

Fortran 90/95 Programming Manual

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Fortran 90/95 Programming Manual

Brief History of Fortran

The first FORTRAN (which stands for Formula Translation) compiler was developed in 1957 at IBM. In 1966 the American Standards Association (later the American National Standards Institute, ANSI) released the first standard version of FORTRAN, which later became known as FORTRAN 66. The standard aimed at providing a standardised, portable language, which could easily be transferred from one computer system to the other. In 1977, a revised version of FORTRAN, FORTRAN 77, was completed (the standard was published in 1978). The next version is Fortran 90, which is a major advance over FORTRAN 77. It contains many new features; however, it also contains all of FORTRAN 77. Thus, a standard-conforming FORTRAN 77 program is also a standard-conforming Fortran 90 program. Some of FORTRAN 77's features were identified as "obsolescent", but they were not deleted. Obsolescent features are candidates for deletion in the next standard, and should thus be avoided. The latest standard is Fortran 95. Fortran 95 contains only minor changes to Fortran 90; however, a few of the obsolescent features identified in Fortran 90 were deleted.

Because of the requirement that all of FORTRAN 77's features must be contained in Fortran 90, there are often several ways to do the same thing, which may lead to confusion. For example, an integer-type variable can be declared in FORTRAN 77 format:

```
integer i
```

or in Fortran 90 format:

```
integer :: i
```

In addition, as a legacy from FORTRAN 77, Fortran 90 contains features that are considered bad or unsafe programming practice, but they are not deleted in order to keep the language "backward compatible".

To remedy these problems, a small group of programmers developed the F language. This is basically a subset of Fortran 90, designed to be highly regular and reliable to use. It is much more compact than Fortran 90 (because it does not contain all of FORTRAN 77's features).

There will be a new standard soon, which will be called Fortran 2003 (even though the final international standard will not come out before late 2004). There will be new features in Fortran 2003 (such as support for exception handling, object-oriented programming, and improved interoperability with the C language), but the differences

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It is assumed that you have access to a computer with a Fortran 90 or Fortran 95 compiler. It is strongly recommended to switch on the compiler flag that warns when the compiler encounters source code that does not conform to the Fortran 90 standard, and the flag that shows warning messages. For example:

Silicon Graphics: f90 -ansi -w2 -o executable-name sourcefile.f90

Or even better:

f90 -ansi -fullwarn -o executable-name sourcefile.f90

Sun: f90 -ansi

You can check these flags by typing “man f90” or “man f95” (on a Unix system). You may ask someone in your group for help how to use the compiler and editor on the computer you use.

If you have access to emacs or xemacs, and know how to use it (or are willing to invest a bit of time in learning how to use it), it is recommended to use this editor. It will pay off (emacs can format the source code for you, and thus detect program mistakes early on).

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1. Getting started

Type, compile and run the following program (call the file hello.f90):

```
program hello
! this programs prints "hello world!" to the screen
  implicit none
  print*, "Hello world!"
end program hello
```

Note the following:

- a program starts with `program program_name`
- it ends with `end program program_name`
- `print*` displays data (in this case, the character string “Hello, world!”) on the screen.
- all characters after the exclamation mark (!) (except in a character string) are ignored by the compiler. It is good programming practice to include comments. Comments can also start after a statement, for example:
`print*, “Hello world!” ! this line prints the message “Hello world!”`
- Note the indentation. Indentation is essential to keep a program readable. Additionally, empty lines are allowed and can help to make the program readable.
- Fortran 90 allows both upper and lowercase letters (unlike FORTRAN 77, in which only uppercase was allowed).

2. Types, Variables, Constants, Operators

Names in Fortran 90

A name or “identifier” in Fortran must adhere to fixed rules. They cannot be longer than 31 characters, must be composed of alphanumeric characters (all the letters of the alphabet, and the digits 0 to 9) and underscores (_), and the first character must be a letter. Identifiers are case-insensitive (except in character strings like “Hello world!” in the example above); Thus, `PRINT` and `print` are completely identical.

Types

A *variable* is a data object whose value can be defined and redefined (in contrast to *constants*, see below). Variables and constants have a *type*, which can be one of the five *intrinsic types*, or a *derived type*. Intrinsic types are part of the Fortran language. There

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Real Type

For real numbers (such as 3.14, -100.876, 1.0 etc.). A processor must provide two different real types: The default **real** type and a type of higher precision, with the name **double precision**. Also this is a legacy of FORTRAN 77. Fortran 90 gives much more control over the precision of **real** and **integer** variables (through the **kind** specifier), see chapter on Numeric Precision, and there is therefore no need to use **double precision**. However, you will see **double precision** often used in older programs. For most of the exercises and examples in this manual the real type suffices. In the real world however, double precision is often required.

For now, if you prefer to use double precision in your programs, use:

```
real (kind=kind(1.0d0)) :: variable_name
```

Complex Type

For complex numbers. A complex value consists of two real numbers, the real part and the imaginary part. Thus, the complex number (2.0, -1.0) is equal to $2.0 - 1.0i$.

Logical Type

There are only two logical values: **.true.** and **.false.** (note the dots around the words true and false).

Character Type

Data objects of the character type include characters and strings (a string is a sequence of characters). The length of the string can be specified by **len** (see the examples below). If no length is specified, it is 1.

Constants

A constant is a data object whose value cannot be changed.

A *literal constant* is a constant value without a name, such as 3.14 (a real constant), “Tanja” (a character constant), 300 (an integer constant), (3.0, -3.0) (a complex constant), **.true.** or **.false.** (logical constants. These two are the only logical constants available).

A *named constant* is a constant value with a name. Named constants and variables must be declared at the beginning of a program (or subprogram – see Chapter 4), in a so-called *type declaration statement*. The type declaration statement indicates the type and name of the variable or constant (note the two colons between the type and the name of the variable or constant). Named constants must be declared with the **parameter** attribute:

```
real, parameter :: pi = 3.1415927
```

Variables



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```
character(len=80) :: line      ! a string consisting of 80 characters
```

These can be used in statements such as:

```
total = 6.7
average1 = average2
done = .true.
line = "this is a line"
```

Note that a character string is enclosed in double quotes (“”).

Constants can be assigned trivially to the complex number *cx*:

```
cx = (1.0, 2.0)                ! cx = 1.0 + 2.0i
```

If you need to assign variables to *cx*, you need to use `cmplx`:

```
cx = cmplx (1.0/2.0, -3.0)     ! cx = 0.5 - 3.0i
cx = cmplx (x, y)              ! cx = x + yi
```

The function `cmplx` is one of the intrinsic functions (see below).

Arrays

A series of variables of the same type can be collected in an *array*. Arrays can be one-dimensional (like vectors in mathematics), two-dimensional (comparable to matrices), up to 7-dimensional. Arrays are declared with the `dimension` attribute.

Examples:

```
real, dimension(5) :: vector    ! 1-dim. real array containing 5 elements
integer, dimension (3, 3) :: matrix ! 2-dim. integer array
```

The individual elements of arrays can be *referenced* by specifying their *subscripts*. Thus, the first element of the array `vector`, `vector(1)`, has a subscript of one. The array `vector` contains the real variables `vector(1)`, `vector(2)`, `vector(3)`, `vector(4)`, and `vector(5)`. The array `matrix` contains the integer variables `matrix(1,1)`, `matrix(2,1)`, `matrix(3,1)`, `matrix(1,2)`, ..., `matrix(3,3)`:

vector(1)	vector(2)	vector(3)	vector(4)	vector(5)
-----------	-----------	-----------	-----------	-----------

matrix(1,1)	matrix(1,2)	matrix(1,3)
matrix(2,1)	matrix(2,2)	matrix(2,3)



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The array vector could also have been declared with explicit lower bounds:

```
real, dimension (1:5) :: vector
```

All the following type declaration statements are legal:

```
real, dimension (-10:8) :: a1           ! 1-dim array with 19 elements
integer, dimension (-3:3, -20:0, 1:2, 6, 2, 5:6, 2) :: grid1  ! 7-dim array
```

The number of elements of the integer array grid1 is $7 \times 21 \times 2 \times 6 \times 2 \times 2 \times 2 = 14112$.

You may not be able to use arrays with more than 7 dimensions. The standard requires that a compiler supports up to 7-dimensional arrays. A compiler may allow more than 7 dimensions, but it does not have to.

Character strings

The elements of a character string can be referenced individually or in groups.

With:

```
character (len=80) :: name
name = "Tanja"
```

Then

```
name(1:3) would yield the substring "Tan"
```

A single character must be referenced in a similar way:

```
name(2:2) yields the character "a"
```

If the lower subscript is omitted, it is assumed to be one, and if the upper subscript is omitted, it is supposed to be the length of the string.

Thus:

```
name (:3)    ! yields "Tan"
name (3:)    ! yields "nja"
name (:)     ! yields "Tanja"
```

Implicit typing

Fortran allows *implicit typing*, which means that variables do not have to be declared. If a variable is not declared, the first letter of its name determines its type: if the name of the variable starts with i, j, k, l, m, or n, it is considered to be an integer, in all other cases it is considered to be a real. However, it is good programming practice to declare all variables at the beginning of the program. The statement

```
implicit none
```



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Derived data types

We have seen that the Fortran language contains 5 intrinsic types (integer, real, complex, logical, and character). In addition to these, the user can define *derived types*, which can consist of data objects of different type.

An example of a derived data type:

```
type :: atom
  character (len=2) :: label
  real :: x, y, z
end type atom
```

This type can hold a 2-character atom name, as well as the atom's xyz coordinates.

An object of a derived data type is called a *structure*. A structure of type atom can be created in a type declaration statement like:

```
type(atom) :: carbon1
```

The components of the structure can be accessed using the *component selector* character (%):

```
carbon1%label = "C"
carbon1%x = 0.0000
carbon1%y = 1.3567
carbon1%z = 2.5000
```

Note that no spaces are allowed before and after the %!

One can also make arrays of a derived type:

```
type(atom), dimension (10) :: molecule
```

and use it like

```
molecule(1)%type = "C"
```

Arithmetic operators

The intrinsic arithmetic operators available in Fortran 90 are:

```
=====
**  exponentiation
=====
*   multiplication
/   division
=====
```



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yields 7, but

$3 * (2+1)$

yields 9.

For operators of equal strength the precedence is from left to right. For example:

$a * b / c$

In this statement, first a and b are multiplied, after which the results is divided by c . The exception to this rule is exponentiation:

$2**2**3$

is evaluated as $2**8$, and not as $4**3$.

Numeric expressions

An expression using any of the arithmetic operators ($**$, $*$, $/$, $+$, $-$), like the examples in the previous section, is called a *numeric expression*.

Be careful with integer divisions! The result of an integer division, *i.e.*, a division in which the numerator and denominator are both integers, is an integer, and may therefore have to be truncated. The direction of the truncation is towards zero (the result is the integer value equal or just less than the exact result):

$3/2$ yields 1
 $-3/2$ yields -1
 $3**2$ yields 9
 $3**(-2)$ equals $1/3**2$, which yields 0

Sometimes this is what you want. However, if you do not want the result to be truncated, you can use the `real` function. This function converts its argument to type real. Thus, `real(2)` yields a result of type real, with the value 2.0.

With the examples from above:

`real(2)/3` yields 1.5
`2/real(3)` yields 1.5
`-2/real(3)` yields -1.5
`real(3)**-2` yields 0.1111111111 (which is 1/9)

However:

`real(2/3)` yields 0 (the integer division is performed first, yielding 0, which is then converted to a real.)

Note that the function `real` can have 2 arguments (see the table in the section on intrinsic functions below). The second argument, an integer specifying the precision (kind value)



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Numeric expressions can contain operands of different type (integer, real, complex). If this is the case, the type of the “weaker” operand will be first converted to the “stronger” type. (The order of the types, from strong to weak, is complex, real, integer.) The result will also be of the stronger type.

If we consider the examples above again, in

```
real(2)/3
```

The integer 3 is first converted to a real number 3.0 before the division is performed, and the result of the division is a real number (as we have seen).

Logical operators

The type **logical** can have only two different values: **.true.** and **.false.** (note the dots around the words true and false). Logical variables can be operated upon by logical operators. These are (listed in decreasing order of precedence):

```
=====
      .not.
      .and.
      .or.
      .eqv. and .neqv.
=====
```

The **.and.** is “exclusive”: the result of **a .and. b** is **.true.** only if the expressions **a** and **b** are both true. The **.or.** is “inclusive”: the result of **a .or. b** is **.false.** only if the expressions **a** and **b** are both false. Thus, if we have the logical constants:

```
logical, parameter :: on = .true.
logical, parameter :: off = .false.
```

Then:

```
.not. on           ! equals .false.
.not. off          ! equals .true.
on .and. on        ! equals .true.
on .and. off       ! equals .false.
off .and. off      ! equals .false.
on .or. on         ! equals .true.
on .or. off        ! equals .true.
off .or. off       ! equals .false.
on .eqv. on        ! equals .true.
on .eqv. off       ! equals .false.
off .eqv. off      ! equals .true.
```

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```

=====
<    less than
<=   less than or equal to
>    greater than
>=   greater than or equal to
==   equal to
/=   not equal to
=====

```

Logical expressions

Expressions that use the relational operators are *logical expressions*. The values of logical expressions can be either `.true.` or `.false.` Note that the range of numerical numbers in Fortran ranges from the largest negative number to the largest positive number (thus, -100.0 is smaller than 0.5).

A few examples:

```

real :: val1, val2
logical :: result

val1 = -3.5
val2 = 2.0

result = val1 < val2           ! result equals .true.
result = val1 >= val2          ! result equals .false.
result = val1 < (val2 - 2.0)  ! result equals .true.

```

Be careful though with comparing real numbers. Reals are represented with finite accuracy. Thus:

```
print*, 2 * 3.2
```

may give as output: 6.4000001. So instead of comparing two real variables a and b like:

```
a == b
```

it is safer to compare their difference:

```
real, parameter :: delta = 0.000001
abs(a-b) < delta      ! equals .true. if a and b are numerically identical

```

The function `abs` returns the absolute value of (a-b).

Intrinsic functions

Intrinsic functions are functions that are part of the language. Fortran, as a scientific language aimed at numerical applications, contains a large number of mathematical



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The mathematical functions are:

acos (x)	inverse cosine (arc cosine) function
asin (x)	inverse sine (arc sine) function
atan (x)	inverse tangent (arc tangent) function
atan2 (x)	arc tangent for complex numbers
cos (x)	cosine function
cosh (x)	hyperbolic cosine function
exp (x)	exponential function
log (x)	natural logarithm function
log10 (x)	common logarithm function
sin (x)	sine function
sinh (x)	hyperbolic sine function
sqrt (x)	square root function
tan (x)	tangent function
tanh (x)	hyperbolic tangent function

Some other useful intrinsic functions are:

abs (x)	absolute value of the numerical argument x
complx (x,y [, ikind])	convert to complex. The ikind argument is optional. If not specified, the conversion is to default precision.
floor (x)	greatest integer less than or equal to x. Examples: floor (3.4) equals 3, floor (-3.4) equals -4.
int (x)	convert to integer. If abs (x < 1), the result is 0. If abs (x) >= 1, the result is the largest integer not exceeding x (keeping the sign of x). Examples: int(0.3) equals 0, int (-0.3) equals 0, int (4.9) equals 4, int (-4.9) equals -4.
nint (x [, ikind])	rounds to nearest integer.
real (x [, ikind])	convert to real. The ikind argument is optional. If not specified, the conversion is to default precision.
mod (a,p)	remainder function. Result is a - int (a/p) * p. The arguments a and p must be of the same type (real or integer).
modulo (a,p)	modulo function. Result is a - floor (a/p) * p. The arguments a and p must be of the same type (real or integer).



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```
print*, "The number pi = ", pi
```

might appear on the screen as

```
The number pi = 3.141590
```

The exact format is dependent on the computer system used. Later we will see a more sophisticated form of I/O, using `read` and `write`, which gives the programmer more control over the format.

The following `read` statement (with `x`, `y`, and `z` being declared as variables of type `real`)

```
read*, x, y, z
```

expects three numbers to be typed, separated by a comma, one or more spaces, or a slash (/). The variable `x` will have the value of the first number typed, `y` will have the value of the second number typed, and `z` of the third number typed.

Comments

We have already seen the exclamation mark (!). All characters after the exclamation mark are ignored. Comments can be used for descriptive purposes, or for “commenting out” a line of code.

Continuation lines

The maximum length of a Fortran statement is 132 characters. Sometimes statements are so long that they don't fit on one line. The *continuation mark* (&), placed at the end of the line, allows the statement to continue on the next line. Fortran 90 allows a maximum of 39 continuation lines.

Thus, the following code

```
cos (alpha) = b*b + c*c -      &
    2*b*c*cos (gamma)
```

is identical to

```
cos (alpha) = b*b + c*c - 2*b*c*cos (gamma)
```

Summary

- A program starts with `program program_name` and ends with `end program program_name`.
- The first statement should always be `implicit none`.
- We have learned the different types of variables and constants in Fortran: `integer`, `real`, `complex`, `logical` and `character`, and how to declare them in type declaration statements.



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Exercises

1. Which of the following are valid names in Fortran 90:
 - a. this_is_a_variable
 - b. 3dim
 - c. axis1
 - d. y(x)
 - e. dot.com
 - f. DotCom
 - g. z axis
2. Write a program that reads in a number, and computes the area of a circle that has a diameter of that size.
3. Find out, for your compiler, what the compiler flags are for displaying warning messages, and for issuing a warning when the compiler encounters non-standard source code.
4. Write a program that reads in a time in seconds, and computes how many hours and minutes it contains. Thus, 3700 should yield: 1 hour, 1 minute, and 40 seconds. (Hint: use the mod function).

3. Control Constructs

Control Constructs

A program can consist of several statements, which are executed one after the other:

```

program program_name
  implicit none
  statement1
  statement2
  statement3
  statement4
end program_name
    
```

However, this rigid sequence may not suit the formulation of the problem very well. For example, one may need to execute the same group of statements many times, or two different parts of the program may need to be executed, depending on the value of a variable. For this, Fortran 90 has several constructs that alter the *flow* through the statements. These include *if constructs*, *do loops*, and *case constructs*.



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as in:

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

The statement $x = y$ is only executed if x is smaller than y .

Several statements may appear after the logical expression. The if block can also be given a name, so the more general form of the if construct is:

```
[name:] if (logical expression) then
  ! various statements
  . . .
end if [name]
```

Both `endif` and `end if` are allowed. The name preceding the if is optional (but if it is specified, the name after the `endif` must be the same).

The block if statement can also contain an *else block*:

```
[name:] if (logical expression) then
  ! various statements
  . . .
else
  ! some more statements
  . . .
end if [name]
```



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Block if statements can be nested:

```
[name:] if (logical expression 1) then
    ! block 1
else if (logical expression 2) then
    ! block 2
else if (logical expression 3) then
    ! block 3
else
    ! block 4
end if [name]
```

Example (try to follow the logic in this example):

```
if ( optimisation ) then
    print*, "Geometry optimisation: "
    if ( converged ) then
        print*, "Converged energy is ", energy
    else
        print*, "Energy not converged. Last value: ", energy
    end if
else if (singlepoint ) then
    print*, "Single point calculation: "
    print*, "Energy is ", energy
else
    print*, "No energy calculated."
end if
```

Indentation is optional, but highly recommended: a consistent indentation style helps to keep track of which if, else if, and end if belong together (*i.e.*, have the same “if level”).

Do loops

A program often needs to repeat the same statement many times. For example, you may need to sum all elements of an array.

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You could write:

```

real, dimension (5) :: array1
real :: sum

! here some code that fills array1 with numbers
...

sum = array1(1)
sum = sum + array1(2)
sum = sum + array1(3)
sum = sum + array1(4)
sum = sum + array1(5)
    
```

But that gets obviously very tedious to write, particularly if array1 has many elements. Additionally, you may not know beforehand how many times the statement or statements need to be executed. Thus, Fortran has a programming structure, the do loop, which enables a statement, or a series of statements, to be carried out iteratively.

For the above problem, the do loop would take the following form:

```

real, dimension (5) :: array1
real :: sum
integer :: i      ! i is the "control variable" or counter

! here some code that fills array1 with numbers
...

sum = 0.0  ! sum needs to be initialised to zero
do i = 1, 5
    sum = sum + array1(i)
end do
    
```

Both enddo and end do are allowed.

It is possible to specify a name for the do loop, like in the next example. This loop prints the odd elements of array2 to the screen. The name (print_odd_nums in this case) is optional. The increment 2 specifies that the counter i is incremented with steps of 2, and therefore, only the odd elements are printed to the screen. If no increment is specified, it is 1.

