code>	Double	Integer
Conversion to real	<code>real(a)</code>	<code>real</code>	Integer	Real
		<code>float</code>	Integer	Real
		<code>sngl</code>	Double	Real
<code>max(a1,a2,...)</code>	<code>max(a1,a2,...)</code>	<code>max0</code>	Integer	Integer
		<code>amax1</code>	Real	Real
		<code>dmax1</code>	Double	Double
		<code>amax0</code>	Integer	Real
		<code>max1</code>	Real	Integer
<code>min(a1,a2,...)</code>	<code>min(a1,a2,...)</code>	<code>min0</code>	Integer	Integer
		<code>amin1</code>	Real	Real
		<code>dmin1</code>	Double	Double
		<code>amin0</code>	Integer	Real
		<code>min1</code>	Real	Integer

Table 11.2. Specific intrinsic functions available as actual arguments

Description	Generic Form	Specific Name	Argument Type	Function Type
absolute value of a times sign of b	<code>sign(a,b)</code>	<code>isign</code>	Integer	Integer
		<code>sign</code>	Real	Real
		<code>dsign</code>	Double	Double
max(x-y,0)	<code>dim(x,y)</code>	<code>idim</code>	Integer	Integer
		<code>dim</code>	Real	Real
		<code>ddim</code>	Double	Double
x*y		<code>dprod(x,y)</code>	Real	Double
truncation	<code>aint(a)</code>	<code>aint</code>	Real	Real
		<code>dint</code>	Double	Double
nearest whole number	<code>anint(a)</code>	<code>anint</code>	Real	Real
		<code>dnint</code>	Double	Double
nearest integer	<code>nint(a)</code>	<code>nint</code>	Real	Integer
		<code>idnint</code>	Double	Integer
absolute value	<code>abs(a)</code>	<code>iabs</code>	Integer	Integer
		<code>abs</code>	Real	Real
		<code>dabs</code>	Double	Double
		<code>cabs</code>	Complex	Real
remainder modulo p	<code>mod(a,p)</code>	<code>mod</code>	Integer	Integer
		<code>amod</code>	Real	Real
		<code>dmod</code>	Double	Double
square root	<code>sqrt(x)</code>	<code>sqrt</code>	Real	Real
		<code>dsqrt</code>	Double	Double
		<code>csqrt</code>	Complex	Complex
exponential	<code>exp(x)</code>	<code>exp</code>	Real	Real
		<code>dexp</code>	Double	Double
		<code>cexp</code>	Complex	Complex
Natural logarithm	<code>log(x)</code>	<code>alog</code>	Real	Real
		<code>dlog</code>	Double	Double
		<code>clog</code>	Complex	Complex
Common logarithm	<code>log10(x)</code>	<code>alog10</code>	Real	Real
		<code>dlog10</code>	Double	Double
Sine	<code>sin(x)</code>	<code>sin</code>	Real	Real
		<code>dsin</code>	Double	Double
		<code>csin</code>	Complex	Complex

Cosine	<code>cos(x)</code>	<code>cos</code>	Real	Real
		<code>dcos</code>	Double	Double
		<code>ccos</code>	Complex	Complex
Tangent	<code>tan(x)</code>	<code>tan</code>	Real	Real
		<code>dtan</code>	Double	Double
Arcsine	<code>asin(x)</code>	<code>asin</code>	Real	Real
		<code>dasin</code>	Double	Double
Arccosine	<code>acos(x)</code>	<code>acos</code>	Real	Real
		<code>dacos</code>	Double	Double
Arctangent	<code>atan(x)</code>	<code>atan</code>	Real	Real
		<code>datan</code>	Double	Double
	<code>atan2(y,x)</code>	<code>atan2</code>	Real	Real
		<code>datan2</code>	Double	Double
Hyperbolic sine	<code>sinh(x)</code>	<code>sinh</code>	Real	Real
		<code>dsinh</code>	Double	Double
Hyperbolic cosine	<code>cosh(x)</code>	<code>cosh</code>	Real	Real
		<code>dcosh</code>	Double	Double
Hyperbolic tangent	<code>tanh(x)</code>	<code>tanh</code>	Real	Real
		<code>dtanh</code>	Double	Double
Imaginary part	<code>aimag(z)</code>	<code>aimag</code>	Complex	Real
Complex conjugate	<code>conjg(z)</code>	<code>conjg</code>	Complex	Complex
Character length	<code>len(s)</code>	<code>len</code>	Character	Integer
Starting position	<code>index(s,t)</code>	<code>index</code>	Character	Integer

12. Floating-point exception handling

12.1 Introduction

Exception handling is required for the development of robust and efficient numerical software, a principal application of Fortran. Indeed, the existence of such a facility makes it possible to develop more efficient software than would otherwise be possible. The clear need for exception handling, something that had been left out of the standards so far, led to a facility being developed on a 'fast track' as a Technical Report¹, suitable for immediate implementation as an extension to existing Fortran compilers (Section 1.5).

The subject of this chapter is this extension of Fortran 95. WG5 has promised that it will be included in the next revision of the Fortran standard, apart from correcting any defects found in the field. The intention is that this promise will encourage vendors to implement the feature in their compilers, confident that their efforts will have a secure future.

Similarly, programmers are encouraged to use the feature if it is available to them. Their code may have limited portability initially, but it will eventually become fully portable. This is why we feel that a book on Fortran 95 needs to include its description. This chapter is written with exactly the same aims as the rest of the book: to provide a complete description of all the facilities and provide some explanation of the choices the committees made in their design.

Most computers nowadays have hardware based on the IEEE standard for binary floating-point arithmetic², which later became an ISO Standard³. Therefore, the Fortran exception handling features are based on the ability to test and set the five flags for floating-point exceptions that the IEEE standard specifies. However, non-IEEE computers have not been ignored; they may provide support for some of the features and the programmer is able to find out what is supported or state that certain features are essential.

¹Technical Report ISO/IEC 15580: 1998(E).

²IEEE 754-1985, Standard for binary floating-point arithmetic.

³IEC 559:1989, Binary floating-point arithmetic for microprocessor systems.

Few (if any) computers support every detail of the IEEE standard. This is because considerable economies in construction and increases in execution performance are available by omitting support for features deemed to be necessary to few programmers. It was therefore decided to include inquiry facilities for the extent of support of the standard, and for the programmer to be able to state which features are essential.

The mechanism finally chosen by the committees is based on a set of procedures for setting and testing the flags and inquiring about the features, collected in an intrinsic module called `ieee_exceptions`. An alternative that was seriously considered is described in the next subsection.

Given that procedures were being provided for the IEEE flags, it seemed sensible to provide procedures for other aspects of the IEEE standard. These are collected in a separate intrinsic module, `ieee_arithmetic`, which contains a `use` statement for `ieee_exceptions`.

To provide control over which features are essential, there is a third intrinsic module, `ieee_features` containing named constants corresponding to the features. If a named constant is accessible in a scoping unit, the corresponding feature must be available there.

12.1.1 Abandoned alternative

An alternative approach to providing exception handling that was seriously considered⁴⁵ was based on a construct of the form

```
enable [(exceptions)]
  [enable block]
[handle [(exceptions)]
  handle block]
end enable
```

The idea was that certain exceptions are ‘enabled’ during execution of the enable block and, if any signals, control is transferred to the handle block. The enable block would contain fast code that is usually successful, and slower but more reliable alternative code in the handle block would be executed only if needed. The transfer is imprecise, so the compiler can use all its optimization features within the enable block. If the programmer needed precision, this could be obtained by using short enable blocks, but that may have inhibited optimization. If an exception led to slow execution, the programmer could limit its use to places where it is really needed.

Everyone was attracted to the enable construct, but there were serious difficulties associated with scoping. If a procedure is called in an enable block, it cannot

⁴Reid, J. K. (1995). Exception handling in Fortran. ACM Fortran Forum, 14, 9-15.

⁵Reid, J. K. (1997). Two approaches to exception handling in Fortran 90. In *The quality of numerical software: assessment and enhancement*, Ed R. F. Boisvert, Chapman and Hall (1997), 210-223.

be assumed that the enabled conditions are enabled within the procedure. If a condition signals but there is no local handler, is the condition handled somewhere else in the call chain? If so, what happens in an intermediate scope with no condition enabling? Maintaining good optimization properties when conditions do not signal, while defining precisely what happens when they do, proved to be difficult and confusing. For these reasons the procedures approach, whose effect is easier for everyone to understand, was adopted.

12.2 Intrinsic modules

Fortran 95 does not have the concept of an intrinsic module. This has been introduced as part of this feature. New syntax on the `use` statement provides control over whether it is intended to access an intrinsic or a non-intrinsic module:

```
use, intrinsic    :: ieee_arithmetic
use, non_intrinsic :: my_ieee_arithmetic
```

For the old form of the syntax:

```
use ieee_arithmetic
```

the processor looks first for a non-intrinsic module. The double colon is obligatory when one of the new keywords is present and is permitted when neither is there:

```
use :: ieee_arithmetic
```

All other aspects of the `use` statement, including renaming and the `only` option (see Section 7.10) are unchanged. The `intrinsic` statement itself is not extended.

12.3 The IEEE standard

In this section, we explain those aspects of the IEEE standard that the reader needs to know in order to understand the features of this extension of Fortran 95. We do not attempt to give a complete description of the standard.

Two floating-point data formats are specified, one for real and one for double precision arithmetic. They are supersets of the Fortran model, repeated here (see Section 8.7.1),

$$x = 0$$

and

$$x = s \times b^e \times \sum_{k=1}^p f_k \times b^{-k}$$

where s is ± 1 , p and b are integers exceeding one, e is an integer in a range $e_{\min} \leq e \leq e_{\max}$, and each f_k is an integer in the range $0 \leq f_k < b$ except that f_1 is also nonzero. Both IEEE formats are binary, with $b = 2$. The precisions

are $p = 24$ and $p = 53$, and the exponent ranges are $-125 \leq e \leq 128$ and $-1021 \leq e \leq 1024$, for real and double precision, respectively.

In addition, there are numbers with $e = e_{\min}$ and $f_1 = 0$, which are known as *denormalized* numbers; note that they all have absolute values less than that returned by the intrinsic `tiny` since it considers only numbers within the Fortran model. Also, zero has a sign and both 0 and -0 have inverses, ∞ and $-\infty$. Within Fortran 95, -0 is treated as the same as a zero in all intrinsic operations and comparisons, but it can be detected by the `sign` function and is respected on formatted output.

The IEEE standard also specifies that some of the binary patterns that do not fit the model be used for the results of exceptional operations, such as 0/0. Such a number is known as a *NaN* (Not a Number). A NaN may be *signaling* or *quiet*. Whenever a signaling NaN appears as an operand, the invalid exception signals. Quiet NaNs propagate through almost every arithmetic operation without signaling an exception.

The standard specifies four rounding modes:

nearest rounds the exact result to the nearest representable value.

to-zero rounds the exact result towards zero to the next representable value.

up rounds the exact result towards $+\infty$ to the next representable value.

down rounds the exact result towards $-\infty$ to the next representable value.

Some computers perform division by inverting the denominator and then multiplying by the numerator. The additional roundoff that this involves means that such an implementation does not conform with the IEEE standard. The IEEE standard also species that `sqrt` properly rounds the exact result and returns -0 for $\sqrt{-0}$. The Fortran facilities include inquiry functions for IEEE division and `sqrt`.

The presence of -0, ∞ , $-\infty$, and the NaNs allows IEEE arithmetic to be closed, that is, every operation has a result. This is very helpful for optimization on modern hardware since several operations, none needing the result of any of the others, may actually be progressing in parallel. If an exception occurs, execution continues with the corresponding flag signaling, and the flag remains signaling until explicitly set quiet by the program. The flags are therefore called *sticky*.

There are five flags:

overflow occurs if the exact result of an operation with two normal values is too large for the data format. The stored result is ∞ , `huge(x)`, $-\text{huge}(x)$, or $-\infty$, according to the rounding mode in operation, always with the correct sign.

divide_by_zero occurs if a finite nonzero value is divided by zero. The stored result is ∞ or $-\infty$ with the correct sign.

invalid occurs if the operation is invalid, for example, $\infty \times 0$, $0/0$, or when an operand is a signaling NaN.

underflow occurs if the result of an operation with two finite nonzero values cannot be represented exactly and is too small to represent with full precision. The stored result is the best available, depending on the rounding mode in operation.

inexact occurs if the exact result of an operation cannot be represented in the data format without rounding.

The standard specifies the possibility of exceptions being trapped by user-written handlers, but this inhibits optimization and is not supported by the Fortran feature. Instead it supports the possibility of halting program execution after an exception signals. For the sake of optimization, such halting need not occur immediately.

The standard specifies several functions which are implemented in this Fortran extension as `ieee_copy_sign`, `ieee_logb`, `ieee_next_after`, `ieee_rem`, `ieee_rint`, `ieee_scalb`, and `ieee_unordered`, and which are described in Section 12.9.3.

12.4 Access to the features

To access the features of this chapter, we recommend that the user employ use statements for one or more of the intrinsic modules `ieee_exceptions`, `ieee_arithmetic` (which contains a use statement for `ieee_exceptions`), and `ieee_features`. If the processor does not support a module accessed in a use statement, the compilation must, of course, fail.

If a scoping unit does not access `ieee_exceptions` or `ieee_arithmetic`, the level of support is processor dependent, and need not include support for any exceptions. If a flag is signaling on entry to such a scoping unit, the processor ensures that it is signaling on exit. If a flag is quiet on entry to such a scoping unit, whether it is signaling on exit is processor dependent.

The module `ieee_features` contains the derived type:

`ieee_features_type`

for identifying a particular feature. The only possible values objects of this type may take are those of named constants defined in the module, each corresponding to an IEEE feature. If a scoping unit has access to one of these constants, the compiler must support the feature in the scoping unit or reject the program. For example, some hardware is much faster if denormalized numbers are not supported and instead all underflowed values are flushed to zero. In such a case, the statement

```
use, intrinsic :: ieee_features, only: ieee_denormal
```

will ensure that the scoping unit is compiled with (slower) code supporting denormalized numbers.

The module is unusual in all that all a code ever does is to access it with `use` statements, which affect the way the code is compiled in the scoping units with access to one or more of the module's constants. There is no purpose in declaring data of type `ieee_features_type`, though it is permitted; the components of the type are private, no operation is defined for it, and only intrinsic assignment is available for it. In a scoping unit containing a `use` statement, the effect is that of a compiler directive, but the other properties of `use` make the feature more powerful than would be possible with a directive.

The complete set of named constants in the module and the effect of their accessibility is:

`ieee_datatype` The scoping unit must provide IEEE arithmetic for at least one kind of real.

`ieee_denormal` The scoping unit must support denormalized numbers for at least one kind of real.

`ieee_divide` The scoping unit must support IEEE divide for at least one kind of real.

`ieee_halting` The scoping unit must support control of halting for each flag supported.

`ieee_inexact_flag` The scoping unit must support the inexact exception for at least one kind of real.

`ieee_inf` The scoping unit must support ∞ and $-\infty$ for at least one kind of real.

`ieee_invalid_flag` The scoping unit must support the invalid exception for at least one kind of real.

`ieee_nan` The scoping unit must support NaNs for at least one kind of real.

`ieee_rounding` The scoping unit must support control of the rounding mode for all four rounding modes on at least one kind of real.

`ieee_sqrt` The scoping unit must support IEEE square root for at least one kind of real.

`ieee_underflow_flag` The scoping unit must support the underflow exception for at least one kind of real.

Execution may be slowed on some processors by the support of some features. If `ieee_exceptions` is accessed but `ieee_features` is not accessed, the vendor is free to choose which subset to support. The processor's fullest support is provided when all of `ieee_features` is accessed:

```
use, intrinsic :: ieee_arithmetic
use, intrinsic :: ieee_features
```

but execution may then be slowed by the presence of a feature that is not needed. In all cases, the extent of support may be determined by the inquiry functions of Sections 12.8.2 and 12.9.2.

12.5 The Fortran flags

There are five Fortran exception flags, corresponding to the five IEEE flags. Each has a value that is either quiet or signaling. The value may be determined by the function `ieee_get_flag` (Section 12.8.3). Its initial value is quiet and it signals when the associated exception occurs in a real or complex operation. Its status may also be changed by the subroutine `ieee_set_flag` (Section 12.8.3) or the subroutine `ieee_set_status` (Section 12.8.4). Once signaling, it remains signaling unless set quiet by an invocation of the subroutine `ieee_set_flag` or the subroutine `ieee_set_status`. If any exception is signaling when the program terminates, the processor issues a warning on the unit identified by * in a `write` statement, indicating which conditions are signaling.

