Introduction to structured programming with `Fortran`

https://gogs.elic.ucl.ac.be/pbarriat/learning-fortran

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CISM/CÉCI Training Sessions

Fortran : shall we start ?

- You know already one computer language ?
- You understand the very basic programming concepts :
  - What is a variable, an assignment, function call, etc.?
  - Why do I have to compile my code?
  - What is an executable?
- You (may) already know some Fortran ?
- How to proceed from old Fortran, to much more modern languages like Fortran 90/2003 ?

Why to learn Fortran ?

- Because of the execution `speed` of a program
- Well suited for numerical computations :
  more than 45% of scientific applications are in Fortran
- `Fast` code : compilers can optimize well
- Optimized `numerical libraries` available
- Fortran is a `simple` langage and it is (kind-of) `easy to learn`

Fortran is simple

- **We want to get our science done! Not learn languages!**
- How easy/difficult is it really to learn Fortran ?
- The concept is easy:
  variables, operators, controls, loops, subroutines/functions
- **Invest some time now, gain big later!**

History

FORmula **TRAN**slation

> invented 1954-8 by John Backus and his team at IBM

- FORTRAN 66 (ISO Standard 1972)
- FORTRAN 77 (1978)
- Fortran 90 (1991)
- Fortran 95 (1997)
- Fortran 2003 (2004) → `"standard" version`
- Fortran 2008 (2010)
- Fortran 2018 (11/2018)

Starting with Fortran 77

- Old Fortran provides only the absolute minimum!
- Basic features :
  data containers (integer, float, ...), arrays, basic operators, loops, I/O, subroutines and functions
- But this version has flaws:
  no dynamic memory allocation, old & obsolete constructs, “spaghetti” code, etc.
- Is that enough to write code ?

Fortran 77 → Fortran >90

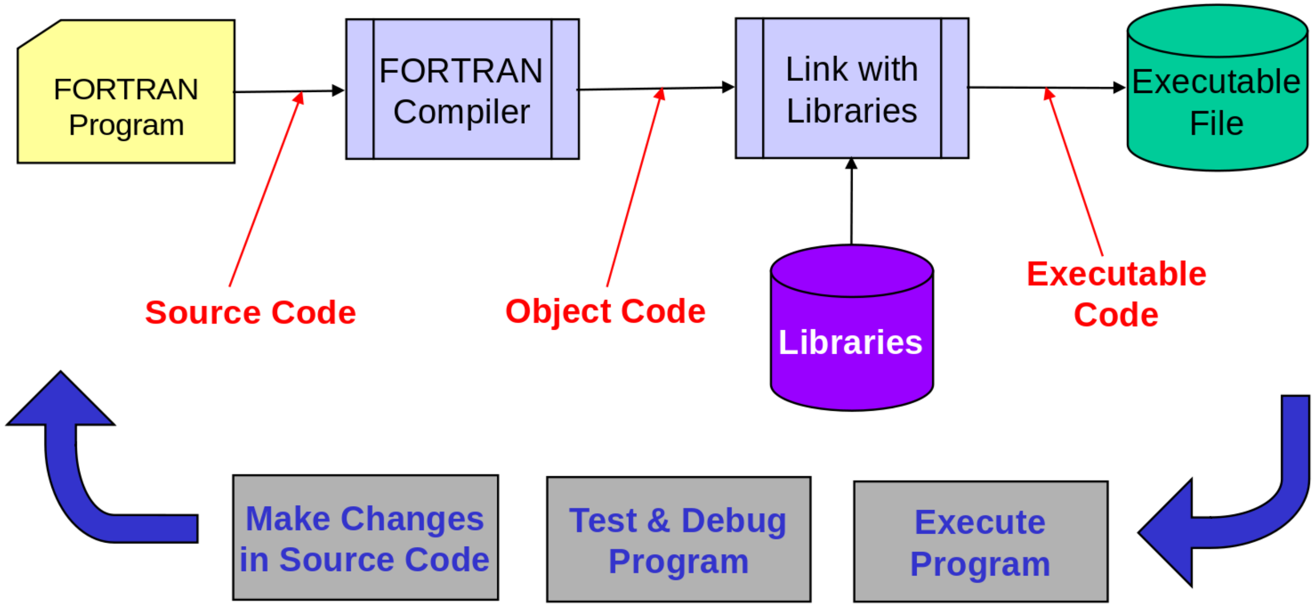
- If Fortran 77 is so simple, why is it then so difficult to write good code?
- Is simple really better?

