High Performance Fortran
Language Specification

High Performance Fortran Forum

January 31, 1997
Version 2.0
The High Performance Fortran Forum (HPFF), with participation from over 40 organizations, met from March 1992 to March 1993 to define a set of extensions to Fortran called High Performance Fortran (HPF). Our goal was to address the problems of writing data parallel programs for architectures where the distribution of data impacts performance. While we hope that the HPF extensions will become widely available, HPFF is not sanctioned or supported by any official standards organization. The HPFF had a second series of meetings from April 1994 to October 1994 to consider requests for corrections, clarifications, and interpretations to the Version 1.0 HPF document and also to develop user requirements for possible future changes to HPF. A third set of meetings took place From January 1995 through December 1996 to incorporate features recommended to meet user needs identified in the 1994 meetings.

This document contains all the technical features proposed for the version of the language known as HPF Version 2.0. This copy of the draft was processed by \LaTeX{} on January 31, 1997.

HPFF encourages requests for interpretation of this document, and comments on the language defined here. We will give our best effort to answering interpretation questions, and general comments will be considered in future HPFF language specifications.

Please send interpretation requests to hpff-interpret@cs.rice.edu. Your request is archived and forwarded to a group of HPFF committee members who attempt to respond to it.

The text of interpretation requests becomes the property of Rice University.

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Acknowledgments

The High Performance Fortran Forum (HPFF) is a coalition of industrial and academic groups working to suggest a set of standard extensions to Fortran that provide support for high performance programming on a wide variety of machines, including massively parallel SIMD and MIMD systems and vector processors. From its beginning, HPFF has included most vendors delivering parallel machines, a number of government laboratories, and university research groups. Public input has been encouraged. This document defining HPF 2.0 is the third in a series of documents resulting from the HPFF. HPF 2.0 is intended to be a language portable from workstations to massively parallel supercomputers while being able to express the algorithms needed to achieve high performance on specific architectures. HPF 2.0 builds on the efforts of the previous HPFF meetings, primarily in 1992 and 1994. Specific acknowledgments for the many people who contributed to the previous versions of HPF are included in Annex D.

HPFF 2 Acknowledgments

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- Chuck Koelbel, Editor, assisted by multiple committee members (names later).

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Part I

Introduction

This major section describes the organization of the document as a whole. It also defines terms and concepts that are common to High Performance Fortran version 2.0 (described in Part II) and the HPF Approved Extensions (described in Part III). Therefore, it provides necessary background for the succeeding sections.
Section 1

Overview

This document specifies the form and establishes the interpretation of programs expressed in the High Performance Fortran (HPF) language. It is designed as a set of extensions and modifications to the established International Standard for Fortran. At the time of publication of this document, the version of the standard used as a base is informally referred to as “Fortran 95” (ISO/IEC 1539:1997). References to that document are made as follows: Section 13.11.6 in that document is referred to here as F95:13.11.6.

In this overview Section of the document, we outline the goals and scope of the language, introduce the HPF language model, highlight the main features of the language, describe the changes between HPF 1.1 and HPF 2.0, and provide a guide to the rest of this document.

1.1 Goals and Scope of High Performance Fortran

The primary goals behind the development of the HPF language include:

- Support for data parallel programming (single threaded, global name space, and loosely synchronous parallel computation);
- Portability across different architectures;
- High performance on parallel computers with non-uniform memory access costs (while not impeding performance on other machines);
- Use of Standard Fortran (currently Fortran 95) as a base;
- Open interfaces and interoperability with other languages (e.g., C) and other programming paradigms (e.g., message passing using MPI).

Secondary goals include:

- Implementation feasibility within a limited time span;
- Provision of input to future standards activities for Fortran and C;
- Provision of an evolutionary path for adding advanced features to the language in a consistent manner.

The first version of the language definition, HPF 1.0 was released in May 1993. A number of language features that were defined in HPF 1.0 have now been absorbed into
the Fortran 95 language standard (e.g., the `FORALL` statement and construct, and `PURE` procedures). These features are therefore no longer detailed in the definition of HPF 2.0. Information about the evolution of the HPF language (through versions 1.0, 1.1, and 2.0) and an enumeration of the differences between HPF 2.0 from HPF 1.1 may be found in subsection 1.4.

### 1.2 HPF Language Model

An important goal of HPF is to achieve code portability across a variety of parallel machines. This requires not only that HPF programs compile on all target machines, but also that a highly-efficient HPF program on one parallel machine be able to achieve reasonably high efficiency on another parallel machine with a comparable number of processors. Otherwise, the effort spent by a programmer to achieve high performance on one machine would be wasted when the HPF code is ported to another machine. Although shared-memory machines and distributed-memory machines may use different low-level primitives, there is broad similarity with respect to the fundamental factors that affect the performance of parallel programs on these machines. Thus, achieving high efficiency across different parallel machines with the same high level HPF program is a feasible goal. Some of the fundamental factors affecting the performance of a parallel program are the degree of available parallelism, exploitation of data locality, and choice of appropriate task granularity. HPF provides mechanisms for the programmer to guide the compiler with respect to these factors.

The first versions of HPF were defined to extend Fortran 90. HPF 2.0 is defined as an extension to the current Fortran Standard (Fortran 95). Future revisions of HPF will include and be consistent with advances in the Fortran standards, as they are approved by ISO.

Building on Fortran, HPF language features fall into four categories:

- HPF directives;
- New language syntax;
- New library routines; and
- Language changes and restrictions.

HPF directives appear as structured comments that suggest implementation strategies or assert facts about a program to the compiler. When properly used, they affect only the efficiency of the computation performed, but do not change the value computed by the program. The form of the HPF directives has been chosen so that a future Fortran standard may choose to include these features as full statements in the language by deleting the initial comment header.

A few new language features have been defined as direct extensions to Fortran syntax and interpretation. The new HPF language features differ from HPF directives in that they are first-class language constructs and can directly affect the result computed by a program.

The HPF library of computational functions defines a standard interface to routines that have proven valuable for high performance computing. These additional functions include those for mapping inquiry, bit manipulation, array reduction, array combining scatter, prefix and suffix, and sorting.
A small number of changes and restrictions to Fortran 95 have also been defined. The most significant restrictions are those imposed on the use of sequence and storage association, since they are not compatible with the data distribution features of HPF. It is however possible to retain sequence and storage association semantics in a program by use of certain explicit HPF directives.

1.2.1 Data Mapping Directives

The fundamental model of parallelism in HPF is that of single-threaded data-parallel execution with a globally shared address space. Fortran array statements and the FORALL statement are natural ways of specifying data parallel computation. In addition, HPF provides the INDEPENDENT directive. It can be used to assert that certain loops do not carry any dependences and therefore may be executed in parallel.

Exploitation of data locality is critical to achieving good performance on a high-performance computer, whether a uniprocessor workstation, a network of workstations, or a parallel computer. On a Non-Uniform-Memory-Access (NUMA) parallel computer, the effective distribution of data among processor memories is very important in reducing data movement overheads. One of the key features of HPF is the facility for user specification of data mapping. HPF provides a logical view of the parallel machine as a rectilinear arrangement of abstract processors in one or more dimensions. The programmer can specify the relative alignment of elements of different program arrays, and the distribution of arrays over the logical processor grid. Data mapping is specified using HPF directives that can aid the compiler in optimizing parallel performance, but have no effect on the semantics of the program. This is illustrated by the following simple example.

```fortran
REAL A(1000,1000)
!HPF$ PROCESSORS procs(4,4)
!HPF$ DISTRIBUTE (BLOCK,BLOCK) ONTO procs :: A
DO k = 1, num_iter
   FORALL (i=2:999, j=2:999)
      A(i,j) = (A(i,j-1) + A(i-1,j) + A(i,j+1) + A(i+1,j))/4
   END FORALL
END DO
```

The code fragment describes a simple Jacobi relaxation computation using a two-dimensional floating-point array A. The HPF directives appear as structured comments. The PROCESSORS directive specifies a logical $4 \times 4$ grid of processors proc. The DISTRIBUTE directive recommends that the compiler partition the array A into equal-sized blocks along each of its dimensions. This will result in a $4 \times 4$ configuration of blocks each containing $250 \times 250$ elements, one block per processor. The PROCESSORS and DISTRIBUTE directive are described in detail later in Section 3.

The outer DO k loop iterates over num_iter Jacobi relaxation steps. The inner loop uses the Fortran 95 FORALL construct. It specifies the execution of the loop body for all values of i and j in the range 2 through 999. The semantics of the FORALL require that the right-hand-side expressions for all iterations (i.e., for all values of i and j between 2 and 999) be evaluated before any of the assignments to the left-hand-side variables are performed.
When targeted for execution on a distributed-memory machine with 16 processors, an HPF compiler generates SPMD code, with each processor locally containing a part of the global array $A$. The outer $k$ loop is executed sequentially while the inner `FORALL` is executed in parallel. Each processor will require some “boundary” elements of $A$ that reside in partitions mapped to the local memories of other processors. Primitives to achieve the necessary inter-processor communication are inserted by the HPF compiler into the generated SPMD code. The single-threaded data-parallel model with a global name-space makes it convenient for the programmer to specify the strategy for parallelization and data partitioning at a higher level of abstraction. The tedious low-level details of translating from an abstract global name space to the local memories of individual processors and the management of explicit inter-processor communication are left to the compiler.

The following example illustrates some of the communication implications of scalar assignment statements. The purpose is to illustrate the implications of data distribution specifications on communication requirements for parallel execution. The explanations given do not necessarily reflect the actual compilation process.

Consider the following code fragment:

```plaintext
REAL a(1000), b(1000), c(1000), x(500), y(0:501)
INTEGER inx(1000)
!HPF$ PROCESSORS procs(10)
!HPF$ DISTRIBUTE (BLOCK) ONTO procs :: a, b, inx
!HPF$ DISTRIBUTE (CYCLIC) ONTO procs :: c
!HPF$ ALIGN x(i) WITH y(i+1)
...
  a(i) = b(i)       ! Assignment 1
  x(i) = y(i+1)     ! Assignment 2
  a(i) = c(i)       ! Assignment 3
  a(i) = a(i-1) + a(i) + a(i+1) ! Assignment 4
  c(i) = c(i-1) + c(i) + c(i+1) ! Assignment 5
  x(i) = y(i)       ! Assignment 6
  a(i) = a(inx(i)) + b(inx(i)) ! Assignment 7
```

In this example, the `PROCESSORS` directive specifies a linear arrangement of 10 processors. The `DISTRIBUTE` directives recommend to the compiler that the arrays $a$, $b$, and $inx$ should be distributed among the 16 processors with blocks of 100 contiguous elements per processor. The array $c$ is to be cyclically distributed among the processors with $c(1)$, $c(11)$, ..., $c(991)$ mapped onto processor $procs(1)$; $c(2)$, $c(12)$, ..., $c(992)$ mapped onto processor $procs(2)$; and so on. The complete mapping of arrays $x$ and $y$ onto the processors is not specified, but their relative alignment is indicated by the `ALIGN` directive. The `ALIGN` statement recommends that $x(i)$ and $y(i+1)$ be stored on the same processor for all values of $i$, regardless of the actual distribution chosen by the compiler for $y(y(0))$ and $y(1)$ are not aligned with any element of $x$). The `PROCESSORS`, `DISTRIBUTE`, and `ALIGN` directives are discussed in detail in Section 3.

In Assignment 1 ($a(i) = b(i)$), the identical distribution of $a$ and $b$ specifies that for all $i$, corresponding elements of $a(i)$ and $b(i)$ should be mapped to the same processor. Therefore, execution of this statement requires no communication of data values between processors.
1.3. **Overview of HPF 2.0 Language Features**

The language defined in this document consists of two main parts:

- **The HPF 2.0 Language (Part II)**
- **HPF 2.0 Approved Extensions (Part III)**

The HPF 2.0 language includes features that are expected to be implementable within a year of release of the language specification. These include basic data distribution features, data parallel features, intrinsic and library routines, and the extrinsic mechanism. The Approved Extensions include advanced features that meet specific needs, but are not likely to be supported in initial compiler implementations.
1.3.1 HPF 2.0 Language Features

1.3.1.1 Data Distribution Features (Sections 3 and 4)

Most parallel and sequential architectures attain their highest speed when the data accessed exhibits locality of reference. The sequential storage order implied by Fortran standards often conflicts with the locality demanded by the architecture. To avoid this, HPF includes features that describe the co-location of data (ALIGN) and the partitioning of data among memory regions or abstract processors (DISTRIBUTE). Compilers may interpret these annotations to improve storage allocation for data, subject to the constraint that semantically every data object has a single value at any point in the program. Section 4 defines how the mapping features interact across subprogram boundaries.

While a goal of HPF is to maintain compatibility with Fortran, full support of Fortran sequence and storage association, however, is not compatible with the goal of high performance through distribution of data in HPF. Sections 3 and 4 describe restrictions and directives related to storage and sequence association.

1.3.1.2 Data Parallel Execution Features (Section 5)

To express parallel computation explicitly, HPF defines the INDEPENDENT directive. It asserts that the statements in a particular section of code do not exhibit any sequentializing dependences; when properly used, it does not change the semantics of the construct, but may provide more information to the language processor to allow optimizations. A REDUCTION clause can be used with the INDEPENDENT directive to identify variables that are updated by commutative and associative operations. This facilitates the utilization of parallelism with reduction operations, in the context of loops where the order of accumulation of updates to a variable is insignificant.

1.3.1.3 Extrinsic Program Units (Section 6)

Because HPF is designed as a high-level machine-independent language, there are certain operations that are difficult or impossible to express directly. For example, an application may benefit from finely-tuned systolic communications on certain machines; HPF’s global address space does not express this well. HPF defines the Extrinsic mechanism to facilitate interfacing with procedures written in other paradigms, such as explicit message-passing subroutine libraries or in other languages, such as C.

1.3.1.4 Intrinsic Functions and Standard Library (Section 7)

Experience with massively parallel machines has identified many basic operations that are useful in parallel algorithm design. The Fortran array intrinsics address some of these. HPF adds several classes of parallel operations to the language definition as intrinsic functions and as standard library functions. In addition, several system inquiry functions useful for controlling parallel execution are provided in HPF.
1.3. OVERVIEW OF HPF 2.0 LANGUAGE FEATURES

1.3.2 HPF 2.0 Approved Extensions

1.3.2.1 Extensions for Data Mapping (Section 8)

The extended mapping features permit greater control over the mapping of data, including facilities for dynamic realignment and redistribution of arrays at run-time (REALIGN, REDISTRIBUTE, DYNAMIC directives), mapping of data among subsets of processors, mapping of pointers and components of derived types, and support for irregular distribution of data (GEN_BLOCK and INDIRECT distributions). In addition, mechanisms are defined that permit the programmer to provide information to the compiler about the range of possible distributions an array might take (RANGE directive) and the amount of buffering to be used with arrays involved in stencil-based nearest-neighbor computations (SHADOW).

1.3.2.2 Extensions for Data and Task Parallelism (Section 9)

The ON directive facilitates explicit computation partitioning. The site of recommended execution of a computation can be specified either as an explicitly identified subset of a processor arrangement, or indirectly as the set of processors onto which a data object or template is mapped.

In order to assist the compiler in generating efficient code, the RESIDENT directive is defined, to be used in conjunction with an ON directive by the programmer. It can be used to assert that all accesses to the specified object within the scope of the ON directive are to be found locally on the executing processor. The TASK_REGION directive allows the user to specify the concurrent execution of different blocks of code on disjoint processor subsets.

1.3.2.3 Extensions for Asynchronous I/O (Section 10)

In order to permit overlap of I/O with computation, an extension has been defined for asynchronous READ/WRITE of direct, unformatted data. This is done through an additional I/O control parameter in the Fortran READ/WRITE statement that specifies non-blocking execution and a new statement (WAIT).

1.3.2.4 Extensions to Intrinsic and Library Procedures (Section 12)

The approved extensions to the HPF intrinsics and library routines relate mostly to mapping inquiry procedures. Some new inquiry routines are defined and other routines defined by the HPF 2.0 language are extended to facilitate inquiry about extended mapping features, such as mapping to processor subsets, GEN_BLOCK, INDIRECT and DYNAMIC distributions. A generalization of the Fortran TRANSPOSE intrinsic is also defined.

1.3.2.5 Approved Extensions for HPF Extrinsic (Section 11)

A number of specific extrinsic interfaces are defined in Section 11 as approved HPF 2.0 extensions. These include interfaces to facilitate interoperability with other languages (e.g., C and FORTRAN 77) as well as interfaces for different models of parallelism (LOCAL for SPMD parallel, and SERIAL for single-process sequential). Library routines useful in the extrinsic models are defined in Section 11.7. Additional extrinsic interfaces that are formally recognized by the HPF Forum, but not defined and maintained by the Forum, are included in Annexes F and G. The policy and mechanism for formal recognition of such extrinsic interfaces is described in Annex E.
1.4 Changes from HPF 1.1

HPF 2.0 differs from HPF 1.1 in a number of ways:

Repartitioning of the Language: The new document describes two components: the HPF 2.0 language (which is expected to be widely and relatively rapidly implemented) and the set of Approved Extensions (which are not part of HPF 2.0 but may be included in future implementations in response to user demand, as the compilation technology matures.)

Features Now in Standard Fortran: Fortran, instead of Fortran 90 is now defined as the base language for extensions; this implies that HPF includes all features added to Fortran at the 1995 revision. With this revision, a few HPF 1.1 features are now part of the Fortran standard, and hence no longer appear as HPF extensions to Fortran.

Features Removed or Restricted in HPF 2.0: Some features of HPF 1.1, that have not been implemented to date, have been removed from the language because experience has shown that the simplicity gained by doing so outweighs the advantage of the features.

Elimination of the HPF Subset: Unlike HPF 1.1, HPF 2.0 no longer has a recommended minimal subset for faster implementation (i.e. Subset HPF), although the original HPF 1.1 Subset is documented in an annex.

Features Moved to Approved Extensions: A few language features have been moved from HPF 1.1 to the category of Approved Extensions.

New Features of HPF 2.0: A few new features have been added to the base language.

New Approved Extensions: A number of further new features are defined as approved extensions to the language.

Recognized Externally-Supported HPF Extrinsics: Finally, the document acknowledges a new category, HPF-related EXTRINSIC interfaces, that are recognized as meeting appropriate standards for such interfaces, but are not included as Approved Extensions. Responsibility for the content of each such interface is assumed by the organization proposing it rather than by the HPF Forum.

Each of these categories is summarized in the following subsections.

1.4.1 Repartitioning of the Language

The HPF Forum had two important goals that were sometimes in conflict:

- Providing advanced language capabilities that users had requested.
- Allowing fast compiler development by vendors.

One compromise made to satisfy both goals was to divide the language definition into two parts. HPF 2.0 is very similar to HPF 1.1, and is expected to be efficiently implemented by a number of vendors within approximately one year from the appearance of this document. Advanced features that require more implementation effort are collected as Approved Extensions. Implementors are encouraged to support these features as rapidly as possible, and users are encouraged to speed this process by making their wishes known to the vendors.
1.4.2 Features Now in Standard Fortran

The following features, which formed part of HPF 1.1, have been removed from the document because they are now part of ISO Fortran:

- The \texttt{FORALL} statement and construct;
- The \texttt{PURE} attribute for procedures;
- Extensions to the \texttt{MINLOC} and \texttt{MAXLOC} intrinsics to include an optional \texttt{DIM} argument.

1.4.3 Features Removed or Restricted in HPF 2.0

The following features have been removed from the language:

- Sequential arrays may no longer be explicitly mapped;
- In any procedure call in which distributed data may require redistribution, the procedure must now have an explicit interface;
- The treatment of the \texttt{INHERIT} directive has been simplified in that it is no longer possible to specify both \texttt{INHERIT} and \texttt{DISTRIBUTE} together.
- The treatment of pointers has been simplified.

1.4.4 Features Moved to Approved Extensions

The \texttt{DYNAMIC} attribute and the \texttt{REDISTRIBUTE} and \texttt{REALIGN} statements have been moved to the Approved Extensions.

1.4.5 New Features of HPF 2.0

The following new constructs have been introduced in HPF 2.0:

- The \texttt{REDUCTION} clause for \texttt{INDEPENDENT} loops;
- The new \texttt{HPF\_LIBRARY} procedures \texttt{SORT\_DOWN}, \texttt{SORT\_UP}.

1.4.6 New Approved Extensions

The Approved Extensions include the following features not part of HPF 1.1:

- Mapping of objects to \texttt{processor subsets};
- Explicit mapping of pointers and components of derived types;
- New distribution formats: \texttt{GEN\_BLOCK} and \texttt{INDIRECT};
- New directives: \texttt{RANGE}, \texttt{SHADOW}, \texttt{ON}, \texttt{RESIDENT}, \texttt{TASK\_REGION};
- Additional intrinsic procedures: \texttt{ACTIVE\_NUM\_PROCS}, \texttt{ACTIVE\_PROCS\_SHAPE}, and a generalized \texttt{TRANSPOSE} intrinsic;
- New \texttt{HPF\_LIBRARY} procedures: \texttt{HPF\_MAP\_ARRAY} and \texttt{HPF\_NUMBER\_MAPPED}; revision of procedures \texttt{HPF\_ALIGNMENT}, \texttt{HPF\_DISTRIBUTION} and \texttt{HPF\_TEMPLATE};
• Support for asynchronous I/O with a new statement \texttt{WAIT}, and an additional I/O control parameter in the Fortran \texttt{READ/WRITE} statement;

• Extensions to the \texttt{EXTRINSIC} facilities to support interoperability with C and \texttt{FORTRAN 77}.

1.4.7 Recognized Externally-Supported HPF Extrinsic{s}

Two externally supported intrinsic interfaces are recognized in this document:

• HPF\_CRAFT: providing an SPMD paradigm with HPF features;

• The Fortran 77 Local Library: defining library support for calling Fortran 77 procedures in local mode.
Section 2

Notation and Syntax

This chapter describes the notational conventions employed in this document and the syntax of HPF directives.

2.1 Notation

This document uses the same notation as the Fortran 95 standard. In particular, the same conventions are used for syntax rules. BNF descriptions of language features are given in the style used in the Fortran standard. To distinguish HPF syntax rules from Fortran rules, each HPF rule has an identifying number of the form Hsnn, where s corresponds to the section number and nn is a two-digit sequence number. Nonterminals not defined in this document are defined in the Fortran standard. Also note that certain technical terms such as “storage unit” are defined by the Fortran standard.

As previously noted in Section 1, a reference of the form F95:2.4.7 in the text refers to Section 2.4.7 of the Fortran 95 standard.

Part III describes the approved extensions. In some cases this requires extending the syntax rules already introduced in an earlier section. In particular, the syntax rules here are often supersets of similar syntax rules in Part II; in these cases, the names of the nonterminals include the suffix -extended. Thus, when a non-terminal such as name is redefined it is referred to as name-extended under the proviso that any reference to name is to be replaced by name-extended in the rest of the syntax rules.

When a constraint or restriction in Part II is modified by an approved extension, this fact is noted, in the text, and a forward reference is provided. A downward-pointing double arrow is used in the margin (as here) to highlight such a forward reference.

Each such modification (in Part III) contains a backward reference to the original language in Part II that is modified. An upward-pointing double arrow is used in the margin (as here) to highlight such a backward reference.

Rationale. Throughout this document, material explaining the rationale for including features, for choosing particular feature definitions, and for making other decisions, is set off in this format. Readers interested only in the language definition may wish to skip these sections, while readers interested in language design may want to read them more carefully. (End of rationale.)

Advice to users. Throughout this document, material that is primarily of interest to users (including most examples of syntax and interpretation) is set off in this format.
Readers interested only in technical material may wish to skip these sections, while readers wanting a more tutorial approach may want to read them more carefully. (End of advice to users.)

Advice to implementors. Throughout this document, material that is primarily of interest to implementors is set off in this format. Readers interested only in the language definition may wish to skip these sections, while readers interested in compiler implementation may want to read them more carefully. (End of advice to implementors.)

2.2 Syntax of Directives

HPF directives are consistent with Fortran syntax in the following sense: if any HPF directive were to be adopted as part of a future Fortran standard, the only change necessary to convert an HPF program would be to replace the directive-origin with blanks.

H201  hpf-directive-line is directive-origin hpf-directive

H202  directive-origin is !HPF$ or CHPF$ or +HPF$

H203  hpf-directive is specification-directive or executable-directive

H204  specification-directive is processors-directive or align-directive or distribute-directive or inherit-directive or template-directive or combined-directive or sequence-directive

H205  executable-directive is independent-directive

Constraint: An hpf-directive-line cannot be commentary following another statement on the same line.

Constraint: A specification-directive may appear only where a declaration-construct may appear.

Constraint: An executable-directive may appear only where an executable-construct may appear.

Constraint: An hpf-directive-line follows the rules of either Fortran free form (F95:3.3.1.1) or fixed form (F95:3.3.2.1) comment lines, depending on the source form of the surrounding Fortran source form in that program unit. (F95:3.3)

An hpf-directive is case insensitive and conforms to the rules for blanks in free source form (3.3.1), even in an HPF program otherwise in fixed source form. However an HPF-conforming language processor is not required to diagnose extra or missing blanks in an HPF.


2.2. **SYNTAX OF DIRECTIVES**

directive. Note that, due to Fortran rules, the *directive-origin* in free source form must be the characters `!HPF$`. HPF directives may be continued, in which case each continued line also begins with a *directive-origin*. No statements may be interspersed within a continued HPF-directive. HPF directive lines must not appear within a continued statement. HPF directive lines may include trailing commentary.

The blanks in the adjacent keywords `END FORALL` and `NO SEQUENCE` are optional, in either source form.

An example of an HPF directive continuation in free source form is:

```fortran
!HPF$ ALIGN ANTIDISESTABLISHMENTARIANISM(I,J,K) &
!HPF$  WITH ORNITHORHYNCHUS_ANATINUS(J,K,I)
```

An example of an HPF directive continuation in fixed source form follows. Observe that column 6 must be blank, except when signifying continuation.

```fortran
!HPF$ ALIGN ANTIDISESTABLISHMENTARIANISM(I,J,K)
!HPF$  WITH ORNITHORHYNCHUS_ANATINUS(J,K,I)
```

This example shows an HPF directive continuation that is “universal” in that it can be treated as either fixed source form or free source form. Note that the “&” in the first line is in column 73.

```fortran
!HPF$ ALIGN ANTIDISESTABLISHMENTARIANISM(I,J,K) &
!HPF$&WITH ORNITHORHYNCHUS_ANATINUS(J,K,I)
```

Part III introduces new directives, both specifications and executable ones, for the approved extensions to HPF 2.0. These are included below:

**H206 specification-directive-extended** is processors-directive or subset-directive or align-directive or distribute-directive or inherit-directive or template-directive or combined-directive or sequence-directive or dynamic-directive or range-directive or shadow-directive

**H207 executable-directive-extended** is independent-directive or realign-directive or redistribute-directive or on-directive or resident-directive

The following rule extends rule R215 of Fortran 95:
H208 executable-construct-extended is action-stmt
or case-construct
or do-construct
or if-construct
or where-construct
or on-construct
or resident-construct
or task-region-construct
Part II

High Performance Fortran Language

This major section describes the syntax and semantics of features of the High Performance Fortran language, version 2.0. Some technical terms used herein are defined in Part I; otherwise this description is self-contained. Part III builds upon this material.
Section 3

Data Mapping

HPF data alignment and distribution directives allow the programmer to advise the compiler how to assign array elements to processor memories. This section discusses the basic data mapping features applicable, particularly those that are meaningful within a single scoping unit. Section 4 discusses features that apply when mapped variables appear as procedure arguments.

