

Modern Fortran Explained

Michael Metcalf

Formerly of CERN, Geneva, Switzerland

John Reid

JKR Associates, Oxfordshire

and

Malcolm Cohen

The Numerical Algorithms Group, Oxfordshire

Contents

1	Whence Fortran?	1
1.1	Introduction	1
1.2	Fortran's early history	2
1.3	The drive for the Fortran 90 standard	3
1.4	Language evolution	4
1.5	Fortran 95	4
1.6	Extensions to Fortran 95	5
1.7	Fortran 2003	6
1.8	Fortran 2008	7
1.9	Conformance	7
2	Language elements	9
2.1	Introduction	9
2.2	Fortran character set	9
2.3	Tokens	10
2.4	Source form	11
2.5	Concept of type	13
2.6	Literal constants of intrinsic type	14
2.6.1	Integer literal constants	14
2.6.2	Real literal constants	15
2.6.3	Complex literal constants	17
2.6.4	Character literal constants	17
2.6.5	Logical literal constants	19
2.7	Names	20
2.8	Scalar variables of intrinsic type	20
2.9	Derived data types	21
2.10	Arrays of intrinsic type	23
2.11	Character substrings	26
2.12	Objects and subobjects	27
2.13	Pointers	27
2.14	Summary	29
3	Expressions and assignments	33
3.1	Introduction	33

3.2	Scalar numeric expressions	34
3.3	Defined and undefined variables	37
3.4	Scalar numeric assignment	38
3.5	Scalar relational operators	38
3.6	Scalar logical expressions and assignments	39
3.7	Scalar character expressions and assignments	41
3.8	Structure constructors and scalar defined operators	42
3.9	Scalar defined assignments	45
3.10	Array expressions	46
3.11	Array assignment	48
3.12	Pointers in expressions and assignments	48
3.13	The nullify statement	51
3.14	Summary	51
4	Control constructs	55
4.1	Introduction	55
4.2	The if construct and statement	55
4.3	The case construct	57
4.4	The do construct	59
4.5	The go to statement	62
4.6	Summary	63
5	Program units and procedures	67
5.1	Introduction	67
5.2	Main program	68
5.3	The stop statement	69
5.4	External subprograms	69
5.5	Modules	70
5.6	Internal subprograms	73
5.7	Arguments of procedures	73
5.7.1	Pointer arguments	75
5.7.2	Restrictions on actual arguments	76
5.7.3	Arguments with the target attribute	76
5.8	The return statement	77
5.9	Argument intent	77
5.10	Functions	78
5.10.1	Prohibited side-effects	80
5.11	Explicit and implicit interfaces	80
5.12	Procedures as arguments	82
5.13	Keyword and optional arguments	83
5.14	Scope of labels	85
5.15	Scope of names	85
5.16	Direct recursion	88
5.17	Indirect recursion	89
5.18	Overloading and generic interfaces	90

5.19	Assumed character length	93
5.20	The subroutine and function statements	95
5.21	Summary	96
6	Array features	99
6.1	Introduction	99
6.2	Zero-sized arrays	99
6.3	Assumed-shape arrays	100
6.4	Automatic objects	100
6.5	Allocation of data	102
6.5.1	The allocatable attribute	102
6.5.2	The allocate statement	103
6.5.3	The deallocate statement	104
6.5.4	Allocatable dummy arguments	105
6.5.5	Allocatable functions	105
6.5.6	Allocatable components	106
6.5.7	Allocatable arrays vs. pointers	109
6.6	Elemental operations and assignments	110
6.7	Array-valued functions	110
6.8	The where statement and construct	111
6.9	The forall statement and construct	114
6.10	Pure procedures	117
6.11	Elemental procedures	118
6.12	Array elements	119
6.13	Array subobjects	120
6.14	Arrays of pointers	123
6.15	Pointers as aliases	124
6.16	Array constructors	125
6.17	Mask arrays	126
6.18	Summary	127
7	Specification statements	133
7.1	Introduction	133
7.2	Implicit typing	133
7.3	Declaring entities of differing shapes	134
7.4	Named constants and constant expressions	134
7.5	Initial values for variables	137
7.5.1	Initialization in type declaration statements	137
7.5.2	The data statement	138
7.5.3	Pointer initialization and the function null	140
7.5.4	Default initialization of components	141
7.6	The public and private attributes	142
7.7	The pointer, target, and allocatable statements	144
7.8	The intent and optional statements	144
7.9	The save attribute	145