  ⇒ Using a language allows us to express our thoughts (on a computer)
- A more sophisticated language allows for more complex thoughts
- More language elements to get organized

  ⇒ Fortran 90/95/2003 (recursive, OOP, etc)

How to Build a FORTRAN Program

FORTRAN is a compiled language (like C) so the source code (what you write) must be converted into machine code before it can be executed (e.g. Make command)



Fortran 77 source code hello_world.f

FORTRAN 77 Format

This version requires a fixed format for programs

```
      PROGRAM MAIN
C COMMENTS ARE ALLOWED IF A “C” IS PLACED IN COLUMN #1
      DIMENSION X(10)
      READ(5,*) (X(I),I=1,10)
      WRITE(6,1000) X
 1000 FORMAT(1X,’THIS IS A VERY LONG LINE OF TEXT TO SHOW HOW TO CONTINUE ’
     *  ‘THE STATEMENT TO A SECOND LINE’,/,10F12.4)
```

1-5 Label | 6 | 7-72 Statements | 73-80 Optional Line #s

Any character: continuation line

- max length variable names is 6 characters
- alphanumeric only, must start with a letter
- character strings are case sensitive

FORTRAN >90 Format

Versions >90 relaxe these requirements:

- comments following statements (! delimiter)
- long variable names (31 characters)
- containing only letters, digits or underscore
- max row length is 132 characters
- can be max 39 continuation lines
- if a line is ended with ampersand (&), the line continues onto the next line
- semicolon (;) as a separator between statements on a single line
- allows free field input

Program Organization

Most FORTRAN programs consist of a main program and one or more subprograms

There is a fixed order:

```
Heading
Declarations
Variable initializations
Program code
Format statements

Subprogram definitions
(functions & subroutines)
```

Data Type Declarations

Basic data types are :

- `INTEGER` : integer numbers (+/-)
- `REAL` : floating point numbers
- `DOUBLE PRECISION` : extended precision floating point
- `CHARACTER*n` : string with up to **n** characters
- `LOGICAL` : takes on values `.TRUE.` or `.FALSE.`

Data Type Declarations

`INTEGER` and `REAL` can specify number of bytes to use

- Default is: `INTEGER*4` and `REAL*4`
- `DOUBLE PRECISION` is same as `REAL*8`

Arrays of any type must be declared:

- `DIMENSION A(3,5)` - declares a 3 x 5 array
- `CHARACTER*30 NAME(50)` - directly declares a character array with 30 character strings in each element

Implicit vs Explicit Declarations

By default, an implicit type is assumed depending on the first letter of the variable name:

- `A-H, O-Z` define REAL variables
- `I-N` define INTEGER variables

Can use the IMPLICIT statement:

```
IMPLICIT REAL (A-Z)
```

> makes all variables REAL if not declared

Implicit vs Explicit Declarations

```
IMPLICIT CHARACTER*2 (W)
```

> makes variables starting with W be 2-character strings

```
IMPLICIT DOUBLE PRECISION (D)
```

> makes variables starting with D be double precision

Good habit: force explicit type declarations

```
IMPLICIT NONE
```

> user must explicitly declare all variable types

Assignment Statements

Old assignment statement: `<label> <variable> = <expression>`

- `<label>` : statement label number (1 to 99999)
- `<variable>` : FORTRAN variable
  (max 6 characters, alphanumeric only for standard FORTRAN 77)

Expression:

- Numeric expressions: `VAR = 3.5*COS(THETA)`
- Character expressions: `DAY(1:3) = 'TUE'`
- Relational expressions: `FLAG = ANS .GT. 0`
- Logical expressions: `FLAG = F1 .OR. F2`

Numeric Expressions

Arithmetic operators: precedence: `**` *(high)* → `-` *(low)*

Operator	Function
`**`	exponentiation
`*`	multiplication
`/`	division
`+`	addition
`-`	subtraction

Numeric Expressions

Numeric expressions are up-cast to the highest data type in the expression according to the precedence:

(low) logical → integer → real → complex *(high)*

and smaller byte size *(low)* to larger byte size *(high)*

Examples:

> Fortran 77 source code arith.f
> Fortran 77 source code sphere.f

Character Expressions

Only built-in operator is **Concatenation** defined by `//`

```
'ILL'//'-'//'ADVISED'
```

`character` arrays are most commonly encountered

- treated like any array (indexed using : notation)
- fixed length (usually padded with blanks)

Character Expressions

Example:

```
CHARACTER FAMILY*16
FAMILY = ‘GEORGE P. BURDELL’

PRINT*,FAMILY(:6)
PRINT*,FAMILY(8:9)
PRINT*,FAMILY(11:)
PRINT*,FAMILY(:6)//FAMILY(10:)
```

```
GEORGE
P.
BURDELL
GEORGE BURDELL
```

Relational Expressions

Two expressions whose values are compared to determine whether the relation is true or false

- may be numeric (common) or non-numeric

`character` strings can be compared

- done character by character
- shorter string is padded with blanks for comparison

Relational Expressions

Operator	Relationship
`.LT.` or `<`	less than
`.LE.` or `<=`	less than or equal to
`.EQ.` or `==`	equal to
`.NE.` or `/=`	not equal to
`.GT.` or `>`	greater than
`.GE.` or `>=`	greater than or equal to

Logical Expressions

Consists of one or more logical operators and logical, numeric or relational operands

- values are `.TRUE.` or `.FALSE.`
- need to consider overall operator precedence

> can combine logical and integer data with logical operators but this is tricky (**avoid!**)

Logical Expressions

<table>
<tr><th>F77 Operator</th><th>>F90 Operator</th><th>Example</th><th>Meaning</th></tr>
<tr><td><code>.AND.</code></td><td><code>&&</code></td><td><code>A .AND. B</code></td><td>logical <code>AND</code></td></tr>
<tr><td><code>.OR.</code></td><td><code>||</code></td><td><code>A .OR. B</code></td><td>logical <code>OR</code></td></tr>
<tr><td><code>.EQV.</code></td><td><code>==</code></td><td><code>A .EQV. B</code></td><td>logical equivalence</td></tr>
<tr><td><code>.NEQV.</code></td><td><code>/=</code></td><td><code>A .NEQV. B</code></td><td>logical inequivalence</td></tr>
<tr><td><code>.XOR.</code></td><td><code>/=</code></td><td><code>A .XOR. B</code></td><td>exclusive <code>OR</code> (same as <code>.NEQV.</code>)</td></tr>
<tr><td><code>.NOT.</code></td><td><code>!</code></td><td><code>.NOT. A</code></td><td>logical negation</td></tr>
</table>

Arrays in FORTRAN

Arrays can be multi-dimensional (up to 7 in F77) and are indexed using `( )`:

- `TEST(3)` or `FORCE(4,2)`

> Indices are by default defined as `1...N`

We can specify index range in declaration

- `INTEGER K(0:11)` : `K` is dimensioned from `0-11` (12 elements)

Arrays are stored in column order (1st column, 2nd column, etc) so accessing by incrementing row index first usually is fastest

Whole array reference (only in >F90): `K(:)=-8` assigns 8 to all elements in K

> Avoid `K=-8` assignement

Unconditional `GO TO` in F77

This is the only GOTO in FORTRAN 77

- Syntax: `GO TO label`
- Unconditional transfer to labeled statement

```
 10   -code-
      GO TO 30
      -code that is bypassed-
 30   -code that is target of GOTO-
      -more code-
      GO TO 10
```

- **Problem** : leads to confusing *"spaghetti code"* 💥

`IF ELSE IF` Statement

Basic version:

```
IF (KSTAT.EQ.1) THEN
  CLASS='FRESHMAN'
ELSE IF (KSTAT.EQ.2) THEN
  CLASS='SOPHOMORE'
ELSE IF (KSTAT.EQ.3) THEN
  CLASS='JUNIOR'
ELSE IF (KSTAT.EQ.4) THEN
  CLASS='SENIOR'
ELSE
  CLASS='UNKNOWN'
ENDIF
```

Spaghetti Code in F77 (and before)

Use of `GO TO` and arithmetic `IF`'s leads to bad code that is very hard to maintain

Here is the equivalent of an `IF-THEN-ELSE` statement:

```
10  IF (KEY.LT.0) GO TO 20
    TEST=TEST-1
    THETA=ATAN(X,Y)
    GO TO 30
20  TEST=TEST+1
    THETA=ATAN(-X,Y)
30  CONTINUE
```

Now try to figure out what a complex `IF ELSE IF` statement would look like coded with this kind of simple `IF`...