3.1 Model

HPF adds directives to Fortran to allow the user to advise the compiler on the allocation of data objects to processor memories. The model is that there is a two-level mapping of data objects to memory regions, referred to as “abstract processors.” Data objects (typically array elements) are first aligned relative to one another; this group of arrays is then distributed onto a rectilinear arrangement of abstract processors. (The implementation then uses the same number, or perhaps some smaller number, of physical processors to implement these abstract processors. This mapping of abstract processors to physical processors is implementation-dependent.)

The following diagram illustrates the model:

The underlying assumptions are that an operation on two or more data objects is likely to be carried out much faster if they all reside in the same processor, and that it may
be possible to carry out many such operations concurrently if they can be performed on different processors.

Fortran provides a number of features, notably array syntax, that make it easy for a compiler to determine that many operations may be carried out concurrently. The HPF directives provide a way to inform the compiler of the recommendation that certain data objects should reside in the same processor: if two data objects are mapped (via the two-level mapping of alignment and distribution) to the same abstract processor, it is a strong recommendation to the implementation that they ought to reside in the same physical processor. There is also a provision for recommending that a data object be stored in multiple locations, which may complicate any updating of the object but makes it faster for multiple processors to read the object.

There is a clear separation between directives that serve as specification statements and directives that serve as executable statements (in the sense of the Fortran standards). Specification statements are carried out on entry to a program unit, as if all at once; only then are executable statements carried out. (While it is often convenient to think of specification statements as being handled at compile time, some of them contain specification expressions, which are permitted to depend on run-time quantities such as dummy arguments, and so the values of these expressions may not be available until run time, specifically the very moment that program control enters the scoping unit.)

The basic concept is that every array (indeed, every object) is created with some alignment to an entity, which in turn has some distribution onto some arrangement of abstract processors. If the specification statements contain explicit specification directives specifying the alignment of an array \( A \) with respect to another array \( B \), then the distribution of \( A \) will be dictated by the distribution of \( B \); otherwise, the distribution of \( A \) itself may be specified explicitly. In either case, any such explicit declarative information is used when the array is created.

*Advice to implementors.* This model gives a better picture of the actual amount of work that needs to be done than a model that says “the array is created in some default location, and then realigned and/or redistributed if there is an explicit directive.” Using \texttt{ALIGN} and \texttt{DISTRIBUTE} specification directives doesn’t have to cause any more work at run time than using the implementation defaults. (*End of advice to implementors.*)

In the case of an allocatable object, we say that the object is created whenever it is allocated. Specification directives for an allocatable object may appear in the specification-part of a program unit, but take effect each time the object is created, rather than on entry to the scoping unit.

Alignment is considered an attribute (in the Fortran sense) of a data object. If an object \( A \) is aligned with an object \( B \), which in turn is already aligned to an object \( C \), this is regarded as an alignment of \( A \) with \( C \) directly, with \( B \) serving only as an intermediary at the time of specification. We say that \( A \) is \textit{immediately aligned} with \( B \) but \textit{ultimately aligned} with \( C \). If an object is not explicitly aligned with another object, we say that it is ultimately aligned with itself. The alignment relationships form a tree with everything ultimately aligned to the object at the root of the tree; however, the tree is always immediately “collapsed” so that every object is related directly to the root.

Every object that is the root of an alignment tree has an associated \texttt{template} or index space. Typically, this template has the same rank and size in each dimension as the object
associated with it. (The most important exception to this rule is dummy arguments with the INHERIT attribute, described in Section 4.4.2.) We often refer to “the template for an array,” which means the template of the object to which the array is ultimately aligned. (When an explicit TEMPLATE (see section 3.7) is used, this may be simply the template to which the array is explicitly aligned.)

The distribution step of the HPF model technically applies to the template of an array, although because of the close relationship noted above we often speak loosely of the distribution of an array. Distribution partitions the template among a set of abstract processors according to a given pattern. The combination of alignment (from arrays to templates) and distribution (from templates to processors) thus determines the relationship of an array to the processors; we refer to this relationship as the mapping of the array. (These remarks also apply to a scalar, which may be regarded as having an index space whose sole position is indicated by an empty list of subscripts.)

Every object is created as if according to some complete set of specification directives; if the program does not include complete specifications for the mapping of some object, the compiler provides defaults. By default an object is not aligned with any other object; it is ultimately aligned with itself. The default distribution is implementation-dependent, but must be expressible as explicit directives for that implementation. Identically declared objects need not be provided with identical default distribution specifications; the compiler may, for example, take into account the contexts in which objects are used in executable code. The programmer may force identically declared objects to have identical distributions by specifying such distributions explicitly. (On the other hand, identically declared processor arrangements are guaranteed to represent “the same processors arranged the same way.” This is discussed in more detail in section 3.6.)

Sometimes it is desirable to consider a large index space with which several smaller arrays are to be aligned, but not to declare any array that spans the entire index space. HPF allows one to declare a TEMPLATE, which is like an array whose elements have no content and therefore occupy no storage; it is merely an abstract index space that can be distributed and with which arrays may be aligned.

An object is considered to be explicitly mapped if it appears in an HPF mapping directive within the scoping unit in which it is declared; otherwise it is implicitly mapped. A mapping directive is an ALIGN, or DISTRIBUTE, or INHERIT directive, or any directive that confers an alignment, a distribution, or the INHERIT attribute.

Note that we extend this model in Section 8 to allow dynamic redistribution and remapping of objects.

3.2 Syntax of Data Alignment and Distribution Directives

Specification directives in HPF have two forms: specification statements, analogous to the DIMENSION and ALLOCATABLE statements of Fortran; and an attribute form analogous to type declaration statements in Fortran using the "::" punctuation.

The attribute form allows more than one attribute to be described in a single directive. HPF goes beyond Fortran in not requiring that the first attribute, or indeed any of them, be a type specifier.
The **INHERIT** attribute is related to subroutine call conventions and will be discussed in Section 4.

Constraint: The same kind of **combined-attribute** must not appear more than once in a given **combined-directive**.

Constraint: If the **DIMENSION** attribute appears in a **combined-directive**, any entity to which it applies must be declared with the HPF **TEMPLATE** or **PROCESSORS** type specifier.

The following rules constrain the declaration of various attributes, whether in separate directives or in a **combined-directive**.

If the **DISTRIBUTE** attribute is present, then every name declared in the **combined-decl-list** is considered to be a **distributee** and is subject to the constraints listed in section 3.3.

If the **ALIGN** attribute is present, then every name declared in the **entity-decl-list** is considered to be an **alignee** and is subject to the constraints listed in section 3.4.

The HPF keywords **PROCESSORS** and **TEMPLATE** play the role of type specifiers in declaring processor arrangements and templates. The HPF keywords **ALIGN**, **DISTRIBUTE**, and **INHERIT** play the role of attributes. Attributes referring to processor arrangements, to templates, or to entities with other types (such as **REAL**) may be combined in an HPF directive without having the type specifier appear.

No entity may be given a particular attribute more than once.

Dimension information may be specified after an **hpf-entity** or in a **DIMENSION** attribute. If both are present, the one after the **object-name** overrides the **DIMENSION** attribute (this is consistent with the Fortran standard). For example, in:

```fortran
!HPF$ TEMPLATE,DIMENSION(64,64) :: A,B,C(32,32),D
```

A, B, and D are 64 x 64 templates; C is 32 x 32.

Directives mapping a variable must be in the same scoping unit where the variable is declared.

If a specification expression includes a reference to the value of an element of an array specified in the same specification-part, any explicit mapping or **INHERIT** attribute for the array must be completely specified in prior specification-directives. (This restriction is inspired by and extends F95:7.1.6.2 in the Fortran standard, which states in part: If a specification expression includes a reference to the value of an element of an array specified in the same specification-part, the array bounds must be specified in a prior declaration.)

A comment on asterisks: The asterisk character "*" appears in the syntax rules for HPF alignment and distribution directives in three distinct roles:
When a lone asterisk appears as a member of a parenthesized list, it indicates either a collapsed mapping, wherein many elements of an array may be mapped to the same abstract processor, or a replicated mapping, wherein each element of an array may be mapped to many abstract processors. See the syntax rules for \textit{align-source} and \textit{align-subscript} (see section 3.4) and for \textit{dist-format} (see section 3.3).

An asterisk appearing in an \textit{align-subscript-use} expression represents the usual integer multiplication operator.

When an asterisk appears before a left parenthesis "C" or after the keyword \texttt{WITH} or \texttt{ONTO}, it indicates a descriptive or transcriptional mapping for dummy arguments of subprograms (see Section 4) and for mapping of pointers under the approved extensions (see section 8.8).

An asterisk can also be used in the \texttt{PASS\_BY} attribute in an interface block to describe dummy arguments passed by reference to an extrinsic routine written in C (see Section 11.2).

### 3.3 The \texttt{DISTRIBUTE} Directive

The \texttt{DISTRIBUTE} directive specifies a mapping of data objects to abstract processors in a processor arrangement. For example,

```
REAL SALAMI(10000)
!HPF$ DISTRIBUTE SALAMI(BLOCK)
```

specifies that the array \texttt{SALAMI} should be distributed across some set of abstract processors by slicing it uniformly into blocks of contiguous elements. If there are 50 processors, the directive implies that the array should be divided into groups of \(\left\lceil \frac{10000}{50} \right\rceil = 200\) elements, with \texttt{SALAMI(1:200)} mapped to the first processor, \texttt{SALAMI(201:400)} mapped to the second processor, and so on. If there is only one processor, the entire array is mapped to that processor as a single block of 10000 elements.

The block size may be specified explicitly:

```
REAL WEISSWURST(10000)
!HPF$ DISTRIBUTE WEISSWURST(BLOCK(256))
```

This specifies that groups of exactly 256 elements should be mapped to successive abstract processors. (There must be at least \(\left\lceil \frac{10000}{256} \right\rceil = 40\) abstract processors if the directive is to be satisfied. The fortieth processor will contain a partial block of only 16 elements, namely \texttt{WEISSWURST(9985:10000)}.)

\texttt{HPF} also provides a cyclic distribution format:

```
REAL DECK\_OF\_CARDS(52)
!HPF$ DISTRIBUTE DECK\_OF\_CARDS(CYCLIC)
```

If there are 4 abstract processors, the first processor will contain \texttt{DECK\_OF\_CARDS(1:49:4)}, the second processor will contain \texttt{DECK\_OF\_CARDS(2:50:4)}, the third processor will contain \texttt{DECK\_OF\_CARDS(3:51:4)}, and the fourth processor will contain \texttt{DECK\_OF\_CARDS(4:52:4)}. Successive array elements are dealt out to successive abstract processors in round-robin fashion.

Distributions are specified independently for each dimension of a multidimensional array:
INTEGER CHESS_BOARD(8,8), GO_BOARD(19,19)
!HPF$ DISTRIBUTE CHESS_BOARD(BLOCK, BLOCK)
!HPF$ DISTRIBUTE GO_BOARD(CYCLIC,*)

The CHESS_BOARD array will be carved up into contiguous rectangular patches, which will be distributed onto a two-dimensional arrangement of abstract processors. The GO_BOARD array will have its rows distributed cyclically over a one-dimensional arrangement of abstract processors. (The "*" specifies that GO_BOARD is not to be distributed along its second axis; thus an entire row is to be distributed as one object. This is sometimes called "on-processor" distribution.)

The DISTRIBUTE directive may appear only in the specification-part of a scoping unit and can contain only a specification-expr as the argument to a BLOCK or CYCLIC option.

The syntax of the DISTRIBUTE directive is:

H305  distribute-directive is DISTRIBUTED distributee dist-directive-stuff
H306  dist-directive-stuff is dist-format-clause [ dist-onto-clause ]
H307  dist-attribute-stuff is dist-directive-stuff or dist-onto-clause
H308  distributee is object-name or template-name
H309  dist-format-clause is ( dist-format-list ) or * ( dist-format-list ) or *
H310  dist-format is BLOCK [ ( scalar-int-expr ) ] or CYCLIC [ ( scalar-int-expr ) ] or *
H311  dist-onto-clause is ONTO dist-target
H312  dist-target is processors-name or * processors-name or *

The full syntax is given here for completeness. However, some of the forms are discussed only in Section 4. These "interprocedural" forms are:

- The last two options of rule H309 (containing the * form)
- The last two options of rule H310 (containing the * form)

Constraint: An object-name mentioned as a distributee must be a simple name and not a subobject designator or a component-name.

Constraint: An object-name mentioned as a distributee may not appear as an alignee.

Constraint: An object-name mentioned as a distributee may not have the POINTER attribute.

Constraint: An object-name mentioned as a distributee may not have the TARGET attribute.
Constraint: If the distributee is scalar, the dist-format-list (and its surrounding parentheses) must not appear. In this case, the statement form of the directive is allowed only if a dist-format-clause of "*" is present.

Constraint: If a dist-format-list is specified, its length must equal the rank of each distributee to which it applies.

Constraint: If both a dist-format-list and a dist-target appear, the number of elements of the dist-format-list that are not "*" must equal the rank of the specified processor arrangement.

Constraint: If a dist-target appears but not a dist-format-list, the rank of each distributee must equal the rank of the specified processor arrangement.

Constraint: If either the dist-format-clause or the dist-target in a DISTRIBUTE directive begins with "*" then every distributee must be a dummy argument.

Constraint: Any scalar-int-expr appearing in a dist-format of a DISTRIBUTE directive must be a specification-expr.

Advice to users. Some of the above constraints are relaxed under the approved extensions (see Section 8): mapping of derived type components (relaxes constraint 1), and mapping of pointers and targets (relaxes constraints 3, 4, and 9). (End of advice to users.)

Note that the possibility of a DISTRIBUTE directive of the form

```latex
!HPF$ DISTRIBUTE dist-attribute-stuff :: distributee-list
```

is covered by syntax rule H301 for a combined-directive.

Examples:

```latex
!HPF$ DISTRIBUTE D1(BLOCK)
!HPF$ DISTRIBUTE (BLOCK,*,BLOCK) ONTO SQUARE:: D2,D3,D4
```

The meanings of the alternatives for dist-format are given below.

Define the ceiling division function \( CD(J,K) = (J + K - 1) / K \) (using Fortran integer arithmetic with truncation toward zero.)

Define the ceiling remainder function \( CR(J,K) = J - K \times CD(J,K) \).

The dimensions of a processor arrangement appearing as a dist-target are said to correspond in left-to-right order with those dimensions of a distributee for which the corresponding dist-format is not *. In the example above, processor arrangement SQUARE must be two-dimensional; its first dimension corresponds to the first dimensions of D2, D3, and D4 and its second dimension corresponds to the third dimensions of D2, D3, and D4.

Let \( d \) be the size of a distributee in a certain dimension and let \( p \) be the size of the processor arrangement in the corresponding dimension. For simplicity, assume all dimensions have a lower bound of 1. Then \( \text{BLOCK}(m) \) means that a distributee position whose index along that dimension is \( j \) is mapped to an abstract processor whose index along the corresponding dimension of the processor arrangement is \( CD(j,m) \) (note that \( m \times p \geq d \) must be true), and is position number \( m \times CR(j,m) \) among positions mapped to that abstract processor. The first distributee position in abstract processor \( k \) along that axis is position number \( 1 + m \times (k-1) \).
The block size $m$ must be a positive integer.

**BLOCK** by definition means the same as **BLOCK(CD($d$, $p$)).**

**CYCLIC($m$)** means that a *distribution* position whose index along that dimension is $j$ is mapped to an abstract processor whose index along the corresponding dimension of the processor arrangement is $1+\text{MODULO}(CD(j, m)-1, p)$. The first *distribution* position in abstract processor $k$ along that axis is position number $1+m*(k-1)$.

The block size $m$ must be a positive integer.

**CYCLIC** by definition means the same as **CYCLIC(1).**

**CYCLIC($m$)** and **BLOCK($m$)** imply the same distribution when $m \times p \geq d$, but **BLOCK($m$)** additionally asserts that the distribution will not wrap around in a cyclic manner, which a compiler cannot determine at compile time if $m$ is not constant. Note that **CYCLIC** and **BLOCK** (without argument expressions) do not imply the same distribution unless $p \geq d$, a degenerate case in which the block size is 1 and the distribution does not wrap around.

Suppose that we have 16 abstract processors and an array of length 100:

```hpf
!HPF$ PROCESSORS SEDECIM(16)
REAL CENTURY(100)
```

Distributing the array **BLOCK** (which in this case would mean the same as **BLOCK(7)**):

```hpf
!HPF$ DISTRIBUTE CENTURY(BLOCK) ONTO SEDECIM
```

results in this mapping of array elements onto abstract processors:

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</tbody>
</table>
```

Distributing the array **BLOCK(8)**:

```hpf
!HPF$ DISTRIBUTE CENTURY(BLOCK(8)) ONTO SEDECIM
```

results in this mapping of array elements onto abstract processors:

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```
### 3.3. **THE DISTRIBUTE DIRECTIVE**

Distributing the array `BLOCK(6)` is not HPF-conforming because $6 \times 16 < 100$.

Distributing the array `CYCLIC` (which means exactly the same as `CYCLIC(1)`):

```hpf
!HPF$ DISTRIBUTE CENTURY(CYCLIC) ONTO SEDECIM
```

results in this mapping of array elements onto abstract processors:

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<table>
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</tbody>
</table>
```

Distributing the array `CYCLIC(3)`:

```hpf
!HPF$ DISTRIBUTE CENTURY(CYCLIC(3)) ONTO SEDECIM
```

results in this mapping of array elements onto abstract processors:

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<td>12</td>
<td>15</td>
<td>18</td>
<td>21</td>
<td>24</td>
<td>27</td>
<td>30</td>
<td>33</td>
<td>36</td>
<td>39</td>
<td>42</td>
<td>45</td>
</tr>
<tr>
<td>16</td>
<td>8</td>
<td>5</td>
<td>8</td>
<td>11</td>
<td>14</td>
<td>17</td>
<td>20</td>
<td>23</td>
<td>26</td>
<td>29</td>
<td>32</td>
<td>35</td>
<td>38</td>
<td>41</td>
<td>44</td>
</tr>
</tbody>
</table>
```

Note that it is perfectly permissible for an array to be distributed so that some processors have no elements. Indeed, an array may be “distributed” so that all elements reside on one processor. For example,

```hpf
!HPF$ DISTRIBUTE CENTURY(BLOCK(256)) ONTO SEDECIM
```

results in having only one non-empty block—a partially-filled one at that, having only 100 elements—on processor 1, with processors 2 through 16 having no elements of the array.

The statement form of a `DISTRIBUTE` directive may be considered an abbreviation for an attributed form that happens to mention only one `distributee`; for example,

```hpf
!HPF$ DISTRIBUTE distributee ( dist-format-list ) ONTO dist-target
```
is equivalent to

\[
!\text{HPF} \text{ } \text{DISTRIBUTE ( dist-format-list ) ONTO dist-target :: distributee}
\]

Note that, to prevent syntactic ambiguity, the \textit{dist-format-clause} must be present in the statement form, so in general the statement form of the directive may not be used to specify the mapping of scalars.

If the \textit{dist-format-clause} is omitted from the attributed form, then the language processor may make an arbitrary choice of distribution formats for each template or array. So the directive

\[
!\text{HPF} \text{ } \text{DISTRIBUTE ONTO P :: D1,D2,D3}
\]

means the same as

\[
!\text{HPF} \text{ } \text{DISTRIBUTE ONTO P :: D1}
!\text{HPF} \text{ } \text{DISTRIBUTE ONTO P :: D2}
!\text{HPF} \text{ } \text{DISTRIBUTE ONTO P :: D3}
\]

to which a compiler, perhaps taking into account patterns of use of D1, D2, and D3 within the code, might choose to supply three distinct distributions such as, for example,

\[
!\text{HPF} \text{ } \text{DISTRIBUTE D1(BLOCK, BLOCK) ONTO P}
!\text{HPF} \text{ } \text{DISTRIBUTE D2(CYClic, BLOCK) ONTO P}
!\text{HPF} \text{ } \text{DISTRIBUTE D3(BLOCK(43), CYClic) ONTO P}
\]

Then again, the compiler might happen to choose the same distribution for all three arrays.

In either the statement form or the attributed form, if the \textbf{ONTO} clause is present, it specifies the processor arrangement that is the target of the distribution. If the \textbf{ONTO} clause is omitted, then a implementation-dependent processor arrangement is chosen arbitrarily for each \textit{distributee}. So, for example,

\[
\text{REAL, DIMENSION(1000) :: ARTHUR, ARNOLD, LINUS, LUCY}
!\text{HPF} \text{ } \text{PROCESSORS EXCALIBUR(32)}
!\text{HPF} \text{ } \text{DISTRIBUTE (BLOCK) ONTO EXCALIBUR :: ARTHUR, ARNOLD}
!\text{HPF} \text{ } \text{DISTRIBUTE (BLOCK) :: LINUS, LUCY}
\]

causes the arrays \texttt{ARTHUR} and \texttt{ARNOLD} to have the same mapping, so that corresponding elements reside in the same abstract processor, because they are the same size and distributed in the same way (\texttt{BLOCK}) onto the same processor arrangement (\texttt{EXCALIBUR}). However, \texttt{LUCY} and \texttt{LINUS} do not necessarily have the same mapping because they might, depending on the implementation, be distributed onto differently chosen processor arrangements; so corresponding elements of \texttt{LUCY} and \texttt{LINUS} might not reside on the same abstract processor. (The \texttt{ALIGN} directive provides a way to ensure that two arrays have the same mapping without having to specify an explicit processor arrangement.)

In a given environment, for some distributions, there may be no appropriate processor arrangement.
The ALIGN Directive

The ALIGN directive is used to specify that certain data objects are to be mapped in the same way as certain other data objects. Operations between aligned data objects are likely to be more efficient than operations between data objects that are not known to be aligned (because two objects that are aligned are intended to be mapped to the same abstract processor). The ALIGN directive is designed to make it particularly easy to specify explicit mappings for all the elements of an array at once. While objects can be aligned in some cases through careful use of matching DISTRIBUTE directives, ALIGN is more general and frequently more convenient.

The ALIGN directive may appear only in the specification-part of a scoping unit and can contain only a specification-expr as a subscript or in a subscript-triplet.

The syntax of ALIGN is as follows:

H313 align-directive is ALIGN alignee align-directive-stuff
H314 align-directive-stuff is ( align-source-list ) align-with-clause
H315 align-attribute-stuff is [ ( align-source-list ) ] align-with-clause
H316 alignee is object-name
H317 align-source is :
    or *
    or align-dummy
H318 align-dummy is scalar-int-variable

Constraint: An object-name mentioned as an alignee must be a simple name and not a subobject designator or a component-name.

Constraint: An object-name mentioned as an alignee may not appear as a distributee.

Constraint: An object-name mentioned as an alignee may not have the POINTER attribute.

Constraint: An object-name mentioned as an alignee may not have the TARGET attribute.

Constraint: If the alignee is scalar, the align-source-list (and its surrounding parentheses) must not appear. In this case the statement form of the directive is not allowed.

Constraint: If the align-source-list is present, its length must equal the rank of each alignee to which it applies.

Constraint: An align-dummy must be a named variable.

Constraint: An object may not have both the INHERIT attribute and the ALIGN attribute.

Advice to users. Some of the above constraints are relaxed under the approved extensions (see Section 8): mapping of derived type components (relaxes constraint 1) and mapping of pointers and targets (relaxes constraints 3 and 4). (End of advice to users.)

Note that the possibility of an ALIGN directive of the form
is covered by syntax rule H301 for a combined-directive.

The statement form of an ALIGN directive may be considered an abbreviation of an attributed form that happens to mention only one alignee:

```
!HPF$ ALIGN aligne-list WITH align-spec
```

is equivalent to

```
!HPF$ ALIGN ( align-source-list ) WITH align-spec
```

If the `align-source-list` is omitted from the attributed form and the `alignees` are not scalar, the `align-source-list` is assumed to consist of a parenthesized list of ";" entries, equal in number to the rank of the `alignees`. Similarly, if the `align-subscript-list` is omitted from the `align-spec` in either form, it is assumed to consist of a parenthesized list of ";" entries, equal in number to the rank of the `align-target`. So the directive

```
!HPF$ ALIGN WITH B :: A1, A2, A3
```

means

```
!HPF$ ALIGN (:,:) WITH B(:,:) :: A1, A2, A3
```

which in turn means the same as