If a flag is signaling on entry to a procedure, the processor will set it to quiet on entry and restore it to signaling on return. This allows exception handling within the procedure to be independent of the state of the flags on entry, while retaining their ‘sticky’ properties: within a scoping unit, a signaling flag remains signaling until explicitly set quiet.

If a scoping unit has access to `ieee_exceptions` and references an intrinsic procedure that executes normally, the values of the overflow, divide-by-zero and invalid flags are as on entry to the intrinsic procedure, even if one or more signals during the calculation. If a real or complex result is too large for the intrinsic procedure to handle, overflow may signal. If a real or complex result is a NaN because of an invalid operation (for example, $\log(-1.0)$), invalid may signal. Similar rules apply to the evaluation of specification expressions on entry to a procedure, to format processing, and to intrinsic operations: no signaling flag shall be set quiet and no quiet flag shall be set signaling because of an intermediate calculation that does not affect the result.

An implementation may provide alternative versions of an intrinsic procedure; for example, one might be rather slow but be suitable for a call from a scoping unit with access to `ieee_exceptions`, while an alternative faster one might be suitable for other cases.

If it is known that an intrinsic procedure will never need to signal an exception, there is no requirement for it to be handled – after all, there is no way that the programmer will be able to tell the difference. The same principle applies to a sequence of in-line code with no invocations of `ieee_get_flag`, `ieee_set_flag`, `ieee_get_status`, `ieee_set_status`, or `ieee_set_halting`. If the code, as written, includes an operation that would signal a flag, but after execution of the sequence no value of a variable depends on that operation, whether the exception signals is processor dependent. Thus, an implementation is permitted to optimize such an operation away. For example, when `y` has the value zero, whether the code

```
x = 1.0/y
x = 3.0
```

signals divide-by-zero is processor dependent. Another example is:

```
real, parameter :: x=0.0, y=6.0
:
if (1.0/x == y) print *, 'Hello world'
```

where the processor is permitted to discard the `if` statement since the logical expression can never be true and no value of a variable depends on it.

An exception does not signal if this could arise only during execution of code not required or permitted by the standard. For example, the statement

```
if (f(x) > 0.0) y = 1.0/z
```

must not signal divide-by-zero when both $f(x)$ and z are zero and the statement

```
where(a > 0.0) a = 1.0/a
```

must not signal divide-by-zero. On the other hand, when x has the value 1.0 and y has the value 0.0, the expression

```
x > 0.00001 .or. x/y > 0.00001
```

is permitted to cause the signaling of divide-by-zero.

The processor need not support the invalid, underflow, and inexact exceptions. If an exception is not supported, its flag is always quiet. The function `ieee_support_flag` (Section 12.8.2) may be used to inquire whether a particular flag is supported. If invalid is supported, it signals in the case of conversion to an integer (by assignment or an intrinsic procedure) if the result is too large to be representable.

12.6 Halting

Some processors allow control during program execution of whether to abort or continue execution after an exception has occurred. Such control is exercised by invocation of the subroutine `ieee_set_halting_mode` (Section 12.8.3). Halting is not precise and may occur any time after the exception has occurred. The function `ieee_support_halting` (Section 12.8.2) may be used to inquire whether this facility is available. The initial halting mode is processor dependent.

In a procedure other than `ieee_set_halting_mode`, the processor does not change the halting mode on entry, and on return ensures that the halting mode is the same as it was on entry.

12.7 The rounding modes

Some processors support alteration of the rounding mode during execution. In this case, the subroutine `ieee_set_rounding_mode` (Section 12.9.4) may be used

to alter it. The function `ieee_support_rounding` (Section 12.9.2) may be used to inquire whether this facility is available for a particular mode.

In a procedure other than `ieee_set_rounding_mode`, the processor does not change the rounding mode on entry, and on return ensures that the rounding mode is the same as it was on entry.

Note that the value of a literal constant is not affected by the rounding mode.

12.8 The module `ieee_exceptions`

When the module `ieee_exceptions` is accessible, the overflow and divide-by-zero flags are supported in the scoping unit for all available kinds of real and complex data. This minimal level of support has been designed to be possible also on a non-IEEE computer. Which other exceptions are supported may be determined by the function `ieee_support_flag`, see Section 12.8.2. Whether control of halting is supported may be determined by the function `ieee_support_halting`, see Section 12.8.2. The extent of support of the other exceptions may be influenced by the accessibility of the named constants `ieee_inexact_flag`, `ieee_invalid_flag`, and `ieee_underflow_flag` of the module `ieee_features`, see Section 12.4.

The module contains two derived types (Section 12.8.1), named constants of these types (Section 12.8.1), and a collection of generic procedures (Sections 12.8.2, 12.8.3, and 12.8.4). None of the procedures is permitted as an actual argument.

12.8.1 Derived types

The module `ieee_exceptions` contains two derived types:

`ieee_flag_type` for identifying a particular exception flag. The only possible values that can be taken by objects of this type are those of named constants defined in the module:

```
ieee_overflow  ieee_divide_by_zero  ieee_invalid
ieee_underflow  ieee_inexact
```

and these are used in the module to define the named array constants

```
type(ieee_flag_type), parameter :: &
ieee_usual(3) = &
    (/ieee_overflow, ieee_divide_by_zero, ieee_invalid/), &
'ieee_all(5) = (/ieee_usual, ieee_underflow, ieee_inexact/)
```

These array constants are convenient for inquiring about the state of several flags at once by using elemental procedures. Besides convenience, such elemental calls may be more efficient than a sequence of calls for single flags.

`ieee_status_type` for saving the current floating-point status, which includes the values of all the flags supported. It also includes the current rounding mode if dynamic control of rounding is supported and the halting mode if dynamic control of halting is supported.

The components of both types are private. No operation is defined for them and only intrinsic assignment is available for them.

12.8.2 Inquiry functions for IEEE exceptions

The module `ieee_exceptions` contains two inquiry functions. Their argument `flag` must be of type `type(ieee_flag_type)` with one of the values `ieee_invalid`, `ieee_overflow`, `ieee_divide_by_zero`, `ieee_underflow`, and `ieee_inexact`. The inquiries are in terms of reals, but the same level of support is provided for the corresponding kinds of complex type.

`ieee_support_flag (flag [,x])` returns `.true.` if the processor supports the exception flag for all reals (`x` absent) or for reals of the same kind type parameter as the real argument `x`. Otherwise, it returns `.false..`

`ieee_support_halting (flag)` returns `.true.` if the processor supports the ability to control during program execution whether to abort or continue execution after the exception flag. Otherwise, it returns `.false..`

12.8.3 Elemental subroutines

The module `ieee_exceptions` contains the following elemental subroutines:

`call ieee_get_flag (flag, flag_value)` where:

`flag` is of type `type(ieee_flag_type)` and has intent in. It specifies a flag.

`flag_value` is of type default logical and has intent out. If the value of `flag` is `ieee_invalid`, `ieee_overflow`, `ieee_divide_by_zero`, `ieee_underflow`, or `ieee_inexact`, `flag_value` is given the value true if the corresponding exception flag is signaling and false otherwise.

`call ieee_get_halting_mode (flag, halting)` where:

`flag` is of type `type(ieee_flag_type)` and has intent in. It must have one of the values `ieee_invalid`, `ieee_overflow`, `ieee_divide_by_zero`, `ieee_underflow`, or `ieee_inexact`.

`halting` is of type default logical has intent out. If the exception specified by `flag` will cause halting, `halting` is given the value true; otherwise, it is given the value false.

`call ieee_set_flag (flag, flag_value) where:`

`flag` is of type `type(ieee_flag_type)` and has intent in. It specifies a flag.

`flag_value` is of type default logical and has intent in. If the value of `flag` is `ieee_invalid`, `ieee_overflow`, `ieee_divide_by_zero`, `ieee_underflow`, or `ieee_inexact`, the corresponding flag is set to be signaling if `flag_value` has the value true, and to be quiet if `flag_value` has the value false.

`call ieee_set_halting_mode (flag, halting) where:`

`flag` is of type `type(ieee_flag_type)` and has intent in. It must have one of the values `ieee_invalid`, `ieee_overflow`, `ieee_divide_by_zero`, `ieee_underflow`, or `ieee_inexact`.

`halting` is of type default logical has intent in. If the value is true, the exception specified by `flag` will cause halting. Otherwise, execution will continue after this exception. The processor must either already be treating this exception in this way or be capable of changing the mode so that it does.

12.8.4 Non-elemental subroutines

The module `ieee_exceptions` contains the following non-elemental subroutines:

`call ieee_get_status (status_value) where:`

`status_value` is scalar and of type `type(ieee_status_type)` and has intent out. It returns the floating-point status, including all the exception flags, the rounding mode, and the halting mode.

`call ieee_set_status (status_value) where:`

`status_value` is scalar and of type `type(ieee_status_type)` and has intent in. Its value must have been set in a previous invocation of `ieee_get_status`. The floating-point status, including all the exception flags, the rounding mode, and the halting mode, is reset to as it was then.

These subroutines have been included for convenience and efficiency when a subsidiary calculation is to be performed, and one wishes to resume the main calculation with exactly the same environment, as shown in Figure 12.1. There are no facilities for finding directly the value held within such a variable of a particular flag, of the rounding mode, or of the halting mode.

Figure 12.1

```

use, intrinsic      :: ieee_arithmetic
type(ieee_status_type) :: status_value
:
call ieee_get_status(status_value) ! Get the flags
call ieee_set_flag(ieee_all,.false.) ! Set the flags quiet.
: ! Calculation involving exception handling
call ieee_set_status(status_value) ! Restore the flags

```

12.9 The module `ieee_arithmetic`

The module `ieee_arithmetic` contains a `use` statement for the module `ieee_exceptions`, so all the features of `ieee_exceptions` are accessed when `ieee_arithmetic` is accessed.

The module contains two derived types (Section 12.9.1), named constants of these types (Section 12.9.1), and a collection of generic procedures (Sections 12.9.2, 12.9.3, 12.9.4 and 12.9.5). None of the procedures is permitted as an actual argument.

12.9.1 Derived types

The module `ieee_arithmetic` contains two derived types:

`ieee_class_type` for identifying a class of floating-point values. The only possible values objects of this type may take are those of the named constants defined in the module:

<code>ieee_signaling_nan</code>	<code>ieee_quiet_nan</code>
<code>ieee_negative_inf</code>	<code>ieee_negative_normal</code>
<code>ieee_negative_denormal</code>	<code>ieee_negative_zero</code>
<code>ieee_positive_zero</code>	<code>ieee_positive_denormal</code>
<code>ieee_positive_normal</code>	<code>ieee_positive_inf</code>

`ieee_round_type` for identifying a particular rounding mode. The only possible values objects of this type may take are those of the named constants defined in the module:

<code>ieee_nearest</code>	<code>ieee_to_zero</code>
<code>ieee_up</code>	<code>ieee_down</code>

for the IEEE modes and

`ieee_other`

for any other mode.

The components of both types are private. No operation is defined for them and only intrinsic assignment is available for them.

12.9.2 Inquiry functions for IEEE arithmetic

The module `ieee_arithmetic` contains the following inquiry functions. The inquiries are in terms of reals, but the same level of support is provided for the corresponding kinds of complex type.

`ieee_support_datatype ([x])` returns `.true.` if the processor supports IEEE arithmetic for all reals (`x` absent) or for reals of the same kind type parameter as the real argument `x`. Otherwise, it returns `.false..` Complete conformance with the IEEE standard is not required for `.true.` to be returned, but the normalized numbers must be exactly those of IEEE single or IEEE double; the arithmetic operators `+`, `-`, and `*` must be implemented with at least one of the IEEE rounding modes; and the functions `ieee_copy_sign`, `ieee_scalb`, `ieee_logb`, `ieee_next_after`, `ieee_rem`, and `ieee_unordered` must implement the corresponding IEEE functions.

`ieee_support_denormal ([x])` returns `.true.` if the processor supports the IEEE denormalized numbers for all reals (`x` absent) or for reals of the same kind type parameter as the real argument `x`. Otherwise, it returns `.false..`

`ieee_support_divide ([x])` returns `.true.` if the processor supports divide with the accuracy specified by the IEEE standard for all reals (`x` absent) or for reals of the same kind type parameter as the real argument `x`. Otherwise, it returns `.false..`

`ieee_support_inf ([x])` returns `.true.` if the processor supports the IEEE infinity facility for all reals (`x` absent) or for reals of the same kind type parameter as the real argument `x`. Otherwise, it returns `.false..`

`ieee_support_nan ([x])` returns `.true.` if the processor supports the IEEE Not-A-Number facility for all reals (`x` absent) or for reals of the same kind type parameter as the real argument `x`. Otherwise, it returns `.false..`

`ieee_support_rounding (round_value [,x])` for a `round_value` of the type `ieee_round_type` returns `.true.` if the processor supports that rounding mode for all reals (`x` absent) or for reals of the same kind type parameter as the argument `x`. Otherwise, it returns `.false..` Here, support includes the ability to change the mode by the invocation

```
call ieee_set_rounding_mode (round_value)
```

`ieee_support_sqrt ([x])` returns .true. if `sqrt` implements IEEE square root for all reals (`x` absent) or for reals of the same kind type parameter as the real argument `x`. Otherwise, it returns .false..

`ieee_support_standard ([x])` returns .true. if the processor supports all the IEEE facilities defined in this chapter for all reals (`x` absent) or for reals of the same kind type parameter as the real argument `x`. Otherwise, it returns .false..

12.9.3 Elemental functions

The module `ieee_arithmetic` contains the following elemental functions for the reals `x` and `y` for which the values of `ieee_support_datatype(x)` and `ieee_support_datatype(y)` are true:

`ieee_class (x)` is of type `type(ieee_class_type)` and returns the IEEE class of the real argument `x`. The possible values are explained in Section 12.9.1.

`ieee_copy_sign (x, y)` returns a real with the same type parameter as `x`, holding the value of `x` with the sign of `y`. This is true even for the IEEE special values, such as `NaN` and ∞ (on processors supporting such values).

`ieee_is_finite (x)` returns the value .true. if `ieee_class (x)` has one of the values

```
ieee_negative_normal  ieee_negative_denormal
ieee_negative_zero   ieee_positive_zero
ieee_positive_denormal  ieee_positive_normal
```

and .false. otherwise.

`ieee_is_nan (x)` returns the value .true. if the value of `x` is an IEEE `NaN` and .false. otherwise.

`ieee_is_negative (x)` returns the value .true. if `ieee_class (x)` has one of the values

```
ieee_negative_normal  ieee_negative_denormal
ieee_negative_zero   ieee_negative_inf
```

and .false. otherwise.

`ieee_is_normal (x)` returns the value .true. if `ieee_class (x)` has one of the values

```
ieee_negative_normal  ieee_negative_zero
ieee_positive_zero   ieee_positive_normal
```

and `.false.` otherwise.

`ieee_logb (x)` returns a real with the same type parameter as `x`. If `x` is neither zero, infinity, nor NaN, the value of the result is the unbiased exponent of `x`, that is, `exponent(x)-1`. Otherwise,

- i) If `x==0`, `ieee_divide_by_zero` signals and the result is $-\infty$ if `ieee_support_inf(x)` is true and `-huge(x)` otherwise.
- ii) If `x` has an infinite value, the result is $+\infty$.
- iii) If `x` has a quiet NaN value, the result is the same NaN.
- iv) If `x` has a signaling NaN value, the result is a quiet NaN.

`ieee_next_after (x, y)` returns a real with the same type parameter as `x`. If `x==y`, the result is `x`, without an exception ever signaling. Otherwise, the result is the neighbour of `x` in the direction of `y`. The neighbours of zero (of either sign) are both nonzero. If either `x` or `y` is a NaN, the result is one of the input NaNs. Overflow is signaled when `x` is finite but `ieee_next_after (x, y)` is infinite; underflow is signaled when `ieee_next_after (x, y)` is denormalized; in both cases, `ieee_inexact` signals.

`ieee_rem (x, y)` returns a real with the same type parameter as `x` and value exactly $x-y*n$, where `n` is the integer nearest to the exact value x/y ; whenever $|n - x/y| = 1/2$, `n` is even. If the result value is zero, the sign is that of `x`.

`ieee_rint (x, y)` returns a real with the same type parameter as `x` whose value is that of `x` rounded to an integer value according to the current rounding mode.