7.10	The use statement	146
7.11	Derived-type definitions	149
7.12	The type declaration statement	150
7.13	Type and type parameter specification	152
7.14	Specification expressions	153
	7.14.1 Specification functions	153
7.15	The namelist statement	155
7.16	Summary	156
8	Intrinsic procedures	161
8.1	Introduction	161
	8.1.1 Keyword calls	161
	8.1.2 Categories of intrinsic procedures	162
	8.1.3 The intrinsic statement	162
	8.1.4 Argument intents	162
8.2	Inquiry functions for any type	162
8.3	Elemental numeric functions	163
	8.3.1 Elemental functions that may convert	163
	8.3.2 Elemental functions that do not convert	164
8.4	Elemental mathematical functions	165
8.5	Elemental character and logical functions	166
	8.5.1 Character–integer conversions	166
	8.5.2 Lexical comparison functions	167
	8.5.3 String-handling elemental functions	167
	8.5.4 Logical conversion	168
8.6	Non-elemental string-handling functions	168
	8.6.1 String-handling inquiry function	168
	8.6.2 String-handling transformational functions	168
8.7	Numeric inquiry and manipulation functions	168
	8.7.1 Models for integer and real data	168
	8.7.2 Numeric inquiry functions	169
	8.7.3 Elemental functions to manipulate reals	170
	8.7.4 Transformational functions for kind values	171
8.8	Bit manipulation procedures	171
	8.8.1 Inquiry function	172
	8.8.2 Elemental functions	172
	8.8.3 Elemental subroutine	173
8.9	Transfer function	173
8.10	Vector and matrix multiplication functions	174
8.11	Transformational functions that reduce arrays	175
	8.11.1 Single argument case	175
	8.11.2 Optional argument dim	175
	8.11.3 Optional argument mask	176
8.12	Array inquiry functions	176
	8.12.1 Allocation status	176

8.12.2	Bounds, shape, and size	176
8.13	Array construction and manipulation functions	177
8.13.1	The merge elemental function	177
8.13.2	Packing and unpacking arrays	177
8.13.3	Reshaping an array	177
8.13.4	Transformational function for replication	178
8.13.5	Array shifting functions	178
8.13.6	Matrix transpose	179
8.14	Transformational functions for geometric location	179
8.15	Transformational function for pointer disassociation	179
8.16	Non-elemental intrinsic subroutines	180
8.16.1	Real-time clock	180
8.16.2	CPU time	181
8.16.3	Random numbers	181
8.17	Summary	182
9	Data transfer	185
9.1	Introduction	185
9.2	Number conversion	185
9.3	I/O lists	186
9.4	Format definition	188
9.5	Unit numbers	190
9.6	Internal files	191
9.7	Formatted input	193
9.8	Formatted output	194
9.9	List-directed I/O	195
9.10	Namelist I/O	197
9.11	Non-advancing I/O	198
9.12	Edit descriptors	200
9.12.1	Repeat counts	200
9.12.2	Data edit descriptors	201
9.12.3	Character string edit descriptor	205
9.12.4	Control edit descriptors	205
9.13	Unformatted I/O	208
9.14	Direct-access files	209
9.15	Execution of a data transfer statement	210
9.16	Summary	211
10	Operations on external files	213
10.1	Introduction	213
10.2	Positioning statements for sequential files	214
10.2.1	The backspace statement	214
10.2.2	The rewind statement	214
10.2.3	The endfile statement	215
10.2.4	Data transfer statements	215