```
!HPF$ ALIGN A1(:,:) WITH B(:,)
!HPF$ ALIGN A2(:,:) WITH B(:,)
!HPF$ ALIGN A3(:,:) WITH B(:,)
```

because an attributed-form directive that mentions more than one `alignee` is equivalent to a series of identical directives, one for each `alignee`; all `alignees` must have the same rank.

With this understanding, we will assume below, for the sake of simplifying the description, that an ALIGN directive has a single `alignee`.

Each `align-source` corresponds to one axis of the `alignee`, and is specified as either ";" or "*" or a dummy variable:

- If it is ";", then positions along that axis will be spread out across the matching axis of the `align-spec` (see below).
- If it is "*", then that axis is `collapsed`: positions along that axis make no difference in determining the corresponding position within the `align-target`. (Replacing the "*" with a dummy variable name not used anywhere else in the directive would have the same effect; "*" is merely a convenience that saves the trouble of inventing a variable name and makes it clear that no dependence on that dimension is intended.)
- A dummy variable is considered to range over all valid index values for that dimension of the `alignee`.

The `WITH` clause of an ALIGN has the following syntax:
3.4. THE ALIGN DIRECTIVE

H319  align-with-clause is WITH align-spec
H320  align-spec is align-target [ ( align-subscript-list ) ]
or * align-target [ ( align-subscript-list ) ]
H321  align-target is object-name
or template-name
H322  align-subscript is int-expr
or align-subscript-use
or subscript-triplet
or *

H323  align-subscript-use is [ [ int-level-two-expr ] add-op ]
      align-add-operand
or align-subscript-use add-op int-add-operand
H324  align-add-operand is [ int-add-operand * ] align-primary
or align-add-operand * int-mult-operand
H325  align-primary is align-dummy
or ( align-subscript-use )
H326  int-add-operand is add-operand
H327  int-mult-operand is mult-operand
H328  int-level-two-expr is level-2-expr

The full syntax is given here for completeness. However, some of the forms are discussed only in Section 4. These “interprocedural” forms are those using the second option of rule H320 (containing the * form).

Constraint: An object-name mentioned as an align-target must be a simple name and not a subobject designator or a component-name.

Constraint: An align-target may not have the OPTIONAL attribute.

Constraint: If the align-spec in an ALIGN directive begins with “*” then every alignee must be a dummy argument.

Constraint: In an align-directive any int-expr, int-level-two-expr, int-add-operand or int-mult-operand must be a specification expression.

Constraint: Any subscript or stride in a subscript-triplet that is an align-subscript in an align-directive must be a specification expression.

Constraint: Each align-dummy may appear at most once in an align-subscript-list.

Constraint: An align-subscript-use expression may contain at most one occurrence of an align-dummy.

Constraint: A scalar-int-variable that is used as an align-dummy may not appear anywhere in the align-spec except where explicitly permitted to appear by virtue of the grammar shown above. Paraphrased, one may construct an align-subscript-use only by starting with an align-dummy and then doing additive
and multiplicative things to it with integer specification expressions that contain no align-dummy.

Constraint: A subscript within an align-subscript may not contain occurrences of any align-dummy.

Constraint: An int-add-opernd, int-mult-opernd, or int-level-two-expr must be of type integer.

Advice to users. Some of the above constraints are relaxed under the approved extensions (see Section 8): mapping of derived type components (relaxes constraint 1), mapping of pointers (relaxes constraint 3) and remapping of data objects (relaxes constraints 4 and 5). (End of advice to users.)

The syntax rules for an align-subscript-use take account of operator precedence issues, but the basic idea is simple: an align-subscript-use is intended to be a linear (more precisely: affine) function of a single occurrence of an align-dummy.

For example, the following align-subscript-use expressions are valid, assuming that each of J, K, and M is an align-dummy and N is not an align-dummy:

\[
\begin{align*}
J &\to J+1 & 3-K & 2*M & N*M & 100-3*M \\
-J &\to -K+3 & M+2\times3 & M+N & -(4\times7\times10(6,9))\times K-(13-5/3) \\
M*2 &\to N*(M-N) & 2*(J+1) & 5-K+3 & 10000-M*3 & 2*(3*(K-1)+13)-100
\end{align*}
\]

The following expressions are not valid align-subscript-use expressions:

\[
\begin{align*}
J+J &\to J*K & 3/K & 2**M & M*K & K-3*M \\
K-J &\to IOR(J,1) & -K/3 & M*(2*M) & M*(M-N) & 2**(2*J-3*J+J)
\end{align*}
\]

The align-spec must contain exactly as many subscript-triplets as the number of colons ("::") appearing in the align-source-list. These are matched up in corresponding left-to-right order, ignoring, for this purpose, any align-source that is not a colon and any align-subscript that is not a subscript-triplet. Consider a dimension of the alignace for which a colon appears as an align-source and let the lower and upper bounds of that dimension be LA and UA. Let the corresponding subscript triplet be LT:UT:ST or its equivalent. Then the colon could be replaced by a new, as-yet-unused dummy variable, say J, and the subscript triplet by the expression (J-LA)*ST+LT without affecting the mapping specified by the directive. However, the colon form additionally requires that the axes must conform, which means that

\[
\max(0, UA - LA + 1) = \max(0, [(UT - LT + 1)/ST])
\]

must be true. (This is entirely analogous to the treatment of array assignment.)

To simplify the remainder of the discussion, we assume that every colon in the align-source-list has been replaced by new dummy variables in exactly the fashion just described, and that every "*" in the align-source-list has likewise been replaced by an otherwise unused dummy variable. For example,

```
!HPFS ALIGN A(:,*,K,:,*,*) WITH B(31,:,K+3,20:100:3)
```

may be transformed into its equivalent
![HPF] ALIGN A(I,J,K,L,M,N) WITH B(I-LBOUND(A,1)+31, &
![HPF] L-LBOUND(A,4)+LBOUND(B,2),K+3,(M-LBOUND(A,5))*3+20)

with the attached requirements

\[
\begin{align*}
\text{SIZE}(A,1) & \ .EQ. \text{UBOUND}(B,1)-30 \\
\text{SIZE}(A,4) & \ .EQ. \text{SIZE}(B,2) \\
\text{SIZE}(A,5) & \ .EQ. \ (100-20+3)/3 \\
\end{align*}
\]

Thus we need consider further only the case where every \emph{align-source} is a dummy variable and no \emph{align-subscript} is a \emph{script-triplet}.

Each dummy variable is considered to range over all valid index values for the corresponding dimension of the \emph{alignee}. Every combination of possible values for the index variables selects an element of the \emph{alignee}. The \emph{align-spec} indicates a corresponding element (or section) of the \emph{align-target} with which that element of the \emph{alignee} should be aligned; this indication may be a function of the index values, but the nature of this function is syntactically restricted (as discussed above) to linear (precisely: affine) functions in order to limit the complexity of the implementation. Each \emph{align-dummy} variable may appear at most once in the \emph{align-spec} and only in certain rigidly prescribed contexts. The result is that each \emph{align-subscript} expression may contain at most one \emph{align-dummy} variable and the expression is constrained to be a linear function of that variable. (Therefore skew alignments are not possible.)

An asterisk "*" as an \emph{align-subscript} indicates a replicated representation. Each element of the \emph{alignee} is aligned with every position along that axis of the \emph{align-target}.

\textit{Rationale.} It may seem strange to use "*" to mean both collapsing and replication; the rationale is that "*" always stands conceptually for a dummy variable that appears nowhere else in the statement and ranges over the set of indices for the indicated dimension. Thus, for example,

\begin{verbatim}
!HPF$ ALIGN A(:) WITH D(:,*)
\end{verbatim}

means that a copy of A is aligned with every column of D, because it is conceptually equivalent to

\begin{quote}
\textit{for every legitimate index } j, \textit{align } A(:) \textit{ with } D(:,j)
\end{quote}

just as

\begin{verbatim}
!HPF$ ALIGN A(:,*) WITH D(:)
\end{verbatim}

is conceptually equivalent to

\begin{quote}
\textit{for every legitimate index } j, \textit{align } A(:,j) \textit{ with } D(:)
\end{quote}

Note, however, that while HPF syntax allows

\begin{verbatim}
!HPF$ ALIGN A(:,*) WITH D(:)
\end{verbatim}

to be written in the alternate form


!HPFS ALIGN A(:,J) WITH D(:)

it does not allow

!HPFS ALIGN A(:) WITH D(:,*)

to be written in the alternate form

!HPFS ALIGN A(:) WITH D(:,J)

because that has another meaning (only a variable appearing in the align-source-list following the alignee is understood to be an align-dummy, so the current value of the variable J is used, thus aligning A with a single column of D).

Replication allows an optimizing compiler to arrange to read whichever copy is closest. (Of course, when a replicated data object is written, all copies must be updated, not just one copy. Replicated representations are very useful for small lookup tables, where it is much faster to have a copy in each physical processor but without giving it an extra dimension that is logically unnecessary to the algorithm. (*End of rationale.*)

By applying the transformations given above, all cases of an align-subscript may be conceptually reduced to either an int-expr (not involving an align-dummy) or an align-subscript-use, and the align-source-list may be reduced to a list of index variables with no "*" or ":". An align-subscript-list may then be evaluated for any specific combination of values for the align-dummy variables simply by evaluating each align-subscript as an expression. The resulting subscript values must be legitimate subscripts for the align-target. (This implies that the alignee is not allowed to "wrap around" or "extend past the edges" of an align-target.) The selected element of the alignee is then considered to be aligned with the indicated element of the align-target; more precisely, the selected element of the alignee is considered to be ultimately aligned with the same object with which the indicated element of the align-target is currently ultimately aligned (possibly itself).

More examples of ALIGN directives:

```
INTEGER D1(N)
LOGICAL D2(N,N)
!HPFS ALIGN X(:,*) WITH D1(:)
!HPFS ALIGN (:,*') WITH D1:: A,B,C,AR1,AR2A
!HPFS ALIGN WITH D2:: P,Q,R,S
```

Note that, in a alignee-list, the alignees must all have the same rank but need not all have the same shape; the extents need match only for dimensions that correspond to colons in the align-source-list. This turns out to be an extremely important convenience; one of the most common cases in current practice is aligning arrays that match in distributed ("parallel") dimensions but may differ in collapsed ("on-processor") dimensions:

```
REAL A(3,N), B(4,N), C(43,N), Q(N)
!HPFS DISTRIBUTES Q(BLOCK)
!HPFS ALIGN (*,:), WITH Q:: A,B,C
```
Here there are processors (perhaps $N$ of them) and arrays of different sizes (3, 4, 43) within each processor are required. As far as HPF is concerned, the numbers 3, 4, and 43 may be different, because those axes will be collapsed. Thus array elements with indices differing only along that axis will all be aligned with the same element of $Q$ (and thus be specified as residing in the same processor).

In the following examples, each directive in a group means the same thing, assuming that corresponding axis upper and lower bounds match:

```fortran
!Second axis of X is collapsed
!HPF$ ALIGN X(:,*) WITH D1(:)
!HPF$ ALIGN X(J,*) WITH D1(J)
!HPF$ ALIGN X(J,K) WITH D1(J)

!Replicated representation along second axis of D3
!HPF$ ALIGN X(:,:) WITH D3(:,*,:)
!HPF$ ALIGN X(J,K) WITH D3(J,*,K)

!Transposing two axes
!HPF$ ALIGN X(J,K) WITH D2(K,J)
!HPF$ ALIGN X(J,:) WITH D2(:,J)
!HPF$ ALIGN X(:,K) WITH D2(K,:)

!But there isn't any way to get rid of *both* index variables;
! the subscript-triplet syntax alone cannot express transposition.

!Reversing both axes
!HPF$ ALIGN X(J,K) WITH D2(M-J+1,N-K+1)
!HPF$ ALIGN X(:,:) WITH D2(M:1:-1,N:1:-1)

!Simple case
!HPF$ ALIGN X(J,K) WITH D2(J,K)
!HPF$ ALIGN X(:,:) WITH D2(:,:)
!HPF$ ALIGN (J,K) WITH D2(J,K): X
!HPF$ ALIGN (:,:) WITH D2(:,:): X
!HPF$ ALIGN WITH D2:: X
```

### 3.5 Allocatable Arrays and Pointers

A variable with the `ALLOCATABLE` attribute may appear as an *alignee* in an `ALIGN` directive or as a *distributee* in a `DISTRIBUTE` directive. Such directives do not take effect immediately, however; they take effect each time the array is allocated by an `ALLOCATE` statement, rather than on entry to the scoping unit. The values of all specification expressions in such a directive are determined once on entry to the scoping unit and may be used multiple times (or not at all). For example:

```fortran
SUBROUTINE MILLARD_FILLMORE(N,M)
REAL, ALLOCATABLE, DIMENSION(:) :: A, B
!HPF$ ALIGN B(I) WITH A(I+N)
!HPF$ DISTRIBUTE A(BLOCK(M*2))
N = 43
```
The values of the expressions \( N \) and \( M/2 \) on entry to the subprogram are conceptually retained by the \texttt{ALIGN} and \texttt{DISTRIBUTE} directives for later use at allocation time. When the array \( A \) is allocated, it is distributed with a block size equal to the retained value of \( M/2 \), not the value 182. When the array \( B \) is allocated, it is aligned relative to \( A \) according to the retained value of \( N \), not its new value 43.

Note that it would have been incorrect in the \texttt{MILLARD_FILLMORE} example to perform the two \texttt{ALLOCATE} statements in the opposite order. In general, when an object \( X \) is created it may be aligned to another object \( Y \) only if \( Y \) has already been created or allocated. The following example illustrates several related cases.

```fortran
SUBROUTINE WARREN_HARDING(P, Q)
REAL P(:)
REAL Q(:)
REAL R(SIZE(Q))
REAL, ALLOCATABLE :: S(:,T(:))
!HPF$ ALIGN P(I) WITH T(I) !Nonconforming
!HPF$ ALIGN Q(I) WITH T(I) !Nonconforming
!HPF$ ALIGN R(I) WITH T(I) !Nonconforming
!HPF$ ALIGN S(I) WITH T(I)
ALLOCATE(S(SIZE(Q))) !Nonconforming
ALLOCATE(T(SIZE(Q)))
```

Three \texttt{ALIGN} directives are not HPF-conforming because the array \( T \) has not yet been allocated at the time that the various alignments must take place. The four cases differ slightly in their details. The arrays \( P \) and \( Q \) already exist on entry to the subroutine, but because \( T \) is not yet allocated, one cannot correctly prescribe the alignment of \( P \) or describe the alignment of \( Q \) relative to \( T \). (See Section 4 for a discussion of prescriptive and descriptive directives.) The array \( R \) is created on subroutine entry and its size can correctly depend on the \texttt{SIZE} of \( Q \), but the alignment of \( R \) cannot be specified in terms of the alignment of \( T \) any more than its size can be specified in terms of the size of \( T \). It is permitted to have an alignment directive for \( S \) in terms of \( T \), because the alignment action does not take place until \( S \) is allocated; however, the first \texttt{ALLOCATE} statement is nonconforming because \( S \) needs to be aligned but at that point in time \( T \) is still unallocated.

When an array is allocated, it will be aligned to an existing object or template if there is an explicit \texttt{ALIGN} directive for the allocatable variable. If there is no explicit \texttt{ALIGN} directive, then the array will be ultimately aligned with itself. It is forbidden for any other object to be ultimately aligned to an array at the time the array becomes undefined by reason of deallocation. All this applies regardless of whether the name originally used in the \texttt{ALLOCATE} statement when the array was created had the \texttt{ALLOCATABLE} attribute or the \texttt{POINTER} attribute.

Pointers cannot be explicitly mapped in HPF and thus can only be associated with objects which are not explicitly mapped. When used for allocation, the compiler may choose any arbitrary mapping for data allocated through the pointer. Explicit mapping of pointers is allowed under the approved extensions (see section 8.8). Also, the relationship of pointers and sequence attributes is described in section 3.8.
3.6 The PROCESSORS Directive

The PROCESSORS directive declares one or more rectilinear processor arrangements, specifying for each one its name, its rank (number of dimensions), and the extent in each dimension. It may appear only in the specification-part of a scoping unit. Every dimension of a processor arrangement must have nonzero extent; therefore a processor arrangement cannot be empty.

In the language of F95:14.1.2 in the Fortran standard, processor arrangements are local entities of class (1); therefore a processor arrangement may not have the same name as a variable, named constant, internal procedure, etc., in the same scoping unit. Names of processor arrangements obey the same rules for host and use association as other names in the long list in F95:12.1.2.2.1 in the Fortran standard.

A processor arrangement declared in a module has the default accessibility of the module.

Rationale. Because the name of a processor arrangement is not a first-class entity in HPF, but must appear only in directives, it cannot appear in an access-stmt (PRIVATE or PUBLIC). If directives ever become full-fledged Fortran statements rather than structured comments, then it would be appropriate to allow the accessibility of a processor arrangement to be controlled by listing its name in an access-stmt. (End of rationale.)

If two processor arrangements have the same shape, then corresponding elements of the two arrangements are understood to refer to the same abstract processor. (It is anticipated that implementation-dependent directives provided by some HPF implementations could overrule the default correspondence of processor arrangements that have the same shape.)

If directives collectively specify that two objects be mapped to the same abstract processor at a given instant during the program execution, the intent is that the two objects be mapped to the same physical processor at that instant.

The intrinsic functions NUMBER_OF_PROCESSORS and PROCESSORS_SHAPE may be used to inquire about the total number of actual physical processors used to execute the program. This information may then be used to calculate appropriate sizes for the declared abstract processor arrangements.

H329 processors-directive is PROCESSORS processors-decl-list
H330 processors-decl is processors-name
   [ ( explicit-shape-spec-list ) ]

Examples:

!HPF$ PROCESSORS P(N)
!HPF$ PROCESSORS Q(NUMBER_OF_PROCESSORS()), &
!HPF$ R(8,NUMBER_OF_PROCESSORS()/8)
!HPF$ PROCESSORS BIZARRO(1972:1997,-20:17)
!HPF$ PROCESSORS SCALARPROC

If no shape is specified, then the declared processor arrangement is conceptually scalar.
Rationale. A scalar processor arrangement may be useful as a way of indicating that certain scalar data should be kept together but need not interact strongly with distributed data. Depending on the implementation architecture, data distributed onto such a processor arrangement may reside in a single “control” or “host” processor (if the machine has one), or may reside in an arbitrarily chosen processor, or may be replicated over all processors. For target architectures that have a set of computational processors and a separate scalar host computer, a natural implementation is to map every scalar processor arrangement onto the host processor. For target architectures that have a set of computational processors but no separate scalar “host” computer, data mapped to a scalar processor arrangement might be mapped to some arbitrarily chosen computational processor or replicated onto all computational processors. (End of rationale.)

An HPF compiler is required to accept any PROCEESSORS declaration in which the product of the extents of each declared processor arrangement is equal to the number of physical processors that would be returned by the call NUMBER_OF_PROCESSORS(). It must also accept all declarations of scalar PROCESSOR arrangements. Other cases may be handled as well, depending on the implementation.

For compatibility with the Fortran attribute syntax, an optional “::” may be inserted. The shape may also be specified with the DIMENSION attribute:

```fortran
!HPF$ PROCESSORS :: RUBIK(3,3,3)
!HPF$ PROCESSORS, DIMENSION(3,3,3) :: RUBIK
```

As in Fortran, an explicit-shape-spec-list in a processors-decl will override an explicit DIMENSION attribute:

```fortran
!HPF$ PROCESSORS, DIMENSION(3,3,3) :: &
!HPF$ RUBIK, RUBIKS_REVENGE(4,4,4), SOMA
```

Here RUBIKS_REVENGE is $4 \times 4 \times 4$ while RUBIK and SOMA are each $3 \times 3 \times 3$. (By the rules enunciated above, however, such a statement may not be completely portable because no HPF language processor is required to handle shapes of total sizes 27 and 64 simultaneously.)

Returning from a subprogram causes all processor arrangements declared local to that subprogram to become undefined. It is not HPF-conforming for any array or template to be distributed onto a processor arrangement at the time the processor arrangement becomes undefined unless at least one of two conditions holds:

- The array or template itself becomes undefined at the same time by virtue of returning from the subprogram.
- Whenever the subprogram is called, the processor arrangement is always locally defined in the same way, with identical lower bounds and identical upper bounds.

Rationale. Note that this second condition is slightly less stringent than requiring all expressions to be constant. This allows calls to NUMBER_OF_PROCESSORS or PROCESSORS_SHAPE to appear without violating the condition. (End of rationale.)

Variables in COMMON or having the SAVE attribute may be mapped to a locally declared processor arrangement, but because the first condition cannot hold for such variables (they
don't become undefined), the second condition must be observed. This allows COMMON
variables to work properly through the customary strategy of putting identical declarations
in each scoping unit that needs to use them, while allowing the processor arrangements to
which they may be mapped to depend on the value returned by NUMBER_OF_PROCESSORS.
(See section 3.8 for further information on mapping common variables.)

Advice to implementors. It may be desirable to have a way for the user to specify at compile time the number of physical processors on which the program is to be executed. This might be specified either by an implementation-dependent directive, for example, or through the programming environment (for example, as a UNIX command-line argument). Such facilities are beyond the scope of the HPF specification, but as food for thought we offer the following illustrative hypothetical examples:

!Declaration for multiprocessor by ABC Corporation
!ABC$ PHYSICAL PROCESSORS(8)

!Declaration for mpp by XYZ Incorporated
!XYZ$ PHYSICAL PROCESSORS(65536)

!Declaration for hypercube machine by PDQ Limited
!PDQ$ PHYSICAL PROCESSORS(2,2,2,2,2,2,2,2,2)

!Declaration for two-dimensional grid machine by TLA GmbH
!TLA$ PHYSICAL PROCESSORS(128,64)

!One of the preceding might affect the following:
!HPF$ PROCESSORS P(NUMBER_OF_PROCESSORS())

It may furthermore be desirable to have a way for the user to specify the precise mapping of the processor arrangement declared in a PROCESSORS statement to the physical processors of the executing hardware. Again, this might be specified either by a implementation-dependent directive or through the programming environment (for example, as a UNIX command-line argument); such facilities are beyond the scope of the HPF specification, but as food for thought we offer the following illustrative hypothetical example:

!PDQ$ PHYSICAL PROCESSORS(2,2,2,2,2,2,2,2,2,2)
!HPF$ PROCESSORS G(8,64,16)
!PDQ$ MACHINE LAYOUT G(:GRAY(0:2),:GRAY(6:11),:BINARY(3:5,12))

This might specify that the first dimension of G should use hypercube axes 0, 1, 2 with a Gray-code ordering; the second dimension should use hypercube axes 6 through 11 with a Gray-code ordering; and the third dimension should use hypercube axes 3, 4, 5, and 12 with a binary ordering. (End of advice to implementors.)

3.7 The TEMPLATE Directive

The TEMPLATE directive declares one or more templates, specifying for each the name, the rank (number of dimensions), and the extent in each dimension. It must appear in the specification-part of a scoping unit.

In the language of F95:14.1.2 in the Fortran standard, templates are local entities of class (1); therefore a template may not have the same name as a variable, named constant,
A template declared in a module has the default accessibility of the module.

Rationale. Because the name of a template is not a first-class entity in HPF, but must appear only in directives, it cannot appear in an access-stmt (PRIVATE or PUBLIC). If directives ever become full-fledged Fortran statements rather than structured comments, then it would be appropriate to allow the accessibility of a template to be controlled by listing its name in an access-stmt. (End of rationale.)

A template is simply an abstract space of indexed positions; it can be considered as an “array of nothings” (as compared to an “array of integers,” say). A template may be used as an abstract align-target that may then be distributed.

**Examples:**

```fortran
!HPF$ TEMPLATE A(N)
!HPF$ TEMPLATE B(N,N) , C(N,2*N)
!HPF$ TEMPLATE DOPEY(100,100) , SNEEZY(24) , GRUMPY(17,3,5)
```

If the “::” syntax is used, then the declared templates may optionally be distributed in the same combined-directive. In this case all templates declared by the directive must have the same rank so that the \texttt{DISTRIBUTE} attribute will be meaningful. The \texttt{DIMENSION} attribute may also be used.

```fortran
!HPF$ TEMPLATE, DISTRIBUTE(BLOCK,*): &
 !HPF$ WHINEY(64,64),MOPEY(128,128)
!HPF$ TEMPLATE, DIMENSION(91,91): & BORED,WHEEZY,PERKY
```

Templates are useful in the particular situation where one must align several arrays relative to one another but there is no need to declare a single array that spans the entire index space of interest. For example, one might want four \( N \times N \) arrays aligned to the four corners of a template of size \( (N+1) \times (N+1) \):

```fortran
!HPF$ TEMPLATE, DISTRIBUTE(BLOCK,BLOCK): & EARTH(N+1,N+1)
   REAL, DIMENSION(N,N): & NW, NE, SW, SE
!HPF$ ALIGN NW(I,J) WITH EARTH(I,J)
!HPF$ ALIGN NE(I,J) WITH EARTH(I,J+1)
!HPF$ ALIGN SW(I,J) WITH EARTH(I+1,J)
!HPF$ ALIGN SE(I,J) WITH EARTH(I+1,J+1)
```

Templates may also be useful in making assertions about the mapping of dummy arguments (see Section 4).

Unlike arrays, templates cannot be in \texttt{COMMON}. So two templates declared in different scoping units will always be distinct, even if they are given the same name. The only way for two program units to refer to the same template is to declare the template in a module that is then used by the two program units.
Templates are not passed through the subprogram argument interface. The template to which a dummy argument is aligned is always distinct from the template to which the actual argument is aligned, though it may be a copy (see section 4.4.2). On exit from a subprogram, an HPF implementation arranges that the actual argument is aligned with the same template with which it was aligned before the call.

Returning from a subprogram causes all templates declared local to that subprogram to become undefined. It is not HPF-conforming for any variable to be aligned to a template at the time the template becomes undefined unless at least one of two conditions holds:

- The variable itself becomes undefined at the same time by virtue of returning from the subprogram.
- Whenever the subprogram is called, the template is always locally defined in the same way, with identical lower bounds, identical upper bounds, and identical distribution information (if any) onto identically defined processor arrangements (see section 3.6).

Rationale. Note that this second condition is slightly less stringent than requiring all expressions to be constant. This allows calls to `NUMBER_OF_PROCESSORS` or `PROCESSORS_SHAPE` to appear without violating the condition. (End of rationale.)

Variables in `COMMON` or having the `SAVE` attribute may be mapped to a locally declared template, but because the first condition cannot hold for such variable (they don’t become undefined), the second condition must be observed.

### 3.8 Storage and Sequence Association

HPF allows the mapping of data objects across multiple processors in order to improve parallel performance. Fortran specifies relationships between the storage for data objects associated through `COMMON` and `EQUIVALENCE` statements, and the order of array elements during association at procedure boundaries between actual arguments and dummy arguments. Otherwise, the location of data is not constrained by the language.

`COMMON` and `EQUIVALENCE` statements constrain the alignment of different data items based on the underlying model of storage units and storage sequences:

*Storage association is the association of two or more data objects that occurs when two or more storage sequences share or are aligned with one or more storage units.*

— Fortran Standard (F95:14.6.3.1)

The model of storage association is a single linearly addressed memory, based on the traditional single address space, single memory unit architecture. This model can cause severe inefficiencies on architectures where storage for data objects is mapped.

Sequence association refers to the order of array elements that Fortran requires when an array expression or array element is associated with a dummy array argument:

*The rank and shape of the actual argument need not agree with the rank and shape of the dummy argument, ...*

— Fortran Standard (F95:12.4.1.4)
As with storage association, sequence association is a natural concept only in systems with a linearly addressed memory.

As an aid to porting FORTRAN 77 codes, HPF allows codes that rely on sequence and storage association to be valid in HPF. Some modification to existing FORTRAN 77 codes may nevertheless be necessary. This section explains the relationship between HPF data mapping and sequence and storage association.

### 3.8.1 Storage Association

#### 3.8.1.1 Definitions

1. **COMMON** blocks are either *sequential* or *nonsequential*, as determined by either explicit directive or compiler default. A sequential **COMMON** block has a single **COMMON** block storage sequence (F95:5.5.2.1).

2. An *aggregate variable group* is a collection of variables whose individual storage sequences are parts of a single storage sequence.

   Variables associated by **EQUIVALENCE** statements or by a combination of **EQUIVALENCE** and **COMMON** statements form an aggregate variable group. The variables of a sequential **COMMON** block form a single aggregate variable group.

3. The *size* of an aggregate variable group is the number of storage units in the group’s storage sequence (F95:14.6.3.1).

4. Data objects are either *sequential* or *nonsequential*. A data object is *sequential* if and only if any of the following holds:

   (a) it appears in a sequential **COMMON** block;
   
   (b) it is a member of an aggregate variable group;
   
   (c) it is an assumed-size array;
   
   (d) its type is a sequence type;
   
   (e) it is a subobject of a sequential data object; or
   
   (f) it is declared to be sequential in an HPF **SEQUENCE** directive.

   A sequential object can be storage associated or sequence associated; nonsequential objects cannot.

5. A **COMMON** block contains a sequence of *components*. Each component is either an aggregate variable group, or a variable that is not a member of any aggregate variable group. A sequential **COMMON** block contains a single component. A nonsequential **COMMON** block may contain several components each of which may be a sequential variable, an aggregate variable group, or a nonsequential variable.

#### 3.8.1.2 Examples of Definitions

*Example 1:*

```fortran
COMMON /FOO/ A(100), B(100), C(100), D(100), E(100)
DIMENSION X(100), Y(150), Z(200)
EQUIVALENCE ( A(1), Z(1) )
```
Four components: (A, B), C, D, E
Sizes are: 200, 100, 100, 100

Example 2:

```fortran
COMMON /FOO/ A(100), B(100), C(100), D(100), E(100)
DIMENSION X(100), Y(150), Z(200)
EQUIVALENCE ( A(51), X(1) ) ( B(100), Y(1) )
```

Two components (A, B, C, D), E
Sizes are: 400, 100

Example 3:

```fortran
COMMON /FOO/ A(100), B(100), C(100), D(100), E(100)
DIMENSION X(100), Y(150), Z(200)
!HPF$ SEQUENCE /FOO/
!The COMMON has one component, (A, B, C, D, E)
!Size is 500
```

The COMMON block /FOO/ is nonsequential in Examples 1 and 2. Aggregate variable groups are shown as components in parentheses.

### 3.8.2 The SEQUENCE Directive

A SEQUENCE directive is defined to allow a user to declare explicitly that data objects or COMMON blocks are to be treated by the compiler as sequential. (COMMON blocks are by default nonsequential. Data objects are nonsequential unless Definition 4 of Section 3.8 applies.) Some implementations may supply an optional compilation environment where the SEQUENCE directive is applied by default. For completeness in such an environment, HPF defines a NO SEQUENCE directive to allow a user to establish that the usual nonsequential default should apply to a scoping unit or to selected data objects and COMMON blocks within the scoping unit.