`ieee_scalb (x, i)` returns a real with the same type parameter as `x` whose value is $2^i x$ if this is within the range of normalized numbers. If $2^i x$ is too large, `ieee_overflow` signals; if `ieee_support_inf(x)` is true, the result value is infinity with the sign of `x`; otherwise, it is `sign(huge(x), x)`. If $2^i x$ is too small, `ieee_underflow` signals; the result is the nearest representable number with the sign of `x`.

`ieee_unordered (x, y)` returns `.true.` if `x` or `y` is a NaN or both are, and `.false.` otherwise.

`ieee_value (x, class)` is of type `type(ieee_class_type)` with a value specified by `class`. The argument `class` may have value

`ieee_signaling_nan` or `ieee_quiet_nan` if `ieee_support_nan(x)` is true,

`ieee_negative_inf` or `ieee_positive_inf` if `ieee_support_inf(x)` is true,

`ieee_negative_denormal` or `ieee_positive_denormal` if the value of `ieee_support_denormal(x)` is true, or

`ieee_negative_normal`, `ieee_negative_zero`, `ieee_positive_zero`, or `ieee_positive_normal`.

Although in most cases the value is processor dependent, it does not vary between invocations for any particular kind type parameter of `x` and value of `class`.

12.9.4 Non-elemental subroutines

The module `ieee_arithmetic` contains the following non-elemental subroutines:

`call ieee_get_rounding_mode (round_value) where:`

`round_value` is scalar and of type `type(ieee_round_type)` and has intent out. It returns the floating-point rounding mode, with value `ieee_nearest`, `ieee_to_zero`, `ieee_up`, or `ieee_down` if one of the IEEE modes is in operation, and `ieee_other` otherwise.

`call ieee_set_rounding_mode (round_value) where:`

`round_value` is scalar, of type `type(ieee_round_type)`, and has intent in. It specifies the mode to be set. The value of `ieee_support_rounding (round_value, x)` must be true for any `x` such that the value of `ieee_support_datatype(x)` is true.

The example in Figure 12.2 shows the use of these subroutines to store all the exception flags, perform a calculation involving exception handling, and restore them later.

Figure 12.2

```
use, intrinsic :: ieee_arithmetic
type(ieee_round_type) round_value
:
call ieee_get_rounding_mode(round_value) ! Store the rounding
                                         ! mode
call ieee_set_rounding_mode(ieee_nearest)
                                         ! Calculation with round to nearest
call ieee_set_rounding_mode(round_value) ! Restore the
                                         ! rounding mode
```

12.9.5 Transformational function for kind value

The module `ieee_arithmetic` contains the following transformational function:

`ieee_selected_real_kind ([p][, r])` is just like `selected_real_kind` (Section 8.7.4) except that the result is the kind value of a real x for which `ieee_support_datatype(x)` is true.

12.10 Examples

12.10.1 Dot product

Our first example, Figure 12.3, is of a module for the dot product of two real arrays of rank 1. It contains a logical scalar `dot_error`, which acts as an error flag. If the sizes of the arrays are different, an immediate return occurs with `dot_error` true. If overflow occurs during the actual calculation, the overflow flag will signal and `dot_error` is set true. If all is well, its value is unchanged.

Figure 12.3

```
module dot
  ! Module for dot product of two real arrays of rank 1.
  ! The caller must ensure that exceptions do not cause halting.
  use, intrinsic :: ieee_exceptions
  logical         :: dot_error = .false.
  interface operator(.dot.)
    module procedure mult
  end interface
contains
  real function mult(a,b)
    real, intent(in) :: a(:), b(:)
    integer          :: i
    logical          :: overflow
    if (size(a)/=size(b)) then
      dot_error = .true.
      return
    end if
    ! The processor ensures that ieee_overflow is quiet
    mult = 0.0
    do i = 1, size(a)
      mult = mult + a(i)*b(i)
    end do
    call ieee_get_flag(ieee_overflow,overflow)
    if (overflow) dot_error = .true.
  end function mult
end module dot
```

12.10.2 Calling alternative procedures

Suppose the function `fast_inv` is a code for matrix inversion that ‘lives dangerously’ and may cause a condition to signal. The alternative function `slow_inv` is far less likely to cause a condition to signal, but is much slower. The following code, Figure 12.4, tries `fast_inv` and, if necessary, makes another try with `slow_inv`. If this still fails, a message is printed and the program stops. Note, also, that it is important to set the flags quiet before the second try. The state of all the flags is stored and restored.

Figure 12.4

```
use, intrinsic :: ieee_exceptions
use, intrinsic :: ieee_features, only: ieee_invalid_flag
! The other exceptions of ieee_usual (ieee_overflow and
! ieee_divide_by_zero) are always available with ieee_exceptions
type(ieee_status_type) :: status_value
logical, dimension(3) :: flag_value
:
call ieee_get_status(status_value)
call ieee_set_halting_mode(ieee_usual,.false.) ! Needed in case the
! default on the processor is to halt on exceptions.
call ieee_set_flag(ieee_usual,.false.) ! Elemental
! First try the "fast" algorithm for inverting a matrix:
matrix1 = fast_inv(matrix) ! This must not alter matrix.
call ieee_get_flag(ieee_usual,flag_value) ! Elemental
if (any(flag_value)) then
! "Fast" algorithm failed; try "slow" one:
    call ieee_set_flag(ieee_usual,.false.)
    matrix1 = slow_inv(matrix)
    call ieee_get_flag(ieee_usual,flag_value)
    if (any(flag_value)) then
        write (*, *) 'Cannot invert matrix'
        stop
    end if
end if
call ieee_set_status(status_value)
```

12.10.3 Calling alternative in-line code

This example, Figure 12.5, is similar to the inner part of the previous one, but here the code for matrix inversion is in line, we know that only overflow can signal, and the transfer is made more precise by adding extra tests of the flag.

Figure 12.5

```

use, intrinsic :: ieee_exceptions
logical       :: flag_value
:
call ieee_set_halting_mode(ieee_overflow,.false.)
call ieee_set_flag(ieee_overflow,.false.)
! First try a fast algorithm for inverting a matrix.
do k = 1, n
:
call ieee_get_flag(ieee_overflow,flag_value)
if (flag_value) exit
end do
if (flag_value) then
! Alternative code which knows that k-1 steps have
! executed normally.
:
end if

```

12.10.4 Reliable hypotenuse function

The most important use of a floating-point exception handling facility is to make possible the development of much more efficient software than is otherwise possible. The code in Figure 12.6 for the ‘hypotenuse’ function, $\sqrt{x^2 + y^2}$, illustrates the use of the facility in developing efficient software.

An attempt is made to evaluate this function directly in the fastest possible way. This will work almost every time, but if an exception occurs during this fast computation, a safe but slower way evaluates the function. This slower evaluation may involve scaling and unscaling, and in (very rare) extreme cases this unscaling can cause overflow (after all, the true result might overflow if x and y are both near the overflow limit). If the overflow or underflow flag is signaling on entry, it is reset on return by the processor, so that earlier exceptions are not lost.

Figure 12.6

```

real function hypot(x, y)
! In rare circumstances this may lead to the signaling of
! ieee_overflow.
! The caller must ensure that exceptions do not cause halting.
use, intrinsic :: ieee_arithmetic
use, intrinsic :: ieee_features, only: ieee_underflow_flag
! ieee_overflow is always available with ieee_arithmetic
real                  :: x, y
real                  :: scaled_x, scaled_y, scaled_result
logical, dimension(2) :: flags
type(ieee_flag_type), parameter, dimension(2) ::           &
    out_of_range = (/ ieee_overflow, ieee_underflow /)
intrinsic :: sqrt, abs, exponent, max, digits, scale
! The processor clears the flags on entry
! Try a fast algorithm first
hypot = sqrt( x**2 + y**2 )
call ieee_get_flag(out_of_range, flags)
if ( any(flags) ) then
    call ieee_set_flag(out_of_range, .false.)
    if ( x==0.0 .or. y==0.0 ) then
        hypot = abs(x) + abs(y)
    else if ( 2*abs(exponent(x))-exponent(y)) > digits(x)+1 ) then
        hypot = max( abs(x), abs(y) )! We can ignore one of x and y
    else      ! Scale so that abs(x) is near 1
        scaled_x = scale( x, -exponent(x) )
        scaled_y = scale( y, -exponent(x) )
        scaled_result = sqrt( scaled_x**2 + scaled_y**2 )
        hypot = scale(scaled_result, exponent(x)) ! May cause
        end if                                         ! overflow
    end if
! The processor resets any flag that was signaling on entry
end function hypot

```

13. Allocatable array extensions

13.1 Introduction

The subject of this chapter is another extension¹ of Fortran 95. It involves the use of allocatable arrays as dummy arguments, function results, and components of structures. Pointer arrays may be used instead in Fortran 90/95, but there are significant advantages for memory management and execution speed in using allocatable arrays when the added functionality of pointers is not needed.

This is another extension that WG5 has promised will be included in the next revision of the Fortran standard, apart from correcting any defects found in the field. Again, the intention is that this promise will encourage vendors to implement the feature in their compilers, confident that their efforts will have a secure future (Section 1.5).

Why is this extension needed? Firstly, code for a pointer array is likely to be less efficient because allowance has to be made for strides other than unity. For example, its target might be the section `vector(1:n:2)` or the section `matrix(i,1:n)` with non-unit strides, whereas most computers hold allocatable arrays in contiguous memory.

Secondly, if a defined operation involves a temporary variable of a derived type with a pointer component, the compiler will probably be unable to deallocate its target when storage for the variable is freed. Consider, for example, the statement

`a = b + c*d` ! a, b, c, and d are of the same derived type

This will create a temporary for `c*d`, which is not needed once `b + c*d` has been calculated. The compiler is unlikely to be sure that no other pointer has the component or part of it as a target, so is unlikely to deallocate it.

Thirdly, intrinsic assignment is often unsuitable for a derived type with a pointer component because the assignment

`a = b`

will leave `a` and `b` sharing the same target for their pointer component. Therefore, a defined assignment that allocates a fresh target and copies the data will be used instead. However, this is very wasteful if the right-hand side is a temporary such as that of the assignment of the previous paragraph.

¹Technical Report ISO/IEC 15581: 1998(E).

Fourthly, similar considerations apply to a function invocation within an expression. The compiler will be unlikely to be able to deallocate the pointer after the expression has been calculated.

Although the Fortran standard does not mention descriptors, it is very helpful to think of an allocatable array as being held as a descriptor that records whether it is allocated and, if so, its address and its bounds in each dimension. This is like a descriptor for a pointer, but no strides need be held since these are always unity. As for pointers, the expectation is that the array itself is held separately.

13.2 Allocatable dummy arguments

A dummy argument is permitted to have the allocatable attribute. In this case, the corresponding actual argument must be an allocatable array of the same type, kind parameters, and rank; also, the interface must be explicit. The dummy argument always receives the allocation status (descriptor) of the actual argument on entry and the actual argument receives that of the dummy argument on return. In both cases, this may be ‘not currently allocated’.

Our expectation is that some compilers will perform copy in / copy out of the descriptor. Rule i) of Section 5.7.2 is applicable and is designed to permit compilers to do this. In particular, this means that no reference to the actual argument (for example, through it being a module variable) is permitted from the invoked procedure if the dummy array is allocated or deallocated there.

For the array itself, we see no need for the compiler ever to perform copy in / copy out since the actual argument has to be allocatable too. However, it is permitted even if both arrays have the target attribute². No reliance should be placed on pointer associations with the actual argument on entry applying also to the dummy argument, or pointer associations with the dummy argument on return applying also to the actual argument.

An allocatable dummy argument is permitted to have intent and this applies not to the allocation status (the descriptor) but to the array itself. If the intent is in, the array is not permitted to be allocated or deallocated since this would, of necessity, alter the value. An example of the application of an allocatable dummy argument to reading arrays of variable bounds is shown in Figure 13.1.

13.3 Allocatable functions

A function result is permitted to have the allocatable attribute. The allocation status on each entry to the function is ‘not currently allocated’. The result may be allocated and deallocated any number of times during execution of the procedure, but it must be allocated and have a defined value on return.

²The Technical Report does not specify what happens when both arrays have the target attribute. Our belief is that an interpretation is likely to specify that pointer associations will be valid in this case, that is, copy in / copy out will not be permitted. For the moment, this cannot be relied upon.

Figure 13.1

```

subroutine load(array, unit)
    real, allocatable, intent(out), dimension(:,:,:,:) :: array
    integer, intent(in) :: unit
    integer :: n1, n2, n3

    read(unit) n1, n2, n3
    if (allocated(array)) deallocate(array)
    allocate(array(n1, n2, n3))
    read(unit) array
end subroutine load

```

The interface must be explicit in any scoping unit in which the function is referenced. The result array is automatically deallocated after execution of the statement in which the reference occurs, even if it has the target attribute. We can thus recast the example in Section 5.10, and safely use the function result in an expression as shown in Figure 13.2, without fearing a memory leak.

Figure 13.2

```

program no_leak
    real, dimension(100) :: x, y
    :
    y(:size(compact(x))) = compact(x)**2
    :

contains

    function compact(x) ! A procedure to remove duplicates from
                        ! the array x
        real, allocatable, dimension(:) :: compact
        real, dimension(:), intent(in) :: x
        integer :: n
        :
                    ! Find the number of distinct values, n
        allocate(compact(n))
        :
                    ! Copy the distinct values into compact
    end function compact
end program no_leak

```

13.4 Allocatable components

Components of derived type are permitted to have the `allocatable` attribute. For example, given the type declaration

```
type stack
    integer :: index
    integer, allocatable :: content(:)
end type stack
```

for each scalar variable of type `type(stack)`, the bounds of component `content` are determined by an `allocate` statement, by assignment, or by argument association.

In Section 9.3, we used the term *ultimate component* when a sequence of component selections involves no pointer components of derived type and ends with an intrinsic type. It is convenient to extend the term to include the case that ends with a component of derived type that is allocatable or is a pointer. For example, if the components called `alloc` are allocatable and the components called `point` are pointers, the components `obj%point` and `obj%alloc` are ultimate components, but `obj%point%comp` and `obj%alloc%comp` are not. The parent object (`obj` in our example) may be allocatable or a pointer.

Just as for an ordinary allocatable array, the initial state of an allocable component is always ‘not currently allocated’. This is also true for an ultimate allocatable component of an object created by an `allocate` statement. Hence, there is no need for default initialization of allocatable components. In fact, initialization in a derived type definition (Section 7.11) of an allocatable component is not permitted.

In a structure constructor (Section 3.8), an expression corresponding to an allocatable component must be an array or `null()`. If it is an allocatable array, the component takes the same allocation status and, if allocated, the same bounds and value. If it is an array, but not an allocatable array, the component is allocated with the same bounds and is assigned the same value. If it is `null()`, the component receives the allocation status of ‘not currently allocated’.

Allocatable components are illustrated in Figure 13.3, where code to manipulate polynomials with variable numbers of terms is shown.

Just as an allocatable array is not permitted to have the `parameter` attribute (be a constant), so an object with an ultimate allocatable component is not permitted to have the `parameter` attribute. An array constructor of such a type cannot be a constant and cannot participate in an initialization expression (Section 7.4). To correspond with this, a variable of such a type is not permitted to be initialized.

In an array subobject (Section 6.13), a *part-ref* to the right of a *part-ref* with nonzero rank must not be an element of an allocatable component, for example,

Figure 13.3

```

module real_polynomial_module
    type real_polynomial
        real, allocatable, dimension(:) :: coeff
    end type real_polynomial
    interface operator(+)
        module procedure rp_add_rp
    end interface operator(+)
contains
    function rp_add_rp(p1, p2)
        type(real_polynomial)           :: rp_add_rp
        type(real_polynomial), intent(in) :: p1, p2
        integer                          :: m, m1, m2
        m1 = ubound(p1%coeff,1)
        m2 = ubound(p2%coeff,1)
        allocate(rp_add_rp%coeff(0:max(m1,m2)))
        m = min(m1,m2)
        rp_add_rp%coeff(:m) = p1%coeff(:m) + p2%coeff(:m)
        if (m1 > m) rp_add_rp%coeff(m+1:) = p1%coeff(m+1:)
        if (m2 > m) rp_add_rp%coeff(m+1:) = p2%coeff(m+1:)
    end function rp_add_rp
end module real_polynomial_module
program example
    use real_polynomial_module
    type(real_polynomial) :: p, q, r
    p = real_polynomial((/4.0, 2.0, 1.0/)) ! Set p to 4+2x+x**2
    q = real_polynomial((-1.0, 1.0))
    r = p + q
    print *, 'Coefficients are: ', r%coeff
end program example

```

```

type(stack) :: a(10) ! The type was declared at the
                      ! start of this section.
... a(:)%content(1) ! Not permitted.