```

real, dimension (100) :: array2
integer :: i

! here some code that fills array2 with numbers
...
    
```



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Do loops can be nested (one do loop can contain another one), as in the following example:

```

real, dimension (10,10) :: a, b, c ! matrices
integer :: i, j, k

! here some code to fill the matrices a and b
...

! now perform matrix multiplication: c = a + b
do i = 1, 10
  do j = 1, 10
    c(i, j) = 0.0
    do k = 1, 10
      c(i, j) = c(i, j) + a(i, k) + b(k, j)
    end do
  end do
end do

```

Note the indentation, which makes the code more readable.

Endless Do

The endless do loop takes the following form:

```

[doname:] do
    ! various statements
    exit [doname]
    ! more statements
end do [doname]

```

Note the absence of the control variable (counter). As before, the name of the do loop is optional (as indicated by the square brackets).

To prevent the loop from being really “endless”, an `exit` statement is needed. If the exit statement is executed, the loop is exited, and the execution of the program continues at the first executable statement after the `end do`.

The exit statement usually takes the form

```

if (expression) then
  exit
end if

```



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as in the following example:

```

program integer_sum
! this program sums a series of numbers given by the user
! example of the use of the endless do construct

implicit none
integer :: number, sum

sum = 0
do
  print*, "give a number (type -1 to exit): "
  read*, number

  if (number == -1) then
    exit
  end if

  sum = sum + number
end do

print*, "The sum of the integers is ", sum
end program integer_sum

```

The name of the do loop can be specified in the exit statement. This is useful if you want to exit a loop in a nested do loop construct:

```

iloop: do i = 1, 3
  print*, "i: ", i
  jloop: do j = 1, 3
    print*, "j: ", j
    kloop: do k = 1, 3
      print*, "k: ", k

      if (k==2) then
        exit jloop
      end if
    end do kloop
  end do jloop
end do iloop

```

When the exit statement is executed, the program continues at the next executable statement after end do jloop. Thus, the first time that exit is reached is when i=1, j=1, k=2, and the program continues with i=2, j=1, k=1.



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Example:

```

program cycle_example
  implicit none
  character (len=1) :: answer
  integer :: i
  do i = 1, 10
    print*, "print i (y or n)?"
    read*, answer
    if (answer == "n") then
      cycle
    end if
    print*, i
  end do
end program cycle_example

```

Case constructs

The case construct has the following form:

```

[name:]      select case (expression)
              case (selector1)
                ! some statements
              ...
              case (selector2)
                ! other statements
              ...
              case default
                ! more statements
              ...
            end select [name]

```

As usual, the name is optional. The value of the selector, which can be a logical, character, or integer (but not real) expression, determines which statements are executed. The case default block is executed if the expression in `select case (expression)` does not match any of the selectors.

A range may be specified for the selector, by specifying an lower and upper limit separated by a colon:



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Example:

```
select case (number)
  case ( : -1)
    print*, "number is negative"
  case (0)
    print*, "number is zero"
  case (1 : )
    print*, "number is positive"
end select
```

The following example program asks the user to enter a number between 1 and 3. The print and read are in an endless loop, which is exited when a number between 1 and 3 has been entered.

```
program case_example
  implicit none
  integer :: n
  ! Ask for a number until 1, 2, or 3 has been entered
  endless: do
    print*, "Enter a number between 1 and 3: "
    read*, n
    select case (n)
      case (1)
        print*, "You entered 1"
        exit endless
      case (2)
        print*, "You entered 2"
        exit endless
      case (3)
        print*, "You entered 3"
        exit endless
      case default
        print*, "Number is not between 1 and 3"
    end select
  end do endless
```



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Summary

In this chapter we learned the following control constructs:

- block if statements.
- do loops (including endless do loops).
- case statements.

Exercises

5. Write a program which calculates the roots of the quadratic equation $ax^2 + bx + c = 0$. Distinguish between the three cases for which the discriminant ($b^2 - 4ac$) is positive, negative, or equal to zero. Use an if construct. You will also need to use the intrinsic function `cmplx`.
6. Consider the Fibonacci series:
1 1 2 3 5 8 13 ...
Each number in the series (except the first two, which are 1) is the sum from the two previous numbers. Write a program that reads in an integer limit, and which prints the first limit terms of the series. Use an nested if block structure. (You need to distinguish between several cases: limit < 0, limit =1, etc.)
7. Rewrite the previous program using a case construct.
8. Write a program that defines an integer array to have 10 elements
 - a) fills the array with ten numbers
 - b) reads in 2 numbers (in the range 1-10)
 - c) reverses the order of the array elements in the range specified by the two numbers. Try not to use an additional array.
9. Write a program that reads in a series of integer numbers, and determines how many positive odd numbers are among them. Numbers are read until a negative integer is given. Use `cycle` and `exit`.

4. Procedures

Program units

A program can be built up from a collection of program units (the main program, modules and external subprograms or procedures). Each program must contain one (and only one) main program, which has the familiar form:

```
program program_name
```

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Procedures

A subprogram or procedure is a computation that can be “called” (invoked) from the program. Procedures generally perform a well-defined task. They can be either functions or subroutines. Information (data) is passed between the main program and procedures via *arguments*. (Another way of passing information is via modules, see Chapter 6.) A function *returns* a single quantity (of any type, including array), and should, in principle, not modify any of its arguments. (In the stricter F language, a function is simply not allowed to modify its arguments). The quantity that is returned is the *function value* (having the name of the function). We have already seen one type of functions in Chapter 2, namely built-in or intrinsic functions, which are part of the Fortran 90 language (such as `cos` or `sqrt`).

An example of a function:

```
function circle_area (r)
! this function computes the area of a circle with radius r

  implicit none

  ! function result
  real :: circle_area

  ! dummy arguments
  real :: r

  ! local variables
  real :: pi

  pi = 4 * atan (1.0)
  circle_area = pi * r**2

end function circle_area
```

The structure of a procedure closely resembles that of the main program. Note also the use of `implicit none`. Even if you have specified `implicit none` in the main program, you need to specify it again in the procedure.

The `r` in the function `circle_area` is a so-called *dummy argument*. Dummy arguments are replaced by *actual arguments* when the procedure is called during execution of the program. Note that the function has a “dummy arguments” block and a “local variables” block, separated by comments. While this is not required, it makes the program clearer.

The function can be used in a statement like:

```
a = circle_area (2.0)
```



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The result of a function can be given a different name than the function name by the result option:

```
function circle_area (r) result (area)
! this function computes the area of a circle with radius r
  implicit none
  ! function result
  real :: area
  ! dummy arguments
  real :: r
  ! local variables
  real, parameter :: pi = 3.141592654
  area = pi * r**2
end function circle_area
```

The name specified after result (area in this case) *must* be different from the function name (circle_area). Also note the type declaration for the function result (area). This function is used in the same way as before:

```
a = circle_area (radius)
```

The result option is in most cases optional, but it is required for recursive functions, *i.e.*, functions that call themselves (see paragraph on “recursive functions” below).

An example of a subroutine:

```
subroutine swap (x, y)
  implicit none
  ! dummy arguments
  real :: x, y
  ! local variables
  real :: buffer
  buffer = x      ! store value of x in buffer
  x = y
  y = buffer
end subroutine swap
```

A subroutine is different from a function in several ways. Subroutines can modify their

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The general rule is that it is best to use a function if the procedure computes only one result, and does not much else. In all other cases, use a procedure.

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External procedures

An example of a program that contains two functions:

```

program angv1v2
  implicit none
  real, dimension (3) :: v1, v2
  real :: ang

  ! define two vectors v1 and v2
  v1(1) = 1.0
  v1(2) = 0.0
  v1(3) = 2.0

  v2(1) = 1.5
  v2(2) = 3.7
  v2(3) = 2.0

  print*, "angle = ", ang (v1, v2)
end program angv1v2

! ang computes the angle between 2 vectors vect1 and vect2
function ang (vect1, vect2 )
  implicit none

  ! function result
  real :: ang

  ! dummy arguments
  real, dimension (3), intent (in) :: vect1, vect2

  ! local variables
  real :: cosang, norm

  cosang = vect1(1)*vect2(1) + vect1(2)*vect2(2) + vect1(3)*vect2(3)
  cosang = cosang / (norm(vect1)*norm(vect2))
  ang = acos (cosang)

end function ang

! norm returns the norm of the vector v
function norm (v)
  implicit none

```



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This program illustrates that the actual argument (v1 and v2) may have a name different from the dummy arguments vect1 and vect2 of the function ang. This allows the same function to be called with different arguments. The intent attribute is explained in the next paragraph. Note that the type of the function norm must be declared in the function ang. An alternative to this is to provide an explicit interface, see section on Interfaces below.

As mentioned before, a subroutine must be “call”ed, as the following program illustrates:

```

program swap_xy
  implicit none
  real :: x, y
  x = 1.5
  y = 3.4
  print*, "x = ", x, " y = ", y
  call swap (x,y)
  print*, "x = ", x, " y = ", y
end program swap_xy

subroutine swap (x, y)
  implicit none
  ! dummy arguments
  real, intent (inout) :: x, y
  ! local variables
  real :: buffer
  buffer = x          ! store value of x in buffer
  x = y
  y = buffer
end subroutine swap
  
```

When executed, this program gives as output:

```

x = 1.5 y = 3.4
x = 3.4 y = 1.5
  
```

(The exact format of the displayed numbers is dependent on the computer system used.)

Note that the functions appear after the end of the main program. Subroutines or functions that are not contained in the main program are called *external procedures*. These are the most common type of procedures. External procedures are stand-alone procedures, which may be developed and compiled independently of other procedures.



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```
f90 -ansi -fullwarn -o angle angle.f90 vector.f90
```

The compiler flag `-ansi` causes the compiler to generate messages when it encounters source code that does not conform to the Fortran 90 standard, `-fullwarn` turns on all warning messages, and `-o` specifies the name of the output file, to which the executable will be written to.