```
H333 sequence-directive is SEQUENCE [ [ :: ] association-name-list ]
    or NO SEQUENCE [ [ :: ] association-name-list ]

H334 association-name is object-name
    or / [ common-block-name ] /
```

Constraint: An object name or COMMON block name may appear at most once in a sequence-directive within any scoping unit.

Constraint: Only one sequence directive with no association-name-list is permitted in the same scoping unit.

A sequential pointer can be associated only with sequential objects. A nonsequential pointer can be associated only with nonsequential objects.

### 3.8.2.1 Storage Association Rules

1. A sequence-directive with an empty association-name-list is treated as if it contained the names of all implicitly mapped objects and COMMON blocks in the scoping unit that
cannot otherwise be determined to be sequential or nonsequential by their language context.

2. A sequential object may not be explicitly mapped.

3. No explicit mapping may be given for a component of a derived type having the Fortran `SEQUENCE` attribute. Note that this rule is applicable only under the approved extensions since components of derived types cannot be explicitly mapped in HPF.

4. If a `COMMON` block is nonsequential, then all of the following must hold:

   (a) Every occurrence of the `COMMON` block has exactly the same number of components with each corresponding component having a storage sequence of exactly the same size;

   (b) If a component is a nonsequential variable in any occurrence of the `COMMON` block, then it must be nonsequential with identical type, shape, and mapping attributes in every occurrence of the `COMMON` block; and

   (c) Every occurrence of the `COMMON` block must be nonsequential.

3.8.2.2 Storage Association Discussion

Advice to users. Under these rules, variables in a `COMMON` block can be mapped as long as the components of the `COMMON` block are the same in every scoping unit that declares the `COMMON` block.

Correct Fortran programs will not necessarily be correct without modification in HPF. The use of `EQUIVALENCE` with `COMMON` blocks can impact the mappability of data objects in subtle ways. To allow maximum optimization for performance, the HPF default for data objects is to consider them mappable. In order to get correct separate compilation for subprograms that use `COMMON` blocks with different aggregate variable groups in different scoping units, it will be necessary to insert the HPF `SEQUENCE` directive.

As a check-list for a user to determine the status of a data object or `COMMON` block, the following questions can be applied, in order:

- Does the object appear in some explicit language context which dictates that the object be sequential (e.g. `EQUIVALENCE`) or nonsequential?
- If not, does the object appear in an explicit mapping directive?
- If not, does the object or `COMMON` block name appear in the list of names on a `SEQUENCE` or `NO SEQUENCE` directive?
- If not, does the scoping unit contain a nameless `SEQUENCE` or `NO SEQUENCE`?
- If not, is the compilation affected by some special implementation-dependent environment which dictates that names default to `SEQUENCE`?
- If not, then the compiler will consider the object or `COMMON` block name nonsequential and is free to apply data mapping optimizations that disregard Fortran sequence and storage association.

(End of advice to users.)
Advice to implementors. In order to protect the user and to facilitate portability of older codes, two implementation options are strongly recommended. First, every implementation should supply some mechanism to verify that the type and shape of every mappable array and the sizes of aggregate variable groups in COMMON blocks are the same in every scoping unit unless the COMMON blocks are declared to be sequential. This same check should also verify that identical mappings have been selected for the variables in COMMON blocks. Implementations without interprocedural information can use a link-time check. The second implementation option recommended is a mechanism to declare that data objects and COMMON blocks for a given compilation should be considered sequential unless declared otherwise. The purpose of this feature is to permit compilation of large old libraries or subprograms where storage association is known to exist without requiring that the code be modified to apply the HPF SEQUENCE directive to every COMMON block. (End of advice to implementors.)
Section 4

Data Mapping in Subprogram Interfaces

In this Section, phrases such as “the caller must pass...” are constraints on the implementation (i.e., on the generated code produced by the compiler), not on the source code produced by the programmer.

4.1 Introduction

This introduction gives an overview of the ways in which mapping directives interact with argument passing to subprograms. The language used here, however, is not definitive; the subsequent subsections of this Section contain the authoritative rules.

In addition to the data mapping features described in Section 3, HPF allows a number of options for describing the mapping of dummy arguments.

The mapping of each such dummy argument may be related to the mapping of its associated actual argument in the calling main program or procedure (the “caller”) in several different ways. To allow for this, mapping directives applied to dummy arguments can have three different syntactic forms: prescriptive, descriptive, and transcriptive.

HPF provides these three forms to allow the programmer either to specify that the data is to be left in place, or to specify that during the execution of the call the data must be automatically remapped into a new and presumably more efficient mapping for the duration of the execution of the called subprogram.

The meaning of these forms is as follows:

prescriptive The directive describes the mapping of the dummy argument. However, the actual argument need not have this mapping. If it does not, it is the responsibility of the compiler to generate code to remap the argument as specified, and to restore the original mapping on exit. This code may be generated either in the caller or in the called subprogram; the requirements for explicit interfaces in Section 4.6 insure that the necessary information will be available at compile time to perform the mapping in either place.

Prescriptive directives are syntactically identical to directives occurring elsewhere in the program. For instance, if A is a dummy argument,

!HPF$ DISTRIBUT A (BLOCK, CYCLIC)
is a prescriptive directive.

**descriptive** Descriptive syntax has exactly the same meaning as prescriptive syntax, except that in addition it amounts to a weak assertion by the programmer that the actual argument requires no remapping.

The assertion is characterized as "weak" because if it is false, the program is still standard-conforming. In such a case, the compiler must generate the appropriate remapping.

If the compiler can prove that the assertion is false, or if the compiler cannot verify that it is true, it may issue a warning or informational diagnostic message.

*Advice to users.* The purpose of descriptive, as opposed to prescriptive, directives is simply to provide a possible way for the compiler to report information to the programmer that may be useful in program development and debugging. Note that any diagnostic message that may be produced as a result of the use of descriptive directives is not a portable feature of this language. In particular, there are instances in which no remapping is needed but where this fact would be impossible or highly non-trivial for a compiler to ascertain. Different compilers may well emit messages in different circumstances; and there is no requirement that any such messages be emitted at all. *(End of advice to users.)*

Descriptive directives look like prescriptive directives, except that an asterisk precedes the description. For instance,

```
!HPF$ DISTRIBUTE A *(BLOCK, CYCLIC)
```

is a descriptive directive.

**transcriptive** The mapping is unspecified. The called subprogram must accept the mapping of the argument as it is passed. Of course this means that (the implementation of) the caller must pass this mapping information at run-time.

Transcriptive directives are written with a single asterisk for distributions and processor arrangements; for instance

```
!HPF$ DISTRIBUTE A *
!HPF$ DISTRIBUTE B * ONTO *
```

are transcriptive directives. The **INHERIT** directive (see Section 4.4.2) is used to specify a transcriptive alignment.

Both distribution formats and processor arrangements can be specified prescriptively, descriptively, or transscriptively. Alignment is more complicated, because of the need to specify the template with which the dummy is aligned. This template may be unspecified (in this case of course there is no **ALIGN** directive), in which case it is the natural template of the dummy. ("Natural template" is defined in Section 4.4.1 below.) Otherwise, one of the following disjoint possibilities must be true:

- The template is explicitly specified by a prescriptive **ALIGN** directive.
• The template is explicitly specified by a descriptive ALIGN directive.

• The template is inherited. This is specified by giving the dummy the INHERIT attribute (described in Section 4.4.2 below). This implicitly specifies the template to be a copy of the template with which the corresponding actual argument is ultimately aligned; further, the alignment of the dummy with that template is the same as that of the corresponding actual. This is, in effect, a transcriptive form of alignment.

This is restated more precisely in Section 4.4.1 below.

Advice to users. Although it is possible to write some combinations of mapping directives that are partially prescriptive and partially transcriptive, for instance, there is probably no virtue in doing so. The point of these directives is to enable the compiler to handle any necessary remapping correctly and efficiently. Now remapping can happen for one or more of the following reasons:

• to make the alignment of the actual and the dummy agree;
• to make the distribution of the actual and the dummy agree;
• to make the processor arrangement of the actual and the dummy agree.

For most machines, there is no real difference in the cost of remapping for any of these reasons. It is therefore a better practice (for readability, at least) to make a mapping either purely transcriptive, purely prescriptive, or purely descriptive.

While transcriptive mappings can be useful in writing libraries, they impose a runtime cost on the subprogram. They should therefore be avoided in normal user code. (End of advice to users.)

4.2 What Remapping Is Required and Who Does It

If there is an explicit interface for the called subprogram and that interface contains prescriptive or descriptive mapping directives for a dummy argument, and if a remapping of the corresponding actual argument is necessary, the call should proceed as if the data were copied to a temporary variable to match the mapping of the dummy argument as expressed by the directives in the explicit interface. The template of the dummy will then be as declared in the interface.

If there is no explicit interface, then no remapping will be necessary; this is a consequence of the requirements in Section 4.6.

The reader should note that for reasons of brevity, not all such required explicit interfaces are included in the code fragments in this Section.

An overriding principle is that any remapping of arguments is not visible to the caller. That is, when the subprogram returns and the caller resumes execution, all objects accessible to the caller after the call are mapped exactly as they were before the call. It is not possible for a procedure to change the mapping of any object in a manner visible to its caller.

Advice to users. Some Approved Extensions relax this restriction; see for instance Sections 8.6 and 8.8. (End of advice to users.)
4.3 Distributions and Processor Arrangements

In a `DISTRIBUTE` directive where every `distributee` is a dummy argument, either the `dist-format-clause` or the `dist-target`, or both, may begin with, or consist of, an asterisk.

- Without an asterisk, a `dist-format-clause` or `dist-target` is prescriptive; the clause describes a distribution and constitutes a request of the language processor to make it so. This might require (the implementation of) either the caller or the called subprogram to remap or copy the actual argument on entry at run time in order to satisfy the requested distribution for the dummy.

- Starting with an asterisk, a `dist-format-clause` or `dist-target` is descriptive. Such a directive is equivalent in every respect to a prescriptive directive, except that if the compiler cannot verify that no remapping of the actual is required, it may issue a diagnostic message to that effect. See Section 4.1 for further information on this point.

- Consisting of only an asterisk, a `dist-format-clause` or `dist-target` is transcriptive; the clause says nothing about the distribution but constitutes a request to the language processor to copy that aspect of the distribution from that of the actual argument. (The intent is that if the argument is passed by reference, no movement of the data will be necessary at run time.)

It is possible that, in a single `DISTRIBUTE` directive, the `dist-format-clause` might have an asterisk but not the `dist-target`, or vice versa.

4.3.1 Examples

These examples of `DISTRIBUTE` directives for dummy arguments illustrate the various combinations:

```plaintext
!HPF$ DISTRIBUTE URANIA (CYCLIC) ONTO GALILEO
```

The language processor should do whatever it takes to cause URANIA to have a CYCLIC distribution on the processor arrangement GALILEO.

```plaintext
!HPF$ DISTRIBUTE POLYHYMNIA * ONTO ELVIS
```

The language processor should do whatever it takes to cause POLYHYMNIA to be distributed onto the processor arrangement ELVIS, using whatever distribution format it currently has (which might be on some other processor arrangement).

```plaintext
!HPF$ DISTRIBUTE THALIA *(CYCLIC) ONTO *FLIP
```

The language processor should do whatever it takes to cause THALIA to have a CYCLIC distribution on the processor arrangement FLIP; the programmer believes that the actual is already distributed in this fashion and that no remapping is required.

```plaintext
!HPF$ DISTRIBUTE EUTERPE (CYCLIC) ONTO *
```

The language processor should do whatever it takes to cause EUTERPE to have a CYCLIC distribution onto whatever processor arrangement the actual was distributed onto.
4.4. ALIGNMENT

!HPF$ DISTRIBUTE ERATO * ONTO *

The mapping of ERATO should not be changed from that of the actual argument.

Note that DISTRIBUTE ERATO * ONTO * does not mean the same thing as

!HPF$ DISTRIBUTE ERATO (*) ONTO *

This latter means: distribute ERATO * (that is, on-processor) onto whatever processor arrangement the actual was distributed onto. The processor arrangement is necessarily scalar in this case.

4.3.2 What Happens When a Clause Is Omitted

One may omit either the dist-formal-clause or the dist-onto-clause for a dummy argument. This is understood as follows:

If the dummy argument has the INHERIT attribute (see Section 4.4.2), then no distribution directive is allowed in any case: the distribution as well as the alignment is inherited from the actual argument.

In any other case in which distribution information is omitted, the compiler may choose the distribution format or a target processor arrangement arbitrarily.

Here are two examples:

!HPF$ DISTRIBUTE WHEEL_OF_FORTUNE *(CYCLIC)

The programmer believes that the actual argument corresponding to the dummy argument WHEEL_OF_FORTUNE is already distributed CYCLIC. The compiler should insure that the mapping of the passed data is in fact CYCLIC, and remap it if necessary if it is not. It may in addition be remapped onto some other processor arrangement, but there is no reason to; most likely the programmer would be surprised if such a remapping occurred.

!HPF$ DISTRIBUTE ONTO *TV :: DAVID_LETTERMAN

The programmer believes that the actual argument corresponding to the dummy argument DAVID_LETTERMAN is already distributed onto TV in some fashion. The compiler should insure that this is so, and make it so if it is not. The distribution format may be changed as long as DAVID_LETTERMAN is kept on TV. (Note that this declaration must be made in attributed form; the statement form

!HPF$ DISTRIBUTE DAVID_LETTERMAN ONTO *TV       !Nonconforming

does not conform to the syntax for a DISTRIBUTE directive.)

4.4 Alignment

4.4.1 The Template of the Dummy Argument

Here we describe precisely how to determine the template with which the dummy argument is ultimately aligned:

Templates are not passed through the subprogram argument interface. A dummy argument and its corresponding actual argument may be aligned to the same template only if that template is accessible in both the caller and the called subprogram either through host association or use association. In any other case, the template with which a dummy
argument is aligned is always distinct from the template with which the actual argument is aligned, though it may be a copy (see Section 4.4.2). On exit from a procedure, an HPF implementation arranges that the actual argument is aligned with the same template with which it was aligned before the call.

The template of the dummy argument is arrived at in one of three ways:

- If the dummy argument appears explicitly as an alignee in an ALIGN directive, its template is the align-target if the align-target is a template; otherwise its template is the template with which the align-target is ultimately aligned.

- If the dummy argument is not explicitly aligned and does not have the INHERIT attribute (described in Section 4.4.2 below), then the template has the same shape and bounds as the dummy argument; this is called the natural template for the dummy. (Thus, all the examples in Section 4.3 use the natural template.)

- If the dummy argument is not explicitly aligned and does have the INHERIT attribute, then the template is "inherited" from the actual argument according to the following rules:

  - If the actual argument is a whole array, the template of the dummy is a copy of the template with which the actual argument is ultimately aligned.

  - If the actual argument is an array section of array $A$ where no subscript is a vector subscript, then the template of the dummy is a copy of the template with which $A$ is ultimately aligned.

  - If the actual argument is any other expression, the shape and distribution of the template may be chosen arbitrarily by the language processor (and therefore the programmer cannot know anything a priori about its distribution).

In all of these cases, we say that the dummy has an inherited template.

### 4.4.2 The INHERIT Directive

The INHERIT directive specifies that a dummy argument should be aligned to a copy of the template of the corresponding actual argument in the same way that the actual argument is aligned.

\[
\begin{align*}
\text{H401} & \quad \text{inherit-directive} \quad \text{is} \quad \text{INHERIT} \quad \text{inheritee-list} \\
\text{H402} & \quad \text{inheritee} \quad \text{is} \quad \text{object-name}
\end{align*}
\]

Constraint: An inheritee must be a dummy argument.

Constraint: An inheritee must not be an alignee.

Constraint: An inheritee must not be a distributee.

*Advice to users.* The first of these three constraints is relaxed for pointers under the approved extensions (see Section 8.8). *(End of advice to users.)*
The **INHERIT** directive causes the named subprogram dummy arguments to have the **INHERIT** attribute. Only dummy arguments may have the **INHERIT** attribute. An object must not have both the **INHERIT** attribute and the **ALIGN** attribute. An object must not have both the **INHERIT** attribute and the **DISTRIBUTE** attribute. The **INHERIT** directive may appear only in a **specification-part** of a scoping unit.

The **INHERIT** attribute specifies that the template for a dummy argument should be inherited, by making a copy of the template of the actual argument. Moreover, no other explicit mapping directive may appear for an argument with the **INHERIT** attribute: the **INHERIT** attribute implies a distribution of **DISTRIBUTE * ONTO * for the inherited template.** Thus, the net effect is to tell the compiler to leave the data exactly where it is, and not attempt to remap the actual argument. The dummy argument will be mapped in exactly the same manner as the actual argument; the subprogram must be compiled in such a way as to work correctly no matter how the actual argument may be mapped onto abstract processors.

Note that if A is an array dummy argument, the directive

``` HPF
!HPF$ INHERIT A
```

is more general than

``` HPF
!HPF$ DISTRIBUTE A * ONTO *
```

for the following reason: The **INHERIT** directive states that the (inherited) template with which A is aligned is distributed * ONTO *, but that A may be aligned in some non-trivial manner with that template. On the other hand, the **DISTRIBUTE** directive states that A is aligned trivially with its natural template, which in turn is distributed * ONTO *.

For example, the following code is not permitted:

``` HPF
!HPF$ PROCESSORS P(2)
REAL, DIMENSION(100) :: A
!HPF$ DISTRIBUTE (BLOCK) ONTO P :: A

CALL FOO(A(1:50))
...

SUBROUTINE FOO(D)
REAL, DIMENSION(50) :: D
!HPF$ DISTRIBUTE D * ! Nonconforming
```

The transcriptive distribution for D is nonconforming because the natural template for D is not distributed BLOCK. On the other hand, it would be correct to replace the illegal directive by

``` HPF
!HPF$ INHERIT D
```

### 4.4.2.1 Examples

Here is a straightforward example of the use of **INHERIT**:

``` HPF
!HPF$ INHERIT A
```
REAL DOUGH(100)
!HPF$ DISTRIBUTED DOUGH(BLOCK(10))
CALL PROBATE( DOUGH(7:23:2) )
...
SUBROUTINE PROBATE(BREAD)
REAL BREAD(9)
!HPF$ INHERIT BREAD

The inherited template of BREAD has shape [100]; element BREAD(I) is aligned with element \(5 + 2I\) of the inherited template, and that template has a BLOCK(10) distribution.

More complicated examples can easily be constructed. It is important to bear in mind that the rank of the inherited template may be different from the rank of the dummy, and it might even be different from the rank of the actual. For instance, one might have a program containing the following:

REAL A(100,100)
!HPF$ TEMPLATE T(100,100,100)
!HPF$ DISTRIBUTED T(BLOCK,CYCLIC,*)
!HPF$ ALIGN A(I,J) with T(J,3,I)
CALL SUBR(A(:,:))
...
SUBROUTINE SUBR(D)
REAL D(100)
!HPF$ INHERIT D

In this case, the dummy D has rank 1. It corresponds to a 1-dimensional section of a 2-dimensional actual A, which in turn is aligned with a 2-dimensional section of a 3-dimensional template T. The template of D is a copy of this three-dimensional template. D is aligned with the section \((7, 3, :)\) of this inherited template. Thus, the “visible” dimension of the dummy D is distributed *, although if the call statement had been

CALL SUBR(A(7,:))

for instance, the “visible” dimension of the dummy would be distributed BLOCK.

### 4.4.3 Descriptive ALIGN Directives

The presence or absence of an asterisk at the start of an align-spec has the same meaning as in a dist-format-clause: it specifies whether the ALIGN directive is descriptive or prescriptive, respectively.

If an align-spec that does not begin with * is applied to a dummy argument, the meaning is that the dummy argument will be forced to have the specified alignment on entry to the subprogram. This may require (the implementation of) either the caller or the subprogram to temporarily remap the data of the actual argument or a copy thereof.

Note that a dummy argument may also be used as an align-target.

SUBROUTINE NICHOLAS(TSAR,CZAR)
REAL, DIMENSION(1918) :: TSAR,CZAR
!HPF$ INHERIT :: TSAR
!HPF$ ALIGN WITH TSAR :: CZAR
In this example the first dummy argument, TSAR, remains aligned with the corresponding actual argument, while the second dummy argument, CZAR, is forced to be aligned with the first dummy argument. If the two actual arguments are already aligned, no remapping of the data will be required at run time. If they are not, some remapping will take place.

If the align-spec begins with "*", then the alignee must be a dummy argument. The "*" indicates that the programmer believes that the actual argument already has the specified alignment, and that no action to remap it is required at run time. (As before, there is no requirement that the programmer’s belief is correct, and the compiler must generate a remapping if one appears to be necessary, just as in the case of a prescriptive alignment.)

For example, if in the above example the alignment directive were changed to

```
!HPF$ ALIGN WITH *TSAR :: CZAR
```

then the programmer is expressing a belief that no remapping of the actual argument corresponding to TSAR will be necessary.

It is not permitted to say simply “ALIGN WITH *”; an align-target must follow the asterisk. (The proper way to say “accept any alignment” is INHERIT.)

If a dummy argument has no explicit ALIGN or DISTRIBUTE attribute, then the compiler provides an implicit alignment and distribution specification, one that could have been described explicitly without any “assertion asterisks”.

### 4.4.3.1 Example

If the INHERIT directive is not used, explicit alignment of a dummy argument may be necessary to insure that no remapping takes place at the subprogram boundary. Here is an example:

```
LOGICAL FRUG(128)

!HPF$ PROCESSORS DANCE_FLOOR(16)

!HPF$ DISTRIBUTE (BLOCK) ONTO DANCE_FLOOR::FRUG

CALL TERPSICHORE(FRUG(1:40:3))
```

The array section `FRUG(1:40:3)` is mapped onto abstract processors in the following manner:

```
<p>| | | | | | | | | | | | | | | | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>5</td>
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<td>10</td>
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<td>19</td>
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<td>37</td>
<td>22</td>
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</tr>
</tbody>
</table>
```

Suppose first that the interface to the subroutine `TERPSICHORE` looks like this:
SUBROUTINE TERPSICHORE(FOXTROT)
LOGICAL FOXTROT(:)
!HPF$ INHERIT FOXTROT

The template of FOXTROT is a copy of the 128 element template of the whole array FRUG. The template is mapped like this:

```
  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16
1  9 17 25 33 41 49 57 65 73 81 89 97 105 113 121
2 10 18 26 34 42 50 58 66 74 82 90 98 106 114 122
3 11 19 27 35 43 51 59 67 75 83 91 99 107 115 123
4 12 20 28 36 44 52 60 68 76 84 92 100 108 116 124
5 13 21 29 37 45 53 61 69 77 85 93 101 109 117 125
6 14 22 30 38 46 54 62 70 78 86 94 102 110 118 126
7 15 23 31 39 47 55 63 71 79 87 95 103 111 119 127
8 16 24 32 40 48 56 64 72 80 88 96 104 112 120 128
```

FOXTROT(I) is aligned with element 3*I-2 of the template.

Suppose, on the other hand, that the interface to TERPSICHORE were to look like this instead:

```
SUBROUTINE TERPSICHORE(FOXTROT)
LOGICAL FOXTROT(:)
!HPF$ DISTRIBUTE FOXTROT(BLOCK)
```

In this case, the template of FOXTROT is its natural template; it has the same size 14 as FOXTROT itself. The actual argument, FRUG(1:40:3) is mapped to the 16 processors in this manner:

<table>
<thead>
<tr>
<th>Abstract processor of FRUG</th>
<th>Elements of FRUG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>2</td>
<td>4, 5, 6</td>
</tr>
<tr>
<td>3</td>
<td>7, 8</td>
</tr>
<tr>
<td>4</td>
<td>9, 10, 11</td>
</tr>
<tr>
<td>5</td>
<td>12, 13, 14</td>
</tr>
<tr>
<td>6–16</td>
<td>none</td>
</tr>
</tbody>
</table>

That is, the original positions (in the template of the actual argument) of the elements of the dummy are as follows:
This layout (3 elements on the first processor, 3 on the second, 2 on the third, 3 on the fourth, ...) cannot properly be described as a BLOCK distribution. Therefore, remapping will take place at the call.

Remapping can be avoided without using INHERIT by explicitly aligning the dummy to a declared template of size 128 distributed BLOCK:

```fortran
SUBROUTINE TERPSICHORE(FOXTROT)
  LOGICAL FOXTROT(:)
  !HPF$ PROCESSORS DANCE_FLOOR(16)
  !HPF$ TEMPLATE, DISTIBUTE(BLOCK) ONTO DANCE_FLOOR::GURF(128)
  !HPF$ ALIGN FOXTROT(I) WITH GURF(3*I-2)
```

Advice to users. The advantage of this latter technique is that, where it can be used, it gives the compiler more information; this information can often be used to generate more efficient code. (End of advice to users.)

### 4.5 Equivalence and Partial Order on the Set of Mappings

The set of mappings of named objects is endowed with a partial order modulo a certain equivalence. Roughly speaking, if $P$ and $Q$ are two mappings, then to say that $Q$ is a specialization of $P$ (i.e., “$Q$ is below $P$” in this ordering) is to say that $P$ is partially specified and that $Q$ is one of the mappings that is consistent with $P$. This notion is used below in Section 4.6, and also in Section 8.8.

Advice to users. Since these conditions are complex to state, it is worth noting that if you always provide explicit interfaces (which, as explained below, is quite easy and generally happens automatically) and if you don’t use mapped pointers (an Approved Extension, explained below in Section 8.8), then you need not read this Section. (End of advice to users.)

The precise definition is as follows.

First, we define a notion of equivalence for `dist-format` specifications:

1. Using the notation $\equiv$ for the phrase “is equivalent to”,

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```
2. Other than this, no two lexically distinct \textit{dist-format} specifications are equivalent.

This is an equivalence relation in the usual mathematical sense. Now we define the partial order on mappings: Let \( S \) ("special") and \( G \) ("general") be two data objects.

The mapping of \( S \) is a \textit{specialization} of the mapping of \( G \) if and only if either:

1. \( G \) has the \textbf{INHERIT} attribute, or
2. \( S \) does not have the \textbf{INHERIT} attribute, and the following constraints all hold:

   (a) \( S \) is a named object, and
   (b) The shapes of the ultimate align targets of \( S \) and \( G \) are the same, and
   (c) Corresponding dimensions of \( S \) and \( G \) are mapped to corresponding dimensions of their respective ultimate align targets, and corresponding elements of \( S \) and \( G \) are aligned with corresponding elements of their respective ultimate align targets, and
   (d) Either
      i. The ultimate align targets of both \( S \) and \( G \) are not explicitly distributed, or
      ii. The ultimate align targets of both \( S \) and \( G \) are explicitly distributed. In this case, the distribution directive specified for the ultimate align target of \( G \) must satisfy one of the following conditions:
         A. It has no \textit{dist-onto-clause}, or
         B. It has a \textit{dist-onto-clause} of \texttt{ONTO *}, or
         C. It has a \textit{dist-onto-clause} specifying a processor arrangement having the same shape as that explicitly specified in a distribution directive for the ultimate align target of \( S \),

and must also satisfy one of the following conditions:

A. It has no \textit{dist-format-clause}, or
B. It has a \textit{dist-format-clause} of \texttt{*}, or
C. Each \textit{dist-format} is equivalent (in the sense defined above) to the \textit{dist-format} in the corresponding position of the \textit{dist-format-clause} in an explicit distribution directive for the ultimate align target of \( S \).

With this definition,

- Any mapping of a named object is a specialization of itself.
- If \( A \), \( B \), and \( C \) are named objects, and if the mapping of \( A \) is a specialization of the mapping of \( B \) and the mapping of \( B \) is a specialization of the mapping of \( C \), then the mapping of \( A \) is a specialization of the mapping of \( C \).

That is, the specialization relation, as applied to mappings of named objects, is reflexive and transitive, and it can therefore be applied to produce an equivalence relation on the set of mappings of named objects: two such mappings can be said to be equivalent iff each is a specialization of the other. With this definition, the specialization relation yields a partial ordering on the set of mappings of named objects, modulo equivalence. The INHERIT mapping is the unique maximal element in this partial order.

### 4.6 Conditions for Omitting Explicit Interfaces

Under certain conditions, an explicit interface for a subprogram is not required. The conditions in Fortran under which this is allowable are tightened considerably for HPF programs that use mapping directives.

**Advice to users.** These conditions are complex. The important thing to realize is that you don’t have to read any of this if you have an explicit interface. So if there is any doubt in your mind, just make sure you have an explicit interface. (End of advice to users.)

An explicit interface is required except when all of the following conditions hold:

1. Fortran does not require one, and
2. No dummy argument is distributed transcriptively or with the INHERIT attribute, and
3. For each pair of corresponding actual and dummy arguments, either:
   - (a) They are both implicitly mapped, or
   - (b) They are both explicitly mapped and the mapping of the actual argument is a specialization of the mapping of the dummy argument,

   and

4. For each pair of corresponding actual and dummy arguments, either:
   - (a) Both are sequential, or
   - (b) Both are nonsequential.

**Rationale.** This has the following consequences:

- A plain Fortran program (i.e., with no HPF directives) will be HPF-conforming without the need to add additional interfaces, at least in a compilation environment in which all variables are sequential by default. This is insured by items 1, 2, 3(a), and 4(a).
- If remapping is necessary, this fact will be visible to the caller. Thus the implementation may choose to have all remapping performed by the caller.
Advice to users.  This requirement pushes the user strongly in the direction of always providing explicit interfaces. This is a good thing—explicit interfaces allow many errors to be caught at compile-time and greatly speed up the process of robust software development.

Note that an explicit interface can be provided in three ways:

1. A module subprogram has an explicit interface.
2. An internal subprogram has an explicit interface.
3. An explicit interface may be provided by an interface block.

In addition, an intrinsic procedure always has an explicit interface by definition.

The idiomatic Fortran way of programming makes extensive use of modules; every subprogram, for instance, can be in a module. This provides explicit interfaces automatically, with no extra effort on the part of the programmer. It should very seldom be necessary to write an interface block. (End of advice to users.)

4.7 Characteristics of Procedures

The characteristics of dummy data objects and function results as given in the Fortran standard (F95:12.2) are extended to include also the HPF-characteristics of such objects, which are defined recursively as follows:

- A processor arrangement has one HPF-characteristic: its shape.
- A template has up to three HPF-characteristics:
  1. its shape;
  2. its distribution, if explicitly stated;
  3. the HPF-characteristic (i.e., the shape) of the processor arrangement onto which it is distributed, if explicitly stated.

- A dummy data object has the following HPF-characteristics:
  1. its alignment, if explicitly stated, as well as all HPF-characteristics of its align target;
  2. its distribution, if explicitly stated, as well as the HPF-characteristic (i.e., the shape) of the processor arrangement onto which it is distributed, if explicitly stated.

- A function result has the same HPF-characteristics as a dummy data object. Specifically, it has the following HPF-characteristics:
  1. its alignment, if explicitly stated, as well as all HPF-characteristics of its align target;
2. its distribution, if explicitly stated, as well as the HPF-characteristic (i.e., the
shape) of the processor arrangement onto which it is distributed, if explicitly
stated.

Rationale. In case an explicit interface is given by an interface block, the Fortran
standard specifies what information must be specified in that interface block; it does
this using the concept of a Fortran characteristic. Characteristics of dummy data
objects, for instance, include their types. Characteristics must be specified in interface
blocks; F95:12.3.2.1 in the Fortran standard states

An interface body specifies all of the procedure's characteristics and these
shall be consistent with those specified in the procedure definition ...

Normally, an interface block for a procedure is a textual copy of the appropriate
declarations of that procedure. This Section simply says that such a textual copy
must include any explicit mapping directives relevant to dummy arguments of the
procedure. (End of rationale.)

4.8 Argument Passing and Sequence Association

For actual arguments in a procedure call, Fortran allows an array element (scalar) to be
associated with a dummy argument that is an array. It furthermore allows the shape of a
dummy argument to differ from the shape of the corresponding actual array argument, in
effect reshaping the actual argument via the procedure call. Storage sequence properties of
Fortran are used to identify the values of the dummy argument. This feature, carried over
from FORTRAN 77, has been widely used to pass starting addresses of subarrays, rows,
or columns of a larger array, to procedures. For HPF arrays that are potentially mapped
across processors, this feature is not fully supported.

4.8.1 Sequence Association Rules

1. When an array element or the name of an assumed-size array is used as an actual
argument, the associated dummy argument must be a scalar or specified to be a
sequential array.

An array-element designator of a nonsequential array must not be associated with a
dummy array argument.

2. When an actual argument is an array or array section and the corresponding dummy
argument differs from the actual argument in shape, then the dummy argument must
be declared sequential and the actual array argument must be sequential.

3. An object of type character (scalar or array) is nonsequential if it conforms to the
requirements of Definition 4 of Section 3.8.1.1. If the length of an explicit-length
character dummy argument differs from the length of the actual argument, then both
the actual and dummy arguments must be sequential.

4. Without an explicit interface, a sequential actual may not be associated with a nonse-
quential dummy and a nonsequential actual may not be associated with a sequential
dummy. (This item merely repeats part of Section 4.6).
4.8.2 Discussion of Sequence Association

When the shape of the dummy array argument and its associated actual array argument differ, the actual argument must not be an expression. There is no HPF mechanism for declaring that the value of an array-valued expression is sequential. In order to associate such an expression as an actual argument with a dummy argument of different rank, the actual argument must first be assigned to a named array variable that is forced to be sequential according to Definition 4 of Section 3.8.1.1.

4.8.3 Examples of Sequence Association

Given the following subroutine fragment:

```fortran
SUBROUTINE HOME (X)
DIMENSION X (20,10)
```

By rule 1

```fortran
CALL HOME (ET (2,1))
```

is legal only if X is declared sequential in HOME and ET is sequential in the calling procedure. Likewise, by rules 2 and 4

```fortran
CALL HOME (ET)
```

requires either that ET and X are both sequential arrays or that ET and X have the same shape and (in the absence of an explicit interface) have the same sequence attribute.

Rule 3 addresses a special consideration for objects of type character. Change of the length of character objects across a call, as in

```fortran
CHARACTER (LEN=44) one_long_word
one_long_word = 'Chargoggagoggmanchaugagoggchaubunagungamaugg'
CALL webster(one_long_word)
```

```fortran
SUBROUTINE webster(short_dictionary)
CHARACTER (LEN=4) short_dictionary (11)
!Note that short_dictionary(3) is 'agog', for example
```

is conceptually legal in Fortran. In HPF, both the actual argument and dummy argument must be sequential. (Chargoggagoggmanchaugagoggchaubunagungamaugg is the original Nipmuc name for what is now called Lake Webster in Massachusetts.)
Section 5

INDEPENDENT and Related Directives

The HPF INDEPENDENT directive allows the programmer to give information to the compiler concerning opportunities for parallel execution. The user can assert that no data object is defined by one iteration of a DO loop and used (read or written) by another; similar information can be provided about the combinations of index values in a FORALL statement. Such information is sometimes valuable to enable compiler optimization, but may require knowledge of the application that is available only to the programmer. HPF therefore allows a user to make these assertions, and the compiler may rely on them in its translation process. If the assertion is true, the semantics of the program are not changed; if it is false, the program is not HPF-conforming and has no defined meaning.

In contrast to HPF 1.0, the INDEPENDENT assertion of HPF 2.0 allows reductions to be performed in INDEPENDENT loops, provided the reduction operator is a built-in, associative and commutative Fortran operator (such as .AND.) or function (such as MAX). It is often the case that a data parallel computation cannot be expressed in HPF 1.0 as an INDEPENDENT loop because several loop iterations update one or more variables. In such cases parallelism may be possible and desirable because the order of updates is immaterial to the final result. This is most often the case with accumulations, such as the following loop:

```fortran
DO I = 1, 1000000000
   X = X + COMPLICATED_FUNCTION(I)
END DO
```

This loop can run in parallel as long as its iterations make their modifications to the shared variable X in an atomic manner. Alternatively, the loop can be run in parallel by making updates to temporary local accumulator variables, with a (short) final phase to merge the values of these variables with the initial value of X. In either case, the computation is conceptually parallel, but it cannot be asserted to be INDEPENDENT by the strict definition found in HPF 1.0.

It is worth mentioning that Fortran now includes several means to express data parallel computation:

- Array assignments, including the WHERE statement.
- Elemental invocation of intrinsic and user-defined functions.
- The FORALL statement and construct, including element-wise invocation of PURE functions.
- Transformational intrinsics such as SUM and TRANSPOSE.

FORALL and PURE were adopted by Fortran from HPF version 1.0. As these are all now part of Fortran, they are not discussed separately in this document.

5.1 The INDEPENDENT Directive

The INDEPENDENT directive can precede an indexed DO loop or FORALL statement. It asserts to the compiler that the iterations in the following DO loop or the operations in the following FORALL may be executed independently—that is, in any order, or interleaved, or concurrently—without changing the semantics of the program.

The INDEPENDENT directive precedes the DO loop or FORALL for which it asserts behavior, and is said to apply to that loop or FORALL. The syntax of the INDEPENDENT directive is

```
H501  independent-directive is INDEPENDENT [ , new-clause ]
      [ , reduction-clause ]
H502  new-clause is NEW ( variable-name-list )
H503  reduction-clause is REDUCTION ( reduction-variable-list )
H504  reduction-variable is array-variable-name
     or scalar-variable-name
     or structure-component
```

Constraint: The first non-comment line following an independent-directive must be a do-stmt, forall-stmt, or a forall-construct.

Constraint: If the first non-comment line following an independent-directive is a do-stmt, then that statement must contain a loop-control option containing a do-variable.

Constraint: If either the NEW clause or the REDUCTION clause is present, then the first non-comment line following the directive must be a do-stmt.

Constraint: A variable named in the NEW or the REDUCTION clause and any component or element thereof must not:

- Be a dummy argument;
- Have the SAVE or TARGET attribute;
- Occur in a COMMON block;
- Be storage associated with another object as a result of appearing in an EQUIVALENCE statement;
- Be use associated;
- Be host associated; or
- Be accessed in another scoping unit via host association.
Constraint: A variable that occurs as a reduction-variable may not appear in a new-clause in the same independent-directive, nor may it appear in either a new-clause or a reduction-clause in the range (i.e., the lexical body) of the following do-stmt, forall-stmt, or forall-construct to which the independent-directive applies.

Constraint: A structure-component in a reduction-variable may not contain a subscript-section-list.

Constraint: A variable that occurs as a reduction-var must be of intrinsic type. It may not be of type CHARACTER.

Rationale. The second constraint means that an INDEPENDENT directive cannot be applied to a WHILE loop or a simple DO loop (i.e., a “do forever”). An INDEPENDENT in such cases could only correctly describe a loop with zero or one trips; the potential confusion was felt to outweigh the possible benefits. (End of rationale.)

When applied to a DO loop, an INDEPENDENT directive is an assertion by the programmer that no iteration can interfere with any other iteration, either directly or indirectly. The following operations define such interference:

- Any two operations that assign to the same atomic object interfere with each other.
  (A data object is called atomic if it contains no subobjects.)
  - Exception: If a variable appears in a NEW clause, then operations assigning values to it in separate iterations of the DO loop do not interfere. The reason for this is explained in Section 5.1.2.
  - Exception: If a variable appears in a REDUCTION clause, then assignments to it by reduction statements in the range of the DO loop do not interfere with assignments to it by other reduction statements in the same loop. The reason for this is explained in Section 5.1.3.

Operations that assign to objects include:

- Assignment statements assign to their left-hand side and all its subobjects.
- ASSIGN statements assign to their integer variables.
- ALLOCATE and DEALLOCATE statements with the STAT= specifier assign to the STAT variable.
- DO statements assign to their indices.
- I/O statements with the IOSTAT= specifier assign to the IOSTAT variable. They may also assign to other objects, as described below.
- Asynchronous READ and WRITE statements (as described in Section 10) assign to their ID= variable.
- READ statements assign to all variables in their input item list and any variables accessed at runtime through their NAMELIST. READ statements with the SIZE= specifier assign to the SIZE variable.
- INQUIRE statements assign to all variables in their specifier list, except the UNIT and FILE specifiers.
- Compound statements (e.g., IF statements) cause assignments to objects if their component statements do.
- Subprogram invocations cause assignments to objects if operations in the subprogram execution do.

• An operation that assigns to an atomic object interferes with any operation that uses the value of that object.

- Exception: If a variable appears in a NEW clause, then operations assigning values to it in one iteration of the DO loop do not interfere with uses of the variable in other iterations. The reason for this is explained in Section 5.1.2.
- Exception: If a variable appears in a REDUCTION clause, then assignments to it by reduction statements in the range of the DO loop do not interfere with the allowed uses of it by reduction statements in the same loop. The reason for this is explained in Section 5.1.3.

Any expression that computes the value of a variable uses that object. This includes uses on the right-hand side of assignment statements, uses in subscripts on the left-hand side of assignment statements, conditional expressions, specification lists for I/O statements, output lists for WRITE statements, allocation shape specifications in ALLOCATE statements, and similar situations.

Rationale. These are the classic Bernstein conditions to enable parallel execution. Note that two assignments of the same value to a variable interfere with each other and thus an INDEPENDENT loop with such assignments is not HPF-conforming. This is not allowed because such overlapping assignments are difficult to support on some hardware, and because the given definition was felt to be conceptually clearer. Similarly, it is not HPF-conforming to assert that assignment of multiple values to the same location is INDEPENDENT, even if the program logically can accept any of the possible values. In this case, both the "conceptually clearer" argument and the desire to avoid indeterminate behavior favored the given solution. (End of rationale.)

• An ALLOCATE statement, DEALLOCATE statement, NULLIFY statement or pointer assignment statement interferes with any other access, pointer assignment, allocation, deallocation, or nullification of the same pointer. In addition, an ALLOCATE or DEALLOCATE statement interferes with any other use of or assignment to the object that is allocated by ALLOCATE or deallocated by DEALLOCATE.

Rationale. These constraints extend Bernstein’s conditions to pointers. Because a Fortran pointer is an alias to an object or subobject rather than a first-class data type, a bit more care is needed than for other variables. (End of rationale.)

• Any transfer of control to a branch target statement outside the body of the loop interferes with all other operations in the loop.

• Any execution of an EXIT, STOP, or PAUSE statement interferes with all other operations in the loop.
**Rationale.** Branching (by GOTO or ERR= branches in I/O statements) implies that some iterations of the loop are not executed, which is drastic interference with these computations. The same is true for EXIT and the other statements. Note that these conditions do not restrict procedure calls in INDEPENDENT loops, except to disallow taking alternate returns to statements outside the loop, executing a STOP, or executing a PAUSE. *(End of rationale.)*

- Any two file I/O operations except INQUIRE associated with the same file or unit interfere with each other. Two INQUIRE operations do not interfere with each other; however, an INQUIRE operation interferes with any other I/O operation associated with the same file.

**Rationale.** Because Fortran carefully defines the file position after a data transfer or file positioning statement, these operations affect the global state of a program. (Note that file position is defined even for direct access files.) Multiple non-advancing data transfer statements affect the file position in ways similar to multiple assignments of the same value to a variable, and is disallowed for the same reason. Multiple OPEN and CLOSE operations affect the status of files and units, which is another global side effect. INQUIRE does not affect the file status, and therefore does not affect other inquiries. However, other file operations may affect the properties reported by INQUIRE. *(End of rationale.)*

- Any data realignment or redistribution performed by subprogram invocation (see Section 4) interferes with any access to or any other remapping of the same data.

**Rationale.** Remapping may change the processor storing a particular array element, which interferes with any assignment or use of that element. This applies even though the remappings are “undone” when the call returns. During the execution of the call, the homes of the array elements have changed, thus interfering with accesses in the caller, accesses in other invocations of the same procedure, and remappings of the array due to another procedure call. *(End of rationale.)*

**Advice to users.** Data remapping performed by the REALIGN and REDISTRIBUTE approved extensions also causes interference under this rule. See Chapter 8.5 for details. *(End of advice to users.)*

The interpretation of INDEPENDENT for FORALL is similar to that for DO: it asserts that no combination of the FORALL indices assigns to an atomic storage unit that is read by another combination. A DO and a FORALL with the same body are equivalent if they both have the INDEPENDENT directive. This is illustrated in Section 5.1.1.

If a procedure is called from within an INDEPENDENT loop or FORALL, then any local variables in that procedure are considered distinct on each call unless they have the SAVE attribute. This is consistent with the Fortran standard. Therefore, uses of local variables without the SAVE attribute in calls from different iterations do not cause interference as defined above.

**Advice to implementors.** A conforming Fortran implementation can often avoid creating distinct storage for locals on every call. The same is true for an HPF implementation; however, such an implementation must still interpret INDEPENDENT in the
same way. If locals are not allocated unique storage locations on every call, then the \texttt{INDEPENDENT} loop must be serialized to respect these semantics (or other techniques must be used to avoid conflicting accesses). \textit{(End of advice to implementors.)}

Note that all these rules describe interfering behavior; they do not disallow specific syntax. Statements that appear to violate one or more of these restrictions are allowed in an \texttt{INDEPENDENT} loop, if they are not executed due to control flow. These restrictions allow an \texttt{INDEPENDENT} loop to be executed safely in parallel if computational resources are available. The directive is purely advisory and a compiler is free to ignore it if it cannot make use of the information.

\textit{Advice to implementors.} Although the restrictions allow safe parallel implementation of \texttt{INDEPENDENT} loops, they do not imply that this will be profitable (or even possible) on all architectures or all programs. For example,

- An \texttt{INDEPENDENT} loop may call a routine with explicitly mapped local variables. The implementation must then either implement the mapping (which may require serializing the calls, under some implementation strategies) or override the explicit directives (which may surprise the user).

- An \texttt{INDEPENDENT} loop may have very different behavior on different iterations. For example,

\begin{verbatim}
!HPFS INDEPENDENT
   DO i = 1, 3
      IF (i.EQ.1) CALL F(A)
      IF (i.EQ.2) CALL G(B)
      IF (i.EQ.3) CALL H(C)
   END DO
\end{verbatim}

This poses obvious problems for implementations on SIMD machines.

- An \texttt{INDEPENDENT} loop may call a subroutine that accesses global mapped data. On distributed-memory machines, generating the communication to reference the data may be challenging, since there is in general no guarantee that the owners of the data will also call the subroutine.

In all cases, it is the implementation's responsibility to produce correct behavior, which may in turn limit optimization. It is recommended that implementations provide some feedback if an \texttt{INDEPENDENT} assertion may be ignored. \textit{(End of advice to implementors.)}

\section*{5.1.1 Visualization of \texttt{INDEPENDENT} Directives}

Graphically, the \texttt{INDEPENDENT} directive can be visualized as eliminating edges from a precedence graph representing the program. Figure 5.1 shows some of the dependences that may normally be present in a \texttt{DO} and a \texttt{FORALL}. (Most of the transitive dependences are not shown.) An arrow from a left-hand-side node (for example, \texttt{"lhsa(1)"}) to a right-hand-side node (\texttt{"rhsb(1)"}) means that the right-hand side computation might use values assigned in the left-hand-side node; thus the right-hand side must be computed after the left-hand side completes its store. Similarly, an arrow from a right-hand-side node to a left-hand-side node means that the left-hand side may overwrite a value needed by the right-hand side.
5.1. THE INDEPENDENT DIRECTIVE

```fortran
DO i = 1, 3
   lhsa(i) = rhsa(i)
   lhsb(i) = rhsb(i)
END DO
```

```fortran
FORALL ( i = 1:3 )
   lhsa(i) = rhsa(i)
   lhsb(i) = rhsb(i)
END FORALL
```

Figure 5.1: Dependences in DO and FORALL without INDEPENDENT assertions

```fortran
!HPF$ INDEPENDENT
DO i = 1, 3
   lhsa(i) = rhsa(i)
   lhsb(i) = rhsb(i)
END DO
```

```fortran
!HPF$ INDEPENDENT
FORALL ( i = 1:3 )
   lhsa(i) = rhsa(i)
   lhsb(i) = rhsb(i)
END FORALL
```

Figure 5.2: Dependences in DO and FORALL with INDEPENDENT assertions
computation, again forcing an ordering. Edges from the `BEGIN` and to the `END` nodes represent control dependences. The `INDEPENDENT` directive asserts that the only dependences that a compiler need enforce are those in Figure 5.2. That is, the programmer who uses `INDEPENDENT` is certifying that if the compiler enforces only these edges, then the resulting program will be equivalent to the one in which all the edges are present. Note that the set of asserted dependences is identical for `INDEPENDENT DO` and `FORALL` statements.

The compiler is justified in producing a warning if it can prove that one of these assertions is incorrect. It is not required to do so, however. A program containing any false assertion of this type is not HPF-conforming, thus is not defined by HPF, and the compiler may take any action it deems appropriate.

### 5.1.1.1 Examples of `INDEPENDENT`

```fortran
!HPF$ INDEPENDENT
DO i = 2, 99
   A(i) = B(i-1) + B(i) + B(i+1)
END DO
```

This is one of the simplest examples of an `INDEPENDENT` loop. (For simplicity, all examples in this section assume there is no storage or sequence association between any variables used in the code.) Every iteration assigns to a different location in the `A` array, thus satisfying the first condition above. Since no elements of `A` are used on the right-hand side, no location that is assigned in the loop is also read, thus satisfying the second condition. Note, however, that many elements of `B` are used repeatedly; this is allowed by the definition of `INDEPENDENT`. This loop is `INDEPENDENT` regardless of the values of the variables involved.

```fortran
!HPF$ INDEPENDENT
FORALL ( I=2:N ) A(I) = B(I-1) + B(I) + B(I+1)
```

This example is equivalent in all respects to the first example.