```

This is because such an object would not be an ordinary array – its elements are likely to be stored without any regular pattern, each having been separately given storage by an `allocate` statement.

When a variable of derived type is deallocated, any ultimate allocatable component that is currently allocated is also deallocated, as if by a `deallocate` statement. The variable may be a pointer or an allocatable array, and the rule applies recursively, so that all allocated allocatable components at all levels (apart from any lying beyond pointer components) are deallocated. Note the convenience to the programmer of this feature; to avoid memory leakage with pointer components,

the programmer would need to deallocate each one explicitly and be careful to order the deallocations correctly.

Intrinsic assignment

variable = *expr*

for a type with an ultimate allocatable component consists of the following steps for each such component:

- i) If the component of *variable* is currently allocated, it is deallocated.
- ii) If the component of *expr* is currently allocated, the component of *variable* is allocated with the same bounds and the value is then transferred using intrinsic assignment.

If the allocatable component of *expr* is ‘not currently allocated’, nothing happens in step ii), so the component of *variable* is left ‘not currently allocated’. Note that if the component of *variable* is already allocated with the same shape, the compiler may choose to avoid the overheads of deallocation and reallocation. Note also that if the compiler can tell that there will be no subsequent reference to *expr*, because it is a function reference or a temporary variable holding the result of expression evaluation, no allocation or assignment is needed – all that has to happen is the deallocation of any allocated ultimate allocatable components of *variable* followed by copying of the descriptor.

If an actual argument and the corresponding dummy argument have an ultimate allocatable component, rule i) of Section 5.7.2 is applicable and requires all allocations and deallocations of the component to be performed through the dummy argument, in case copy in / copy out is in effect.

If a statement contains a reference to a function whose result is of a type with an ultimate allocatable component, any allocated ultimate allocatable components of the function result are deallocated after execution of the statement. This parallels the rule for allocatable function results (Section 13.3).

Just as for pointer components (see Section 9.3), a structure with an ultimate allocatable component is not permitted in an I/O list. The reason is the intention to add defined edit descriptors for data structures to Fortran 2000. Programmers will be able to write procedures that are called as part of the I/O processing. Such a procedure will be much better able to handle structures whose size and composition vary dynamically, the usual case with allocatable components.

Similarly, such a structure is not permitted in a namelist group (Section 7.15). This is entirely consistent with not permitting allocatable arrays or structures with pointer components here.

A sequence type (Section 11.2.1) is permitted to have an allocatable component, which permits independent declarations of the same type in different scopes, but such a type has an unspecified storage unit, that is, does not have numeric or character storage association (as for a type with a pointer component).

This dynamic feature is ill adapted to the fixed storage model implied by storage association, and so, just as for pointer components (see Section 11.2.2),

a structure with an ultimate allocatable component is not permitted as an object in an equivalence statement. Just as for allocatable arrays (see Section 11.2.3), a structure with an ultimate allocatable component, is not permitted in a common block. Thus, such a structure is not permitted at all in a storage association context.

A. Intrinsic procedures

Name	Section	Description
<code>abs (a)</code>	8.3.1	Absolute value.
<code>achar (i)</code>	8.5.1	Character in position i of ASCII collating sequence.
<code>acos (x)</code>	8.4	Arc cosine (inverse cosine) function.
<code>adjustl (string)</code>	8.5.3	Adjust left, removing leading blanks and inserting trailing blanks.
<code>adjustr (string)</code>	8.5.3	Adjust right, removing trailing blanks and inserting leading blanks.
<code>aimag (z)</code>	8.3.1	Imaginary part of complex number.
<code>aint (a [,kind])</code>	8.3.1	Truncate to a whole number.
<code>all (mask [,dim])</code>	8.11	True if all elements are true.
<code>allocated (array)</code>	8.12.1	True if the array is allocated.
<code>anint (a [,kind])</code>	8.3.1	Nearest whole number.
<code>any (mask [,dim])</code>	8.11	True if any element is true.
<code>asin (x)</code>	8.4	Arcsine (inverse sine) function.
<code>associated (pointer [,target])</code>	8.2	True if pointer is associated with target.
<code>atan (x)</code>	8.4	Arctangent (inverse tangent) function.
<code>atan2 (y, x)</code>	8.4	Argument of complex number (x, y).
<code>bit_size (i)</code>	8.8.1	Maximum number of bits that may be held in an integer.
<code>btest (i, pos)</code>	8.8.2	True if bit pos of integer i has value 1.

<code>ceiling (a [, kind])</code>	8.3.1	Least integer greater than or equal to its argument (kind permitted only in Fortran 95).
<code>char (i [,kind])</code>	8.5.1	Character in position <i>i</i> of the processor collating sequence.
<code>cmplx (x [,y] [,kind])</code>	8.3.1	Convert to complex type.
<code>conjg (z)</code>	8.3.2	Conjugate of a complex number.
<code>cos (x)</code>	8.4	Cosine function.
<code>cosh (x)</code>	8.4	Hyperbolic cosine function.
<code>count (mask [,dim])</code>	8.11	Number of true elements.
<code>cpu_time (time)</code>	8.16.2	Processor time (Fortran 95 only)
<code>cshift (array, shift [,dim])</code>	8.13.5	Perform circular shift.
<code>call date_and_time ([date] [,time] [,zone] [,values])</code>	8.16.1	Real-time clock reading date and time.
<code>dble (a)</code>	11.4.1	Convert to double precision real.
<code>digits (x)</code>	8.7.2	Number of significant digits in the model for <i>x</i> .
<code>dim (x, y)</code>	8.3.2	$\max(x-y, 0)$.
<code>dot_product (vector_a, vector_b)</code>	8.10	Dotproduct.
<code>dprod (x, y)</code>	11.4.1	Double precision real product of two default real scalars.
<code>eoshift (array, shift [,boundary] [,dim])</code>	8.13.5	Perform end-off shift.
<code>epsilon (x)</code>	8.7.2	Number that is almost negligible compared with one in the model for numbers like <i>x</i> .
<code>exp (x)</code>	8.4	Exponential function.
<code>exponent (x)</code>	8.7.3	Exponent part of the model for <i>x</i> .
<code>floor (a [, kind])</code>	8.3.1	Greatest integer less than or equal to its argument (kind permitted only in Fortran 95).
<code>fraction (x)</code>	8.7.3	Fractional part of the model for <i>x</i> .
<code>huge (x)</code>	8.7.2	Largest number in the model for numbers like <i>x</i> .
<code>iachar (c)</code>	8.5.1	Position of character <i>c</i> in ASCII collating sequence.

iand (i, j)	8.8.2	Logical and on the bits.
ibclr (i, pos)	8.8.2	Clear bit pos to zero.
ibits (i, pos, len)	8.8.2	Extract a sequence of bits.
ibset (i, pos)	8.8.2	Set bit pos to one.
ichar (c)	8.5.1	Position of character c in the processor collating sequence.
ieor (i, j)	8.8.2	Exclusive or on the bits.
index (string, substring [,back])	8.5.3	Starting position of substring within string.
int (a [,kind])	8.3.1	Convert to integer type.
ior (i, j)	8.8.2	Inclusive or on the bits.
ishft (i, shift)	8.8.2	Logical shift on the bits.
ishftc (i, shift [,size])	8.8.2	Logical circular shift on a set of bits on the right.
kind (x)	8.2	Kind type parameter value.
lbound (array [,dim])	8.12.2	Array lower bounds.
len (string)	8.6.1	Character length.
len_trim (string)	8.5.3	Length of string without trailing blanks.
lge (string_a, string_b)	8.5.2	True if string_a equals or follows string_b in ASCII collating sequence.
lgt (string_a, string_b)	8.5.2	True if string_a follows string_b in ASCII collating sequence.
lle (string_a, string_b)	8.5.2	True if string_a equals or precedes string_b in ASCII collating sequence.
llt (string_a, string_b)	8.5.2	True if string_a precedes string_b in ASCII collating sequence.
log (x)	8.4	Natural (base e) logarithm function.
logical (l, [,kind])	8.5.4	Convert between kinds of logicals.
log10 (x)	8.4	Common (base 10) logarithm function.
matmul (matrix_a, matrix_b)	8.10	Matrix multiplication.
max (a1, a2 [,a3,...])	8.3.2	Maximum value.

<code>maxexponent (x)</code>	8.7.2	Maximum exponent in the model for numbers like <code>x</code> .
<code>maxloc (array [,mask])</code> or <code>maxloc (array, dim [,mask])</code>	8.14	Location of maximum array element (<code>dim</code> in Fortran 95 only).
<code>maxval (array [,mask])</code> or <code>maxval (array, dim [,mask])</code>	8.11	Value of maximum array element (<code>mask</code> as second positional argument in Fortran 95 only).
<code>merge (tsource, fsource, mask)</code>	8.13.1	<code>tsource</code> when <code>mask</code> is true and <code>fsource</code> otherwise.
<code>min (a1, a2 [,a3,...])</code>	8.3.2	Minimum value.
<code>minexponent (x)</code>	8.7.2	minimum exponent in the model for numbers like <code>x</code> .
<code>minloc (array [,mask])</code> or <code>minloc (array, dim [,mask])</code>	8.14	Location of minimum array element (<code>dim</code> in Fortran 95 only).
<code>minval (array [,mask])</code> or <code>minval (array, dim [,mask])</code>	8.11	Value of minimum array element (<code>mask</code> as second positional argument in Fortran 95 only).
<code>mod (a, p)</code>	8.3.2	Remainder modulo <code>p</code> , that is <code>a - int(a/p)*p</code> .
<code>modulo (a, p)</code>	8.3.2	<code>a</code> modulo <code>p</code> .
<code>call mvbits (from, frompos, len, to, topos)</code>	8.8.3	Copy bits.
<code>nearest (x, s)</code>	8.7.3	Nearest different machine number in the direction given by the sign of <code>s</code> .
<code>nint (a [,kind])</code>	8.3.1	Nearest integer.
<code>not (i)</code>	8.8.2	Logical complement of the bits.
<code>null([mold])</code>	8.15	Disassociated pointer (Fortran 95 only).
<code>pack (array, mask [,vector])</code>	8.13.2	Pack elements corresponding to true elements of <code>mask</code> into rank-one result.
<code>precision (x)</code>	8.7.2	Decimal precision in the model for <code>x</code> .
<code>present (a)</code>	8.2	True if optional argument is present.

<code>product (array [,mask])</code> or <code>product (array, dim [,mask])</code>	8.11	Product of array elements (mask as second positional argument in Fortran 95 only).
<code>radix (x)</code>	8.7.2	Base of the model for numbers like <code>x</code> .
<code>call random_number (harvest)</code>	8.16.3	Random numbers in range $0 \leq x < 1$.
<code>call random_seed ([size] [put] [get])</code>	8.16.3	Initialize or restart random number generator.
<code>range (x)</code>	8.7.2	Decimal exponent range in the model for <code>x</code> .
<code>real (a [,kind])</code>	8.3.1	Convert to real type.
<code>repeat (string, ncopies)</code>	8.6.2	Concatenates <code>ncopies</code> of <code>string</code> .
<code>reshape (source, shape [,pad] [,order])</code>	8.13.3	Reshape source to shape <code>shape</code> .
<code>rrspacing (x)</code>	8.7.3	Reciprocal of the relative spacing of model numbers near <code>x</code> .
<code>scale (x, i)</code>	8.7.3	$x \times b^i$, where $b=\text{radix}(x)$.
<code>scan (string, set [,back])</code>	8.5.3	Index of left-most (right-most if <code>back</code> is true) character of <code>string</code> that belongs to <code>set</code> ; zero if none belong.
<code>selected_int_kind (r)</code>	8.7.4	Kind of type parameter for specified exponent range.
<code>selected_real_kind ([p] [,r])</code>	8.7.4	Kind of type parameter for specified precision and exponent range.
<code>set_exponent (x, i)</code>	8.7.3	Model number whose sign and fractional part are those of <code>x</code> and whose exponent part is <code>i</code> .
<code>shape (source)</code>	8.12.2	Array (or scalar) shape.
<code>sign (a, b)</code>	8.3.2	Absolute value of <code>a</code> times sign of <code>b</code> .
<code>sin (x)</code>	8.4	Sine function.
<code>sinh (x)</code>	8.4	Hyperbolic sine function.
<code>size (array [,dim])</code>	8.12.2	Array size.
<code>spacing (x)</code>	8.7.3	Absolute spacing of model numbers near <code>x</code> .
<code>spread (source, dim, ncopies)</code>	8.13.4	<code>ncopies</code> copies of <code>source</code> forming an array of rank one greater.

<code>sqrt (x)</code>	8.4	Square root function.
<code>sum (array [,mask])</code> or <code>sum(array, dim [,mask])</code>	8.11	Sum of array elements (<code>mask</code> as second positional argument in Fortran 95 only).
<code>call system_clock ([count] [,count_rate] [,count_max])</code>	8.16.1	Integer data from real-time clock.
<code>tan (x)</code>	8.4	Tangent function.
<code>tanh (x)</code>	8.4	Hyperbolic tangent function.
<code>tiny (x)</code>	8.7.2	Smallest positive number in the model for numbers like <code>x</code> .
<code>transfer (source, mold [,size])</code>	8.9	Same physical representation as <code>source</code> , but type of <code>mold</code> .
<code>transpose (matrix)</code>	8.13.6	Matrix transpose.
<code>trim (string)</code>	8.6.2	Remove trailing blanks from a single string.
<code>ubound (array [,dim])</code>	8.12.2	Array upper bounds.
<code>unpack (vector, mask, field)</code>	8.13.2	Unpack elements of <code>vector</code> corresponding to true elements of <code>mask</code> .
<code>verify (string, set [,back])</code>	8.5.3	Zero if all characters of <code>string</code> belong to <code>set</code> or index of left-most (right-most if <code>back</code> true) that does not.

B. Fortran 90/95 statements

Notes:

- Obsolescent features (see Appendix C) have not been included in this list.
- Where no optional blank is indicated between two adjacent keywords, the blank is mandatory.

Statement	Section
NON-EXECUTABLE STATEMENTS	
Program Units and Subprograms	
<i>program</i> <i>program-name</i>	5.2
<i>module</i> <i>module-name</i>	5.5
<i>end[][module [module-name]]</i>	5.5
<i>use module-name [,rename-list]</i>	7.10
<i>use module-name, only: [only-list]</i>	7.10
<i>private [[::] access-id-list]</i>	7.6 & 7.11
<i>public [[::] access-id-list]</i>	7.6
<i>external external-name-list</i>	5.11
<i>intrinsic :: intrinsic-name-list</i> (:: in Fortran 95 only)	8.1.3
<i>[prefix] subroutine subroutine-name ([dummy-argument-list])</i>	5.20
where <i>prefix</i> is recursive or, for Fortran 95, pure or elemental	
<i>[prefix] function function-name ([dummy-argument-list])</i>	5.20
<i>[result(result-name)]</i>	
where <i>prefix</i> is <i>type</i> [recursive] or recursive [<i>type</i>] or also, for Fortran 95, pure or elemental	
<i>entry entry-name ([dummy-argument-list]) [result(result-name)]</i>	11.2.6
<i>intent (inout) :: dummy-argument-name-list</i>	7.8
where <i>inout</i> is <i>in</i> , <i>out</i> , or <i>in[]out</i>	
<i>optional :: dummy-argument-name-list</i>	7.8
<i>save [::] saved-entity-list]</i>	7.9

where <i>saved-entity</i> is <i>variable-name</i> or <i>/common-block-name</i> contains	5.2
interface [<i>generic-spec</i>]	5.18
where <i>generic-spec</i> is <i>generic-name</i> , <i>operator(defined-operator)</i> , or <i>assignment(=)</i>	
end[]interface [<i>generic-spec</i>] (<i>generic-spec</i> in Fortran 95 only)	5.18
module procedure <i>procedure-name-list</i>	5.18

Data Specification

<i>type</i> [[, <i>attribute</i>]... ::] <i>entity-list</i>	7.12
where <i>type</i> is <i>integer</i> (([<i>kind</i> =] <i>kind-value</i>)),	7.13
<i>real</i> (([<i>kind</i> =] <i>kind-value</i>)),	
<i>logical</i> (([<i>kind</i> =] <i>kind-value</i>)),	
<i>complex</i> (([<i>kind</i> =] <i>kind-value</i>)),	
<i>character</i> [<i>actual-parameter-list</i>],	
<i>double</i> [] <i>precision</i> , or	
<i>type</i> (<i>type-name</i>)	
and <i>attribute</i> is <i>parameter</i> , <i>public</i> , <i>private</i> , <i>pointer</i> , <i>target</i> , <i>allocatable</i> , <i>dimension</i> (<i>bounds-list</i>), <i>intent(inout)</i> , <i>external</i> , <i>intrinsic</i> , <i>optional</i> or <i>save</i>	7.12
<i>implicit none</i>	7.2
<i>implicit type</i> (<i>letter-spec-list</i>) [, <i>type</i> (<i>letter-spec-list</i>)...]	7.2
<i>type</i> [[, <i>access</i>]::] <i>type-name</i>	7.11
where <i>access</i> is <i>public</i> or <i>private</i>	7.6
<i>type</i> [[, <i>component-attr</i>]... ::] <i>component-decl-list</i>	7.11
where <i>component-attr</i> is <i>pointer</i> or <i>dimension</i> (<i>bounds-list</i>) and <i>component-decl</i> is <i>component-name</i> ((<i>bounds-list</i>)) [* <i>char-len</i>] [<i>comp-init</i>] and <i>comp-init</i> (Fortran 95 only) is = <i>expr</i> or => <i>null()</i>	
<i>end</i> [] <i>type</i> [<i>type-name</i>]	7.11
<i>sequence</i>	11.2.1
<i>data</i> <i>object-list</i> / <i>value-list</i> / [[,] <i>object-list</i> / <i>value-list</i> /]...	7.5.2
<i>block</i> [] <i>data</i> [<i>block-data-name</i>]	11.2.4
<i>end</i> [[] <i>block</i> [] <i>data</i> [<i>block-data-name</i>]]	11.2.4
<i>parameter</i> (<i>named-constant-definition-list</i>)	11.4.2
<i>namelist</i> / <i>namelist-group-name</i> / <i>variable-name-list</i>	7.15
[[,]/ <i>namelist-group-name</i> / <i>variable-name-list</i>]...	
<i>dimension</i> [::] <i>array-name</i> (<i>array-spec</i>)	11.4.2
[, <i>array-name</i> (<i>array-spec</i>)...]	
<i>allocatable</i> [::] <i>array-name</i> [(<i>array-spec</i>)]	7.7
[, <i>array-name</i> [(<i>array-spec</i>)]]...	