The compilation can also be done in two steps:

```
f90 -ansi -fullwarn -c angle.f90 vector.f90
f90 -ansi -fullwarn -o angle angle.o vector.o
```

The first step creates binary object files `vector.o` and `angle.o`. The second (link) step creates the executable (`angle`).

Intent

Fortran allows the specification of the “intention” with which arguments are used in the procedure:

```
intent (in):    Arguments are only used, and not changed
intent (out):   Arguments are overwritten
intent (inout): Arguments are used and overwritten
```

Consider the following example:

```
subroutine intent_example (a, b, c)
  implicit none
  ! dummy arguments
  real, intent (in) :: a
  real, intent (out) :: b
  real, intent (inout) :: c

  b = 2 * a
  c = c + a * 2.0

end subroutine intent_example
```

In this subroutine, `a` is not modified, and thus has `intent (in)`; `b` is given a value and has therefore `intent (out)`; `c` is used and modified, `intent (inout)`. It is good programming practice to use `intent`. Firstly, it makes procedures more transparent, *i.e.*, it is clearer what the procedure does. Secondly, the compiler may catch programming mistakes, because most compilers will warn you if you, for example, try to modify an argument that has `intent (in)`. Thirdly, it may help optimisation if the compiler knows which arguments are changed in a subroutine.



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Even though it is advisable to use intent, it is possible to introduce bugs in the program by giving arguments the wrong intent. Consider the following code:

```

program test
  implicit none
  integer, dimension (10) :: array
  integer :: i
  do i = 1, 10
    array(i) = i
  end do
  call modify_array (a)
end program test

subroutine modify_array (a)
  implicit none
  ! dummy arguments
  integer, dimension (10), intent (inout) :: a

  ! local variables
  integer :: i

  do i = 1,3
    a(i) = 0.0
  end do

end subroutine modify_array

```

The intent of array **a** in the subroutine has to be **inout**, even though it seems like you are only writing into the array, and do not need to know the values of its elements. If you would make the intent **out** however, then it is possible that, after calling the subroutine, the elements **a(4)** to **a(10)** contain “garbage” (unpredictable contents), because the subroutine did not read in these elements (so cannot know their values), but did write them out (thereby overwriting their previous values).

Interfaces

The interface of a procedure is a collection of the names and properties of the procedure and its arguments. When a procedure is external, the compiler will (in most cases) not know about its interface, and cannot check if the procedure call is consistent with the procedure declaration (for example, if the number and types of the arguments match).



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The interface block contains the name of the procedure, and the names and attributes (properties) of all dummy arguments (and the properties of the result, if it defines a function).

If we take as example the program swap_xy from above, then the interface for the subroutine swap would look like:

```
interface
  subroutine swap (x, y)
    real, intent (inout) :: x, y
  end subroutine swap
end interface
```

The interface block is placed at the beginning of the program (or at the beginning of a procedure), together with the declaration statements:

```
program swap_xy
  implicit none
  ! local variables
  real :: x, y
  ! external procedures
  interface
    subroutine swap (x, y)
      real, intent (inout) :: x, y
    end subroutine swap
  end interface
  x = 1.5
  y = 3.4
  print*, "x = ", x, " y = ", y
  call swap (x,y)
  print*, "x = ", x, " y = ", y
end program swap_xy
subroutine swap (x, y)
  implicit none
  ! dummy arguments
  real, intent (inout) :: x, y
  ! local variables
  real :: x, y
```



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If a procedure `proc1` calls another procedure `proc2`, then the interface block of `proc2` should be placed at the beginning of the procedure `proc1`.

Another way of providing explicit interfaces will be discussed in the chapter on Modules (Chapter 6).

Recursive procedures

A procedure that calls itself (directly or indirectly) is called a recursive procedure. Its declaration must be preceded by the word `recursive`. When a function is used recursively, the `result` option must be used.

The factorial of a number ($n!$) can be computed using a recursive function:

```
recursive function nfactorial (n) result (fac)
! computes the factorial of n (n!)

implicit none

! function result
integer :: fac

! dummy arguments
integer, intent (in) :: n

select case (n)
case (0:1)
fac = 1
case default
fac = n * nfactorial (n-1)
end select

end function nfactorial
```

Internal procedures

Internal procedures are contained within a program unit. A main program containing internal procedures has the following form:

```
program program_name
implicit none
! type declaration statements
! executable statements
...
contains
! internal procedures
```



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With our function `circle_area` from above:

```

program area
  implicit none
  real :: radius, a

  radius = 1.4
  a = circle_area (radius)
  print*, "The area of a circle with radius ", radius, " is ", a
contains
  function circle_area (r)
    ! this function computes the area of a circle with radius r
    implicit none
    ! function result
    real :: circle_area

    ! dummy arguments
    real, intent (in) :: r

    ! local variables
    real, parameter :: pi = 3.141592654

    circle_area = pi * r**2
  end function circle_area
end program area

```

An internal procedure is local to its *host* (the program unit containing the internal procedure), and the environment (*i.e.*, the variables and other declarations) of the host program is known to the internal procedure.

Thus, the function `circle_area` knows the value of the variable `radius`, and we could have written the function also like:

```

function circle_area
  ! this function computes the area of a circle with radius r
  implicit none
  ! function result
  real :: circle_area
  ! local variables

```



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and simple called the function like:

```
a = circle_area
```

However, the first form allows the function to be called with varying arguments (and it more transparent as well):

```
a1 = circle_area (radius)
a2 = circle_area (3.5)
```

Internal procedures are not very common. In most cases, it is better to use external procedures. External procedures can be called from more than one program unit, and they are safer: The variables of the calling program are hidden from the procedure, *i.e.*, the procedure does not know the values of the variables (unless they are passed as arguments), and it can only change them if they are passed as arguments with intent (inout). However, an advantage of internal procedures is that they can be better optimised by the compiler.

Assumed character length

A character dummy argument can be declared with an asterisk for the length the `len` parameter. This allows the procedure to be called with character strings of any length. The length of the dummy argument is taken from that of the actual argument.

Example:

```
program assumed_char
  implicit none
  character (len=5) :: name
  name = "Tanja"
  call print_string (name)
end program assumed_char

subroutine print_string (name)
  implicit none
  ! dummy arguments
  character (len=*), intent (in) :: name
  print*, name
end subroutine print_string
```

Summary



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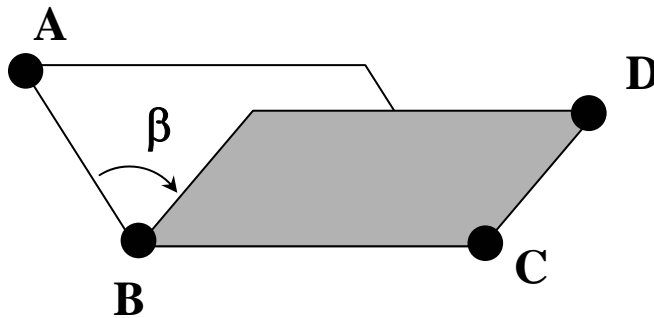
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Good programming practice requires the use of the `intent` attribute for the dummy arguments of procedures, and the use of `interface` blocks for external procedures.

Exercises

Choose any two of exercises 11-13:

- Write a program that, given the xyz coordinates of four atoms, returns the dihedral between the atoms. The dihedral (or torsion) angle of four atoms A-B-C-D is defined as the angle between the plane containing the atoms A, B, and C, and the plane containing B, C, and D.



- Consider the Fibonacci series:
 1 1 2 3 5 8 13 ...
 Each number in the series (except the first 2, which are 1) is the sum from the two previous numbers. Write a program that computes the *n*th number in the Fibonacci series, where *n* is given by the user. Use a recursive function.
- Bubble sort.
 Create an unordered data set of integers (for example by reading them in), and write a subroutine to sort them in ascending order. One of the easiest sort algorithms is bubble sort. Start at the lower end of the array. Compare elements 1 and 2, and swap them if necessary. Then proceed to the next 2 elements (2 and 3), and continue this process through the entire array. Repeat the whole process *ndim* (dimension of array) times. Note that in successive rounds you only have to go through smaller and smaller sections of the array, because the last element(s) should now already be sorted. This process is called “bubble sort” because the larger elements appear to bubble through the array to reach their places.

5 More on Arrays

Declaring arrays



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An alternative way of declaring these arrays is as follows:

```
real :: coords(3)
integer :: block(10,10)
```

In this manual, the first method is used.

Arrays can also be declared with explicit lower bounds. For the above arrays:

```
real, dimension (1:3) :: coords
integer, dimension (-5:5, 0:9) :: block
```

The type declaration statement for the array `block` shows that the lower bound does not have to be 1. If the lower bound is not specified explicitly, it is taken to be 1.

Array terminology

Rank: The rank of an array is the number of dimensions it has. In our examples above, the rank of `coords` is 1 and the rank of `block` is 2.

Extent: The number of elements along a dimension is its extent. Thus, the extent of `coords` is 3 and the extent of both the first and second dimension of `block` is 10.

Shape: The shape of an array is a one-dimensional integer array, containing the number of elements (the extent) in each dimension. Thus, the shape of array `coords` is (3), and the shape of `block` is (10,10). Two arrays of the same shape are “conformable”.

Size: The size of an array is the number of elements it contains. The size of `coords` is 3 and the size of `block` is 100.

Array assignment statements

Array elements can be given a value in the usual way:

```
coords(1) = 3.5
block(3,2) = 7
```

Or in a loop:

```
do i = 1,3
  coords(i) = 0.0
end do
```

For arrays of rank one (one-dimensional arrays), the following shorthand notation is also possible:

```
coords = (/ 1.3, 5.6, 0.0 /)
```

These shorthand notations of “constructing” the array elements are called *array*



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The following constructors are also allowed:

```
coords = (/ (2.0*i, i = 1, 3) /)      ! yields (2.0, 4.0, 6.0)
odd_ints = (/ (i, i = 1, 10, 2) /)    ! yields (1, 3, 5, 7, 9)
```

These two examples use so-called *implied do loops*. Note the additional parentheses around the implied do loop.