```fortran
!HPF$ INDEPENDENT
DO I=1, 100
   A(P(I)) = B(I)
END DO
```

This `INDEPENDENT` directive asserts that the array `P` does not have any repeated entries (else they would cause interference when `A` was assigned). The `DO` loop is therefore equivalent to the Fortran statement

```
A(P(1:100)) = B(1:100)
```

### 5.1.2 `NEW` Variables

The `NEW` clause asserts that the named variables act as private variables to each iteration of the `INDEPENDENT` loop. That is, there would be no interfering assignments and uses in the loop, and thus no change in the behavior of the program, if new objects were created for the `NEW` variables for each iteration of the `DO` loop and those objects were destroyed at the end of each iteration. Thus, no values flow into `NEW` variables from execution before the loop, no values flow from `NEW` variables to execution after the loop, and (most importantly) no values flow from one iteration to another through `NEW` variables.
Advice to users. A pointer or allocatable variable may appear in a \texttt{NEW} clause. The interpretation of the paragraph above, in these cases, is that one should not rely on the value, the association status, or the allocation status of such a variable on entry to the loop; rather, such variables should be allocated or pointer assigned in the loop body before they are used. It would also be advisable to deallocate or nullify such a variable in the loop body after its last use as well. (End of advice to users.)

Rationale. \texttt{NEW} variables provide the means to declare temporaries in \texttt{INDEPENDENT} loops. Without this feature, many conceptually independent loops would need substantial rewriting (including expansion of scalars into arrays) to meet the rather strict requirements described above. Note that a temporary must be declared \texttt{NEW} only at the innermost lexical level at which it is assigned, since all enclosing \texttt{INDEPENDENT} assertions must take that \texttt{NEW} into account. Note also that index variables for nested \texttt{DO} loops must be declared \texttt{NEW}; the alternative was to limit the scope of an index variable to the loop itself, which changes Fortran semantics. \texttt{FORALL} indices, however, are restricted by the semantics of the \texttt{FORALL}; they require no \texttt{NEW} declarations. (End of rationale.)

5.1.2.1 Examples of \texttt{NEW}

\begin{verbatim}
!HPF$ INDEPENDENT, NEW(I)
DO I = 1, 10
    A(I) = B(I-1)
END DO
\end{verbatim}

This example would be correct either with or without the \texttt{NEW} clause; in either case, the compiler could confidently parallelize the assignments to array \texttt{A}. Additionally however, the \texttt{NEW} clause asserts that the loop index \texttt{I} is not used after the completion of the loop. Some compilers may be able to use this information to avoid updating replicated copies of \texttt{I} on other processors, or to enable other optimizations.

\begin{verbatim}
!HPF$ INDEPENDENT, NEW (I2)
DO I1 = 1,N1
    !HPF$ INDEPENDENT, NEW (I3)
    DO I2 = 1,N2
        DO I3 = 2,N3    ! The inner loop is NOT independent!
            A(I1,I2,I3) = A(I1,I2,I3) - A(I1,I2,I3-1)*B(I1,I2,I3)
        END DO
    END DO
END DO
\end{verbatim}

The inner loop is not independent because each element of \texttt{A} is computed from the preceding one. However, the two outer loops are independent because they access different elements of \texttt{A}. The \texttt{NEW} clauses are required, since the inner loop indices are assigned and used in different iterations of the outermost loops.

5.1.3 \texttt{REDUCTION} Variables and Statements

The \texttt{REDUCTION} clause asserts that the named variables are updated in the \texttt{INDEPENDENT} loop by a series of operations that are associative and commutative. Furthermore, the
intermediate values of the REDUCTION variables are not used within the loop (except, of course, in the updates themselves). Thus, the value of a REDUCTION variable after the loop may be computed as the result of a reduction tree.

*Rationale.* REDUCTION variables provide the means to accumulate values generated in an INDEPENDENT loop. Without this feature, the programmer must store update information in a temporary array whose size is equal to the number of loop iterations, and then use an intrinsic reduction function or XXX_SCATTER library function after the loop. The problem with this approach is that the temporary array may be excessively large. (*End of rationale.*)

The semantics of reductions are discussed in detail in Section 5.1.4. This section defines correct syntax.

Any variable whose name occurs as a reduction-variable is said to be protected while the immediately following DO loop is active (i.e. being executed). It may not be referenced while the loop in which it is protected is active, with one exception. It may occur in special locations in assignment statements of a special form, and these statements must be in the range (i.e. the lexical body) of the loop. In particular, it may not occur in any HPF directive, including the variable list in a NEW clause. This includes any NEW clause in the same INDEPENDENT directive.

A reduction statement is an assignment statement of the following special form that occurs in the range of an independent DO loop for which the name of its reduction variable occurs in a reduction clause. This description is not part of the grammar of HPF; rather, it serves to define the restricted assignment statements in which reduction variables are allowed.

```
H505 reduction-stmt
    is variable = variable mult-op mult-operand
    or variable = add-operand * variable
    or variable = variable add-op add-operand
    or variable = level-2-expr * variable
    or variable = variable and-op and-operand
    or variable = and-operand and-op variable
    or variable = variable or-op or-operand
    or variable = or-operand or-op variable
    or variable = variable equiv-op equiv-operand
    or variable = equiv-operand equiv-op variable
    or variable = reduction-function ( variable , expr )
    or variable = reduction-function ( expr , variable )

H506 reduction-function
    is MAX
    or MIN
    or IAND
    or IOR
    or IEOR
```

Constraint: The two occurrences of variable in a reduction-stmt must be textually identical.

The first two assertions of Section 5.1 account for the fact that the occurrences of reduction variables in their allowed positions in reduction statements do not cause interference between iterations of an INDEPENDENT loop. Any other assignment to or reference to
a reduction variable *does* interfere with the reduction statement; this includes occurrences
in subprograms and in the *expr* part of a reduction statement.

A variable that is updated by reduction statements in an independent loop must be
protected by explicit appearance in a reduction clause. This clause must appear in the
*INDEPENDENT* directive for the outermost independent loop that

- Contains the reduction statement;
- Does not have a *NEW* clause naming the reduction variable; and
- Lies within the innermost independent loop, if any, that contains the reduction state-
ment and does have a *NEW* clause naming the reduction variable.

If the same variable is updated by two or more reduction statements, then the operators in
those statements must be in the same class (e.g. both must be an *add-op* if one is).

*Advice to users.* When a reduction statement is executed, some nest of DO loops
will be active. If there are several nested *INDEPENDENT* DO loops surrounding the
reduction statements in which the variable is updated, which one is the right one to
get the reduction clause? The answer is the outermost one, subject to the constraint
that a reduction variable may not appear in a *NEW* clause for that loop or a contained
loop. Consider

```fortran
!HPF$ INDEPENDENT, NEW(J), REDUCTION(X)
DO I = 1, 10
   !HPF$ INDEPENDENT
   DO J = 1, 20
      X = X + J
   END DO
END DO
```

It would be incorrect to move the reduction clause to the inner *INDEPENDENT* directive.
Since X is updated by reduction operations (twenty times) for each iteration of the
outer loop, it does not have a well-defined value until the completion of the outer
loop. (*End of advice to users.*)

The *reduction-variable* reference may be an array element or array section. The two
references that occur in a reduction statement must be lexically identical. The Fortran rules
of operator precedence and the use of parentheses in the expression must ensure that the
reduction operator is the top-level operator (i.e. it is evaluated last) on the right-hand side.
Therefore,

```
X = X * A + 1
```

is not a correctly formed reduction statement.

Note that the syntax of the *INDEPENDENT* directive does not allow an array element or
array section to be designated as a reduction variable in the reduction clause. Even though
such a subobject may occur in a reduction statement, it is the entire array or character
variable that is treated as a reduction variable.
The allowed reduction operators and functions are all associative (in their mathematical definitions, even though the usual implementations of the arithmetic operators by Fortran language processors and the underlying hardware are not).

In most cases, only one operator will be used in the reduction statements (if there are more than one) that update a given reduction variable. It is sensible, however, to use + and - together on the same reduction variable: mathematically, subtraction is just addition of the additive inverse. For example:

```
!HPFS$ INDEPENDENT, REDUCTION(X)
DO I = 1, 100
  X(IDX(I,1)) = X(IDX(I,1)) + Y(I)
  X(IDX(I,2)) = X(IDX(I,2)) - Y(I)
END DO
```

The same is true for multiplication (*) and division (/). No other mixing of operators is allowed.

*Advice to users.* While it is true that

\[ X = I + X \]

is permitted as a reduction statement, for most purposes

\[ X = X + I \]

is stylistically cleaner. (*End of advice to users.*)

### 5.1.4 Semantics and Implementation of Reduction

HPF specifies an allowed parallel implementation of an `INDEPENDENT DO` loop with reduction statements, thereby specifying the semantics of such a loop.

Just as the result of the Fortran intrinsic function \texttt{SUM} is defined to be a implementation-dependent approximation to the sum of the elements of its argument array, the value of a reduction variable on exit from its `INDEPENDENT DO` loop is likewise not completely specified by HPF. One possible value is that which would have been computed by sequential execution of the loop, but other implementation-dependent approximations to this value may be produced. Any such implementation-dependent value is, however, an approximation to the value produced by sequential execution of the loop. If rounding error, underflow, and overflow do not occur, it will be identical to that value.

*Advice to users.* If overflow, underflow, or rounding occur, this is one of the few places where an HPF directive in a conforming program may cause that program to produce different output. However, the same problems occur in other systems that attempt to parallelize these operations, for the same reasons. (*End of advice to users.*)

Since no reference to a protected reduction variable can occur except in a reduction statement, it is not necessary to define the values that these variables may have while protected.
**Advice to users.** The following “advice to implementors” is useful for understanding the behavior of an INDEPENDENT loop with reduction statements. (*End of advice to users.*)

**Advice to implementors.** In the discussion in this section, the term “processor” means a single physical processor or a group of physical processors that together sequentially execute some or all of the iterations of an independent loop.

We describe a simple implementation mechanism that applies to commutative reduction operations. On entry to an independent loop, every executing processor allocates a private accumulator variable associated with each variable in the reduction clause on the INDEPENDENT directive, and initializes it to the identity element for the corresponding intrinsic reduction operator. The private accumulator variable has the same shape, type, and kind type parameter as the reduction variable.

The identity elements for the intrinsic operators are defined in Table 5.1.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Identity Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>*</td>
<td>1</td>
</tr>
<tr>
<td>/</td>
<td>1</td>
</tr>
<tr>
<td>.AND.</td>
<td>.TRUE.</td>
</tr>
<tr>
<td>.OR.</td>
<td>.FALSE.</td>
</tr>
<tr>
<td>.EQV.</td>
<td>.TRUE.</td>
</tr>
<tr>
<td>.NEQV.</td>
<td>.FALSE.</td>
</tr>
</tbody>
</table>

Table 5.1: Identity elements for intrinsic reduction operators.

<table>
<thead>
<tr>
<th>Function</th>
<th>Identity element</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAND(I,J)</td>
<td>NOT(0) (all one-bits)</td>
</tr>
<tr>
<td>IOR(I,J)</td>
<td>0</td>
</tr>
<tr>
<td>IEOR(I,J)</td>
<td>0</td>
</tr>
<tr>
<td>MIN(X,Y)</td>
<td>the positive number of largest absolute value that has the same type and kind type parameter as the reduction variable</td>
</tr>
<tr>
<td>MAX(X,Y)</td>
<td>the negative number of largest absolute value that has the same type and kind type parameter as the reduction variable</td>
</tr>
</tbody>
</table>

Table 5.2: Identity elements for intrinsic reduction functions.

The intrinsic functions that may be used as reduction functions are listed, together with their identity elements, in Table 5.2.

Each processor performs a subset of the loop iterations; when it encounters a reduction statement, it updates its own accumulator variable. A processor is free to perform its
loop iterations in any order; furthermore, it may start an iteration, suspend work on it, do some or all of the work of other iterations, and resume work on the suspended iteration. However, any update of a private accumulator variable occurs through the execution of a reduction statement, and reduction statements are executed atomically.

The final value of the reduction variable is computed by combining the private accumulator variables with the value of the reduction variable on entry to the loop, using the reduction operator. The ordering of this reduction is language-processor dependent, just as it is for the intrinsic reduction functions (SUM, etc.).

As an example, consider:

```fortran
REAL Z
Z = 5.
!HPF$ INDEPENDENT, REDUCTION(Z)
DO I = 1, 10
   Z = Z + I
END DO
```

The final value of Z will be \(5 + (1+2+3+4+5+6+7+8+9+10) = 60\); the order in which the additions occur is not specified by HPF.

For a second example, here is a SUM_SCATTER done as an independent loop:

```fortran
!HPF$ INDEPENDENT, REDUCTION(X)
DO I = 1, N
   X(INDEX(I)) = X(INDEX(I)) - F(I)
END DO
```

The implementation will most likely make a private copy on every processor of an accumulator array XLOCAL of the same type and shape as X, and initialize it to zero. Each iteration will subtract the value of F(I) from its own XLOCAL(INDEX(I)). To create the final result, the implementation must combine all the private accumulator arrays with the initial value of X. The combining operator is the same as the reduction operator, namely addition, so that the result is the sum of the initial value of X and the accumulator arrays. The implementation has the option of using a sparse data structure to store only the updated elements of the local accumulator.

In an MPI based implementation, the MPI_REDUCE function could be used for this task. (*End of advice to implementors.*)

### 5.2 Further Examples of INDEPENDENT Directives

```fortran
!HPF$ INDEPENDENT
DO I = 1, 10
   WRITE (IOUNIT(I),100) A(I)
END DO
100 FORMAT ( F10.4 )
```
If IOUNIT(I) evaluates to a different value for every value of I from 1 to 10, then the loop writes to a different I/O unit (and thus a different file) on every iteration. The loop is then properly described as independent. On the other hand, if IOUNIT(I)=5 for all I, then the assertion is in error and the directive is not HPF-conforming.

```fortran
!HPF$ INDEPENDENT, NEW (J)
  DO I = 2, 100, 2
    !HPF$ INDEPENDENT, NEW(VL, VR, UL, UR)
    DO J = 2, 100, 2
      VL = P(I,J) - P(I-1,J)
      VR = P(I+1,J) - P(I,J)
      UL = P(I,J) - P(I,J-1)
      UR = P(I,J+1) - P(I,J)
      P(I,J) = F(I,J) + P(I,J) + 0.25 * (VR - VL + UR - UL)
    END DO
  END DO
END DO
```

Without the NEW clause on the J loop, neither loop would be independent, because an interleaved execution of loop iterations might cause other values of VL, VR, UL, and UR to be used in the assignment of P(I,J) than those computed in the same iteration of the loop. The NEW clause, however, specifies that this is not true if distinct storage units are used in each iteration of the loop. Using this implementation makes iterations of the loops independent of each other. Note that there is no interference due to accesses of the array P because of the stride of the DO loop (i.e. I and J are always even, therefore I-1, etc., are always odd.)

When loops are nested, a reduction variable may need to be protected in an independent outer loop even though the reduction operations in which it occurs are nested inside an inner loop. Moreover, the inner loop and any intervening loops may or may not be independent.

```fortran
  ! Nested Loop Example 1. Inner loop is sequential
  X = 10
  OUTER: DO WHILE (X < 1000) ! this loop is sequential
    !HPF$ INDEPENDENT, NEW(J), REDUCTION(X)
    MIDDLE: DO I = 1, N
      INNER: DO J = 1, M
      X = X + J
      ! Note that it would be incorrect to refer to X
      ! here, except in another reduction statement
      END DO INNER
      ! Note that it would be incorrect to refer to X
      ! here, except in another reduction statement
    END DO MIDDLE
    PRINT *, X
  END DO OUTER
```

Since the variable X occurs in a reduction clause for loop MIDDLE, it is a protected reduction variable throughout that loop, including inside the inner loop. If INNER had an INDEPENDENT directive, it would be incorrect to include X in a REDUCTION or a NEW clause of that directive.
The outermost loop is not independent, and so $X$ need not and cannot be protected in that part of its range outside the middle loop.

A variable that occurs in a **NEW** clause must not be a reduction variable in the same or a containing loop, although it may be used as a reduction variable in a contained loop:

```fortran
! Nested Loop Example 2. Outer loop NEW clause.

!HPF$ INDEPENDENT, NEW(I)
OUTER:  DO K = 1, 100
    !HPF$ INDEPENDENT, NEW (J,X)
MIDDLE:  DO I = 1, N
        X = 10
        !HPF$ INDEPENDENT, REDUCTION(X)
INNER:   DO J = 1, M
            X = X + J**2
            ! Note that it would be incorrect to refer to X here, except in another reduction statement
        END DO INNER
        Y(I) = X
    END DO MIDDLE
END DO OUTER

Here, $X$ is a protected reduction variable only in the inner loop.

INTEGER, DIMENSION(M) :: VECTOR

!HPF$ INDEPENDENT, REDUCTION(X, Y)
DO I = 1, N-4
    X(I:I+4) = X(I:I+4) + A(I)  ! As many as 5 updates
    Y(VECTOR) = Y(VECTOR) + B(I,1:N)
END DO

Note that the compiler, if it distributes iterations of this loop in a block-wise manner, will not need to make a private copy of the entire array $X$ on each processor.

If a statement that has the form of a reduction statement occurs while an independent loop is active, but the updated variable is not a protected reduction variable, then the programmer is guaranteeing that no two iterations of the independent loop will update the same location. For example:

```fortran
!HPF$ INDEPENDENT
DO I = 1, N
    ! X is NOT a reduction variable, but
    ! I know there are no repeated values in INDX(I)
    ! Updates will be written directly to X(INDX(I))
    X(INDX(I)) = X(INDX(I)) + F(I)
    ! I also guarantee that the condition in the IF statement
    ! is true for at most one value of I.
    IF (A(I) > B(I)) Y = Y + 1
END DO
```
Section 6

Extrinsic Program Units

The HPF global model of computation extends (and restricts) Fortran to provide programmers with the Fortran model of computation implementable efficiently on a wide class of hardware architectures with, in general, multiple processors, multiple memories with non-uniform access characteristics, and multiple interconnections. This model of computation presents a single logical thread of control, including Fortran’s data parallel features such as array syntax and the `FORALL` statement, and data visibility defined by the scoping rules of Fortran. In particular, this model does not require the use of low-level features such as threads libraries and explicit message passing to exploit such architectures. Programmers expect their HPF compilers to generate efficient code by using HPF’s features to assist in mapping data and computation to the given hardware architecture.

This chapter defines the extrinsic mechanism by which HPF program units may use non-HPF program units that don’t use the HPF global model. It describes how to write an explicit interface for a non-HPF procedure and defines the caller’s assumptions about handling distributed and replicated data at the interface. This allows the programmer to use non-HPF language facilities, for example, to descend to a lower level of abstraction to handle problems that are not efficiently addressed by HPF, to hand-tune critical kernels, or to call optimized libraries. Such an interface can also be used to interface HPF to other languages, such as C.

6.1 Overview

An HPF program may need to call a procedure implemented in a different programming model or in a different programming language. A procedure’s programming model might provide:

- a single logical thread-of-control where one copy of the procedure is conceptually executing and there is a single locus of control within the program text; this model is called global when the underlying target hardware has (potentially) multiple processors or memories and is called serial when the underlying target hardware is treated as a uniprocessor (or a single node in a multiprocessor),

- multiple threads-of-control, one per processor, each thread executing the same procedure; this model is called local or, more generally, SPMD (Single Program, Multiple Data), or
- some other model, not discussed here, such as multiple threads-of-control, perhaps with dynamic assignment of loop iterations to processors or explicit dynamic process forking, where there is, at least initially upon invocation, one copy of the procedure that is conceptually executing but that may spawn multiple loci of control, possibly changing in number over time, within the program text.

A programming language provides a specific syntax (language features), semantics (meanings), and pragmatics (purposes). Examples of programming languages include Fortran (an ANSI and ISO standard—the most recent revision is expected to be approved by 1997), HPF (a specification of extensions and restrictions to Fortran), Fortran 77 (a previous ANSI and ISO standard), C, C++, Java, Visual Basic, and COBOL.

A program unit's language and model, when taken together, constitute its extrinsic kind. This extrinsic kind may be specified explicitly by an extrinsic-prefix or implicitly by the selection of a compiler and its invocation with a particular set of compiler options. Thus, one might view the compiler as providing a host scoping unit as defined by Fortran. For example, a program unit compiled by an HPF compiler will be of extrinsic kind HPF. Alternatively, its extrinsic kind may be specified explicitly by an extrinsic-prefix such as EXTRINSIC(HPF) or EXTRINSIC(LANGUAGE='HPF',MODEL='GLOBAL').

6.2 Declaration of Extrinsic Program Units

6.2.1 Function and Subroutine Statements

An extrinsic-prefix may appear in a function-stmt or subroutine-stmt (as defined in the Fortran standard) in the same place that the keywords RECURSIVE, PURE, and ELEMENTAL may appear. This is specified by an extension of rule R1219 for prefix-spec in the Fortran standard. Rules R1217 for function-stmt, R1218 for prefix, and R1222 for subroutine-stmt are not changed, but are restated here for reference.

H601 function-stmt is [ prefix ] FUNCTION function-name
   ( [ dummy-arg-name-list ] )
   [ RESULT ( result-name ) ]

H602 subroutine-stmt is [ prefix ] SUBROUTINE subroutine-name
   ( [ dummy-arg-list ] )

H603 prefix is prefix-spec [ prefix-spec ] ...

H604 prefix-spec is type-spec
   or RECURSIVE
   or PURE
   or ELEMENTAL
   or extrinsic-prefix

Constraint: Within any HPF external-subprogram, every internal-subprogram must be of the same extrinsic kind as its host and any internal-subprogram whose extrinsic kind is not given explicitly is assumed to be of that extrinsic kind.

The definition of characteristics of a procedure as given in F95:12.2 is extended to include the procedure's extrinsic kind.
6.2.2 Program, Module, and Block Data Statements

An extrinsic-prefix may also appear at the beginning of a program-stmt, module-stmt, or block-data-stmt. The following syntax definition extends the Fortran 95 syntax rules R1102 for program-stmt, R1105 for module-stmt, and R1111 for block-data-stmt.

H605  program-stmt          is  [ extrinsic-prefix ] PROGRAM  program-name
H606  module-stmt           is  [ extrinsic-prefix ] MODULE  module-name
H607  block-data-stmt       is  [ extrinsic-prefix ] BLOCK DATA
                                 [ block-data-name ]

Constraint: Every module-subprogram of any HPF module must be of the same extrinsic kind as its host, and any module-subprogram whose extrinsic kind is not given explicitly is assumed to be of that extrinsic kind.

Constraint: Every internal-subprogram of any HPF main-program or module-subprogram must be of the same extrinsic kind as its host, and any internal-subprogram whose extrinsic kind is not given explicitly is assumed to be of that extrinsic kind.

6.2.3 The EXTRINSIC Prefix

H608  extrinsic-prefix      is  EXTRINSIC ( extrinsic-spec )
H609  extrinsic-spec        is  extrinsic-spec-arg-list
                               or  extrinsic-kind-keyword
H610  extrinsic-spec-arg     is  language
                               or  model
                               or  external-name
H611  language              is  [ LANGUAGE = ]
                                 scalar-char-initialization-expr
H612  model                 is  [ MODEL = ]
                                 scalar-char-initialization-expr
H613  external-name         is  [ EXTERNAL_NAME = ]
                                 scalar-char-initialization-expr

Constraint: In an extrinsic-spec-arg-list, at least one of language, model, or external-name must be specified and none may be specified more than once.

Constraint: If language is specified without LANGUAGE=, language must be the first item in the extrinsic-spec-arg-list. If model is specified without MODEL=, language without LANGUAGE= must be the first item and model must be the second item in the extrinsic-spec-arg-list. If external-name is specified without EXTERNAL_NAME=, language without LANGUAGE= must be the first item and model without MODEL= must be the second item in the extrinsic-spec-arg-list.

Constraint: The forms with LANGUAGE=, MODEL=, and EXTERNAL_NAME= may appear in any order except as prohibited above.
Note that these rules for extrinsic-spec-any-list are as if EXTRINSIC were a procedure with an explicit interface with a dummy-arg-list of LANGUAGE, MODEL, EXTERNAL_NAME, each of which were OPTIONAL.

Constraint: In language, values of scalar-char-initialization-expr may be:

- 'HPF', referring to the HPF language; if a model is not explicitly specified, the model is implied to be 'GLOBAL';
- 'FORTRAN', referring to the ANSI/ISO standard Fortran language; if a model is not explicitly specified, the model is implied to be 'SERIAL';
- 'F77', referring to the former ANSI/ISO standard FORTRAN 77 language; if a model is not explicitly specified, the model is implied to be 'SERIAL';
- 'C', referring to the ANSI standard C programming language; if a model is not explicitly specified, the model is implied to be 'SERIAL'; or
- an implementation-dependent value with an implementation-dependent implied model.

Note that, for most implementations, 'C' will only be allowed for function-stmts and subroutine-stmts occurring in an interface-body.

Constraint: If language is not specified it is the same as that of the host scoping unit.

Constraint: In model, values of scalar-char-initialization-expr may be:

- 'GLOBAL', referring to the global model,
- 'LOCAL', referring to the local model,
- 'SERIAL', referring to the serial model, or
- an implementation-dependent value.

Constraint: If model is not specified or implied by the specification of a language, it is the same as that of the host scoping unit.

Constraint: All languages and models whose names begin with the three letters HPF are reserved for present or future definition by this specification and its successors.

Constraint: In external-name, the value of scalar-char-initialization-expr is a character string whose use is determined by the extrinsic kind. For example, an extrinsic kind may use the external-name to specify the name by which the procedure would be known if it were referenced by a C procedure. In such an implementation, a user would expect the compiler to perform any transformations of that name that the C compiler would perform. If external-name is not specified, its value is implementation-dependent.

H614 extrinsic-kind-keyword is HPF
or HPF_LOCAL
or HPF_SERIAL
Constraint: `EXTRINSIC(HPF)` is equivalent to `EXTRINSIC('HPF','GLOBAL')`. In the absence of an `extrinsic-prefix` an HPF compiler interprets a compilation unit as if it were of extrinsic kind `HPF`. Thus, for an HPF compiler, specifying `EXTRINSIC(HPF)` or `EXTRINSIC('HPF','GLOBAL')` is redundant. Such explicit specification may, however, be required for use with a compiler that supports multiple extrinsic kinds.

Constraint: `EXTRINSIC(HPF_LOCAL)` is equivalent to `EXTRINSIC('HPF','LOCAL')`. A `main-program` whose extrinsic kind is `HPF_LOCAL` behaves as if it were a subroutine of extrinsic kind `HPF_LOCAL` that is called with no arguments from a main program of extrinsic kind `HPF` whose executable part consists solely of that call.

Constraint: `EXTRINSIC(HPF_SERIAL)` is equivalent to `EXTRINSIC('HPF','SERIAL')`. A `main-program` whose extrinsic kind is `HPF_SERIAL` behaves as if it were a subroutine of extrinsic kind `HPF_SERIAL` that is called with no arguments from a main program of extrinsic kind `HPF` whose executable part consists solely of that call.

Constraint: All `extrinsic-kind-keywords` whose names begin with the three letters `HPF` are reserved for present or future definition by this specification and its successors.

Advice to implementors.

Other languages or models may be defined and provided by compiler vendors. Although not part of this HPF specification, they are expected to conform to the rules and spirit of HPF extrinsic kinds.

An implementation may place certain restrictions on the programmer; moreover, each extrinsic kind may call for a different set of restrictions.

For example, an implementation on a parallel processor may find it convenient to replicate scalar arguments so as to provide a copy on every processor. This is permitted so long as this process is invisible to the caller. One way to achieve this is to place a restriction on the programmer: on return from the subprogram, all the copies of this scalar argument must have the same value. This implies that if the dummy argument has `INTENT(OUT)`, then all copies must have been updated consistently by the time of subprogram return.

(End of advice to implementors.)