10.3	The open statement	216
10.4	The close statement	218
10.5	The inquire statement	219
10.6	Summary	222
11	Floating-point exception handling	223
11.1	Introduction	223
11.2	The IEEE standard	224
11.3	Access to the features	225
11.4	The Fortran flags	227
11.5	Halting	228
11.6	The rounding mode	228
11.7	The underflow mode (Fortran 2003 only)	229
11.8	The module <code>ieee_exceptions</code>	229
11.8.1	Derived types	229
11.8.2	Inquiry functions for IEEE exceptions	230
11.8.3	Subroutines for the flags and halting modes	230
11.8.4	Subroutines for the whole of the floating-point status	231
11.9	The module <code>ieee_arithmetic</code>	232
11.9.1	Derived types	232
11.9.2	Inquiry functions for IEEE arithmetic	232
11.9.3	Elemental functions	234
11.9.4	Non-elemental subroutines	235
11.9.5	Transformational function for kind value	236
11.10	Examples	237
11.10.1	Dot product	237
11.10.2	Calling alternative procedures	237
11.10.3	Calling alternative in-line code	238
11.10.4	Reliable hypotenuse function	238
11.10.5	Access to IEEE arithmetic values	239
12	Interoperability with C	243
12.1	Introduction	243
12.2	Interoperability of intrinsic types	243
12.3	Interoperability with C pointer types	245
12.4	Interoperability of derived types	246
12.5	Interoperability of variables	247
12.6	The value attribute	248
12.7	Interoperability of procedures	249
12.8	Interoperability of global data	250
12.9	Invoking a C function from Fortran	251
12.10	Invoking Fortran from C	252
12.11	Enumerations	253

13	Type parameters and procedure pointers	255
13.1	Introduction	255
13.2	Deferred type parameters	255
13.3	Type parameter enquiry	256
13.4	Parameterized derived types	256
13.4.1	Defining a parameterized derived type	256
13.4.2	Assumed and deferred type parameters	258
13.4.3	Default type parameter values	258
13.4.4	Derived type parameter enquiry	259
13.5	Abstract interfaces	259
13.6	Procedure pointers	261
13.6.1	Procedure pointer variables	261
13.6.2	Procedure pointer components	261
13.6.3	The pass attribute	262
14	Object-oriented programming	265
14.1	Introduction	265
14.2	Type extension	265
14.2.1	Type extension and type parameters	267
14.3	Polymorphic entities	267
14.3.1	Establishing the dynamic type	268
14.3.2	Limitations on the use of a polymorphic variable	269
14.3.3	Polymorphic arrays and scalars	269
14.3.4	Unlimited polymorphic entities	269
14.3.5	Polymorphic entities and generic resolution	270
14.4	The associate construct	271
14.5	The select type construct	272
14.6	Type-bound procedures	274
14.6.1	Specific type-bound procedures	274
14.6.2	Generic type-bound procedures	277
14.6.3	Type extension and type-bound procedures	279
14.7	Deferred bindings and abstract types	280
14.8	Finalization	281
14.8.1	Type extension and final subroutines	284
14.9	Procedure encapsulation example	284
14.10	Type inquiry functions	286
15	Establishing and moving data	289
15.1	Introduction	289
15.2	Mixed component accessibility	289
15.3	Structure constructors	289
15.4	The allocate statement	291
15.4.1	Typed allocation and deferred type parameters	291
15.4.2	Polymorphic variables and typed allocation	292
15.4.3	Sourced allocation	292