Loop Statements (old versions)

`DO` loop: structure that executes a specified number of times

Spaghetti Code Version

```
      K=2
 10   PRINT*,A(K)
      K=K+2
      IF (K.LE.11) GO TO 10
 20   CONTINUE
```

F77 Version

```
      DO 100 K=2,10,2
      PRINT*,A(K)
100   CONTINUE
```

Loop Statements (>F90)

```
DO K=2,10,2
  WRITE(*,*) A(K)
END DO
```

- Loop _control can include variables and a third parameter to specify increments, including negative values
- Loop always executes ONCE before testing for end condition

```
READ(*,*) R
DO WHILE (R.GE.0)
  VOL=2*PI*R**2*CLEN
  READ(*,*) R
END DO
```

- Loop will not execute at all if logical_expr is not true at start

Comments on Loop Statements

In old versions:

- to transfer out (exit loop), use a `GO TO`
- to skip to next loop, use `GO TO` terminating statement (this is a good reason to always make this a `CONTINUE` statement)

In new versions:

- to transfer out (exit loop), use `EXIT` statement and control is transferred to statement following loop end. This means you cannot transfer out of multiple nested loops with a single `EXIT` statement (use named loops if needed - `myloop : do i=1,n`). This is much like a `BREAK` statement in other languages.
- to skip to next loop cycle, use `CYCLE` statement in loop.

File-Directed Input and Output

Much of early FORTRAN was devoted to reading input data from Cards and writing to a line printer

Today, most I/O is to and from a file: it requires more extensive I/O capabilities standardized until FORTRAN 77

I/O = communication between a program and the outside world

- opening and closing a file with `OPEN` & `CLOSE`
- data reading & writing with `READ` & `WRITE`
- can use **unformatted** `READ` & `WRITE` if no human readable data are involved (much faster access, smaller files)

> Fortran 77 source code plot.f

`OPEN` & `CLOSE` example

Once opened, file is referred to by an assigned device number (a unique id)

```
character(len=*) :: x_name
integer          :: ierr, iSize, guess_unit
logical          :: itsopen, itexists
!
inquire(file=trim(x_name), size=iSize, number=guess_unit, opened=itsopen, exist=itexists)
if ( itsopen ) close(guess_unit, status='delete')
!
open(902,file=trim(x_name),status='new',iostat=ierr)
!
if (iSize <= 0 .OR. .NOT.itexists) then
  open(902,file=trim(x_name),status='new',iostat=ierr)
  if (ierr /= 0) then
    ...
    close(902)
  endif
  ...
endif
```

`READ` Statement

- syntax: `READ(dev_no, format_label) variable_list`
- read a record from `dev_no` using `format_label` and assign results to variables in `variable_list`

```
      READ(105,1000) A,B,C
1000  FORMAT(3F12.4)
```

> device numbers 1-7 are defined as standard I/O devices

- each `READ` reads one or more lines of data and any remaining data in a line that is read is dropped if not translated to one of the variables in the `variable_list`
- `variable_list` can include implied `DO` such as: `READ(105,1000)(A(I),I=1,10)`

`READ` Statement - cont'd

- input items can be integer, real or character
- characters must be enclosed in `' '`
- input items are separated by commas
- input items must agree in type with variables in `variable_list`
- each `READ` processes a new record (line)

```
INTEGER K
REAL(8) A,B
OPEN(105,FILE='path_to_existing_file')
READ(105,*) A,B,K
```

> read one line and look for floating point values for A and B and an integer for K

`WRITE` Statement

- syntax: `WRITE(dev_no, format_label) variable_list`
- write variables in `variable_list` to output `dev_no` using format specified in format statement with `format_label`

```
      WRITE(*,1000) A,B,KEY
1000 FORMAT(F12.4,E14.5,I6)
```

```
|----+----o----+----o----+----o----+----|
    1234.5678  -0.12345E+02     12
```