The array constructors allow the definition of array constants:

```
integer, dimension (8), parameter :: primes = (/ 1, 2, 3, 7, 11, 13, 17, 19 /)
```

Array sections

Sections of arrays can be referenced. For example, consider an integer array **a** with dimension (3,4).

a(1,1)	a(1,2)	a(1,3)	a(1,4)
a(2,1)	a(2,2)	a(2,3)	a(2,4)
a(3,1)	a(3,2)	a(3,3)	a(3,4)

Then, `a(1:2, 3)` references the elements `a(1,3)` and `a(2,3)`. The whole last column can be referenced as `a(1:3,4)` or simply `a(:, 4)`, and the first row as `a(1, :)`. Optionally, a stride can be specified as well. The syntax is (for each dimension):

`[lower] : [upper] [: stride]`

In `a(1, 1:4:2)` lower= 1, upper = 4 and stride = 2 (for the second dimension). Thus, `a(1, 1:4:2)` references the elements `a(1,1)` and `a(1,3)`.

Array expressions

The arithmetic operators (`**`, `*`, `/`, `+`, `-`) can be applied to arrays (or array sections) that have the same shape (are conformable).

For example, a two-dimensional array `b(2,3)` can be added to the array section `a(2:3, 1:3)` of the array `a` of the previous section. If the array `c` is an array of dimension (2,3), then the expression

```
c = a(2:3,1:3) + b
```

causes the elements of the array `c` to have the following values:

```
c(1,1) = a(2,1) + b(1,1)
```

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The same can be achieved by using a do loop:

```
do i = 1, 3
  do j = 1, 2
    c(j,i) = a(j+1,i) + b(j,i)
  end do
end do
```

But the expression $c = a(2:3,1:3) + b$ is clearly more concise.

The operator $+$ in the above example can be replaced by any of the other arithmetic operators. The following expressions are all valid:

```
c = a(2:3,1:3) * b           ! c(1,1) = a(2,1) * b(1,1), etc.
c = a(2:3,1:3) / b          ! c(1,1) = a(2,1) / b(1,1), etc.
c = a(2:3,1:3) - b          ! c(1,1) = a(2,1) - b(1,1), etc.
c = a(2:3,1:3) ** b         ! c(1,1) = a(2,1) ** b(1,1), etc.
```

Note that the operation is done element by element. Thus, the result of the multiplication $a(2:3,1:3) * b$ is not a matrix product!

Scalars can be used in an array expression as well. Thus, $a / 2.0$ has the effect of dividing all elements of the array a by 2.0, and $a**2$ raises all the elements of a to the power 2.

Array expressions can be used to avoid do-loops. For example, the expression

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

Is equivalent to

```
do i = 1, 4
  a(i) = a(i+1)
end do
```

However, if the do loop iterations are interdependent, then the do loop and the array expression are not equivalent. This is because in the do loop the elements of the array are updated after each iteration, and in the array expression the updating is done only after all the elements have been processed.

For example, if the array a contains the numbers 1, 2, 3, 4, 5, then

```
do i = 1,4
  a(i+1) = a(i)
end do
```

yields 1, 1, 1, 1, 1



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Using array syntax instead of do loops may help an optimising compiler to optimise the code better in specialised cases (for example on a parallel machine).

Dynamic arrays

Sometimes you don't know the necessary size of an array until the program is run, the size may for example depend on some calculations, or be defined by the user. In Fortran 90, this can be done by using *dynamic arrays*. A dynamic array is an array of which the size is not known at compile time (the rank must be specified, however), but becomes known when running the program.

A dynamic array has to be declared with the attribute `allocatable`, and it has to be "allocated" when its size is known and before it is used.

```

program dynamic_array
  implicit none
  real, dimension (:,:), allocatable :: a
  integer :: dim1, dim2
  integer :: i, j
  print*, "Give dimensions dim1 and dim2: "
  read*, dim1, dim2
  ! now that the size of a is know, allocate memory for it
  allocate ( a(dim1,dim2) )
  do i = 1, dim2
    do j = 1, dim1
      a(j,i) = i*j
      print*, "a(",j,",",",i,") = ", a(j,i)
    end do
  end do
  deallocate (a)
end program dynamic_array

```

When the array is no longer needed, it should be deallocated. This frees up the storage space used for the array for other use.



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Assumed shape arrays

Arrays can be passed as arguments to procedures, as the following example illustrates:

```

program dummy_array
  implicit none
  integer, dimension (10) :: a
  call fill_array (a)
  print, a
end program dummy_array

subroutine fill_array (a)
  implicit none
  ! dummy arguments
  integer, dimension (10), intent (out) :: a

  ! local variables
  integer :: i

  do i = 1, 10
    a(i) = i
  end do
end subroutine fill_array

```

However, written like this, the subroutine `fill_array` can only be called with arrays of dimension 10. It would clearly be advantageous if routines can be used for arrays of any size. To accomplish this, several techniques can be used to “hide” the array size from the procedure. In Fortran 90, the most flexible way of doing this is by using the *assumed shape* technique. In the procedure, the shape of the array is not specified, but is taken automatically to be that of the corresponding actual argument. The size of the array (the number of elements it contains, `size_a` in the example below), is determined in the subroutine using the intrinsic function `size`. `size (array, dim)` returns the number of elements along a specified dimension `dim`. The argument `dim` is optional. If it not specified, `size` sums the number of elements in each dimension.



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The above program can be rewritten as follows:

```

program dummy_array
  implicit none
  integer, dimension (10) :: a
  interface
    subroutine fill_array (a)
      integer, dimension ( : ) intent (out) :: a
      integer :: i
    end subroutine fill_array
  end interface
  call fill_array (a)
  print, a
end program dummy_array

subroutine fill_array (a)
  implicit none
  ! dummy arguments
  integer, dimension ( : ), intent (out) :: a
  ! local variables
  integer :: i, size_a
  size_a = size (a)
  do i = 1, size_a
    a(i) = i
  end do
end subroutine fill_array

```

Note that, in this case, the explicit interface is required. The procedure fill_array can now be called with arrays of any size.



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Multidimensional arrays can also be passed to procedures in this way:

```

program example_assumed_shape
  implicit none
  real, dimension (2, 3) :: a
  integer :: i, j
  interface
    subroutine print_array (a)
      real, dimension ( : , : ), intent (in) :: a
    end subroutine print_array
  end interface
  do i = 1, 2
    do j = 1, 3
      a(i, j) = i * j
    end do
  end do
  call print_array (a)
end program example_assumed_size

subroutine print_array
  implicit none
  ! dummy arguments
  real,dimension ( : , : ), intent (in) :: a
  print*, a
end subroutine print_array

```

Note that the rank (*i.e.*, the number of dimensions) must be explicitly defined in the procedure, but the shape (the extent of each dimension) is taken from the actual argument. If required, in the subroutine `print_array` the size of the array can be found out by the function `size`. In this case, `size (a)` would yield 6, `size (a, 1)` would yield 2, and `size (a, 2)` would yield 3.

Summary

This chapter showed some more advanced array manipulations, such as implied do loops and array expressions. A very useful concept is that of dynamic (allocatable) arrays, which did not exist in FORTRAN 77. We have seen how the shape of an array can be

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Exercises

13. Given the array declaration:

```
real, dimension (24, 10) :: a
```

Write array sections representing:

- the second column of **a**
- the last row of **a**
- the block in the upper left corner of size 2 x 2.

14. Rewrite exercise 3.8 using array syntax instead of do loops.

6. Modules

Modules

A module serves as a packaging means for subprograms, data and interface blocks. Modules are a new and powerful feature of Fortran 90. They make common blocks (routinely used in FORTRAN 77) and include statements obsolete.

A module consists of two parts: a specification part for the declaration statements (including interface blocks and type and parameter declarations), and a subprogram part.

The general form of a module is:

```
module module_name
  ! specification statements
contains
  ! procedures
end module module_name
```

Modules can contain just the specification part or the subprogram part, or both.

The following example contains both:

```
module constants
implicit none
real, parameter :: pi = 3.1415926536
real, parameter :: e = 2.7182818285
contains
  subroutine show_consts()
    print "pi = " pi
```

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Note the implicit none. Just like with procedures, it is good programming practice to use implicit none in modules. It only needs to be specified once *i.e.*, it is not necessary to specify implicit none again in the module's procedures.

Modules are accessed by the use statement:

```
program module_example
  use constants
  implicit none

  real :: twopi

  twopi = 2 * pi
  call show_consts()
  print*, "twopi = ", twopi
end program module_example
```

The use statement makes available to the main program all the code (specification statements and subprograms) in the module constants. It supplies an explicit interface of all the module's procedures. The use statement has to be the first statement in the program (it comes even before implicit none), only comments are allowed before use.

When a subroutine is defined in a module, then there is no need to provide an explicit interface in the calling program (as long as the module's contents are made available to the program via the use statement).

Accessibility

By default, everything in a module is publicly available, that is, the use statement in the main program makes available all of the code in the module. However, accessibility can be controlled by the private and public attributes. Everything that is declared private is not available outside the module.

The logo for Cartagena99 features the text "Cartagena99" in a stylized, blue, serif font. The "99" is significantly larger and more prominent than the "Cartagena" part. The text is set against a light blue background with a subtle gradient and a soft shadow effect.