6.3 Calling HPF Extrinsic Subprograms

A call to an extrinsic procedure behaves, as observed by a calling program coded in HPF, exactly as if the subprogram were coded in HPF. If a function or subroutine called from a program unit of an HPF extrinsic kind does not have an explicit interface visible in the caller, it is assumed to have the same extrinsic kind as the caller.

In order to call a subprogram of an extrinsic kind other than that of the caller, that subprogram must have an explicit interface visible in the caller, and the subprogram is expected to behave, as observed by the caller, roughly as if it had been written as code of the same extrinsic kind as the caller. Some of the responsibility for meeting this requirement
SECTION 6. EXTRINSIC PROGRAM UNITS

<table>
<thead>
<tr>
<th>Extrinsic kind of the used module</th>
<th>HPF</th>
<th>HPF_SERIAL</th>
<th>HPF_LOCAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extrinsic kind of the using</td>
<td>HPF</td>
<td>T P D</td>
<td>T P</td>
</tr>
<tr>
<td>program unit</td>
<td>HPF_SERIAL</td>
<td>T</td>
<td>T P D</td>
</tr>
<tr>
<td>HPF_LOCAL</td>
<td>HPF</td>
<td>T</td>
<td>T P D</td>
</tr>
</tbody>
</table>

T = derived type definitions  
P = procedures and procedure interfaces  
D = data objects

Table 6.1: Entities that a using program unit is entitled to access from a module, according to the HPF extrinsic kind of each.

may rest on the compiler and some on the programmer. This interface defines the “HPF view” of the extrinsic procedure.

A called procedure that is written in a model or language other than HPF, whether or not it uses the local procedure execution model, should be declared EXTRINSIC within an HPF program that calls it. The EXTRINSIC prefix declares what sort of interface should be used when calling indicated subprograms. If there is no extrinsic specification, then the users must assume full responsibility for correctness of the implementation-dependent interface.

A function-stmt or subroutine-stmt that appears within an interface-block within a program unit of an HPF extrinsic kind may have an extrinsic prefix mentioning any extrinsic kind supported by the language implementation. If no extrinsic-prefix appears in such a function-stmt or subroutine-stmt, then it is assumed to be of the same HPF extrinsic kind as the program unit in which the interface block appears.

The procedure characteristics defined by an interface-body must be consistent with the procedure’s definition.

The definition and rules for a procedure with an extrinsic interface lies outside the scope of HPF. However, explicit interfaces to such procedures must conform to HPF. Note that any particular HPF implementation is free to support any selection of extrinsic kinds, or none at all except for HPF itself, which clearly must be supported by an HPF implementation.

6.3.1 Access to Types, Procedures, and Data

In general, program units of a given extrinsic kind may use names of types, procedures, or data of another program unit of the same extrinsic kind, subject to the scoping rules of Fortran.

Use of names of types, procedures, or data of another program unit of a different extrinsic kind are subject to additional restrictions summarized in Table 6.1 and described below.

Note that, if a module X of one HPF extrinsic kind is used by a program unit Y of another HPF extrinsic kind, then only names of items in X that Y is entitled to use or invoke may be use associated; that is, either X must make private all items that Y is not entitled to use, or the USE statement in Y must have an ONLY option that lists only names of items it is entitled to use.
6.3.1.1 Types

Derived type definitions without explicitly mapped components may be thought of as “extrinsic kind neutral”; a program unit of any HPF extrinsic kind may use derived type definitions from a module of any HPF extrinsic kind. Note that an Approved Extension permits the mapping of components of derived types.

6.3.1.2 Procedures

An HPF global program or procedure may call other HPF procedures that are global, local, or serial.

An HPF local program or procedure may call only other HPF local procedures and not HPF global or serial procedures.

An HPF serial program or procedure may call only other HPF serial procedures and not HPF global or local procedures.

6.3.1.3 Data

A named COMMON block in any program unit of an HPF kind will be associated with the COMMON block, if any, of that same name in every other program unit of that same extrinsic kind; similarly for unnamed COMMON. (Such COMMON storage behaves like other declared data objects within program units of that extrinsic kind; in particular, for HPF LOCAL code there will be one copy of the COMMON block on each processor.)

It is not permitted for any given COMMON block name to be used in program units of different HPF kinds within a single program; similarly, it is not permitted for unnamed COMMON to be used in program units of different HPF kinds within a single program.

6.3.2 The Effect of a Call

A call to an extrinsic procedure must be semantically equivalent to a call of an ordinary HPF procedure that does not remap its arguments. Thus a call to an extrinsic procedure must behave as if the following actions occur. The HPF technical term as if means that the described actions should appear to a user as if they occurred, in the order specified; an implementation may carry out any actions in any order that provide the correct user-visible effects.

1. All actions of the caller preceding the subprogram invocation should be completed before any action of the subprogram is executed; and all actions of the subprogram should be completed before any action of the caller following the subprogram invocation is executed.

2. Each actual argument is remapped, if necessary, according to the directives (explicit or implicit) in the declared interface for the extrinsic procedure. Thus, HPF mapping directives appearing in the interface are binding—the compiler must obey these directives in calling local extrinsic procedures. As in the case of non-extrinsic subprograms, actual arguments may be mapped in any way; if necessary, they are copied automatically to correctly mapped temporaries before invocation of—and copied back to the actual arguments after return from—the extrinsic procedure. Scalar dummy
arguments and scalar function results behave as if they are replicated on each processor. These mappings may, optionally, be explicit in the interface, but any other explicit mapping is not HPF conforming.

3. **IN, OUT, and INOUT** intent restrictions should be observed.

4. No HPF variable is modified unless it could be modified by an HPF procedure with the same explicit interface. Note that even though HPF LOCAL and HPF SERIAL routines are not permitted to access and modify HPF global data, other kinds of extrinsic routines may do so to the extent that an HPF procedure could.

5. When a procedure returns and the caller resumes execution, all objects accessible to the caller after the call are mapped exactly as they were before the call. In particular, the original distribution of arguments is restored, if necessary.

6. Exactly the same set of processors is visible to the HPF environment before and after the subprogram call.

*Advice to implementors.*

To ensure that all actions that logically precede the call are completed, multiple processors may need to be synchronized before the call is made.

If a variable accessible to the called routine has a replicated representation, then all copies may need to be updated prior to the call to contain the correct current value according to the sequential semantics of the source program.

Replicated variables, if updated in the procedure, must be updated consistently. More precisely, if a variable accessible to a procedure has a replicated representation and is updated by (one or more copies of) the procedure, then all copies of the replicated variable must have identical values when the last processor returns from the local procedure.

An implementation might check, before returning from the local subprogram, to make sure that replicated variables have been updated consistently by the subprogram. Note, however, that there is no requirement for an implementation to do so; it is merely an implementation tradeoff between speed and, for instance, debuggability.

Note that, as with a global HPF subprogram, actual arguments may be copied or remapped in any way, so long as the effect is undone on return from the subprogram.

To ensure that all actions of the procedure logically complete before execution in the caller is resumed, multiple processors may need to be synchronized after the call.

*(End of advice to implementors.)*

### 6.4 Examples of Extrinsic Procedures

Consider:

```plaintext
PROGRAM DUMPLING
INTERFACE
EXTRINSIC('HPF','LOCAL') SUBROUTINE GNOCCHI(P, L, X)
```
6.4. EXAMPLES OF EXTRINSIC PROCEDURES

The main program, DUMPLING, when compiled by an HPF compiler, is implicitly of extrinsic kind HPF. Interfaces are declared to three external subroutines GNOCCHI, POTSTICKER, and LEBERKNOEDEL. The first two are of extrinsic kind HPF LOCAL and the third is of an extrinsic kind specified by the language COBOL and the local model. Now, GNOCCHI accepts two dummy procedure arguments and no interfaces must be declared for those. Because no extrinsic-prefix is given for dummy argument P, its extrinsic kind is that of its host scoping unit, the declaration of subroutine GNOCCHI, which has extrinsic kind HPF LOCAL. The declaration of the corresponding actual argument POTSTICKER needs to have an explicit extrinsic-prefix because its host scoping unit is program DUMPLING, of extrinsic kind HPF.

Here are some more examples. In the first example, note that the declaration of the explicit size of BAGEL as 100 refers to its global size and not its local size:

```fortran
 INTERFACE
   EXTRINSIC('HPF', 'LOCAL') FUNCTION BAGEL(X)
   REAL BAGEL(100)
   REAL X(:)
     !HPF$ DISTRIBUTE (CYCLIC) :: BAGEL, X
 END FUNCTION
 END INTERFACE

 In the next example, note that the ALIGN statement asserts that X, Y, and Z all have the same shape:

 INTERFACE OPERATOR (+)
   EXTRINSIC('C', 'LOCAL') FUNCTION LATKES(X, Y) RESULT(Z)
   REAL, DIMENSION(:,:), INTENT(IN) :: X
   REAL, DIMENSION(:,:), INTENT(IN) :: Y
```
INTERFACE KNISH
  FUNCTION RKNISH(X)               !normal HPF interface
    REAL X(:,), RKNISH
  END RKNISH
  EXTRINSIC('SISAL') FUNCTION CKNISH(X)  !extrinsic interface
    COMPLEX X(:,), CKNISH
  END CKNISH
END INTERFACE

In the interface block in this final example, two external procedures, one of them extrinsic and one not, are associated with the same generic procedure name, which returns a scalar of the same type as its array argument:
Section 7

Intrinsic and Library Procedures

HPF includes Fortran’s intrinsic procedures. It also adds new intrinsic procedures in two categories: system inquiry intrinsic functions and computational intrinsic functions.

In addition to the new intrinsic functions, HPF defines a library module, HPF_LIBRARY, that must be provided by vendors of any full HPF implementation.


7.1 Notation

In the examples of this section, T and F are used to denote the logical values true and false.

7.2 System Inquiry Intrinsic Functions

In a multi-processor implementation, the processors may be arranged in an implementation-dependent multi-dimensional processor array. The system inquiry functions return values related to this underlying machine and processor configuration, including the size and shape of the underlying processor array. NUMBER_OF_PROCESSORS returns the total number of processors available to the program or the number of processors available to the program along a specified dimension of the processor array. PROCESSORS_SHAPE returns the shape of the processor array.

The Fortran definition of restricted expression is extended to permit references to the HPF system inquiry intrinsic functions. In particular, at the end of the numbered list in Section 7.1.6.2 of the Fortran standard, add:

(13) A reference to one of the system inquiry functions NUMBER_OF_PROCESSORS or PROCESSORS_SHAPE, where any argument is a restricted expression.

A variable that appears in a restricted expression in an HPF directive in the scoping unit of a module or main program must be an implied-DO variable or an argument in a reference to an array inquiry function, bit inquiry function, character inquiry function, kind inquiry function, or numeric inquiry function.

The values returned by the system inquiry intrinsic functions remain constant for the duration of one program execution. Thus, NUMBER_OF_PROCESSORS and PROCESSORS_SHAPE have values that are restricted expressions and may be used wherever any other Fortran
restricted expression may be used. In particular, \texttt{NUMBER\_OF\_PROCESSORS} may be used in a specification expression.

The values of system inquiry functions may not occur in initialization expressions, because they may not be assumed to be constants. In particular, HPF programs may be compiled to run on machines whose configurations are not known at compile time.

Note that the system inquiry functions query the physical machine, and have nothing to do with any \texttt{PROCESSORS} directive that may occur. If an HPF program is running on a physical partition of a larger machine, then it is the smaller partition that actually executes the HPF program whose parameters are returned by the system inquiry functions.

Some machines may not have a "natural" shape to return as the value of the function \texttt{PROCESSORS\_SHAPE}, for example, a machine with a tree topology. In these cases, the implementation must provide some reasonable, consistent description of the machine, such as an rank-one array of size \texttt{NUMBER\_OF\_PROCESSORS()}. The compiler will also have to arrange to map between this description and the underlying hardware processor identification mechanism.

\textit{Advice to users.} \texttt{SIZE(PROCESSORS\_SHAPE())} returns the rank of the processor array. References to system inquiry functions may occur in array declarations and in HPF directives, as in:

\begin{verbatim}
INTEGER, DIMENSION(SIZE(PROCESSORS\_SHAPE())) :: PSHAPE
!HPF$ TEMPLATE T(100, 3*NUMBER\_OF\_PROCESSORS())
\end{verbatim}

\textit{(End of advice to users.)}

### 7.3 Computational Intrinsic Functions

HPF adds one new computational intrinsic function, \texttt{ILEN}, which computes the number of bits needed to store an integer value.

### 7.4 Library Procedures

The mapping inquiry subroutines and computational functions described in this section are available in the HPF library module, \texttt{HPF\_LIBRARY}. Use of these procedures must be accompanied by an appropriate \texttt{USE} statement in each scoping unit in which they are used. They are not intrinsic.

#### 7.4.1 Mapping Inquiry Subroutines

HPF provides data mapping directives that are advisory in nature. The mapping inquiry subroutines allow the program to determine the actual mapping of an array at run time. It may be especially important to know the exact mapping when an \texttt{EXTRINSIC} subprogram is invoked. For these reasons, HPF includes mapping inquiry subroutines which describe how an array is actually mapped onto a machine. To keep the number of routines small, the inquiry procedures are structured as subroutines with optional \texttt{INTENT (OUT)} arguments.
7.4.2 Bit Manipulation Functions

The HPF library includes three elemental bit-manipulation functions. **LEADZ** computes the number of leading zero bits in an integer's representation. **POPCNT** counts the number of one bits in an integer. **POPPAR** computes the parity of an integer.

7.4.3 Array Reduction Functions

HPF adds additional array reduction functions that operate in the same manner as the Fortran **SUM** and **ANY** intrinsic functions. The new reduction functions are **IALL**, **IANY**, **IPARITY**, and **PARITY**, which correspond to the commutative, associative binary operations **IAND**, **IOR**, **IEOR**, and **.NEQV.** respectively.

In the specifications of these functions, the terms "XXX reduction" are used, where XXX is one of the binary operators above. These are defined by means of an example. The **IAND** reduction of all the elements of **array** for which the corresponding element of **mask** is true is the scalar integer computed in **result** by

```fortran
result = IAND.IDENTITY_ELEMENT
DO i_1 = LBOUND(array,1), UBOUND(array,1)
  ... DO i_n = LBOUND(array,n), UBOUND(array,n)
    IF ( mask(i_1,i_2,...,i_n) ) &
    result = IAND( result, array(i_1,i_2,...,i_n) )
  END DO
  ... END DO
```

Here, n is the rank of **array** and IAND.IDENTITY_ELEMENT is the integer which has all bits equal to one. (The interpretation of an integer as a sequence of bits is given in F95:13.5.7.) The other three reductions are similarly defined. The identity elements for **IOR** and **IEOR** are zero. The identity element for **.NEQV.** is **.FALSE.**

7.4.4 Array Combining Scatter Functions

The **XXX_SCATTER** functions are generalized array reduction functions in which an arbitrary subset of the elements of an array can be combined to produce an element of the result; the subset corresponding to the result's elements are nonoverlapping. Each of the eleven reduction operation in the language corresponds to one of the scatter functions, while **COPY_SCATTER** supports overwriting an existing value with any one of the values in the corresponding subset. The way that elements of the source array are associated with the elements of the result is described in this section; the method of combining their values is described in the specifications of the individual functions in Section 7.7.

These functions have the general form

```
XXX_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)
```

except in the special cases noted below. The allowed values of **XXX** are **ALL**, **ANY**, **COPY**, **COUNT**, **IALL**, **IANY**, **IPARITY**, **MAXVAL**, **MINVAL**, **PARITY**, **PRODUCT**, and **SUM**. **ARRAY**, **MASK**, and all the **INDX** arrays are conformable. The **INDX** arrays are integer, and the number
of \texttt{INDX} arguments must equal the rank of \texttt{BASE}. The argument \texttt{MASK} is logical, and it is optional. Except for \texttt{COUNT\_SCATTER}, \texttt{ARRAY} and \texttt{BASE} are arrays of the same type. For \texttt{COUNT\_SCATTER}, \texttt{ARRAY} is of type logical and \texttt{BASE} is of type integer. (For \texttt{ALL\_SCATTER}, \texttt{ANY\_SCATTER}, \texttt{COUNT\_SCATTER}, and \texttt{PARITY\_SCATTER}, the \texttt{ARRAY} argument must be logical. These functions do not have an optional \texttt{MASK} argument. To conform with the conventions of the Fortran standard, the required \texttt{ARRAY} argument to these functions is called \texttt{MASK} in their specifications in Section 7.7.) In all cases the result array is an array with the same type, kind type parameter, and shape as \texttt{BASE}.

For every element \(a\) in \texttt{ARRAY} there is a corresponding element in each of the \texttt{INDX} arrays, since they all have the same shape as \texttt{ARRAY}. For each \(j = 1, 2, \ldots, n\), where \(n\) is the rank of \texttt{BASE}, let \(s_j\) be the value of the element of \texttt{INDXj} that corresponds to element \(a\) in \texttt{ARRAY}. These indices determine the element of the result that is affected by element \(a\) of \texttt{ARRAY}. For each of the indices \(s_j\), let the corresponding index for \texttt{BASE} be given by \(b_j = s_j + \text{LBIND}(\text{BASE}, j) - 1\).

The integers \(b_j, j = 1, \ldots, n\), form a subscript selecting an element of \texttt{BASE}:
\[
\text{BASE}(b_1, b_2, \ldots, b_n).
\]
Because \texttt{BASE} and the result are conformable, for each element of \texttt{BASE} there is a corresponding element of the result.

Thus the \texttt{INDX} arrays establish a mapping from all the elements of \texttt{ARRAY} onto selected elements of the result and \texttt{BASE}. Viewed in the other direction, this mapping associates with each element \(b\) of \texttt{BASE} a set \(S\) of elements from \texttt{ARRAY}.

If \(S\) is empty, then the element of the result corresponding to the element \(b\) of \texttt{BASE} has the same value as \(b\).

If \(S\) is non-empty, then the elements of \(S\) will be combined with element \(b\) to produce an element of the result. The detailed specifications of the scatter functions describe the particular means of combining these values. As an example, for \texttt{SUM\_SCATTER}, if the elements of \(S\) are \(a_1, \ldots, a_m\), then the element of the result corresponding to the element \(b\) of \texttt{BASE} is the result of evaluating \(\text{SUM}((a_1, a_2, \ldots, a_m, b))\).

Note that the elements of the \texttt{INDX} arrays must be non-negative, and that \texttt{INDXj} may not exceed \texttt{SIZE}(\texttt{BASE}, \(j\)). The result computed is not affected by the declared upper or lower bounds on indices of \texttt{BASE}; it depends only on the shape of \texttt{BASE}.

Note that, since a scalar is conformable with any array, a scalar may be used in place of an \texttt{INDX} array, in which case one hyperplane of the result is selected. See the example below.

If the optional, final \texttt{MASK} argument is present, then only the elements of \texttt{ARRAY} in positions for which \texttt{MASK} is true participate in the operation. All other elements of \texttt{ARRAY} and of the \texttt{INDX} arrays are ignored and cannot have any influence on any element of the result.

For example, if
\[
A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix}, \quad B = \begin{bmatrix} -1 & -2 & -3 \\ -4 & -5 & -6 \\ -7 & -8 & -9 \end{bmatrix},
\]
\[
I1 = \begin{bmatrix} 1 & 1 & 1 \\ 2 & 1 & 1 \\ 3 & 2 & 1 \end{bmatrix}, \quad I2 = \begin{bmatrix} 1 & 2 & 3 \\ 1 & 1 & 2 \\ 1 & 1 & 1 \end{bmatrix},
\]
then

...
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SUM_SCATTER(A, B, I1, I2) is
\[
\begin{bmatrix}
14 & 6 & 0 \\
8 & -5 & -6 \\
0 & -8 & -9 \\
\end{bmatrix};
\]

SUM_SCATTER(A, B, 2, I2) is
\[
\begin{bmatrix}
-1 & -2 & -3 \\
30 & 3 & -3 \\
-7 & -8 & -9 \\
\end{bmatrix};
\]

SUM_SCATTER(A, B, I1, 2) is
\[
\begin{bmatrix}
-1 & 24 & -3 \\
-4 & 7 & -6 \\
-7 & -1 & -9 \\
\end{bmatrix};
\]

SUM_SCATTER(A, B, 2, 2) is
\[
\begin{bmatrix}
-1 & -2 & -3 \\
-4 & 40 & -6 \\
-7 & -8 & -9 \\
\end{bmatrix}.
\]

If A is the array \[10\ 20\ 30\ 40\ -10\], B is the array \[1\ 2\ 3\ 4\], and IND is the array \[3\ 2\ 2\ 1\ 1\], then SUM_SCATTER(A, B, IND, MASK=(A .GT. 0)) is \[41\ 52\ 13\ 4\].

7.4.5 Array Prefix and Suffix Functions

In a scan of a vector, each element of the result is a function of the elements of the vector that precede it (for a prefix scan) or that follow it (for a suffix scan). These functions provide scan operations on arrays and subarrays. The functions have the general form

XXX_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
XXX_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

except in the special cases noted below. The allowed values of XXX are ALL, ANY, COPY, COUNT, IALL, IANY, IPARITY, MAXVAL, MINVAL, PARITY, PRODUCT, and SUM.

When comments below apply to both prefix and suffix forms of the routines, we will refer to them as YYYYFIX functions.

The arguments DIM, MASK, SEGMENT, and EXCLUSIVE are optional. The COPY YYYYFIX functions do not have MASK or EXCLUSIVE arguments. The ALL YYYYFIX, ANY YYYYFIX, COUNTER YYYYFIX, and PARITY YYYYFIX functions do not have MASK arguments. Their ARRAY argument must be of type logical; it is denoted MASK in their specifications in Section 7.7.

The arguments MASK and SEGMENT must be of type logical. SEGMENT must have the same shape as ARRAY. MASK must be conformable with ARRAY. EXCLUSIVE is a logical scalar. DIM is a scalar integer between one and the rank of ARRAY.

Result Value. The result has the same shape as ARRAY, and, with the exception of COUNT YYYYFIX, the same type and kind type parameter as ARRAY. (The result of COUNT YYYYFIX is default integer.)

In every case, every element of the result is determined by the values of certain selected elements of ARRAY in a way that is specific to the particular function and is described in its specification. The optional arguments affect the selection of elements of ARRAY for each element of the result; the selected elements of ARRAY are said to contribute to the result element. This section describes fully which elements of ARRAY contribute to a given element of the result.
If no elements of \texttt{ARRAY} are selected for a given element of the result, that result element is set to a default value that is specific to the particular function and is described in its specification.

For any given element \( r \) of the result, let \( a \) be the corresponding element of \texttt{ARRAY}. Every element of \texttt{ARRAY} contributes to \( r \) unless disqualified by one of the following rules.

1. If the function is \texttt{XXX\_PREFIX}, no element that follows \( a \) in the array element ordering of \texttt{ARRAY} contributes to \( r \). If the function is \texttt{XXX\_SUFFIX}, no element that precedes \( a \) in the array element ordering of \texttt{ARRAY} contributes to \( r \).

2. If the \texttt{DIM} argument is provided, an element \( z \) of \texttt{ARRAY} does not contribute to \( r \) unless all its indices, excepting only the index for dimension \texttt{DIM}, are the same as the corresponding indices of \( a \). (It follows that if the \texttt{DIM} argument is omitted, then \texttt{ARRAY}, \texttt{MASK}, and \texttt{SEGMENT} are processed in array element order, as if temporarily regarded as rank-one arrays. If the \texttt{DIM} argument is present, then a family of completely independent scan operations are carried out along the selected dimension of \texttt{ARRAY}.)

3. If the \texttt{MASK} argument is provided, an element \( z \) of \texttt{ARRAY} contributes to \( r \) only if the element of \texttt{MASK} corresponding to \( z \) is true. (It follows that array elements corresponding to positions where the \texttt{MASK} is false do not contribute anywhere to the result. However, the result is nevertheless defined at all positions, even positions where the \texttt{MASK} is false.)

4. If the \texttt{SEGMENT} argument is provided, an element \( z \) of \texttt{ARRAY} does not contribute if there is some intermediate element \( w \) of \texttt{ARRAY}, possibly \( z \) itself, with all of the following properties:

   (a) If the function is \texttt{XXX\_PREFIX}, \( w \) does not precede \( z \) but does precede \( a \) in the array element ordering; if the function is \texttt{XXX\_SUFFIX}, \( w \) does not follow \( z \) but does follow \( a \) in the array element ordering;

   (b) If the \texttt{DIM} argument is present, all the indices of \( w \), excepting only the index for dimension \texttt{DIM}, are the same as the corresponding indices of \( a \); and

   (c) The element of \texttt{SEGMENT} corresponding to \( w \) does not have the same value as the element of \texttt{SEGMENT} corresponding to \( a \). (In other words, \( z \) can contribute only if there is an unbroken string of \texttt{SEGMENT} values, all alike, extending from \( z \) through \( a \).)

5. If the \texttt{EXCLUSIVE} argument is provided and is true, then \( a \) itself does not contribute to \( r \).

These general rules lead to the following important cases:

\textbf{Case (i):} If \texttt{ARRAY} has rank one, element \( i \) of the result of \texttt{XXX\_PREFIX(ARRAY)} is determined by the first \( i \) elements of \texttt{ARRAY}; element \( \text{SIZE(ARRAY)} - i + 1 \) of the result of \texttt{XXX\_SUFFIX(ARRAY)} is determined by the last \( i \) elements of \texttt{ARRAY}.

\textbf{Case (ii):} If \texttt{ARRAY} has rank greater than one, then each element of the result of \texttt{XXX\_PREFIX(ARRAY)} has a value determined by the corresponding element \( a \) of the \texttt{ARRAY} and all elements of \texttt{ARRAY} that precede \( a \) in array element
order. For **XXX_SUFFIX**, \( a \) is determined by the elements of **ARRAY** that correspond to or follow \( a \) in array element order.

**Case (iii):** Each element of the result of **XXX_PREFIX**(**ARRAY**, **MASK**=**MASK**) is determined by selected elements of **ARRAY**, namely the corresponding element \( a \) of the **ARRAY** and all elements of **ARRAY** that precede \( a \) in array element order, but an element of **ARRAY** may contribute to the result only if the corresponding element of **MASK** is true. If this restriction results in selecting no array elements to contribute to some element of the result, then that element of the result is set to the default value for the given function.

**Case (iv):** Each element of the result of **XXX_PREFIX**(**ARRAY**, **DIM**=**DIM**) is determined by selected elements of **ARRAY**, namely the corresponding element \( a \) of the **ARRAY** and all elements of **ARRAY** that precede \( a \) along dimension **DIM**; for example, in **SUM_PREFIX**(\( A(i_1:i_2, 1:N) \), **DIM**=2), result element \( (i_1, i_2) \) could be computed as **SUM**(\( A(i_1, i_2) \)). More generally, in **SUM_PREFIX**(**ARRAY**, **DIM**), result element \( i_1, i_2, \ldots, i_{DIM}, \ldots, i_n \) could be computed as **SUM**(\( A(i_1, i_2, \ldots, i_{DIM}, \ldots, i_n) \)). (Note the colon before \( i_{DIM} \) in that last expression.)