- device number `*` is by default the screen (or *standard output* - also 6)
- each `WRITE` produces one or more output lines as needed to write out `variable_list` using `format` statement
- `variable_list` can include implied `DO` such as: `WRITE(*,2000)(A(I),I=1,10)`

`FORMAT` Statement

data type	format descriptors	example
`integer`	`iw`	`write(*,'(i5)') int`
`real` (*decimal*)	`fw.d`	`write(*,'(f7.4)') x`
`real` (*exponential*)	`ew.d`	`write(*,'(e12.3)') y`
`character`	`a, aw`	`write(*,'(a)') string`
`logical`	`lw`	`write(*,'(l2)') test`
spaces & tabs	`wx` & `tw`	`write (*,'(i3,2x,f6.3)') i, x`
linebreak	`/`	`write (*,'(f6.3,/,f6.3)') x, y`

`NAMELIST`

It is possible to pre-define the structure of input and output data using `NAMELIST` in order to make it easier to process with `READ` and `WRITE` statements

- Use `NAMELIST` to define the data structure
- Use `READ` or `WRITE` with reference to `NAMELIST` to handle the data in the specified format

> This is not part of standard F77 but it is included in >F90

`NAMELIST` - cont'd

On input, the `NAMELIST` data must be structured as follows:

```
&INPUT
  THICK=0.245,
  LENGTH=12.34,
  WIDTH=2.34,
  DENSITY=0.0034
/
```

> Fortran 90 source code namelist.f90
>
> Namelist file namelist.def

Internal `WRITE` Statement

Internal `WRITE` does same as `ENCODE` in F77 : **a cast to string**

> `WRITE (dev_no, format_label) var_list`
> write variables in `var_list` to internal storage defined by character variable used as `dev_no` = default character variable (not an array)

```
INTEGER*4 J,K
CHARACTER*50 CHAR50
DATA J,K/1,2/
...
WRITE(CHAR50,*) J,K
```

Results:

```
CHAR50='    1      2'
```

Internal `READ` Statement

Internal `READ` does same as `DECODE` in F77 : **a cast from string**

> `READ (dev_no, format_label) var_list`
>
> read variables from internal storage specified by character variable used as
>
> `dev_no` = default character variable (not an array)

```
INTEGER K
REAL A,B
CHARACTER*80 REC80
DATA REC80/'1.2, 2.3, -5'/
...
READ(REC80,*) A,B,K
```

Results:

```
A=1.2, B=2.3, K=-5
```

Structured programming

Structured programming is based on subprograms (functions and subroutines) and control statements (like `IF` statements or loops) :

- structure the control-flow of your programs (eg, give up the `GO TO`)
- improved readability
- lower level aspect of coding in a smart way

It is a **programming paradigm** aimed at improving the quality, clarity, and access time of a computer program

Functions and Subroutines

`FUNCTION` & `SUBROUTINE` are subprograms that allow structured coding

- `FUNCTION`: returns a single explicit function value for given function arguments
  It's also a variable → so must be declared !
- `SUBROUTINE`: any values returned must be returned through the arguments (no explicit subroutine value is returned)
- functions and subroutines are **not recursive in F77**

Subprograms use a separate namespace for each subprogram so that variables are local to the subprogram

- variables are passed to subprogram through argument list and returned in function value or through arguments
- variables stored in `COMMON` may be shared between namespaces

Functions and Subroutines - cont'd

Subprograms must include at least one `RETURN` (can have more) and be terminated by an `END` statement

`FUNCTION` example:

```
REAL FUNCTION AVG3(A,B,C)
AVG3=(A+B+C)/3
RETURN
END
```

Use:

```
AV = WEIGHT*AVG3(A1,F2,B2)
```

> `FUNCTION` type is implicitly defined as REAL

Functions and Subroutines - cont'd

Subroutine is invoked using the `CALL` statement

```
SUBROUTINE AVG3S(A,B,C,AVERAGE)
AVERAGE=(A+B+C)/3
RETURN
END
```

Use:

```
CALL AVG3S(A1,F2,B2,AVR)
RESULT = WEIGHT*AVR
```

Any returned values must be returned through argument list

> Fortran 90 source code newton.f90

Arguments

Arguments in subprogram are `dummy` arguments used in place of the real arguments

- arguments are passed by **reference** (memory address) if given as *symbolic* the subprogram can then alter the actual argument value since it can access it by reference
- arguments are passed by **value** if given as *literal* (so cannot be modified)

```
CALL AVG3S(A1,3.4,C1,QAV)
```

> 2nd argument is passed by value - QAV contains result

```
CALL AVG3S(A,C,B,4.1)
```

> no return value is available since "4.1" is a value and not a reference to a variable!