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Example:

```

module convertT
  implicit none

  real, parameter, private :: factor = 0.555555556
  integer, parameter, private :: offset = 32

  contains

  function CtoF (TinC) result (TinF)
    ! function result
    real :: TinF

    ! dummy argument
    real, intent (in) :: TinC

    TinF = (TinC/factor) + offset
  end function CtoF

  function FtoC (TinF) result (TinC)
    !function result
    real :: TinC

    ! dummy argument
    real :: TinF

    TinC = (TinF-offset) * factor
  end function FtoC
end module convertT

```

The following program uses the module convertT:

```

program convert_temperature
  use convertT
  implicit none

  print*, "20 Celcius = ", CtoF (20.0), " Fahrenheit"
  print*, "100 Fahrenheit = ", FtoC (100.0), " Celcius"
end program convert_temperature

```

The module defines two constants, `factor` and `offset`, which are not available to the program `convert_temperature`. The functions `CtoF` and `FtoC`, however, are available to

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For data objects, like `factor` and `offset` in the example above, the `public` and `private` attributes occur in the type declaration statement:

```
real, private :: factor
integer, private :: offset
```

For procedures, they must be defined in `public` and `private` statements:

```
public :: CtoF, FtoC
```

The default accessibility of the module can be set by the `public` or `private` statements. If `private` is specified, then all module contents are `private`, except those that are explicitly defined as `public`:

```
module convertT
private
public :: CtoF, FtoC
```

Selecting module elements

Generally, the `use` statement makes available all (`public`) elements of a module. However, when only a subset of the module is needed, the accessibility can be restricted with `only`.

The example of the previous section could have been written in the following way:

```
module convertT
  public
  ...
end module convertT

program convert_temperature
  use convertT, only: CtoF, FtoC
  ...
end program convert_temperature
```

The `only` option safeguards the module elements that are not needed by making them inaccessible to the program. It can also make programs more transparent, by showing the origin of data objects or procedures, particularly if the program uses several modules:

```
program only_example
  use module1, only: sphere, triangle
  use module2, only: compute_gradient
```

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Data encapsulation

Modules allow data and operations to be hidden from the rest of the program. *Data encapsulation* refers to the process of hiding data within an “object”, and allowing access to this data only through special procedures, called *member functions* or *methods*. Data encapsulation is one of the concepts of object-oriented programming (see Chapter 11). Data encapsulation functions as a security tool, because the data in the object is only available through the methods, which decreases the possibility of corrupting the data, and it reduces complexity (because the data is hidden within the module).

Consider the following example:

```

module student_class
implicit none
  private
  public :: create_student, get_mark

  type student_data
    character (len=50) :: name
    real :: mark
  end type student_data

  type (student_data), dimension (100) :: student
contains
  subroutine create_student (student_n, name, mark)
    ! here some code to set the name and mark of a student
  end subroutine create_student

  subroutine get_mark (name, mark)
    ! dummy arguments
    character (len=*), intent (in) :: name
    real, intent (out) :: mark

    ! local variables
    integer :: i

    do i = 1,100
      if (student(i)%name == name) then
        mark = student(i)%mark
      end if
    end do
  end subroutine get_mark
end module student_class

```



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accessible from outside the module, all other module contents are private. Thus, one cannot obtain the mark of a student by writing:

```
mark1 = student(1)%mark
```

because the array student is private.

One has to use the public subroutine get_mark for this, as illustrated in the following program:

```
program student_list
  use student_class
  implicit none

  real :: mark

  call create_student (1, "Peter Peterson", 8.5)
  call create_student (2,"John Johnson", 6.3)

  call get_mark ("Peter Peterson", mark)
  print*, "Peter Peterson:", mark
end program student_list
```

Global data management – no more common blocks!

Procedures can communicate with each other via their argument lists. However, a program may consist of many procedures that require access to the same data. It would be convenient if this data were globally accessible to the whole program. In FORTRAN 77, this was accomplished by **common** blocks. However, modules can replace all uses of **common** blocks. Global data can be packed in a module, and all procedures requiring this data can simply **use** the module. Modules are much safer and cleaner than **common** blocks. **Common** blocks have no mechanisms to check errors, variables can be renamed implicitly, and there are no access restrictions. So, don't use **common** blocks, use modules instead!

Summary

This chapter introduced a new and powerful feature in Fortran 90, modules. Modules are a means of packaging data and procedures. They make the old-fashioned **common** blocks obsolete. Modules provide a method to partition code into easily maintained packages, and allow some degree of object-oriented programming (we have seen an example of data hiding and encapsulation).

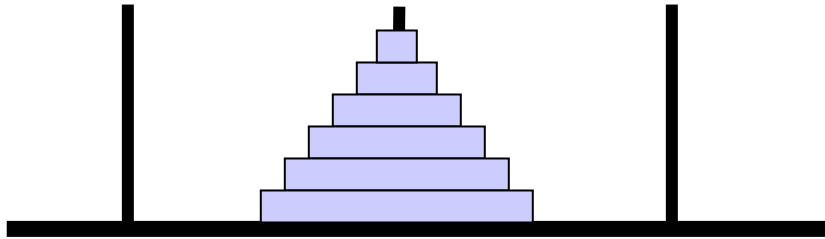
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Exercises

Exercise 16, the Towers of Hanoi, is optional.

15. Finish the program `student_list` by adding to the `student_class` module the procedures `create_student` and `delete_student`.
16. The Towers of Hanoi.
There are three poles. One of them contains discs having different widths stacked in ascending order; the other two poles are empty:



The goal is to move all the discs from the centre pole and stack them on one of the other poles in ascending order. You can only move the top disc of a stack, and you can only move one disc at a time. It is not allowed to stack a disc on top of one that is smaller.

You will have to figure out a way to represent the discs and their location, and an algorithm to move the discs. By printing the occupation of the towers after each move, you can check if your program works correctly.

Hint: The easiest algorithm uses a recursive function. By making the towers (their representation) global (by using modules), printing becomes a lot easier!

7. More on I/O

List-directed input/output

In Chapter 2 we have seen that we can transfer data from the keyboard into the program using `read*`, and write characters to the screen via `print*`. This simple form of I/O is called list-directed input/output. The `*` in `read*` and `print*` means “free format”, that is, the format is defined by the computer system, and is not under the control of the programmer. More control is given to the programmer via *formatted I/O*.

Formatted input/output

Formatted input/output is used to read and write data in a specific format.

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Here, *fmt* denotes a *format specification*, and *variable.list* is a list of variables. This form of read and write reads from the keyboard and writes to the screen, respectively. The *read** and *print** we have used so far are a special case of this form.

Format specifications

A format specification defines in which format data is displayed. A format specification consists of a string, containing a list of *edit descriptors* in parentheses. An edit descriptor specifies the exact format (width, digits after decimal point) in which characters and numbers are displayed.

An example of format specification:

“(a10, i5, f5.3)”

- The a descriptor is for character variables. In *aw*, the number *w* specifies the field width. Thus, a10 means that 10 places will be used to display the character variable. If a field larger than the character variable is specified, the variable will be right-justified (*i.e.*, blanks will appear before the character variable). If no field width is specified, the width of the field is determined from the actual width of the character variable.
- The i descriptor is for integers. The number after the i is again the field width. Another form of the i descriptor is *iw.m*, where *w* defines the field width, and *m* specifies the minimum number of digits to be displayed, if necessary preceded by zeros.
- The f descriptor is for reals. In *fw.d*, *w* specifies the field width, and *d* specifies the number of digits after the decimal point. Thus, f5.3 will display the number 1.30065 as 1.301. Note that this number takes up 5 places: 1 digit before the decimal point, 3 digits after the decimal point, and the decimal point itself.
- Reals can also be displayed using the es descriptor, which displayed the real in scientific notation. The form is the same as for the f descriptor: *esw.d*. Thus, es10.3 would display the real 6.7345 as 6.734E+00 (with a leading blank, because of the field width 10).

As mentioned above, format specifiers are used in formatted I/O (in the following examples, *b* denotes a blank character):

```
pi = 3.1415927
print "(a, i3.3)", "Result = ", 1      ! gives: Result = 001
print "(f6.3)", pi                    ! gives: b3.142
print "(e16.4)", pi/100               ! gives: bbbbbb3.1416E-02
```



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More formatted I/O

As mentioned above, there are two different forms of the formatted input and output statements. The first form is the one we have just seen above:

```
read fmt, variable_list
print fmt, variable_list
```

The other form requires a unit number:

```
read (unit=u, fmt=fmt) variable_list
write (unit=u, fmt=fmt) variable_list
```

fmt is again a format specification, and *u* is a *unit number*, a number associated with a file (see next section).

(In Fortran 90, the “unit=” and “fmt=” in the read and write statements above are in principle not required – if they are omitted, the unit number has to be the first argument, and the format specification the second argument-, but they enhance readability. In F, the “unit=” and “fmt=” are required.)

Several optional specifiers can be specified as well, one of them is *iostat*, which can be used to recover from errors while reading or writing (it is very useful for checking errors while reading a file):

```
read (unit=u, fmt=fmt, iostat=ios) variable_list
write (unit=u, fmt=fmt, iostat=ios) variable_list
```

Here, *ios* must be an integer variable. If no errors occurred during reading or writing, the integer variable is set to 0, a positive integer means an error occurred, and a negative integer means an end-of-file condition occurred.

File handling

Most programs need to receive information, and need to output data. So far, we used the keyboard and screen to input and output information. However, other devices, such as a disk, tape, or cartridge, can be used as well. A collection of data on any of these devices is a *file*. To make a file available to the program (so that the program can read data from, or write data to the file), it must be assigned a unit number. The **open** statement is used for this.

The open statement has the following form:

```
open (unit=u, file=filename, status=st, action=act)
```

- The unit number *u* is a positive integer (or integer expression). This specifier is required.



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- The *filename* is a character expression giving the name of the file. The `file` specifier is required if the status is “old”, “new”, or “replace”, and it must *not* appear if the status is “scratch”.
- The action *act* is a character expression as well; it can be “read” (file cannot be written into), “write” (cannot read from the file) or “readwrite” (no read and write restrictions).

These are the most common specifiers for the open statement (and are all required in F, but note that the filename must not be specified if the `status` is “scratch”). There are optional specifiers as well (`access`, `iostat`, `form`, `recl`, and `position`). The most useful of these is probably `iostat`, which should be set to an integer variable. This variable is set to zero if the open statement is correctly executed, and is set to a positive integer if an error occurred.

Unit numbers cannot be negative, and often the range 1-99 is allowed (although this is processor-specific). Generally, 5 is connected with console input, and 6 with output to screen. The unit number 0 is also often special. Thus, don't use 0, 5, and 6 for external files (files on disk).