15.5	Allocatable entities	293
15.5.1	Allocatable scalars	294
15.5.2	Assignment to an allocatable array	294
15.5.3	Transferring an allocation	295
15.6	Pointer assignment	296
15.7	More control of access from a module	296
15.8	Renaming operators on the use statement	297
15.9	Array constructor syntax	297
15.10	Specification and constant expressions	298
16	Miscellaneous enhancements	301
16.1	Introduction	301
16.2	Pointer intent	301
16.3	The volatile attribute	301
16.3.1	Volatile semantics	302
16.3.2	Volatile scoping	303
16.3.3	Volatile arguments	304
16.4	The import statement	304
16.5	Intrinsic modules	306
16.6	Access to the computing environment	307
16.6.1	Environment variables	307
16.6.2	Information about the program invocation	308
16.7	Support for internationalization	308
16.7.1	Character sets	309
16.7.2	ASCII character set	309
16.7.3	ISO 10646 character set	310
16.7.4	UTF-8 files	310
16.7.5	Decimal comma for input/output	311
16.8	Lengths of names and statements	312
16.9	Binary, octal, and hexadecimal constants	312
16.10	Other changes to intrinsic procedures	313
16.11	Error message retrieval	314
16.12	Enhanced complex constants	314
16.13	Interface block extensions	314
16.14	Public entities of private type	315
17	Input/output enhancements	317
17.1	Introduction	317
17.2	Non-default derived-type input/output	317
17.3	Asynchronous input/output	320
17.4	The asynchronous attribute	322
17.5	Input and output of IEEE exceptional values	323
17.6	Stream access input/output	323
17.7	Recursive input/output	324
17.8	The flush statement	324

17.9	Comma after a P edit descriptor	324
17.10	The iomsg= specifier	325
17.11	The round= specifier	325
17.12	The sign= specifier	325
17.13	Kind type parameters of integer and logical specifiers	325
17.14	More specifiers in read and write statements	326
17.15	Intrinsic functions for I/O status testing	326
17.16	Some inquire statement enhancements	326
17.17	Namelist enhancements	327
18	Enhanced module facilities	329
18.1	Introduction	329
18.2	Submodules	330
18.2.1	Separate module procedures	330
18.2.2	Submodules of submodules	331
18.2.3	Submodule entities	331
18.2.4	Submodules and use association	332
18.3	The advantages of submodules	332
19	Coarrays	333
19.1	Introduction	333
19.2	Referencing images	334
19.3	The properties of coarrays	335
19.4	Accessing coarrays	336
19.5	The sync all statement	337
19.6	Coarrays in procedures	338
19.7	Allocatable coarrays	340
19.8	Coarrays with allocatable or pointer components	341
19.8.1	Data components	341
19.8.2	Procedure pointer components	342
19.9	Coarray components	342
19.10	References to polymorphic subobjects	343
19.11	Volatile and asynchronous attributes	343
19.12	Interoperability	343
19.13	Synchronization	343
19.13.1	Execution segments	343
19.13.2	The sync images statement	344
19.13.3	The lock and unlock statements	345
19.13.4	Critical sections	347
19.13.5	The sync memory statement and atomic subroutines	347
19.13.6	The stat= and errmsg= specifiers in synchronization statements	348
19.13.7	The image control statements	348
19.14	Program termination	348
19.15	Input/output	349
19.16	Intrinsic procedures	351

19.16.1	Inquiry functions	351
19.16.2	Transformational functions	351
20	Other Fortran 2008 enhancements	353
20.1	Trivial syntactic conveniences	353
20.1.1	Implied-shape arrays	353
20.1.2	Implied-do loops in data statements	353
20.1.3	Type-bound procedures	354
20.1.4	Structure constructors	354
20.1.5	Semicolons	355
20.1.6	The stop statement	355
20.1.7	Exit from nearly any construct	355
20.2	Limitation changes	356
20.2.1	64-bit integer support	356
20.2.2	Maximum array rank	356
20.3	Data expressiveness	356
20.3.1	Allocatable components of recursive type	356
20.3.2	Initial pointer association	358
20.4	Performance-oriented features	359
20.4.1	The do concurrent construct	359
20.4.2	The contiguous attribute	361
20.4.3	Simply contiguous array designators	364
20.5	Computational expressiveness	365
20.5.1	Accessing parts of complex variables	365
20.5.2	Pointer functions denoting variables	366
20.5.3	The block construct	366
20.5.4	Impure elemental procedures	368
20.5.5	Internal procedures as actual arguments	370
20.5.6	Specifying the kind of a forall index variable	370
20.5.7	Generic resolution	371
20.6	Data usage and computation	372
20.6.1	Enhancements to the allocate statement	372
20.6.2	Automatic reallocation	373
20.6.3	Elemental subprogram restrictions	373
20.7	Input/output	374
20.7.1	Recursive input/output	374
20.7.2	The newunit= specifier	374
20.7.3	Writing comma-separated values	375
20.8	Intrinsic procedures	376
20.9	Mathematical intrinsic functions	376
20.9.1	Changes to trigonometric functions	376
20.9.2	New hyperbolic trigonometric functions	376
20.9.3	New special mathematical functions	377
20.9.4	Euclidean norms	378
20.10	Bit manipulation	378