Arguments - cont'd

- `dummy` arguments appearing in a subprogram declaration cannot be an individual array element reference, e.g., `A(2)`, or a *literal*, for obvious reasons!
- arguments used in invocation (by calling program) may be *variables*, *subscripted variables*, *array names*, *literals*, *expressions* or *function names*
- using symbolic arguments (variables or array names) is the **only way** to return a value (result) from a `SUBROUTINE`

> It is considered **BAD coding practice**, but functions can return values by changing the value of arguments
> This type of use should be strictly **avoided**!

Arguments - cont'd

The `INTENT` keyword (>F90) increases readability and enables better compile-time error checking

```
SUBROUTINE AVG3S(A,B,C,AVERAGE)
  IMPLICIT NONE
  REAL, INTENT(IN)    :: A, B
  REAL, INTENT(INOUT) :: C            ! default
  REAL, INTENT(OUT)   :: AVERAGE

  A = 10                              ! Compilation error
  C = 10                              ! Correct
  AVERAGE=(A+B+C)/3                   ! Correct
END
```

> Compiler uses `INTENT` for error checking and optimization

`FUNCTION` versus Array

`REMAINDER(4,3)` could be a 2D array or it could be a reference to a function

If the name, including arguments, **matches an array declaration**, then it is taken to be an array, **otherwise**, it is assumed to be a `FUNCTION`

Be careful about `implicit` versus `explicit` type declarations with `FUNCTION`

```
PROGRAM MAIN
  INTEGER REMAINDER
  ...
  KR = REMAINDER(4,3)
  ...
END

INTEGER FUNCTION REMAINDER(INUM,IDEN)
  ...
END
```

Arrays with Subprograms

Arrays present special problems in subprograms

- must pass by reference to subprogram since there is no way to list array values explicitly as literals
- how do you tell subprogram how large the array is ?

> Answer varies with FORTRAN version and vendor (dialect)...

When an array element, e.g. `A(1)`, is used in a subprogram invocation (in calling program), it is passed as a reference (address), just like a simple variable

When an array is used by name in a subprogram invocation (in calling program), it is passed as a reference to the entire array. In this case the array must be appropriately dimensioned in the subroutine (and this can be tricky...)

Arrays - cont'd

Data layout in multi-dimensional arrays

- always increment the left-most index of multi-dimensional arrays in the innermost loop (i.e. fastest)
- **column major** ordering in Fortran vs. **row major** ordering in C
- a compiler (with sufficient optimization flags) may re-order loops automatically

```
do j=1,M
  do i=1,N ! innermost loop
    y(i) = y(i)+ a(i,j)*x(j) ! left-most index is i
  end do
end do
```

Arrays - cont'd

- dynamically allocate memory for arrays using `ALLOCATABLE` on declaration
- memory is allocated through `ALLOCATE` statement in the code and is deallocated through `DEALLOCATE` statement

```
integer :: m, n
integer, allocatable :: idx(:)
real, allocatable :: mat(:,:)
m = 100 ; n = 200
allocate( idx(0:m-1))
allocate( mat(m, n))
...
deallocate(idx , mat)
```

> It exists many array intrinsic functions: SIZE, SHAPE, SUM, ANY, MINVAL, MAXLOC, RESHAPE, DOT_PRODUCT, TRANSPOSE, WHERE, FORALL, etc

`COMMON` & `MODULE` Statement

The `COMMON` statement allows variables to have a more extensive scope than otherwise

- a variable declared in a `Main Program` can be made accessible to subprograms (without appearing in argument lists of a calling statement)
- this can be selective (don't have to share all everywhere)
- **placement**: among type declarations, after `IMPLICIT` or `EXPLICIT`, before `DATA` statements
- can group into **labeled** `COMMON`

With > F90, it's better to use the `MODULE` subprogram instead of the `COMMON` statement