We can read from and write to a disk file, if this file is opened and assigned a unit number:

```
write (unit=8, fmt = "(a2, 3(f10.6) )") atom_type, x, y, z
```

When a file is not longer needed, it should be closed. The `close` statement disconnects a file from a unit. The syntax is:

```
close (unit=u, iostat=ios, status=st)
```

The unit and `iostat` specifiers have the same meaning as above, `status` can be “keep” (the file will still exist after execution of this statement) or “delete” (the file will be deleted). Only the unit specifier is required. If the status is not specified it is “keep”, except for scratch files, for which it is “delete”.

An example:

```
program file_example
  implicit none
  integer :: ierror
  open (unit=13, file="test.dat", status="new", action="write", iostat=ierror)
  if (ierror /= 0) then
    print*, "Failed to open test.dat"
  stop
```

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This program creates a file called test.dat, opens it for writing, and writes a message into the file. After execution of the program the file will still exist. If the open failed, then execution of the program is stopped. It is good programming practice to test if the open statement was successful. If it had failed, the program would have crashed when it tried to write into it.

Internal files

A unit that is associated with an external device (like for example keyboard, screen, disk, or cartridge) is an *external file*. There are also *internal files*, and `read` and `write` can also read from and write into these. An internal file is a character variable. Contrary to external files, an internal file is not connected with a unit number.

Example:

```
character (len=8) :: word
character (len=2) :: ww
integer :: ierror

write (unit=word, fmt="(a)", iostat=ierror) "aabbccdd"
! the character variable "word" now contains the letters aabbccdd

read (unit=word, fmt="(a2)", iostat=ierror) ww
! the character variable "ww" now contains the letters aa
```

String manipulation functions

The following intrinsic functions to manipulate strings can be very useful:

trim

`trim (string)`: returns the string with trailing blanks removed (the length of the string will be reduced)

adjustl

`adjustl (string)`: removes leading blanks, and appends them to the end (so the length of the string remains constant).

adjustr

`adjustr (string)`: removes trailing blanks, and inserts them at the front of the string.

index

`index (string, substring)`: returns the starting position of a substring in a string, or zero if the substring does not occur in the string.

len

`len (string)` returns an integer with the value of the length of the string.

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Examples:

In the following examples, *b* denotes a blank character.

trim (“*bbStringbb*”) gives “*bbString*”
 adjustl (“*bbTanjab*”) gives “*Tanjab*”
 adjustr (“*Wordbbbb*”) gives “*bbbbWord*”
 index (“*Tanja van Mourik*”, “*van*”) yields 7.
 len_trim (*Tanjabbbb*) yields 5.

In the following example the program reads a file and uses the intrinsic `index` to search for the occurrence of the word “energy”:

```
!! Example for reading an output file
program readout
  implicit none
  integer, parameter :: linelength = 120
  character (len=linelength) :: line
  integer :: ierror

  open (unit=10, file="test.dat", action ="read", status="old", iostat=ierror)
  if ( ierror /= 0 ) then
    print*, "Failed to open test.dat!"
    stop
  end if

  readfile : do
    read (unit=10, fmt="(a)", iostat=ierror) line

    if (ierror < 0 ) then
      print*, "end of file reached"
      exit readfile

    else if (ierror > 0) then
      print*, "Error during read"
      exit readfile

    else
      ! line has been read successfully
      ! check if it contains energy
      if (index (line, "energy") > 0) then
        print*, "energy found!"
      end if
    end if
  end do
end program readout
```



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The program reads the file “test.dat” line by line in the “endless” do loop readfile. Each time a line is read in, the program checks if the end of the file has occurred, or if an error occurred during reading. If either of these happened, then the do loop is exited.

Summary

In this chapter we learned formatted input/output and how to deal with files.

Exercises

17. Write a program with a function to eliminate blank characters from a string.
18. Gaussian is a well-known quantum chemical program package. The output of a calculation, for example a geometry optimisation using the MP2 (2nd-order Møller-Plesset) method, contains a lot of data. Most of it is not very useful, and you may just be interested in the final optimised energy.

Write a program that reads a Gaussian output file of an MP2 geometry optimisation, checks if the optimisation finished, and prints the optimised energy to another file. If you have access to Gaussian, create an output of a geometry optimisation (for example, H₂O using MP2 and the 6-31G* basis set), otherwise create a file that has the characteristics specified below, and test your program.

After each geometry optimisation cycle, the energy is printed in a line like:

```
E2 = -0.1199465917D+01 EUMP2 = -0.48968224768908D+03
```

(The actual numbers of course depend on molecule, basis set, optimisation cycle). The MP2 energy is the one labelled EUMP2.

When the geometry optimisation is finished, the program prints “Optimization completed”. This happens after the last (optimised) energy is listed.

(Alternatively, do the above using the output of your favourite computational chemistry program. If you do this, then provide an example of such an output with the solution to this exercise.)

8 Pointers

Pointers

The value of a particular data object, for example a real or an array, is stored somewhere in the computer’s memory. Computer memory is divided into numbered memory locations. Each variable is located at a unique memory location, known as its address. Some objects require more storage space than others, so the address points to the starting location of the object. There is a clear distinction between the object’s value and its

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A pointer variable is declared with the pointer attribute. A pointer variable that is an array must be a *deferred-shape array*. In a deferred-shape array, only the rank (the number of dimensions) is specified. The bounds are specified by just a colon. The extent of the array in each dimension (*i.e.*, number of elements along a dimension) is determined when the pointer is allocated or assigned – see below.

```
integer, pointer :: p           ! pointer to integer
real, pointer, dimension (:) :: rp    ! pointer to 1-dim real array
real, pointer, dimension (:,:) :: rp2 ! pointer to 2-dim real array
```

In contrast to a normal data object, a pointer has initially no space set aside for its contents. It can only be used after space has been associated with it. A target is the space that becomes associated with the pointer.

A pointer can point to:

- an area of dynamically allocated memory, as illustrated in the next section.
- a data object of the same type as the pointer, with the **target** attribute (see section on targets below)

Allocating space for a pointer

Space for a pointer object can be created by the **allocate** statement. This is the same statement we used before to allocate space for dynamic arrays (see Chapter 5).

```
program pointer1
  implicit none
  integer, pointer :: p1

  allocate (p1)
  p1 = 1

end program pointer1
```

The statement

```
integer, pointer :: p1
```

declares the pointer p1, but at this point it is not associated with a target. The **allocate** statement reserves space in memory. This space is the target that the pointer is now associated with.

After the statement

```
p1 = 1
```

the value of the target is 1.



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optimisation by the compiler. It is useful for the compiler to know that a variable that is not a pointer or a target cannot be associated to a pointer. Only an object with the **target** attribute can become the target of a pointer.

The program in the previous section can be rewritten as follows:

```

program pointer2
  implicit none
  integer, pointer :: p1
  integer, target :: t1

  p1 => t1
  p1 = 1
end program pointer2
    
```

After the statement

```
p1 => t1
```

p1 acts as an alias of t1. Changing p1 has the effect of changing t1 as well.

Association

The *association status* of a pointer can be *undefined*, *associated* and *disassociated*. If the association status is not undefined, it can be tested by the function **associated**. The function has 2 forms:

associated (ptr) returns the value true if the pointer **ptr** is associated with a target, and false otherwise.

associated (ptr, trgt) returns true if the pointer **ptr** is associated with the target **trgt**, and false otherwise.

So in the program in the previous section *before* the statement

```
p1 => t1
```

the association status is undefined, but *after* it both

associated (p1) and **associated (p1, t1)** would return true.

A pointer can be explicitly disassociated from a target by the **nullify** statement:

```
nullify (ptr)
```

It is a good idea to nullify pointers instead of leaving their status undefined, because they can then be tested with the **associated** function.

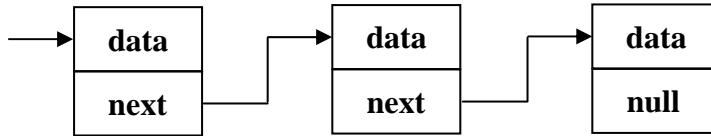


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linked lists, double-linked lists, binary trees). Here we will discuss the simplest, and most common of those, the single-linked list (usually referred to simply as a linked list).

Each element (also called node or link) of a linked list is an object of derived type that consists of a part with data and a pointer to the next object of the same list:



The pointer is of the same type as the other elements of the list. The derived type can for example be something like:

```
type node
  integer :: i
  real :: value
  type (node), pointer :: next
end type node
```

Linked lists are not unlike arrays, but there are differences. Linked lists can be allocated dynamically, so you don't need to know before the program is executed how many elements are needed (this also saves memory space). The size of the list can change during execution (links can be added and removed), and links can be added at any position in the list. The links are not necessarily stored contiguously in memory.

The "next" pointer of the last link in the list should be nullified. You also need a pointer (often referred to as *head pointer*) that refers to the first item in the list.

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Consider the following example:

```

program linkedlist
  implicit none
  type :: link
    integer :: i
    type (link), pointer :: next
  end type link

  type (link), pointer :: first, current
  integer :: number

  nullify (first)
  nullify (current)

  ! read in a number, until 0 is entered
  do

    read*, number

    if (number == 0) then
      exit
    end if

    allocate (current)           ! create new link
    current%i = number
    current%next => first       ! point to previous link
    first => current           ! update head pointer

  end do

  ! print the contents of the list
  current => first              ! point to beginning of the list
  do

    if (.not. associated (current)) then ! end of list reached
      exit
    end if

    print*, current%i
    current => current%next       ! go the next link in the list

  end do
end program linkedlist

```

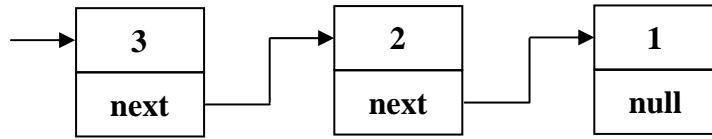


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Thus, if the numbers 1, 2, and 3 are entered (in this order) the list will look like:



The contents of the list are printed in the second do loop. We start at the beginning of the list (`current => first`), and go from one link to the next (`current => current%next`), until the end of the list is reached (indicated by a not associated next pointer).