<code>pointer :: object-name [(array-spec)] [,object-name [(array-spec)]]...</code>	7.7
<code>target :: object-name [(array-spec)] [,object-name [(array-spec)]]...</code>	7.7
<code>equivalence (object, object-list) [, (object, object-list)]...</code>	11.2.2
<code>common [/cname/] vlist [,]/[cname] / vlist]...</code>	11.2.3

EXECUTABLE STATEMENTS

Assignment

`variable = expr`

where `variable` may be an array and may be a subobject Chap. 3

`pointer => target` 3.12

`if (scalar-logical-expr) action-stmt` 4.3.1

`where (logical-array-expr) array-variable = expr` 6.8

`forall(index = lower: upper [:stride] [, index = lower: upper [:stride]]... [,scalar-logical-expr]) assignment` (Fortran 95) 6.9

Program Units and Subprograms

`call subroutine-name ([([actual-argument-list])])` 5.13

`return` 5.8

`end[][unit [unit-name]]` Chap. 5

where `unit` is program, subroutine, or function.

Dynamic Storage Allocation

`allocate (allocation-list [, stat=stat])` 6.5.2

`deallocate (allocate-object-list [, stat=stat])` 6.5.3

`nullify (pointer-object-list)` 6.5.4

Control Constructs

`[do-name:] do [label] [,] do-variable = scalar-integer-expr, scalar-integer-expr [,scalar-integer-expr]]` 4.5

`[do-name:] do [label] [,] while(scalar-logical-expr)` 11.3.2

`cycle [do-name]` 4.5

`exit [do-name]` 4.5

`continue` 4.5

`end[]do [do-name]` 4.5

`[if-name:] if (scalar-logical-expr) then` 4.3.2

`else[[]if (scalar-logical-expr) then] [if-name]` 4.3.2

<code>end[]if [if-name]</code>	4.3.2
<code>[select-name:] select[]case (scalar-expr)</code>	4.4
<code>case (case-value-list) [select-name]</code>	4.4
<code>case default [select-name]</code>	4.4
<code>end[]select [select-name]</code>	4.4
<code>go[]to label</code>	4.2
<code>stop [access-code]</code>	5.3
<code>[where-name:] where (logical-array-expr)</code>	6.8
<code>elsewhere [where-name]</code>	6.8
<code>elsewhere (logical-array-expr) [where-name] (Fortran 95)</code>	6.8.1
<code>end[]where [where-name]</code>	6.8
<code>[forall-name:] forall(index = lower: upper [:stride] [, index = lower: upper [:stride]]... [,scalar-logical-expr]) (Fortran 95)</code>	6.9
<code>end[]forall [forall-name] (Fortran 95)</code>	6.9

Input-Output

<code>read (control-list) [input-list]</code>	9.17
<code>read format [, input-list]</code>	9.7
<code>write (control-list) [output-list]</code>	9.17
<code>print format [, output-list]</code>	9.8
<code>rewind external-file-unit</code>	10.2.2
<code>rewind (position-list)</code>	10.2.2
<code>end[]file external-file-unit</code>	10.2.3
<code>end[]file (position-list)</code>	10.2.3
<code>backspace external-file-unit</code>	10.2.1
<code>backspace (position-list)</code>	10.2.1
<code>open (connect-list)</code>	10.3
<code>close (close-list)</code>	10.4
<code>inquire (inquire-list)</code>	10.5
<code>inquire (iolength = length) olist</code>	10.5
<code>format ([format-list]) (this statement is actually non-executable).</code>	9.4

C. Obsolescent features

C.1 Obsolescent in Fortran 95 only

The features of this section were of first-class status in Fortran 90. However, the Fortran 95 standard defines them to be obsolescent, and they are thus, in a Fortran 95 context, part of this Appendix. Their replacements are described in the relevant subsections.

C.1.1 Fixed source form

The fixed source form has been replaced by the free source form (Section 2.4). In the old form, each statement consists of one or more *lines* exactly 72 characters long,¹ and each line is divided into three *fields*. The first field consists of positions 1 to 5 and may contain a *statement label*. A Fortran statement may be written in the second fields of up to 20 consecutive lines. The first line of a multi-line statement is known as the *initial line* and the succeeding lines as *continuation lines*.

A non-comment line is an initial line or a continuation line depending on whether there is a character, other than zero or blank, in position 6 of the line, which is the second field. The first field of a continuation line must be blank. The ampersand is not used for continuation.

The third field, from positions 7 to 72, is reserved for the Fortran statements themselves. Note that if a construct is named, the name must be placed here and not in the label field.

Except in a character context, blanks are insignificant.

The presence of an asterisk (*) or a character c in position 1 of a line indicates that the whole line is commentary. An exclamation mark indicates the start of commentary, except in position 6, where it indicates continuation.

Several statements separated by a semi-colon (;) may appear on one line. The semi-colon may not, in this case, be in column 6, where it would indicate continuation. Only the first of the statements on a line may be labelled. A semi-colon that is the last non-blank character of a line, or the last non-blank character ahead of commentary, is ignored.

¹This limit is processor dependent if the line contains characters other than those of the default type.

A program unit end statement must not be continued, and any other statement with an initial line that appears to be a program unit end statement must not be continued.

A processor may restrict the appearance of its defined control characters, if any, in the fixed source form.

In applications where a high degree of compatibility between the old and the new source forms is required, for instance in code to be included into several programs which might exist in different forms, observance of the following rules can be of great help:

- confine statement labels to positions 1 to 5 and statements to positions 7 to 72;
- treat blanks as being significant;
- use only ! to indicate a comment (but not in position 6);
- for continued statements, place an ampersand in both position 73 of a continued line and position 6 of a continuing line.

Also, a tool to facilitate the conversion of Fortran 77 code to the free source form can be obtained by anonymous ftp to *ftp.numerical.rl.ac.uk*; the directory is */pub/MandR* and the file name is *convert.f90*. An alternative ftp address is available at *asisftp.cern.ch*, in the directory *dist*.

C.1.2 Computed go to

A form of branch statement is the computed go to, which enables one path among many to be selected, depending on the value of a scalar integer expression. The general form is

`go to (s11, s12, s13, ...) [,] intexpr`

where *s11*, *s12*, *s13* etc. are labels of statements in the same scoping unit, and *intexpr* is any scalar integer expression. The same statement label may appear more than once. An example is

`go to (6,10,20) i(k)**2+j`

which references three statement labels. When the statement is executed, if the value of the integer expression is 1, the first branch will be taken, and control is transferred to the statement labelled 6. If the value is 2, the second branch will be taken, and so on. If the value is less than 1, or greater than 3, no branch will be taken, and the next statement following the go to will be executed.

This statement is replaced by the case construct (Section 4.4).

C.1.3 Character length specification character*

Alternatives to

`character([len=] len-value)`

as a *type* in a type declaration, function, implicit, or component definition statement are

`character*(len-value) [,]`

and

`character*len[,]`

where *len* is an integer literal constant without a specified kind value and the optional comma is permitted only in a type declaration statement and only when `:::` is absent:

`character*20 word, letter*1`

Note that these alternative forms are provided only for default characters.

C.1.4 Data statements among executables

The data statement may be placed among the executable statements, but such placement offers no extra advantage and is rarely used and not recommended, since data initialization properly belongs with the specification statements.

C.1.5 Statement functions

It may happen that within a single program unit there are repeated occurrences of a computation which can be represented as a single statement. For instance, to calculate the parabolic function represented by

$$y = a + bx + cx^2$$

for different values of *x*, but with the same coefficients, there may be references to

```
y1 = 1. + x1*(2. + 3.*x1)
:
y2 = 1. + x2*(2. + 3.*x2)
:
```

etc. In Fortran 77, it was more convenient to invoke a so-called *statement function* (now better coded as an internal subroutine, Section 5.6), which must appear after any implicit and other relevant specification statements and before the executable statements. The example above would become

```

parab(x) = 1. + x*(2. + 3.*x)
:
y1 = parab(x1)
:
y2 = parab(x2)

```

Here, *x* is a dummy argument, which is used in the definition of the statement function. The variables *x1* and *x2* are actual arguments to the function.

The general form is

$$\text{function-name}([\text{dummy-argument-list}]) = \text{scalar-expr}$$

where the *function-name* and each *dummy-argument* must be specified, explicitly or implicitly, to be scalar data objects. To make it clear that this is a statement function and not an assignment to a host array element, we recommend declaring the type by placing the *function-name* in a type declaration statement; this is *required* whenever a host entity has the same name. The *scalar-expr* must be composed of constants, references to scalar variables, references to functions, and intrinsic operations. If there is a reference to a function, the function must not be a transformational intrinsic nor require an explicit interface, the result must be scalar, and any array argument must be a named array. A reference to a non-intrinsic function must not require an explicit interface. A named constant that is referenced or an array of which an element is referenced must be declared earlier in the scoping unit or be accessed by use or host association. A scalar variable referenced may be a dummy argument of the statement function or a variable that is accessible in the scoping unit. A dummy argument of the host procedure must not be referenced unless it is a dummy argument of the main entry or of an entry that precedes the statement function. If any entity is implicitly typed, a subsequent type declaration must confirm the type and type parameters. The dummy arguments are scalar and have a scope of the statement function statement only.

A statement function always has an implicit interface and may not be supplied as a procedure argument. It may appear within an internal procedure, and may reference other statement functions appearing before it in the same scoping unit, but not itself nor any appearing after. A function reference in the expression must not redefine a dummy argument. A statement function is pure (Section 6.10) if it references only pure functions.

A statement function statement is not permitted in an interface block.

Note that statement functions are irregular in that use and host association are not available.

C.1.6 Assumed character length of function results

A non-recursive external function whose result is scalar, character, and non-pointer may have assumed character length as in Figure C.1. Such a function is not permitted to specify a defined operation. In a scoping unit that invokes such

a function, the interface must be implicit and there must be a declaration of the length, as in Figure C.2, or such a declaration must be accessible by use or host association.

Figure C.1

```
function copy(word)
    character(len=*) copy, word
    copy = word
end function copy
```

Figure C.2

```
program main
    external copy           ! Interface block not allowed.
    character(len=10) copy
    write(*, *) copy('This message will be truncated')
end program main
```

This facility is included only for compatibility with Fortran 77 and is completely at variance with the philosophy of Fortran 90/95 that the attributes of a function result depend only on the actual arguments of the invocation and on any data accessible by the function through host or use association.

This facility may be replaced by use of a subroutine whose arguments correspond to the function result and the function arguments.

C.2 Obsolescent in Fortran 90 and 95

The features of this section are obsolescent in both Fortran 90 and Fortran 95. Their replacements are described in the relevant subsections.

C.2.1 Arithmetic if statement

The arithmetic if provides a three-way branching mechanism, depending on whether an arithmetic expression has a value which is less than, equal to, or greater than zero. It is replaced by the if statement and construct (Section 4.3). Its general form is

```
if (expr) s11, s12, s13
```

where *expr* is any scalar expression of type integer or real, and *s11*, *s12*, and *s13* are the labels of statements in the same scoping unit. If the result obtained by evaluating *expr* is negative then the branch to *s11* is taken, if the result is zero the branch to *s12*, and if the result is greater than zero the branch to *s13*. An example is

```

if (p-q) 1,2,3
1 p = 0.
    go to 4
2 p = 1.
    q = 1.
    go to 4
3 q = 0.
4 ...

```

in which a branch to 1, 2 or 3 is taken depending on the value of $p-q$. The arithmetic if may be used as a two-way branch when two of the labels are identical:

```
if (x-y) 1,2,1
```

C.2.2 Shared do loop termination

A do-loop may be terminated on a labelled statement other than an end do or continue. Such a statement must be an executable statement other than go to, return or an end statement of a subprogram, stop or an end statement of a main program, exit, cycle, arithmetic-if, or assigned go to statement. Nested do-loops may share the same labelled terminal statement, in which case all the usual rules for nested blocks hold, but a branch to the label must be from within the innermost loop. Thus we may write a matrix multiplication as

```

a(1:n, 1:n) = 0.
do 1 i = 1,n
    do 1 j = 1,n
        do 1 l = 1,n
1             a(i,j) = a(i,j)+b(i,l)*c(l,j)

```

Execution of a `cycle` statement restarts the loop without execution of the terminal statement. This form of do-loop offers no additional functionality but considerable scope for unexpected mistakes.

C.2.3 Alternate return

When calling certain types of subroutines, it is possible that specific exceptional conditions will arise, which should cause a break in the normal control flow. It is possible to anticipate such conditions, and to code different flow paths following a subroutine call, depending on whether the called subroutine has terminated normally, or has detected an exceptional or abnormal condition. This is achieved using the alternate return facility which uses the argument list in the following manner. Let us suppose that a subroutine `deal` receives in an argument list the number of cards in a shuffled deck, the number of players and the number of cards to be dealt to each hand. In the interests of generality, it would be a reasonable

precaution for the first executable statement of deal to be a check that there is at least one player and that there are, in fact, enough cards to satisfy each player's requirement. If there are no players or insufficient cards, it can signal this to the main program which should then take the appropriate action. This may be written in outline as

```
call deal(nshuff, nplay, nhand, cards, *2, *3)
call play
:
2 ..... ! Handle no-player case.
:
3 ..... ! Handle insufficient-cards case.
:
```

If the cards can be dealt, normal control is returned, and the call to play executed. If an exception occurs, control is passed to the statement labelled 2 or 3, at which point some action must be taken — to stop the game or shuffle more cards. The relevant statement label is defined by placing the statement label preceded by an asterisk as an actual argument in the argument list. It must be a label of an executable statement of the same scoping unit. Any number of such alternate returns may be specified, and they may appear in any position in the argument list. Since, however, they are normally used to handle exceptions, they are best placed at the end of the list.

In the called subroutine, the corresponding dummy arguments are asterisks and the alternate return is taken by executing a statement of the form

```
return intexpr
```

where *intexpr* is any scalar integer expression. The value of this expression at execution time defines an index to the alternate return to be taken, according to its position in the argument list. If *intexpr* evaluates to 2, the second alternate return will be taken. If *intexpr* evaluates to a value which is less than 1, or greater than the number of alternate returns in the argument list, a normal return will be taken. Thus, in deal, we may write simply

```
subroutine deal(nshuff, nplay, nhand, cards, *, *)
:
if (nplay.le.0) return 1
if (nshuff .lt. nplay*nhand) return 2
```

This feature is also available for subroutines defined by entry statements. It is not available for functions or elemental subroutines.