20.10.1	Bitwise (unsigned) comparison	378
20.10.2	Double-width shifting	379
20.10.3	Bitwise reductions	379
20.10.4	Counting bits	380
20.10.5	Producing bitmasks	380
20.10.6	Merging bits	381
20.10.7	Additional shift operations	381
20.11	Miscellaneous intrinsic procedures	382
20.11.1	Procedures supporting coarrays	382
20.11.2	Executing another program	382
20.11.3	Character comparison	383
20.11.4	Array searching	383
20.11.5	Logical parity	383
20.11.6	Decimal arithmetic support	384
20.11.7	Size of an object in memory	384
20.12	Additions to the <code>iso_fortran_env</code> module	385
20.12.1	Compilation information	385
20.12.2	Names for common kinds	385
20.12.3	Kind arrays	386
20.12.4	Coarray support facilities	386
20.13	Changes to other standard intrinsic modules	387
20.13.1	The <code>iso_c_binding</code> module	387
20.13.2	The <code>ieee_arithmetic</code> module	387
20.14	Programs and procedures	388
20.14.1	Saved module entities	388
20.14.2	Automatic pointer targetting	388
20.14.3	Denoting absent arguments	389

A Intrinsic procedures **393**

B Deprecated features **399**

B.1	Introduction	399
B.2	Storage association	399
B.2.1	Storage units	399
B.2.2	The equivalence statement	400
B.2.3	The common block	402
B.2.4	The block data program unit	404
B.2.5	Coarrays and storage association	405
B.3	Shape and character length disagreement	405
B.4	The include line	407
B.5	Other forms of loop control	407
B.5.1	The labelled do construct	407
B.5.2	The do while	408
B.6	Double precision real	408
B.7	The dimension, codimension, and parameter statements	409

B.8	Specific names of intrinsic procedures	410
B.9	Non-default mapping for implicit typing	412
B.10	Fortran 2008 deprecated features	413
B.10.1	The sync memory statement and atomic subroutines	413
B.10.2	Components of type <code>c_ptr</code> or <code>c_funptr</code>	416
B.10.3	Type declarations	416
B.10.4	Redundant contains statement	417
B.10.5	The end statement	417
B.10.6	Referencing <code>atan2</code> by the name <code>atan</code>	418
C	Obsolescent features	419
C.1	Obsolescent in Fortran 95	419
C.1.1	Fixed source form	419
C.1.2	Computed go to	420
C.1.3	Character length specification <code>character*</code>	420
C.1.4	Data statements among executables	420
C.1.5	Statement functions	421
C.1.6	Assumed character length of function results	422
C.1.7	Arithmetic if statement	422
C.1.8	Shared do-loop termination	423
C.1.9	Alternate return	423
C.2	Feature obsolescent in Fortran 2008: Entry statement	424
C.3	Feature deleted in Fortran 2003: Carriage control	426
C.4	Features deleted in Fortran 95	427
D	Avoiding compilation cascades	429
E	Object-oriented list example	433
F	Fortran terms	441
G	Solutions to exercises	453
	Index	475