Exercises

19. Create a linked list. Each link contains a real number, which is read from screen in a do loop. After a number is read in, a new link must be created and added to the list in such a way that the list is sorted (*i.e.*, with increasing (or decreasing) values for the numbers). Preferably, adding the new link is done in a subroutine. Make also a subroutine to print the list, so you can check your program. To add the new link at the appropriate position in the list, you need to distinguish between the following cases:

- First link. (Can be found out by the association status of the head pointer). If it's the first link, create the new link and make the head pointer point to the new link. (Don't forget to nullify the next pointer.)
- Adding to the beginning. If the new number is smaller than the number in the first link, the new link needs to be the first one.
- Second link that should not be before the first one. If you are adding the second link can be found out by testing the association status of the next pointer of the first link. The next pointer of the first link should point to the new link.
- Adding to the middle. To find out where the new link has to be added to the list, you have to go through the list (in a similar way as in the second do loop in the example above), and compare the new number with the ones in the existing links. You need to keep track of three links: the new link, the current link (which is the one that goes through the list as in the example above), and the previous link. You should test if the new link should be added before the current one, and if so, the previous link has to point to the new one (that's why you need the previous link as well), and the new link has to point to the current link.
- Before or after the last link. If the end of the list is reached, then you know that the new link should be added either directly before, or after the last link.



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9 Numeric Precision

Fortran 90 allows the programmer to specify the required precision of *real* variables. If we declare the *real* variable *x*:

```
real :: x
```

then the *x* is represented with the default precision for the processor used. This precision can vary from computer to computer, depending on, among other things, the word length of the processor. Thus, a *real* will be more accurately represented on a 64-bit than on a 32-bit processor. In FORTRAN 77, the precision of *real* variables could be increased by using *double precision* for *reals*, which use two words instead of one to represent the numbers. In Fortran 90, the types *integer*, *real*, *complex* and *logical* have a “default kind” and a number of other kinds. How many other kinds there are for a certain type depends on the particular processor. Each kind has its own *kind type parameter*, which is a integer of positive value. For example, if, for a certain processor, a kind value of 8 yields a precision equivalent to the old *double precision* type of FORTRAN 77, then the following statement

```
real (kind = 8) :: x1
```

is equivalent to the FORTRAN 77 statement

```
double precision x1
```

However, this is not very portable, because the required kind value may be different on another computer. Although many computers use kind values that indicate the number of bytes used for storage of the variable, you cannot rely on this.

Fortran 90 has two intrinsic functions to obtain the kind value for the required precision of integers and reals: `selected_int_kind` and `selected_real_kind`, respectively.

The `selected_real_kind` function returns an integer that is the kind type parameter value necessary for a given decimal precision *p* and decimal exponent range *r*. The decimal precision is the number of significant digits, and the decimal exponent range specifies the smallest and largest representable number. The range is thus from 10^{-r} to 10^{+r} .

As an example:

```
ikind = selected_real_kind (p = 7, r = 99)
```

The integer *ikind* now contains the kind value needed for a precision of 7 decimal places, and a range of at least 10^{-99} to 10^{+99} .



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The function `selected_real_kind` can be used in a number of different forms:

```
! if both precision and range are specified, the "p =" and "r =" are not needed
! the following two statements are therefore identical
    ikind = selected_real_kind (p = 7, r = 99)
    ikind = selected_real_kind (7, 99)

! If only the range is specified, the "r =" is needed
    ikind = selected_real_kind (r = 99)

! if only one argument is used, it is the precision
! the following two statements are therefore identical
    ikind = selected_real_kind (p = 7)
    ikind = selected_real_kind (7)
```

If you want to use the `ikind` value in a type declaration statement, it has to be a constant (*i.e.*, declared with the `parameter` attribute). The real variable `x` declared in the following statement is precise to 7 decimal places, and has a range of at least 10^{-99} to 10^{+99} .

```
integer, parameter :: ikind = selected_real_kind (7, 99)
real (kind = ikind) :: x
```

If the kind value for the required precision or range is not available, a negative integer is returned.

The `selected_int_kind` function returns the lowest kind value needed for integers with the specified range:

```
integer, parameter :: ikind = selected_int_kind (10)
integer (kind = ikind) :: big_number
```

The integer `big_number` can now represent numbers from 10^{-10} to 10^{+10} . As for `selected_real_kind`, if the kind value for the required range is not available, a negative integer is returned.

Exercises

- Write a program that declares a real with a precision of at least 7 decimal places and an integer that can represent the number 1000000000000.

10 Scope and Lifetime of Variables

Local variables in subroutines

The *scope* of an entity is that part of the program in which it is valid. The scope can be as large as the whole program, or as small as (part of) a single statement. Variables defined



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In the following example the variable `int1` in the main program is *not* the same as `int1` in the subroutine `sub1` (they occupy different memory locations), and thus, the print statement in the main program would print 0 (and not 1).

```

program scope
  implicit none
  integer :: int1

  int1 = 0
  call sub1
  print*, int1
end program scope

subroutine sub1
  implicit none
  integer :: int1

  int1 = 1
  print*, int1
end subroutine sub1
    
```

The variable `int1` in the subroutine `sub1` goes out of scope at the end of the subroutine *i.e.*, it then does not exist anymore. Consider the following example:

```

program scope
  implicit none

  call sub1 (.true.)
  call sub1 (.false.)
end program scope

subroutine sub1 (first)
  implicit none
  logical, intent (in) :: first
  integer :: int1

  if (first) then
    int1 = 0
  else
    int1 = int1 + 1
  end if
end subroutine sub1
    
```

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variable in a subroutine needs to be kept between successive calls to the subroutine, it should be given the attribute `save`:

```
subroutine sub1 (first)
  implicit none
  logical, intent (in) :: first
  integer, save :: int1
  [ ... ]
end program sub1
```

Note that initialisation of a variable in the declaration or in a `data` statement implicitly gives it the `save` status. However, it is clearer to explicitly include the `save` attribute also in these cases:

```
integer, save :: int1 = 0
```

One should not give a variable the `save` attribute if it does not need it, as it may impede optimisation by the compiler and it also makes *e.g.*, parallelisation more difficult.

Variables in modules

The lifetime of a variable declared in a module is as long as any routine using this module is running. Consider the following example:

```
module mod1
  implicit none
  integer :: int1
end module mod1
subroutine sub1 (first)
  use mod1
  implicit none
  logical, intent (in) :: first
  if (first) then
    int1 = 0
  else
    int1 = int1 + 1
  end if
end subroutine sub1
```

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The integer `int1` does not need to be declared in `sub1`, because it is already declared in the module `mod1` (and `sub1` uses the module). However, at the end of the subroutine, `int1` goes out of scope (because there is not a subprogram anymore that uses the module `mod1`), and one cannot rely on `int1` containing the number 0 the second time `sub1` is called. So the above program is actually wrong (although it may work with some compilers). To make the above program standard conforming, one would have to either use the module in the main program (in addition to using it in the subroutine), or declare `int1` with the `save` attribute.

11 Debugging

Debuggers

You have probably been using `write` or `print` statements to figure out why a program gives wrong results. The larger the program gets, the more cumbersome it is to search for errors like this. Debuggers are a much more powerful tool for stepping through the code and examining values.

A debugger lets you see each instruction in your program and lets you examine the values of variables and other data objects during execution of the program. The debugger loads the source code, and you run your program from within the debugger.

Most operating systems come with one compiler or the other. Graphical programming environments like Visual Fortran come with an integrated debugger. Full screen debuggers generally show the source code in a separate window.

Most debuggers have the following capabilities:

- Setting breakpoints. A breakpoint tells the debugger at which line the program should stop. Breakpoints allow analysis of the status of variables just before and after a critical line of code. Execution can be resumed after the variables have been examined.
- Stepping through a part of the source code line by line.
- Setting watch points. The debugger can show the value of a variable while the program is running, or break when a particular variable is read or written to.

To produce the information needed for the debugger the program should be compiled with the appropriate compiler flag (generally `-g`).

`gdb`

The GNU debugger, generally comes with Linux. `Xxgdb` is a graphical user interface to `gdb` for X window systems.

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Look at the man pages for more information on gdb.

dbx

The run, cont, next and step commands are the same as in gdb. Breakpoints can be set with stop:

stop [var] stops execution when the value of variable *var* changes
stop in [proc] stops execution when the procedure *proc* is entered.
Stop at [line] sets a breakpoint at the specified line.

Look at the man pages for more information on dbx.

Exercises

21. Find an appropriate debugger on your computer. Recompile one of your programs with the debugger option specified. Use the debugger to step through the program. Set a few breakpoints and examine the value of variables during execution of the program.

Object-Oriented Programming

To discuss the object-oriented (OO) paradigm is beyond the scope of this manual, particular because Fortran is *not* an OO language. (Two of the most well-known OO languages are C++ and Java). However, object-oriented thinking is gaining ground in the programming world, and also Fortran 90 does support (or simulate) some of the OO ideas.

An “object” in a program is supposed to resemble a real-world object (like for example an animal, or a molecule). It has characteristics that distinguish it from other objects, and it can “behave” like its real-world counterpart. In Fortran 90 objects can be modelled with modules. Modules can contain data to define the characteristics of the object, and procedures to manipulate this data.

The four concepts of object-oriented programming are Data Encapsulation, Data Abstraction, Inheritance and Polymorphism. To be an object-oriented language, a language must support all four object-oriented concepts.

Fortran is in principle a “structured” programming language, but Fortran 90 does support some of the ideas of object-oriented thinking. Fortran 90’s modules support data abstraction (grouping together of data and actions that are related to a single entity), data encapsulation (the process of hiding data within an “object”, and allowing access to this data only through special procedures or member functions), but it lacks inheritance (deriving subclasses from a more general data type). Polymorphism refers to the ability to process objects differently depending on their data type (by redefinition of “methods” for derived types) and to the ability to perform the same operation on objects of different

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To learn more about the OO paradigm, see for example:

“Object-Oriented Programming: A New Way of Thinking”

Donald W. and Lori A. MacVittie

CBM Books 1996.

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