This feature is replaced by use of an integer argument holding a return code used in a computed go to following the call statement. A following case construct is now an even better alternative.

C.3 Obsolescent in Fortran 90, deleted in Fortran 95

The features of this section are obsolescent in Fortran 90 and are deleted from the Fortran 95 language entirely. They should thus be regarded, in a Fortran 95 context, as being absent from this book. Although it can be expected that compilers will continue to support these features for some period, their use should be completely avoided to ensure very long-term portability and to avoid unnecessary compiler warning messages. Their replacements are described in the relevant subsections.

C.3.1 Non-Integer do Indices

The do variable and the expressions that specify the limits and stride of a do-construct or an implied-do in an I/O statement may be of type default real or double precision real. We may therefore write a loop such as

```
do 1 a = 1, 15.7, 2.1
```

in which the real variable a will assume the initial value of 1.0 (note the conversion), and will subsequently have the values 3.1, 5.2, etc. up to 15.7.

There are, however, serious problems associated with do-loops with real indices, and in order to understand them we recall how the number of iterations of a do-loop is actually determined:

$$\max(\text{int}((\text{expr2}-\text{expr1}+\text{expr3})/\text{expr3}), 0)$$

A consequence of this formula is rather insidious, and results from the application of the int function. Consider the statement

```
do 1 a = -0.3, -2.1, -0.3
```

which we would normally expect to result in seven iterations of the loop it controls. The number of iterations is obtained from the result of a computation whose intermediate value may not be 7.00000.. but 6.99999.., due to rounding errors. After applying the int function we then have the integer 6 as the number of iterations. Whether or not this rounding error will occur for a given loop on a given computer is difficult to foresee, and this is the reason for avoiding the use of real do-loop parameters. A similar problem can arise with a long loop: the repeated addition of the one to the other can lead to an unexpected loss of precision.

C.3.2 Assigned go to and assigned formats

Another form of branch statement is actually written in two parts, an assign statement and an assigned go to statement. The form is

```
assign s1 to intvar
:
```

```

assign sl2 to intvar
:
go to intvar [[,](sl1,sl2,... )]

```

where *sl1*, *sl2* etc. are labels of statements in the same scoping unit, and *intvar* is a named scalar default integer variable (so cannot be an array element or structure component). When an assign statement is executed, *intvar* acquires a representation of a statement label. Different labels may be assigned in different parts of the scoping unit. When the assigned go to is executed, then depending on the value of *intvar*, the appropriate path is taken. If the optional statement label list in the go to statement is present, it must contain the label in *intvar*, and permits a check that *intvar* has acquired an expected value during program execution. A label may appear more than once in the list.

The assigned go to's main purpose is to control logic flow in a scoping unit having a number of paths which come together at one point at which some common code is executed, and from which a new branch is taken depending on the path taken before. This is shown in Figure C.3, where we see three paths joining before the go to, and three after. For this type of application, an internal subprogram (Section 5.6) is more appropriate.

Figure C.3

```

:
x = y+1.
assign 4 to jump
go to 3
4 :
1 x = y+2.
assign 5 to jump
go to 3
5 :
2 x = y+3.
assign 6 to jump
6 :
3 z = x**2
:
go to jump (4,5,6)
:

```

A default integer variable to which a statement label has been assigned in an assign statement may also be used to specify a format statement:

```

assign 10 to key
:
print key, q
10 format(f10.3)

```

The label must be that of a `format` statement in the same scoping unit as the I/O statement.

This use of the `assign` statement is replaced by character expressions to define format specifiers (Section 9.4). This feature is not part of Fortran 95.

C.3.3 Branching to an `end if` statement

It is permissible to branch to an `end if` statement from outside the construct that it terminates. A branch to the following statement is a replacement for this practice, which is not part of Fortran 95.

C.3.4 The `pause` statement

At certain points in the execution of a program it might be useful to pause, in order to allow some possible external intervention in the running conditions to be made, for instance for an operator to activate a peripheral device required by the program. This can be achieved by executing a `pause` statement which may also contain a default character constant, or a string of up to five digits, for example

```
pause 'Please mount the next disc pack'  
pause 1234
```

Execution is resumed by some form of external command, for instance one given by an operator. The effect may be achieved with a `read` statement that awaits data. This feature is not part of Fortran 95.

C.3.5 H edit descriptor

The `H` (or `h`) edit descriptor provides an alternative character string edit descriptor: the output string is preceded by an `nH` edit descriptor, where `n` is the number of default characters in the following string (blanks being significant):

```
100 format(23HI must count characters)
```

The value `n` must be an integer literal constant without a kind parameter. If the Hollerith string occurs within a character constant delimited by apostrophes and contains an apostrophe, the apostrophe must be represented by two apostrophes, but counts as only one in the `nH` character count, as in the example

```
print '(7H Don''t, a)', caution
```

and similarly for quotes.

The `H` edit descriptor provides the same functionality as the character string edit descriptor but is prone to error as it is easy to miscount the number of characters in the string. The feature is not part of Fortran 95.

D. Pointer example

A recurring problem in computing is the need to manipulate a linked data structure. This might be a simple linked list like the one encountered in Section 2.13, but often a more general tree structure is required.

The example in this Appendix consists of a module that establishes and navigates one or more such trees, organized as a ‘forest’, and a short test program for it. Here, each node is identified by a name and has any number of children, any number of siblings, and (optionally) some associated real data. Each root node is regarded as having a common parent, the ‘forest root’ node, whose name is ‘`forest_root`’. Thus, every node has a parent. The module provides facilities for adding a named node to a specified parent, for enquiring about all the nodes that are offspring of a specified node, for removing a tree or subtree, and for performing I/O operations on a tree or subtree.

The user-callable interfaces are:

start: must be called to initialize a forest.

add_node: stores the data provided at the node whose parent is specified and sets up pointers to the parent and siblings (if any).

remove_node: deallocates all the storage occupied by a complete tree or subtree.

retrieve: retrieves the data stored at a specified node and the names of the parent and children.

dump_tree: writes a complete tree or subtree.

restore_tree: reads a complete tree or subtree.

finish: deallocates all the storage occupied by all the trees of the forest.

The source code can be obtained by anonymous ftp to [ftp.numerical.rl.ac.uk](ftp://ftp.numerical.rl.ac.uk). When prompted for a userid, reply with

anonymous

and give your name as password. The directory is `/pub/MandR` and the file name is `pointer.f90`. An alternative address is `asiftp.cern.ch`, in the directory `dist`.

```

module directory
!
! Strong typing imposed
  implicit none
!
! Only subroutine interfaces, the length of the character
! component, and the I/O unit number are public
  public :: start, add_node, remove_node, retrieve,
            dump_tree, restore_tree, finish           &
  private :: find, remove
!
! Module constants
  character(len=**), private, parameter :: eot = "End-of-Tree....."
  integer, parameter, public :: unit = 4,    ! I/O unit number
                                max_char = 16 ! length of character
                                         ! component
!
! Define the basic tree type
  type, private :: node
    character(len=max_char)      :: name          ! name of node
    real, pointer, dimension(:) :: y             ! stored real data
    type(node), pointer        :: parent         ! parent node
    type(node), pointer        :: sibling        ! next sibling node
    type(node), pointer        :: child          ! first child node
  end type node

!
! Module variables
  type(node), pointer, private :: current       ! current node
  type(node), pointer, private :: forest_root   ! the root of the forest
  integer, private            :: max_data      ! max size of data array
  character(len=max_char), private, allocatable, target, dimension(:) &
                                         :: names
                                         ! for returning list of names
!
! The module procedures
contains

  subroutine start ()
! Initialize the tree.
    allocate (forest_root)
    current => forest_root
    forest_root%name = "forest_root"
    nullify(forest_root%parent, forest_root%sibling, forest_root%child)
    allocate(forest_root%y(0))
    max_data = 0
    allocate (names(0))
  end subroutine start

```

```

subroutine find(name)
    character(len=*), intent(in) :: name
! Make the module variable current point to the node with given name,
! or be null if the name is not there.
    type(node), pointer :: root
! For efficiency, we search the tree rooted at current, and if this
! fails try its parent and so on until the forest root is reached.
    if (associated(current)) then
        root => current
        nullify (current)
    else
        root => forest_root
    end if
    do
        call look(root)
        if (associated(current)) then
            return
        end if
        root => root%parent
        if (.not.associated(root)) then
            exit
        end if
    end do
contains
    recursive subroutine look(root)
        type(node), pointer :: root
! (type(node), intent(in), target :: root is standard conforming too)
! Look for name in the tree rooted at root. If found, make the
! module variable current point to the node
        type(node), pointer :: child
!
        if (root%name == name) then
            current => root
        else
            child => root%child
            do
                if (.not.associated(child)) then
                    exit
                end if
                call look(child)
                if (associated(current)) then
                    return
                end if
                child => child%sibling
            end do
        end if
    end subroutine look
end subroutine find

```

```

subroutine add_node(name, name_of_parent, data)
    character(len=*) , intent(in) :: name, name_of_parent
! For a root, name_of_parent = ""
    real, intent(in), optional, dimension(:) :: data
! Allocate a new tree node of type node, store the given name and
! data there, set pointers to the parent and to its next sibling
! (if any). If the parent is not found, the new node is treated as
! a root. It is assumed that the node is not already present in the
! forest.
    type(node), pointer :: new_node
!
    allocate (new_node)
    new_node%name = name
    if (present(data)) then
        allocate(new_node%y(size(data)))
        new_node%y = data
        max_data = max(max_data, size(data))
    else
        allocate(new_node%y(0))
    end if
!
! If name of parent is not null, search for it.
! If not found, print message.
    if (name_of_parent == "") then
        current => forest_root
    else
        call find (name_of_parent)
        if (.not.associated(current)) then
            print *, "no parent ", name_of_parent, " found for ", name
            current => forest_root
        end if
    end if
    new_node%parent => current
    new_node%sibling => current%child
    current%child => new_node
    nullify(new_node%child)
end subroutine add_node

subroutine remove_node(name)
    character(len=*) , intent(in) :: name
! Remove node and the subtree rooted on it (if any),
! deallocating associated pointer targets.
    type(node), pointer :: parent, child, sibling
!
    call find (name)
    if (associated(current)) then
        parent => current%parent
        child => parent%child
        if (.not.associated(child, current)) then

```

```

! Make it the first child, looping through the siblings to find it
! and resetting the links
    parent%child => current
    sibling => child
    do
        if (associated (sibling%sibling, current)) then
            exit
        end if
        sibling => sibling%sibling
    end do
    sibling%sibling => current%sibling
    current%sibling => child
    end if
    call remove(current)
end if
end subroutine remove_node

recursive subroutine remove (old_node)
! Remove a first child node and the subtree rooted on it (if any),
! deallocating associated pointer targets.
    type(node), pointer :: old_node
    type(node), pointer :: child, sibling
!
    child => old_node%child
    do
        if (.not.associated(child)) then
            exit
        end if
        sibling => child%sibling
        call remove(child)
        child => sibling
    end do
! remove leaf node
    if (associated(old_node%parent)) then
        old_node%parent%child => old_node%sibling
    end if
    deallocate (old_node%y)
    deallocate (old_node)
end subroutine remove

subroutine retrieve(name, data, parent, children)
    character(len=*) , intent(in)          :: name
    real, pointer, dimension(:)           :: data
    character(len=*) , intent(out)         :: parent
    character(len=*) , pointer, dimension(:) :: children
! Returns a pointer to the data at the node, the name of the
! parent, and a pointer to the names of the children.
    integer :: counter, i
    type(node), pointer :: child

```

```

!
    call find (name)
    if (associated(current)) then
        data => current%y
        parent = current%parent%name
! Count the number of children
    counter = 0
    child => current%child
    do
        if (.not.associated(child)) then
            exit
        end if
        counter = counter + 1
        child => child%sibling
    end do
    deallocate (names)
    allocate (names(counter))
! and store their names
    children => names
    child => current%child
    do i = 1, counter
        children(i) = child%name
        child => child%sibling
    end do
    else
        nullify(data)
        parent = ""
        nullify(children)
    end if
end subroutine retrieve

subroutine dump_tree(root)
    character(len=*), intent(in) :: root
! Write out a complete tree followed by an end-of-tree record
! unformatted on the file unit.
    call find (root)
    if (associated(current)) then
        call tree_out(current)
    end if
    write(unit = unit) eot, 0, eot
contains
    recursive subroutine tree_out (root)
! Traverse a complete tree or subtree, writing out its contents
        type(node), intent(in) :: root      ! root node of tree
! Local variable
        type(node), pointer :: child
!
        write(unit = unit) root%name, size(root%y), root%y, &
                           root%parent%name
    end subroutine tree_out
end subroutine dump_tree

```

```

    child => root%child
    do
        if (.not.associated(child)) then
            exit
        end if
        call tree_out (child)
        child => child%sibling
    end do
end subroutine tree_out
end subroutine dump_tree

subroutine restore_tree ()
! Reads a subtree unformatted from the file unit.
    character(len=max_char)      :: name
    integer :: length_y
    real, allocatable, dimension(:) :: y
    character(len=max_char)      :: name_of_parent
!
    allocate(y(max_data))
    do
        read (unit= unit) name, length_y, y(:length_y), name_of_parent
        if (name == eot) then
            exit
        end if
        call add_node( name, name_of_parent, y(:length_y) )
    end do
    deallocate(y)
end subroutine restore_tree

subroutine finish ()
! Deallocate all allocated targets.
    call remove (forest_root)
    deallocate(names)
end subroutine finish

end module directory

module tree_print

use directory
implicit none
private
public :: print_tree

contains

recursive subroutine print_tree(name)
! To print the data contained in a subtree
    character(len=*), intent(in)          :: name

```

```

integer :: i
real, pointer, dimension(:) :: data
character(len=max_char) :: parent, self
character(len=max_char), pointer, dimension(:) :: children
character(len=max_char), allocatable, dimension(:) :: siblings
!
call retrieve(name, data, parent, children)
if (.not.associated(data)) then
    return
end if
self = name
write(unit=*,fmt=*) self, data
write(unit=*,fmt=*) " parent: ", parent
if (size(children) > 0 ) then
    write(unit=*,fmt=*) " children: ", children
end if
allocate(siblings(size(children)))
siblings = children
do i = 1, size(children)
    call print_tree(siblings(i))
end do
deallocate(siblings)
end subroutine print_tree
end module tree_print

program test
use directory
use tree_print
implicit none
!
! Initialize a tree
call start ()
! Fill it with some data
call add_node("ernest","",(/1.0,2.0/))
call add_node("helen","ernest",(/3.0,4.0,5.0/))
call add_node("douglas","ernest",(/6.0,7.0/))
call add_node("john","helen",(/8.0/))
call add_node("betty","helen",(/9.0,10.0/))
call add_node("nigel","betty",(/11.0/))
call add_node("peter","betty",(/12.0/))
call add_node("ruth","betty")
! Manipulate subtrees
open(unit=unit, form="unformatted", status="scratch",   &
      action="readwrite", position="rewind")
call dump_tree("betty")
call remove_node("betty")
write(unit=*,fmt=*)
call print_tree("ernest")
rewind (unit=unit)

```

```
call restore_tree ()  
rewind (unit=unit)  
write(unit=*,fmt=*)  
call print_tree("ernest")  
call dump_tree("john")  
call remove_node("john")  
write(unit=*,fmt=*)  
call print_tree("ernest")  
rewind (unit=unit)  
call restore_tree ()  
write(unit=*,fmt=*)  
call print_tree("ernest")  
! Return storage  
call finish ()  
  
end program test
```


E. Fortran terms

The following is a list of the principal technical terms used in this book and their definitions. To facilitate reference to the standard, we have kept closely to the meanings used there. Where the definition uses a term that is itself defined in this glossary, the first occurrence of the term is printed in italics. Some terms used in Fortran 77 have a different meaning here and we draw the reader's attention to each such term by marking it with a bold asterisk *. We make no reference to obsolescent or deleted features (Appendix C) in this Appendix.

Actual argument An *expression*, a *variable*, or a *procedure* that is specified in a *procedure reference*.

Allocatable array A *named array* having the *allocatable attribute*. Only when it has space allocated for it does it have a *shape* and may it be *referenced* or *defined*.

Argument An *actual argument* or a *dummy argument*.

Argument association The relationship between an *actual argument* and a *dummy argument* during the execution of a *procedure reference*.