> Fortran 77 source code common.f - Fortran 90 source code module.f90

Modular programming (>F90)

Modular programming is about separating parts of programs into independent and interchangeable modules :

- improve testability
- improve maintainability
- re-use of code
- higher level aspect of coding in a smart way
- *separation of concerns*

The principle is that making significant parts of the code independent, replaceable and independently testable makes your programs **more maintainable**

Data Type Declarations

FORTRAN >90 allows user derived types

```
TYPE my_variable
  character(30)            :: name
  integer                  :: id
  real(8)                  :: value
  integer, dimension(3,3) :: dimIndex
END TYPE variable

type(my_variable) var
var%name = "salinity"
var%id   = 1
```

Subprograms type

`MODULE` are subprograms that allow modular coding and data encapsulation

The interface of a subprogram type is **explicit** or **implicit**

Several types of subprograms:

- `intrinsic`: explicit - defined by Fortran itself (trignonometric functions, etc)
- `module`: explicit - defined with `MODULE` statement and used with `USE`
- `internal`: explicit - defined with `CONTAINS` statement inside (sub)programs
- `external`: implicit (but can be manually (re)defined explicit) - e.g. **libraries**

Differ with the **scope**: what data and other subprograms a subprogram can access

MODULE type

```
MODULE example
  IMPLICIT NONE
  INTEGER, PARAMETER :: index = 10
  REAL(8), SAVE      :: latitude
CONTAINS
  FUNCTION check(x) RESULT(z)
  INTEGER :: x, z
  ...
  END FUNCTION check
END MODULE example
```

```
PROGRAM myprog
  USE example, ONLY: check, latitude
  IMPLICIT NONE
  ...
  test = check(a)
  ...
END PROGRAM myprog
```

`internal` subprogams

```
program main
  implicit none
  integer N
  real X(20)
  ...
  write(*,*), 'Processing x...', process()
  ...
contains
  logical function process()
    ! in this function N and X can be accessed directly (scope of main)
    ! Please not that this method is not recommended:
    ! it would be better to pass X as an argument of process
    implicit none
    if (sum(x) > 5.) then
       process = .FALSE.
    else
       process = .TRUE.
    endif
  end function process
end program
```

`external` subprogams

- `external` subprogams are defined in a separate program unit
- to use them in another program unit, refer with the `EXTERNAL` statement
- compiled separately and linked

!!! DO NOT USE THEM: modules are much easier and more robust ❗

They are only needed when subprogams are written with different programming language or when using external libraries (such as BLAS)

> It's **highly** recommended to construct `INTERFACE` blocks for any external subprogams used

`interface` statement

```
SUBROUTINE nag_rand(table)
  INTERFACE
    SUBROUTINE g05faf(a,b,n,x)
      REAL, INTENT(IN)    :: a, b
      INTEGER, INTENT(IN) :: n
      REAL, INTENT(OUT)   :: x(n)
    END SUBROUTINE g05faf
  END INTERFACE
  !
  REAL, DIMENSION(:), INTENT(OUT) :: table
  !
  call g05faf(-1.0,-1.0, SIZE(table), table)
END SUBROUTINE nag_rand
```

Fortran Compiler and libraries

Examples:

```
module load netCDF-Fortran/4.5.3-gompi-2021b
gfortran -ffree-line-length-none \
-o OceanGrideChange.exe 07_OceanGrideChange.f90 \
-I${EBROOTNETCDFMINFORTRAN}/include -L${EBROOTNETCDFMINFORTRAN}/lib -lnetcdff
```

```
module load netCDF-Fortran/4.5.3-iimpi-2021b
ifort -O3 \
-o OceanGrideChange.exe 07_OceanGrideChange.f90 \
-I${EBROOTNETCDFMINFORTRAN}/include -L${EBROOTNETCDFMINFORTRAN}/lib -lnetcdff
```

> Fortran 90 source code OceanGrideChange.f90 with the input file input.nc

Conclusions

- Fortran in all its standard versions and vendor-specific dialects is a rich but confusing language
- Fortran is a modern language that continues to evolve
- Fortran is still ideally suited for numerical computations in engineering and science
    - most new language features have been added since F95
    - "High Performance Fortran" includes capabilities designed for parallel processing