Argument keyword A *dummy argument name*. It may be used in a *procedure reference* ahead of the equals symbol provided the procedure has an *explicit interface*.

Array * A set of *scalar data*, all of the same *type* and *type parameters*, whose individual elements are arranged in a rectangular pattern. It may be a *named array*, an *array section*, a *structure component*, a *function value*, or an *expression*. Its *rank* is at least one. [In Fortran 77, arrays were always named and never constants.]

Array element One of the *scalar data* that make up an *array* that is either *named* or is a *structure component*.

Array pointer A *pointer* that is an *array*.

Array section A *subobject* whose *designator* contains a *subscript triplet*, a *vector subscript*, or an *array component selector* that is followed by one or more further component selectors.

Array-valued Having the property of being an *array*.

Assignment statement A *statement* of the form ‘*variable = expression*’.

Assignment token The *lexical token* = used in an *assignment statement*.

Association *Name association, pointer association, or storage association.*

Assumed-size array A *dummy array* whose *size* is assumed from the associated *actual argument*. Its last upper bound is specified by an asterisk.

Attribute A property of a *data object* that may be specified in a *type declaration statement*.

Belong If an *exit* or a *cycle statement* contains a *construct name*, the statement **belongs** to the do construct using that name. Otherwise, it **belongs** to the innermost do construct in which it appears.

Block A sequence of *executable constructs* embedded in another executable construct, bounded by *statements* that are particular to the construct, and treated as an integral unit.

Block data program unit A *program unit* that provides initial values for *data objects* in *named common blocks*.

Bounds For a *named array*, the limits within which the values of the *subscripts* of its *array elements* must lie.

Character A letter, digit, or other symbol.

Character storage unit The unit of storage for holding a *scalar* of *type* default character and character length one that is not a *pointer*.

Character string A sequence of *characters* numbered from left to right 1, 2, 3,...

Characteristics

- i) Of a *procedure*, its classification as a *function* or *subroutine*, the characteristics of its *dummy arguments*, and the characteristics of its *function result* if it is a function.
- ii) Of a *dummy argument*, whether it is a *data object*, is a *procedure*, or has the *optional attribute*.
- iii) Of a *data object*, its *type*, *type parameters*, *shape*, the exact dependence of an array bound or the character length on other entities, *intent*, whether it is optional, whether it is a *pointer* or a *target*, and whether the *shape*, *size*, or *character length* is assumed.
- iv) Of a *dummy procedure*, whether the interface is explicit, its characteristics as a procedure if the interface is explicit, and whether it is optional.

- v) Of a *function result*, its type, type parameters, whether it is a pointer, rank if it is a pointer, shape if it is not a pointer, the exact dependence of an array bound or the character length on other entities, and whether the character length is assumed.

Collating sequence An ordering of all the different *characters* of a particular *kind type parameter*.

Common block A block of physical storage that may be accessed by any of the *scoping units* in an *executable program*.

Component A constituent of a *derived type*.

Conformable Two *arrays* are said to be **conformable** if they have the same *shape*. A *scalar* is **conformable** with any array.

Conformance An *executable program* conforms to the standard if it uses only those forms and relationships described therein and if the executable program has an interpretation according to the standard. A *program unit* conforms to the standard if it can be included in an executable program in a manner that allows the executable program to be standard conforming. A *processor* conforms to the standard if it executes standard-conforming programs in a manner that fulfills the interpretations prescribed in the standard.

Connected

- i) For an *external unit*, the property of referring to an *external file*.
- ii) For an *external file*, the property of having an *external unit* that refers to it.

Constant * A *data object* whose value must not change during execution of an *executable program*. It may be a *named constant* or a *literal constant*.

Constant expression An *expression* satisfying rules that ensure that its value does not vary during program execution.

Construct A sequence of *statements* starting with a *select case*, *do*, *if*, or *where* statement and ending with the corresponding terminal statement.

Data Plural of *datum*.

Data entity An *entity* that has or may have a data value. It may be a *constant*, a *variable*, an *expression*, or a *function result*.

Data object A *datum* of *intrinsic* or *derived type* or an *array* of such *data*. It may be a *literal constant*, a *named data object*, a *target* of a *pointer*, or it may be a *subobject*.

Data type A *named* category of *data* that is characterized by a set of values, together with a way to denote these values and a collection of *operations* that interpret and manipulate the values. For an *intrinsic* data type, the set of data values depends on the values of the *type parameters*.

Datum A single quantity that may have any of the set of values specified for its *data type*.

Definable A *variable* is **definable** if its value may be changed by the appearance of its *name* or *designator* on the left of an *assignment statement*. A *allocatable array* that has not been allocated is an example of a *data object* that is not definable. An example of a *subobject* that is not definable is *c(i)* when *c* is an *array* that is a *constant* and *i* is an integer variable.

Defined For a *data object*, the property of having or being given a valid value.

Defined assignment statement An *assignment statement* that is not an *intrinsic* assignment statement and is defined by a *subroutine subprogram* and an *interface block*.

Defined operation An *operation* that is not an *intrinsic* operation and is defined by a *function subprogram* and an *interface block*.

Deleted feature A feature in Fortran 77 that has been deleted from Fortran 95. No features in Fortran 77 have been deleted from Fortran 90. Note that a feature designated as an *obsolescent feature* may become a deleted feature in a future revision.

Derived type A *type* whose *data* have *components* each of which is either of *intrinsic* type or of another derived type.

Designator See *subobject designator*.

Disassociated A *pointer* is **disassociated** following execution of a *deallocate* or *nullify statement*.

Dummy argument An *entity* whose *name* appears in the parenthesized list following the *procedure name* in a *function statement*, a *subroutine statement*, an *entry statement*, or a *statement function statement*.

Dummy array A *dummy argument* that is an *array*.

Dummy pointer A *dummy argument* that is a *pointer*.

Dummy procedure A *dummy argument* that is specified or referenced as a *procedure*.

Elemental An adjective applied to an *intrinsic operation*, *procedure*, or *assignment statement* that is applied independently to the elements of an *array* or corresponding elements of a set of *conformable arrays* and *scalars*.

Entity The term used for any of the following: a *program unit*, a *procedure*, an *operator*, an *interface block*, a *common block*, an *external unit*, a *statement function*, a *type*, a *data entity*, a *statement label*, a *construct*, or a *namelist group*.

Executable construct A *case*, *do*, *if*, or *where construct*.

Executable program A set of *program units* that includes exactly one *main program*.

Executable statement An instruction to perform or control one or more computational actions.

Explicit interface For a *procedure referenced* in a *scoping unit*, the property of being an *internal procedure*, a *module procedure*, an *intrinsic procedure*, an *external procedure* that has an *interface block* or is defined by the scoping unit and is recursive, or a *dummy procedure* that has an *interface block*.

Explicit-shape array A *named array* that is declared with *explicit bounds*.

Expression A sequence of *operands*, *operators*, and parentheses. It may be a *variable*, a *constant*, a *function reference*, or may represent a computation.

Extent The size of one dimension of an *array*.

External file A sequence of *records* that exists in a medium external to the *executable program*.

External procedure A *procedure* that is defined by an *external subprogram* or by a means other than Fortran.

External subprogram * A *subprogram* that is not contained in a *main program*, *module*, or another subprogram. [In Fortran 77, a *block data program unit* is called a *subprogram*.]

External unit A mechanism that is used to refer to an *external file*. It is identified by a nonnegative integer.

File An *internal file* or an *external file*.

Function A *procedure* that is invoked in an *expression*.

Function result The *data entity* that returns the value of a *function*.

Function subprogram A sequence of *statements* beginning with a *function statement* that is not in an *interface block* and ending with the corresponding *end statement*.

Generic identifier A *name*, *operator*, or *assignment token* specified in an *interface statement* to provide an alternative means of invoking any of the *procedures* in the *interface block*.

Global entity An *entity* identified by a *lexical token* whose *scope* is an *executable program*. It may be a *program unit*, a *common block*, or an *external procedure*.

Host A *main program* or *subprogram* that contains an *internal subprogram* is called the **host** of the internal subprogram. A *module* that contains a *module subprogram* is called the **host** of the module subprogram.

Host association The process by which a *subprogram* or a *derived type definition* accesses *entities* of its *host*.

Implicit interface A *procedure referenced* in a *scoping unit* is said to have an **implicit interface** if the procedure does not have an *explicit interface* there.

Inquiry function An *intrinsic function* whose result depends on properties of the principal *argument* other than the value of the argument.

Instance of a subprogram The copy of a *subprogram* that is created when a *procedure* defined by the subprogram is *invoked*.

Intent Of a *dummy argument* that is neither a *procedure* nor a *pointer*, whether it is intended to transfer data into the procedure, out of the procedure, or both.

Interface block A sequence of *statements* beginning with an *interface statement* and ending with the corresponding *end interface statement*.

Interface body A sequence of *statements* in an *interface block* beginning with a *function* or *subroutine statement* and ending with the corresponding *end statement*.

Interface of a procedure See *procedure interface*.

Internal file A character *variable* that is used to transfer and convert *data* from internal storage to internal storage.

Internal procedure A *procedure* that is defined by an *internal subprogram*.

Internal subprogram A *subprogram* contained in a *main program* or another *subprogram*.

Intrinsic An adjective applied to *types*, *operations*, *assignment statements*, and *procedures* that are defined in the standard and may be used in any *scoping unit* without further definition or specification.

Invoke

- i) To call a *subroutine* by a *call statement* or by a *defined assignment statement*.

- ii) To call a *function* by a *reference* to it by *name* or *operator* during the evaluation of an *expression*.

Keyword *Statement keyword* or *argument keyword*.

Kind type parameter A parameter whose values label the available kinds of an *intrinsic type*.

Label See *statement label*.

Length of a character string The number of *characters* in the *character string*.

Lexical token A sequence of one or more characters with an indivisible interpretation.

Line A source-form *record* containing from 0 to 132 *characters*.

Literal constant A *constant* without a *name*. [In Fortran 77, this was called a *constant*.]

Local entity An *entity* identified by a *lexical token* whose *scope* is a *scoping unit*.

Main program A *program unit* that is not a *module*, *external subprogram*, or *block data program unit*.

Many-one array section An *array section* with a *vector subscript* having two or more elements with the same value.

Module A *program unit* that contains or accesses definitions to be accessed by other program units.

Module procedure A *procedure* that is defined by a *module subprogram*.

Module subprogram A *subprogram* that is contained in a *module* but is not an *internal subprogram*.

Name * A *lexical token* consisting of a letter followed by up to 30 alphanumeric characters (letters, digits, and underscores). [In Fortran 77, this was called a *symbolic name*.]

Name association *Argument association*, *use association*, or *host association*.

Named Having a *name*.

Named constant * A *constant* that has a *name*. [In Fortran 77, this was called a *symbolic constant*.]

Numeric storage unit The unit of storage for holding a *scalar* of *type* default real, default integer, or default logical that is not a *pointer*.

Numeric type Integer, real, or complex *type*.

Object *Data object.*

Obsolescent feature A feature that is considered to be redundant but that is still in frequent use. It may be deleted in a future revision of the standard.

Operand An *expression* that precedes or succeeds an *operator*.

Operation A computation involving one or two *operands*.

Operator A *lexical token* that specifies an *operation*.

Pointer A *data object* that has the *pointer attribute*. It may not be *referenced* or *defined* unless it is *pointer associated* with a *target*. If it is an *array*, it does not have a *shape* unless it is *pointer associated*.

Pointer assignment The *pointer association* of a *pointer* with a *target* by the execution of a *pointer assignment statement* or the execution of an *assignment statement* for a *data object* of *derived type* having the *pointer* as a *subobject*.

Pointer assignment statement A *statement* of the form ‘*pointer => target*’.

Pointer associated The relationship between a *pointer* and a *target* following a *pointer assignment* or a valid execution of an *allocate statement*.

Pointer association The process by which a *pointer* becomes *pointer associated* with a *target*.

Present A *dummy argument* is *present* in an *instance* of a *subprogram* if it is *associated* with an *actual argument* and the *actual argument* is a *dummy argument* that is *present* in the *invoking procedure* or is not a *dummy argument* of the *invoking procedure*.

Procedure A computation that may be *invoked* during program execution. It may be a *function* or a *subroutine*. It may be an *intrinsic procedure*, an *internal procedure*, an *external procedure*, a *module procedure*, a *dummy procedure*, or a *statement function*. A *subprogram* may define more than one procedure if it contains *entry statements*.

Procedure interface The *characteristics* of a *procedure*, the *name* of the *procedure*, the *name* of each *dummy argument*, and the *generic identifiers* (if any) by which it may be *referenced*.

Processor The combination of a computing system and the mechanism by which *executable programs* are transformed for use on that computing system.

Program See *executable program* and *main program*.

Program unit The fundamental component of an *executable program*. A sequence of *statements* and comment lines. It may be a *main program*, a *module*, an *external subprogram*, or a *block data program unit*.

Rank The number of dimensions of an *array*. Zero for a *scalar*.

Record A sequence of values that is treated as a whole within a *file*.

Reference The appearance of a *data object name* or *subobject designator* in a context requiring the value at that point during execution, or the appearance of a *procedure name*, its *operator symbol*, or a *defined assignment statement* in a context requiring execution of the procedure at that point. Note that neither the act of defining a *variable* nor the appearance of the name of a procedure as an *actual argument* is regarded as a reference.

Scalar

- i) A single *datum* that is not an *array*.
- ii) Not having the property of being an *array*.

Scope That part of an *executable program* within which a *lexical token* has a single interpretation. It may be an *executable program*, a *scoping unit*, a single *statement*, or a part of a statement.

Scoping unit One of the following:

- i) A *derived-type definition*,
- ii) An *interface body*, excluding any derived-type definitions and interface bodies contained within it, or
- iii) A *program unit* or *subprogram*, excluding derived-type definitions, interface bodies, and subprograms contained within it.

Section subscript A *subscript*, *subscript triplet*, or *vector subscript* in an *array section selector*.

Selector A syntactic mechanism for designating

- i) Part of a *data object*. It may designate a *substring*, an *array element*, an *array section*, or a *structure component*.
- ii) The set of values for which a *case block* is executed.

Shape For an *array*, the *rank* and *extents*. The shape may be represented by the rank-one array whose elements are the extents in each dimension.

Size For an *array*, the total number of elements.

Standard module A *module* standardized as a separate collateral standard.

Statement A sequence of *lexical tokens*. It usually consists of a single line, but the ampersand symbol may be used to continue a statement from one line to another and the semicolon symbol may be used to separate statements within a line.

Statement entity An *entity* identified by a *lexical token* whose *scope* is a single *statement* or part of a statement.

Statement function A *procedure* specified by a single *statement* that is similar in form to an *assignment statement*.

Statement keyword A word that is part of the syntax of a *statement* and that may be used to identify the statement.

Statement label A *lexical token* consisting of up to five digits that precedes a *statement* and may be used to refer to the statement.

Storage association The relationship between two *storage sequences* if a storage unit of one is the same as a storage unit of the other.

Storage sequence A sequence of contiguous *storage units*.

Storage unit A *character storage unit*, a *numeric storage unit*, or an *unspecified storage unit*.

Stride The increment specified in a *subscript triplet*.

Structure A *scalar data object* of *derived type*.

Structure component The part of an *object of derived-type* corresponding to a *component* of its type.

Subobject Of a *named data object* or *target* of a *pointer*, a portion that may be *referenced* or *defined* independently of other portions. It may be an *array element*, an *array section*, a *structure component*, or a *substring*.

Subobject designator A *name*, followed by one or more *component selectors*, *array section* selectors, *array element* selectors, and *substring* selectors.

Subprogram * A *function subprogram* or a *subroutine subprogram*. [In Fortran 77, a *block data program unit* was called a subprogram.]

Subroutine A *procedure* that is *invoked* by a *call statement* or by a *defined assignment statement*.

Subroutine subprogram A sequence of *statements* from a *subroutine statement* that is not in an *interface block* to the corresponding *end statement*.

Subscript * One of the list of *scalar integer expressions* in an *array element selector*. [In Fortran 77, the whole list was called the subscript.]

Subscript triplet An item in the list of an *array section selector* that contains a colon and specifies a regular sequence of integer values.

Substring A contiguous portion of a *scalar character string*. Note that an *array section* can include a *substring selector*; the result is called an array section and not a substring.

Target A *named data object* specified in a *type declaration statement* containing the *target attribute*, a data object created by an *allocate statement* for a *pointer*, or a *subobject* of such an object.

Transformational function An *intrinsic function* that is neither an *elemental function* nor an *inquiry function*. It usually has *array arguments* and an array result whose elements have values that depend on the values of many of the elements of the arguments.

Type *Data type*.

Type declaration statement An *integer*, *real*, *double precision*, *complex*, *character*, *logical*, or *type(type-name)* *statement*.

Type parameter A parameter of an *intrinsic data type*.

Type parameter values The values of the *type parameters* of a *data entity* of an *intrinsic data type*.

Ultimate component For a *derived type* or a *structure*, a *component* that is of *intrinsic type*, has the *allocatable* or *pointer attribute*, or is an *ultimate component* of a component that is of derived type and does not have the allocatable or pointer attribute.

Undefined For a *data object*, the property of not having a determinate value.

Unspecified storage unit A unit of storage for holding a *pointer* or a *scalar object* of non-default *intrinsic type* that is not a pointer.

Use association The relationship specified by a *use statement* between two *names* in different *scoping units*.

Variable * A *data object* whose value can be *defined* and redefined during the execution of an *executable program*. It may be a *named data object*, an *array element*, an *array section*, a *structure component*, or a *substring*. [In Fortran 77, a variable was always *scalar* and *named*.]

Vector subscript A *section subscript* that is an integer *expression* of rank one.

F. Solutions to exercises

Note: A few exercises have been left to the reader.

Chapter 2

1.

B is less than M	true
8 is less than 2	false
* is greater than T	not determined
\$ is less than /	not determined
blank is greater than A	false
blank is less than 6	true

2.

x = y	correct
3 a = b+c ! add	correct, with commentary
word = 'string'	correct
a = 1.0; b = 2.0	correct
a = 15. ! initialize a; b = 22. ! and b	incorrect (embedded commentary)
song = "Life is just&	correct, initial line
& a bowl of cherries"	correct, continuation
chide = 'Waste not,	incorrect, trailing & missing
want not!'	incorrect, leading & missing
0 c(3:4) = 'up'	incorrect (invalid statement label; invalid form of character constant)

3.

-43	integer	'word'	character
4.39	real	1.9-4	not legal
0.0001e+20	real	'stuff & nonsense'	character
4 9	not legal	(0.,1.)	complex
(1.e3,2)	complex	'I can't'	character
'(4.3e9, 6.2)'	character	.true._1	legal logical provided kind=1 available
e5	not legal	'shouldn' 't'	not legal

1_2	legal integer provided kind=2 available	"0.K."	character
z10	not legal	z'10'	hexadecimal

4.

name	legal	name32	legal
quotient	legal	123	not legal
a182c3	legal	no-go	not legal
stop!	not legal	burn_	legal
no_go	legal	long_name	legal

5.

```

real, dimension(11)    :: a    a(1), a(10), a(11), a(11)
real, dimension(0:11)   :: b    b(0), b(9), b(10), b(11)
real, dimension(-11:0)  :: c    c(-11), c(-2), c(-1), c(0)
real, dimension(10,10)   :: d    d(1,1), d(10,1), d(1,2), d(10,10)
real, dimension(5,9)    :: e    e(1,1), e(5,2), e(1,3), e(5,9)
real, dimension(5,0:1,4) :: f    f(1,0,1), f(5,1,1), f(1,0,2),
                                 f(5,1,4)

```

Array constructor: (/ (i, i = 1,11) /)

6.

c(2,3)	legal	c(4:3)(2,1)	not legal
c(6,2)	not legal	c(5,3)(9:9)	legal
c(0,3)	legal	c(2,1)(4:8)	legal
c(4,3)(:)	legal	c(3,2)(0:9)	not legal
c(5)(2:3)	not legal	c(5:6)	not legal
c(5,3)(9)	not legal	c(,)	not legal

7.

- a) type vehicle_registration


```

          character(len=3) :: letters
          integer          :: digits
      end type vehicle_registration
      
```
- b) type circle


```

          real             :: radius
          real, dimension(2) :: centre
      end type circle
      
```
- c) type book


```

          character(len=20)           :: title
          character(len=20), dimension(2) :: author
          integer                      :: no_of_pages
      end type book
      
```

Derived type constants:

```
vehicle_registration('PQR', 123)
circle(15.1, (/ 0., 0. /))
book("Pilgrim's Progress", (/ 'John ', 'Bunyan' /), 250 )
```

8.

t	array	t(4)%vertex(1)	scalar
t(10)	scalar	t(5:6)	array
t(1)%vertex	array	t(5:5)	array (size 1)

9.

- a) integer, parameter :: twenty = selected_int_kind(20)
integer (kind = twenty) :: counter
- b) integer, parameter :: high = selected_real_kind(12,100)
real(kind = high) :: big
- c) character(kind=2) :: sign

Chapter 3

1.

a+b	valid	-c	valid
a+c	invalid	d+(-f)	valid
(a+c)**(p+q)	valid	(a+c)(p+q)	invalid
-(x+y)**i	valid	4.((a-d)-(a+4.*x)+1)	invalid

2.

```
c+(4.*f)
((4.*g)-a)+(d/2.)
a**(e**c**d)
((a*e)-((c**d)/a))+e
(i .and. j) .or. k
((.not. l) .or. ((.not. i) .and. m)) .neqv. n
((b(3).and.b(1)).or.b(6)).or.(.not.b(2))
```

3.

3+4/2 = 5	6/4/2 = 0
3.*4**2 = 48.	3.*2/3/2 = 13.5
-1.*2**2 = -1.	(-1.)**3 = -1.

4.

ABCDEFGH	
ABCD0123	
ABCDEFGu	u = unchanged
ABCDbbuu	b = blank

5.

.not.b(1).and.b(2)	valid	.or.b(1)	invalid
b(1).or..not.b(4)	valid	b(2)(.and.b(3).or.b(4))	invalid

6.

d .le. c	valid	p .lt. t > 0	invalid
x-1 /= y	valid	x+y < 3 .or. > 4.	invalid
d.lt.c.and.3.0	invalid	q.eq.r .and. s>t	valid

7.

- a) $4*1$
- b) $b*h/2$.
- c) $4./3.*\pi*r**3$

(assuming π has value π)

8.

```
integer :: n, one, five, ten, twenty_five
twenty_five = (100-n)/25
ten          = (100-n-25*twenty_five)/10
five         = (100-n-25*twenty_five-10*ten)/5
one          = 100-n-25*twenty_five-10*ten-5*five
```

9.

```
a = b + c    valid
c = b + 1.0  valid
d = b + 1    invalid
r = b + c    valid
a = r + 2    valid
```

10.

a = b	valid	c = a(:,2) + b(5,:5)	valid
a = c+1.0	invalid	c = a(2,:) + b(:,5)	invalid
a(:,3) = c	valid	b(2:,3) = c + b(:,3)	invalid

Chapter 4

1.

```
integer                  :: i, j, k, temp
integer, dimension(100) :: reverse
do i = 1,100
    reverse(i) = i
end do
read *, i, j
do k= i, i+(j-i-1)/2
    temp = reverse(k)
    reverse(k) = reverse(j-k+i)
```

```

    reverse(j-k+i) = temp
end do
end

```

Note: A simpler method for performing this operation will become apparent in Section 6.13.

2.

```

integer :: limit, f1, f2, f3
read *, limit
f1 = 1
if (limit.ge.1) print *, f1
f2 = 1
if (limit.ge.2) print *, f2
do i = 3, limit
    f3 = f1+f2
    print *, f3
    f1 = f2
    f2 = f3
end do
end

```

6.

```

real x
do
    read *, x
    if (x.eq.-1.) then
        print *, 'input value -1. invalid'
    else
        print *, x/(1.+x)
        exit
    end if
end do
end

```

7.

```

type(entry), pointer :: first, current, previous
current => first
if (current%index == 10) then
    first => first%next
else
    do
        previous => current
        current => current%next
        if (current%index == 10) exit
    end do
    previous%next => current%next
end if

```

Chapter 5

1.

```

subroutine calculate(x, n, mean, variance, ok)
    integer, intent(in)          :: n
    real, dimension(n), intent(in) :: x
    real, intent(out)           :: mean, variance
    logical :: ok
    integer :: i
    mean = 0.
    variance = 0.
    ok = n > 1
    if (ok) then
        do i = 1, n
            mean = mean + x(i)
        end do
        mean = mean/n
        do i = 1, n
            variance = variance + (x(i) - mean)**2
        end do
        variance = variance/(n-1)
    end if
end subroutine calculate

```

Note: A simpler method will become apparent in Chapter 8. 2.

```

subroutine matrix_mult(a, b, c, i, j, k)
    integer, intent(in)          :: i, j, k, l, m, n
    real, dimension(i,j), intent(in) :: a
    real, dimension(j,k), intent(in) :: b
    real, dimension(i,k), intent(out) :: c
    c(1:i, 1:k) = 0.
    do n = 1, k
        do l = 1, j
            do m = 1, i
                c(m, n) = c(m, n) + a(m,l)*b(l, n)
            end do
        end do
    end do
end subroutine matrix_mult

```

3.

```

subroutine shuffle(cards)
    integer, dimension(52), intent(in) :: cards
    integer                         :: left, choice, i, temp
    real r
    cards = (/ (i, i=1,52) /)      ! Initialize deck.
    do left = 52,1,-1              ! Loop over number of cards left.
        call random_number(r)       ! Draw a card

```

```

choice = r*left + 1      ! from remaining possibilities
temp = cards(left)       ! and swap with last
cards(left) = cards(choice)! one left.
cards(choice) = temp
end do
end subroutine shuffle

```

4.

```

character function earliest(string)
    character(len=*), intent(in) :: string
    integer j, length
    length = len(string)
    if (length <= 0) then
        earliest = ''
    else
        earliest = string(1:1)
        do j = 2, length
            if (string(j:j) < earliest) earliest = string(j:j)
        end do
    end if
end function earliest

```

5.

```

subroutine sample
    real :: r, l, v, pi
    pi = acos(-1.)
    :
    r = 3.
    l = 4.
    v = volume(r, l)
    :
contains
    function volume(radius, length)
        real, intent(in) :: radius, length
        real              :: volume
        volume = pi*radius**2*length
    end function volume
end subroutine sample

```

7.

```

module string_type
    type string
        integer :: length
        character(len=80)  :: string_data
    end type string
    interface assignment(=)
        module procedure c_to_s_assign, s_to_c_assign
    end interface (=)

```

```

interface len
    module procedure string_len
end interface
interface operator(//)
    module procedure string_concat
end interface (//)
contains
    subroutine c_to_s_assign(s, c)
        type (string), intent(out)    :: s
        character(len=*), intent(in) :: c
        s%string_data = c
        s%length = len(c)
        if (s%length > 80) s%length = 80
    end subroutine c_to_s_assign
    subroutine s_to_c_assign(c, s)
        type (string), intent(in)    :: s
        character(len=*), intent(out) :: c
        c = s%string_data(1:s%length)
    end subroutine s_to_c_assign
    function string_len(s)
        integer :: string_len
        type(string) :: s
        string_len = s%length
    end function string_len
    function string_concat(s1, s2)
        type (string), intent(in) :: s1, s2
        type (string)           :: string_concat
        string_concat%string_data = &
            s1%string_data(1:s1%length) // &
            s2%string_data(1:s2%length)
        string_concat%length = s1%length + s2%length
        if (string_concat%length > 80)      &
            string_concat%length = 80
    end function string_concat
end module string_type

```

Note: The intrinsic `len` function, used in subroutine `c_to_s_assign`, is first described in Section 8.6.

Chapter 6

1.

- i) `a(1, :)`
- ii) `a(:, 20)`
- iii) `a(2:50:2, 2:20:2)`
- iv) `a(50:2:-2, 20:2:-2)`
- v) `a(1:0, 1)`

2.

```
where (z.gt.0) z = 2*z
```

3.

```
integer, dimension(16) :: j
```

4.

```
w      explicit-shaped
a, b  assumed-shape
d      pointer
```

5.

```
real, pointer :: x(:, :, :)
x => tar(2:10:2, 2:20:2, 2:30:2)%du(3)
```

6.

```
11 = 11 + 11
11 = mm + nn + n(j:k+1, j:k+1)
```

7.

```
program backwards
    integer :: i, j
    integer, dimension(100) :: reverse
    reverse = (/ (i, i=1, 100) /)
    read *, i, j
    reverse(i:j) = reverse(j:i:-1)
end program backwards
```

Chapter 7

1.

- i) integer, dimension(100) :: bin
- ii) real(selected_real_kind(6, 4)), dimension(0:20, 0:20) :: &
iron_temperature
- iii) logical, dimension(20) :: switches
- iv) character(len=70), dimension(44) :: page

2.

Value of i is 3.1, but may be changed;
value of i is 3.1, but may not be changed.

3.

- i) integer, dimension(100) :: i=(/ (0, k=1, 100) /)
- ii) integer, dimension(100) :: i=(/ (0, 1, k=1, 50) /)
- iii) real, dimension(10, 10) :: x=reshape((/ (1.0, k=1, 100) /), &
(/10, 10/))

iv) character(len=10) :: string = '0123456789'

Note: the reshape function will be met in Section 8.13.3. 4.

	mod	outer	inner	fun
a-b	character(10,2)	-	-	-
c,d,e	real	-	-	-
f	real	-	-	real
g,h	real	-	-	-
i-n	integer	-	-	-
o-w	real	-	-	-
x	real	-	-	real
y	real	-	-	-
z	real	-	complex	-

5.

i) type(person) boss = person('Smith', 48.7, 22)

ii) (a) This is impossible because a pointer component cannot be a constant.

(b)

type(entry) current

data current%value, current%index /1.0, 1/

6.

The following are not:

iv) because of the real exponent, and

viii) because of the pointer component.

Chapter 8

1.

```

program qroots      ! Solution of quadratic equation.
!
    real :: a, b, c, d, x1, x2
!
    read(*, *) a, b, c
    write( *, *) ' a = ', a, 'b = ', b, 'c = ', c
    if (a == 0.) then
        if (b /= 0.) then
            write(*, *) ' Linear: x = ', -c/b
        else
            write(*, *) ' No roots!'
        endif
    else
        d = b**2 - 4.*a*c
        if (d < 0.) then
            write (*, *) ' Complex', -b/(2.*a), '+-',      &
                        sqrt(-d)/(2.*a)
        else
            x1 = -(b + sign(sqrt(d), b))/(2.*a)

```

```

        x2 = c/(x1*a)
        write(*, *) ' Real roots', x1, x2
    endif
endif
end program qroots

```

Historical note: A similar problem was set in one of the first books on Fortran programming — *A FORTRAN Primer* by E. Organick (Addison-Wesley, 1963). It is interesting to compare Organick's solution, written in FORTRAN II, on p. 122 of that book, with the one above. (It is reproduced in the *Encyclopedia of Physical Science & Technology* (Academic Press, 1987), vol. 5, p. 538.)

2.

```

subroutine calculate(x, mean, variance, ok)
    real, intent(in) :: x(:)
    real, intent(out) :: mean, variance
    logical ok
    ok = size(x) > 1
    if (ok) then
        mean = sum(x)/size(x)
        variance = sum((x-mean)**2)/(size(x)-1)
    end if
end subroutine calculate

```

3.

- F p1 and p2 are associated with the same array elements,
 but in reverse order
- T p1 and p2(4:1:-1) are associated with exactly the
 same array elements, a(3), a(5), a(7), a(9)

4.

```

5 1      a has bounds 5:10 and a(:) has bounds 1:6
5 1      p1 has bounds 5:10 and p2 has bounds 1:6
1 1      x and y both have bounds 1:6

```

Chapter 9

1.

- print '(a/ (t1, 10f6.1))', ' grid', grid
- print '(a, " ", 25i5)', ' list', (list(i), i = 1, 49, 2)
 or
 list(1:49:2)
- print '(a/ (" ", 2a12))', ' titles', titles
- print '(a/ (t1, 5en15.6))', ' power', power
- print '(a, 10I2)', ' flags', flags
- print '(a, 5(" (", 2f6.1, ")"))', ' plane', plane

2.

```
character, dimension(3,3) :: tic_tac_toe
integer :: unit
:
write(unit, '(t1, 3a2)' ) tic_tac_toe
```

4.

(a) read(*, *) grid
1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0

(b) read(*, *) list(1:49:2)
25*1

(c) read(*, *) titles
data transfer

(d) read(*, *) power
1.0 1.e-03

(e) read(*, *) flags
t f t f t f f t f t

(f) read(*, *) plane
(0.0, 1.0),(2.3, 4)

5.

```
character function get_char(unit)
    integer :: unit
10    read(unit, '(a1)', advance='no', eor=10) get_char
        return
end function get_char
```

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