**Case (v):** If **ARRAY** has rank one, then element \( i \) of the result of **XXX_PREFIX**(**ARRAY**, **EXCLUSIVE**=.TRUE.) is determined by the first \( i-1 \) elements of **ARRAY**.

**Case (vi):** The options may be used in any combination.

**Advice to users.** A new segment begins at every transition from false to true or true to false; thus a segment is indicated by a maximal contiguous subsequence of like logical values:

\[
\]

----- - - ------ - --- -

seven segments

(End of advice to users.)

**Rationale.**

One existing library delimits the segments by indicating the **start** of each segment. Another delimits the segments by indicating the **stop** of each segment. Each method has its advantages. There is also the question of whether this convention should change when performing a suffix rather than a prefix. HPF adopts the symmetric representation above. The main advantages of this representation are:

(A) It is symmetrical, in that the same segment specifier may be meaningfully used for prefix and suffix without changing its interpretation (start versus stop).

(B) The start-bit or stop-bit representation is easily converted to this form by using **PARITY_PREFIX** or **PARITY_SUFFIX**. These might be standard idioms for a compiler to recognize:
SUM_PREFIX(FOO, SEGMENT=PARITY_PREFIX(START_BITS))
SUM_PREFIX(FOO, SEGMENT=PARITY_SUFFIX(STOP_BITS))
SUM_SUFFIX(FOO, SEGMENT=PARITY_SUFFIX(START_BITS))
SUM_SUFFIX(FOO, SEGMENT=PARITY_PREFIX(STOP_BITS))

(End of rationale.)

Examples. The examples below illustrate all possible combinations of optional arguments for SUM_PREFIX. The default value for SUM_YYYFIX is zero.

Case (i): SUM_PREFIX(/1,3,5,7/) is [1 4 9 16].

Case (ii): If B is the array
\[
\begin{array}{ccc}
1 & 2 & 3 \\
4 & 5 & 6 \\
7 & 8 & 9 \\
\end{array}
\]
then SUM_PREFIX(B) is the array
\[
\begin{array}{ccc}
1 & 14 & 30 \\
5 & 19 & 36 \\
12 & 27 & 45 \\
\end{array}
\]

Case (iii): If A is the array
\[
\begin{array}{cccccc}
3 & 5 & -2 & -1 & 7 & 4 & 8 \\
\end{array}
\]
then SUM_PREFIX(A, MASK = A .LT. 6) is [3 8 6 5 5 9 9].

Case (iv): If B is the array
\[
\begin{array}{ccc}
1 & 2 & 3 \\
4 & 5 & 6 \\
7 & 8 & 9 \\
\end{array}
\]
then SUM_PREFIX(B, DIM=1) is the array
\[
\begin{array}{ccc}
1 & 3 & 6 \\
4 & 9 & 15 \\
7 & 15 & 24 \\
\end{array}
\]
and SUM_PREFIX(B, DIM=2) is the array
\[
\begin{array}{ccc}
1 & 2 & 3 \\
5 & 7 & 9 \\
12 & 15 & 18 \\
\end{array}
\]

Case (v): SUM_PREFIX(/1,3,5,7/, EXCLUSIVE=.`TRUE.`) is [0 1 4 9].

Case (vi): If B is the array
\[
\begin{array}{cccc}
1 & 2 & 3 & 4 \\
6 & 7 & 8 & 9 \\
11 & 12 & 13 & 14 \\
\end{array}
\]
M is the array
\[
\begin{array}{cccc}
T & T & T & T \\
F & F & T & T \\
T & F & T & F \\
\end{array}
\]
S is the array
\[
\begin{array}{cccc}
T & T & F & F \\
F & T & T & F \\
T & T & T & T \\
\end{array}
\]
then:
SUM_PREFIX(B, DIM=2, MASK=M, SEGMENT=S, EXCLUSIVE=.`TRUE.`) is
\[
\begin{array}{cccc}
0 & 1 & 0 & 3 \\
0 & 0 & 0 & 0 \\
0 & 11 & 11 & 24 \\
\end{array}
\]
SUM_PREFIX(B, DIM=2, MASK=M, SEGMENT=S, EXCLUSIVE=.`FALSE.`) is
\[
\begin{array}{cccc}
1 & 3 & 3 & 7 \\
0 & 0 & 8 & 9 \\
11 & 11 & 24 & 24 \\
\end{array}
\]
SUM_PREFIX(B, DIM=2, MASK=M, EXCLUSIVE=.`TRUE.`) is
\[
\begin{array}{cccc}
0 & 1 & 3 & 6 \\
0 & 0 & 0 & 8 \\
0 & 11 & 11 & 24 \\
\end{array}
\]
SUM\_PREFIX(B, DIM=2, MASK=M, EXCLUSIVE=.FALSE.) is
\[
\begin{bmatrix}
1 & 3 & 6 & 10 & 15 \\
0 & 0 & 8 & 17 & 27 \\
11 & 11 & 24 & 24 & 24
\end{bmatrix}.
\]

SUM\_PREFIX(B, DIM=2, SEGMENT=S, EXCLUSIVE=.TRUE.) is
\[
\begin{bmatrix}
0 & 1 & 0 & 3 & 7 \\
0 & 0 & 7 & 0 & 9 \\
0 & 11 & 23 & 36 & 50
\end{bmatrix}.
\]

SUM\_PREFIX(B, DIM=2, SEGMENT=S, EXCLUSIVE=.FALSE.) is
\[
\begin{bmatrix}
1 & 3 & 3 & 7 & 12 \\
6 & 7 & 15 & 9 & 19 \\
11 & 23 & 36 & 50 & 65
\end{bmatrix}.
\]

SUM\_PREFIX(B, DIM=2, EXCLUSIVE=.TRUE.) is
\[
\begin{bmatrix}
0 & 1 & 3 & 6 & 10 \\
0 & 6 & 13 & 21 & 30 \\
0 & 11 & 23 & 36 & 50
\end{bmatrix}.
\]

SUM\_PREFIX(B, DIM=2, EXCLUSIVE=.FALSE.) is
\[
\begin{bmatrix}
1 & 3 & 6 & 10 & 15 \\
6 & 13 & 21 & 30 & 40 \\
11 & 23 & 36 & 50 & 65
\end{bmatrix}.
\]

SUM\_PREFIX(B, MASK=M, SEGMENT=S, EXCLUSIVE=.TRUE.) is
\[
\begin{bmatrix}
0 & 11 & 0 & 0 & 0 \\
0 & 13 & 0 & 4 & 5 \\
0 & 13 & 8 & 0 & 0
\end{bmatrix}.
\]

SUM\_PREFIX(B, MASK=M, SEGMENT=S, EXCLUSIVE=.FALSE.) is
\[
\begin{bmatrix}
1 & 13 & 3 & 4 & 5 \\
0 & 13 & 8 & 13 & 15 \\
11 & 13 & 21 & 0 & 0
\end{bmatrix}.
\]

SUM\_PREFIX(B, MASK=M, EXCLUSIVE=.TRUE.) is
\[
\begin{bmatrix}
0 & 12 & 14 & 38 & 51 \\
1 & 14 & 17 & 42 & 56 \\
1 & 14 & 25 & 51 & 66
\end{bmatrix}.
\]

SUM\_PREFIX(B, MASK=M, EXCLUSIVE=.FALSE.) is
\[
\begin{bmatrix}
1 & 14 & 17 & 42 & 56 \\
1 & 14 & 25 & 51 & 66 \\
12 & 14 & 38 & 51 & 66
\end{bmatrix}.
\]

SUM\_PREFIX(B, SEGMENT=S, EXCLUSIVE=.TRUE.) is
\[
\begin{bmatrix}
0 & 11 & 0 & 0 & 0 \\
0 & 13 & 0 & 4 & 5 \\
0 & 20 & 8 & 0 & 0
\end{bmatrix}.
\]

SUM\_PREFIX(B, SEGMENT=S, EXCLUSIVE=.FALSE.) is
\[
\begin{bmatrix}
1 & 13 & 3 & 4 & 5 \\
6 & 20 & 8 & 13 & 15 \\
11 & 32 & 21 & 14 & 15
\end{bmatrix}.
\]

SUM\_PREFIX(B, EXCLUSIVE=.TRUE.) is
\[
\begin{bmatrix}
0 & 18 & 39 & 63 & 90 \\
1 & 20 & 42 & 67 & 95 \\
7 & 27 & 50 & 76 & 105
\end{bmatrix}.
\]

SUM\_PREFIX(B, EXCLUSIVE=.FALSE.) is
\[
\begin{bmatrix}
1 & 20 & 42 & 67 & 95 \\
7 & 27 & 50 & 76 & 105 \\
18 & 39 & 63 & 90 & 120
\end{bmatrix}.
\]
7.4.6 Array Sorting Functions

HPF includes procedures for sorting multidimensional arrays. The `SORT_UP` and `SORT_DOWN` functions return sorted arrays; the `GRADE_UP` and `GRADE_DOWN` functions return sorting permutations. An array can be sorted along a given axis, or the whole array may be viewed as a sequence in array element order. The grade functions use stable sorts, allowing for convenient sorting of structures by major and minor keys.

7.5 Generic Intrinsic and Library Procedures

For all of the intrinsic and library procedures, the arguments shown are the names that must be used for keywords when using the keyword form for actual arguments. Many of the argument keywords have names that are indicative of their usage, as is the case in Fortran. See Section F95:13.11.

7.5.1 System Inquiry Intrinsic Functions

`NUMBER_OF_PROCESSORS(DIM)` The number of executing processors
Optional DIM

`PROCESSORS_SHAPE()` The shape of the executing processor array

7.5.2 Mapping Inquiry Subroutines

`HPF_ALIGNMENT(ALIGNEE, LB, UB, STRIDE, AXIS_MAP, IDENTITY_MAP, & NCOPIES)` Optional LB, UB, STRIDE, AXIS_MAP, IDENTITY_MAP, NCOPIES

`HPF_DISTRIBUTION(DISTRIBUTEE, AXIS_TYPE, AXIS_INFO, PROCESSORS_RANK, & PROCESSORS_SHAPE)` Optional AXIS_TYPE, AXIS_INFO, PROCESSORS_RANK, PROCESSORS_SHAPE

`HPF_TEMPLATE(ALIGNEE, TEMPLATE_RANK, LB, UB, AXIS_TYPE, AXIS_INFO, & NUMBER_ALIGNED)` Optional TEMPLATE_RANK, LB, UB, AXIS_TYPE, AXIS_INFO, NUMBER_ALIGNED

7.5.3 Bit Manipulation Functions

`ILEN(I)` Bit length (intrinsic)

`LEADZ(I)` Leading zeros

`POPCNT(I)` Number of one bits

`POPPAR(I)` Parity
7.5.4 Array Reduction Functions

- `IALL(ARRAY, DIM, MASK)`: Bitwise logical AND reduction (Optional DIM, MASK)
- `IANY(ARRAY, DIM, MASK)`: Bitwise logical OR reduction (Optional DIM, MASK)
- `IPARITY(ARRAY, DIM, MASK)`: Bitwise logical EOR reduction (Optional DIM, MASK)
- `PARITY(MASK, DIM)`: Logical EOR reduction (Optional DIM)

7.5.5 Array Combining Scatter Functions

- `ALL_SCATTER(MASK, BASE, INDX1 ..., INDXn)`
- `ANY_SCATTER(MASK, BASE, INDX1, ..., INDXn)`
- `COPY_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)` (Optional MASK)
- `COUNT_SCATTER(MASK, BASE, INDX1, ..., INDXn)`
- `IALL_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)` (Optional MASK)
- `IANY_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)` (Optional MASK)
- `IPARITY_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)` (Optional MASK)
- `MAXVAL_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)` (Optional MASK)
- `MINVAL_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)` (Optional MASK)
- `PARITY_SCATTER(MASK, BASE, INDX1, ..., INDXn)` (Optional MASK)
- `PRODUCT_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)` (Optional MASK)
- `SUM_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)` (Optional MASK)

7.5.6 Array Prefix and Suffix Functions

- `ALL_PREFIX(MASK, DIM, SEGMENT, EXCLUSIVE)` (Optional DIM, SEGMENT, EXCLUSIVE)
- `ALL_SUFFIX(MASK, DIM, SEGMENT, EXCLUSIVE)` (Optional DIM, SEGMENT, EXCLUSIVE)
- `ANY_PREFIX(MASK, DIM, SEGMENT, EXCLUSIVE)` (Optional DIM, SEGMENT, EXCLUSIVE)
- `ANY_SUFFIX(MASK, DIM, SEGMENT, EXCLUSIVE)` (Optional DIM, SEGMENT, EXCLUSIVE)
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COPY_PREFIX(ARRAY, DIM, SEGMENT)
Optional DIM, SEGMENT

COPY_SUFFIX(ARRAY, DIM, SEGMENT)
Optional DIM, SEGMENT

COUNT_PREFIX(MASK, DIM, SEGMENT, EXCLUSIVE)
Optional DIM, SEGMENT, EXCLUSIVE

COUNT_SUFFIX(MASK, DIM, SEGMENT, EXCLUSIVE)
Optional DIM, SEGMENT, EXCLUSIVE

IALL_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

IALL_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

IANY_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

IANY_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

IPARITY_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

IPARITY_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

MAXVAL_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

MAXVAL_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

MINVAL_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

MINVAL_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

PARITY_PREFIX(MASK, DIM, SEGMENT, EXCLUSIVE)
Optional DIM, SEGMENT, EXCLUSIVE

PARITY_SUFFIX(MASK, DIM, SEGMENT, EXCLUSIVE)
Optional DIM, SEGMENT, EXCLUSIVE

PRODUCT_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

PRODUCT_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

SUM_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE

SUM_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)
Optional DIM, MASK, SEGMENT, EXCLUSIVE
7.5.7 Array Sort Functions

GRADE_DOWN(ARRAY, DIM)  Permutation that sorts into descending order
    Optional DIM
GRADE_UP(ARRAY, DIM)    Permutation that sorts into ascending order
    Optional DIM
SORT_DOWN(ARRAY, DIM)  Sort into descending order
    Optional DIM
SORT_UP(ARRAY, DIM)    Sort into ascending order
    Optional DIM

7.6 Specifications of Intrinsic Procedures

ILEN(I)

Description. Returns one less than the length, in bits, of the two's-complement representation of an integer.

Class. Elemental function.

Argument. I must be of type integer.

Result Type and Type Parameter. Same as I.

Result Value. If I is nonnegative, ILEN(I) has the value \(\lfloor \log_2(I+1) \rfloor \); if I is negative, ILEN(I) has the value \(\lfloor \log_2(-I) \rfloor \).

Examples. ILEN(4) = 3. ILEN(-4) = 2. 2**ILEN(N-1) rounds N up to a power of 2 (for \(N > 0\)), whereas 2**(ILEN(N)-1) rounds N down to a power of 2. Compare with LEAD2.

The value returned is one less than the length of the two's-complement representation of I, as the following explains. The shortest two's-complement representation of 4 is 0100. The leading zero is the required sign bit. In 3-bit two's complement, 100 represents -4.

NUMBER_OF_PROCESSORS(DIM)

Optional Argument. DIM

Description. Returns the total number of processors available to the program or the number of processors available to the program along a specified dimension of the processor array.

Class. System inquiry function.

Arguments.

DIM (optional) must be scalar and of type integer with a value in the range 1 ≤ DIM ≤ n where n is the rank of the processor array.
RESULT TYPE, TYPE PARAMETER, AND SHAPE. Default integer scalar.

RESULT VALUE. The result has a value equal to the extent of dimension DIM of the implementation-dependent hardware processor array or, if DIM is absent, the total number of elements of the implementation-dependent hardware processor array. The result is always greater than zero.

EXAMPLES. For a computer with 8192 processors arranged in a 128 by 64 rectangular grid, the value of NUMBER_OF_PROCESSORS() is 8192; the value of NUMBER_OF_PROCESSORS(DIM=1) is 128; and the value of NUMBER_OF_PROCESSORS(DIM=2) is 64. For a single-processor workstation, the value of NUMBER_OF_PROCESSORS() is 1; since the rank of a scalar processor array is zero, no DIM argument may be used.

PROCESSORS_SHAPE()  

DESCRIPTION. Returns the shape of the implementation-dependent processor array.

CLASS. System inquiry function.

ARGUMENTS. None

RESULT TYPE, TYPE PARAMETER, AND SHAPE. The result is a default integer array of rank one whose size is equal to the rank of the implementation-dependent processor array.

RESULT VALUE. The value of the result is the shape of the implementation-dependent processor array.

EXAMPLE. In a computer with 2048 processors arranged in a hypercube, the value of PROCESSORS_SHAPE() is [2,2,2,2,2,2,2,2]. In a computer with 8192 processors arranged in a 128 by 64 rectangular grid, the value of PROCESSORS_SHAPE() is [128,64]. For a single processor workstation, the value of PROCESSORS_SHAPE() is [] (the size-zero array of rank one).

7.7 Specifications of Library Procedures

ALL_PREFIX(MASK, DIM, SEGMENT, EXCLUSIVE)  

OPTIONAL ARGUMENTS. DIM, SEGMENT, EXCLUSIVE

DESCRIPTION. Computes a segmented logical AND scan along dimension DIM of MASK.

CLASS. Transformational function.

ARGUMENTS.

MASK must be of type logical. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range 1 ≤ DIM ≤ n, where n is the rank of MASK.
SEGMENT (optional) must be of type logical and must have the same shape as MASK.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as MASK.

Result Value. Element \( r \) of the result has the value ALL(\( / a_1, \ldots, a_m / \)) where \( (a_1, \ldots, a_m) \) is the (possibly empty) set of elements of MASK selected to contribute to \( r \) by the rules stated in Section 7.4.5.

Example. ALL_PREFIX( (/T,F,T,T,T/), SEGMENT= (/F,F,T,T/) ) is 
\[
\begin{bmatrix}
T & F & F & T & T
\end{bmatrix}.
\]

\textbf{ALL_SCATTER(MASK,BASE,INDX1, ..., INDXn)}

Description. Scatters elements of \( \text{MASK} \) to positions of the result indicated by index arrays \( \text{INDX1}, \ldots, \text{INDXn} \). An element of the result is true if and only if the corresponding element of \( \text{BASE} \) and all elements of \( \text{MASK} \) scattered to that position are true.

Class. Transformational function.

Arguments.

\( \text{MASK} \) must be of type logical. It must not be scalar.

\( \text{BASE} \) must be of type logical with the same kind type parameter as \( \text{MASK} \). It must not be scalar.

\( \text{INDX1}, \ldots, \text{INDXn} \) must be of type integer and conformable with \( \text{MASK} \). The number of \( \text{INDX} \) arguments must be equal to the rank of \( \text{BASE} \).

Result Type, Type Parameter, and Shape. Same as \( \text{BASE} \).

Result Value. The element of the result corresponding to the element \( b \) of \( \text{BASE} \) has the value ALL( \( /a_1, a_2, \ldots, a_m, b/ \) ), where \( (a_1, \ldots, a_m) \) are the elements of \( \text{MASK} \) associated with \( b \) as described in Section 7.4.4.

Example. ALL_SCATTER( (/T, T, T, F/), (/T, T, T/, (/1, 1, 2, 2/) ) is 
\[
\begin{bmatrix}
T & F & T
\end{bmatrix}.
\]

\textbf{ALL_SUFFIX(MASK, DIM, SEGMENT, EXCLUSIVE)}

Optional Arguments. \( \text{DIM}, \text{SEGMENT}, \text{EXCLUSIVE} \)

Description. Computes a reverse, segmented logical AND scan along dimension \( \text{DIM} \) of \( \text{MASK} \).

Class. Transformational function.
Arguments.

**MASK**

must be of type logical. It must not be scalar.

**DIM** (optional)

must be scalar and of type integer with a value in the range \(1 \leq \text{DIM} \leq n\), where \(n\) is the rank of **MASK**.

**SEGMENT** (optional)

must be of type logical and must have the same shape as **MASK**.

**EXCLUSIVE** (optional)

must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as **MASK**.

Result Value. Element \(r\) of the result has the value \(\text{ALL}(\{a_1, \ldots, a_m\})\) where \((a_1, \ldots, a_m)\) is the (possibly empty) set of elements of **MASK** selected to contribute to \(r\) by the rules stated in Section 7.4.5.

Example. \(\text{ALL\_SUFFIX}(\{/T,F,T,T,T/\}, \text{SEGMENT}=\{/F,F,F,T,T/\})\) is \([\text{F F T T T}].\)

**ANY\_PREFIX(MASK, DIM, SEGMENT, EXCLUSIVE)**

Optional Arguments. **DIM**, **SEGMENT**, **EXCLUSIVE**

Description. Computes a segmented logical OR scan along dimension **DIM** of **MASK**.

Class. Transformational function.

Arguments.

**MASK**

must be of type logical. It must not be scalar.

**DIM** (optional)

must be scalar and of type integer with a value in the range \(1 \leq \text{DIM} \leq n\), where \(n\) is the rank of **MASK**.

**SEGMENT** (optional)

must be of type logical and must have the same shape as **MASK**.

**EXCLUSIVE** (optional)

must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as **MASK**.

Result Value. Element \(r\) of the result has the value \(\text{ANY}(\{a_1, \ldots, a_m\})\) where \((a_1, \ldots, a_m)\) is the (possibly empty) set of elements of **MASK** selected to contribute to \(r\) by the rules stated in Section 7.4.5.

Example. \(\text{ANY\_PREFIX}(\{/F,T,F,F,F/\}, \text{SEGMENT}=\{/F,F,F,T,T/\})\) is \([\text{F T T F F}].\).
ANY_SCATTER(MASK, BASE, INDX1, ..., INDXn)

**Description.** Scatters elements of MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. An element of the result is true if and only if the corresponding element of BASE or any element of MASK scattered to that position is true.

**Class.** Transformational function.

**Arguments.**

- **MASK** must be of type logical. It must not be scalar.
- **BASE** must be of type logical with the same kind type parameter as **MASK**. It must not be scalar.
- **INDX1, ..., INDXn** must be of type integer and conformable with **MASK**. The number of **INDX** arguments must be equal to the rank of **BASE**.

**Result Type, Type Parameter, and Shape.** Same as **BASE**.

**Result Value.** The element of the result corresponding to the element b of **BASE** has the value ANY( (/a1, a2, ..., am, b/) ), where (a1, ..., am) are the elements of **MASK** associated with b as described in Section 7.4.4.

**Example.** ANY_SCATTER( (/T, F, F, F/), (/F, F, T/), (/1, 1, 2, 2/) ) is [ T F T ].

ANY_SUFFIX(MASK, DIM, SEGMENT, EXCLUSIVE)

**Optional Arguments.** DIM, SEGMENT, EXCLUSIVE

**Description.** Computes a reverse, segmented logical OR scan along dimension DIM of **MASK**.

**Class.** Transformational function.

**Arguments.**

- **MASK** must be of type logical. It must not be scalar.
- **DIM** (optional) must be scalar and of type integer with a value in the range 1 ≤ DIM ≤ n, where n is the rank of **MASK**.
- **SEGMENT** (optional) must be of type logical and must have the same shape as **MASK**.
- **EXCLUSIVE** (optional) must be of type logical and must be scalar.

**Result Type, Type Parameter, and Shape.** Same as **MASK**.

**Result Value.** Element r of the result has the value ANY( (/ a1, ..., am /)) where (a1, ..., am) is the (possibly empty) set of elements of **MASK** selected to contribute to r by the rules stated in Section 7.4.5.

**Example.** ANY_SUFFIX( (/F,T,F,F,F/), SEGMENT= (/F,F,F,T,T/) ) is [ T T F F F ].
SECTION 7. INTRINSIC AND LIBRARY PROCEDURES

COPY_PREFIX(ARRAY, DIM, SEGMENT)

**Optional Arguments.** DIM, SEGMENT

**Description.** Computes a segmented copy scan along dimension DIM of ARRAY.

**Class.** Transformational function.

**Arguments.**

- **ARRAY** may be of any type. It must not be scalar.
- **DIM (optional)** must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of ARRAY.
- **SEGMENT (optional)** must be of type logical and must have the same shape as ARRAY.

**Result Type, Type Parameter, and Shape.** Same as ARRAY.

**Result Value.** Element $r$ of the result has the value $a_1$ where $(a_1, \ldots, a_m)$ is the set, in array element order, of elements of ARRAY selected to contribute to $r$ by the rules stated in Section 7.4.5. Note that this set is never empty.

**Example.** COPY_PREFIX((/1,2,3,4,5/), SEGMENT= (/F,F,F,T,T/) ) is 

\[
\begin{bmatrix}
1 & 1 & 1 & 4 & 4
\end{bmatrix}.
\]

COPY_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)

**Optional Argument.** MASK

**Description.** Scatters elements of ARRAY selected by MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. Each element of the result is equal to one of the elements of ARRAY scattered to that position or, if there is none, to the corresponding element of BASE.

**Class.** Transformational function.

**Arguments.**

- **ARRAY** may be of any type. It must not be scalar.
- **BASE** must be of the same type and kind type parameter as ARRAY.
- **INDX1, ..., INDXn** must be of type integer and conformable with ARRAY. The number of INDX arguments must be equal to the rank of BASE.
- **MASK (optional)** must be of type logical and must be conformable with ARRAY.

**Result Type, Type Parameter, and Shape.** Same as BASE.
7.7. SPECIFICATIONS OF LIBRARY PROCEDURES

Result Value. Let $S$ be the set of elements of $ARRAY$ associated with element $b$ of $BASE$ as described in Section 7.4.4.

If $S$ is empty, then the element of the result corresponding to the element $b$ of $BASE$ has the same value as $b$.

If $S$ is non-empty, then the element of the result corresponding to the element $b$ of $BASE$ is the result of choosing one element from $S$. HPF does not specify how the choice is to be made; the mechanism is implementation dependent.

Example. \texttt{COPY \_SCATTER}((1, 2, 3, 4, 5), (7, 8, 9), (1, 1, 2, 2)) is $[x, y, z]$, where $x$ is a member of the set $\{1, 2\}$ and $y$ is a member of the set $\{3, 4\}$.

COPY\_SUFFIX(ARRAY, DIM, SEGMENT)

Optional Arguments. DIM, SEGMENT

Description. Computes a reverse, segmented copy scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

\begin{itemize}
\item \texttt{ARRAY} may be of any type. It must not be scalar.
\item DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of $ARRAY$.
\item SEGMENT (optional) must be of type logical and must have the same shape as $ARRAY$.
\end{itemize}

Result Type, Type Parameter, and Shape. Same as $ARRAY$.

Result Value. Element $r$ of the result has the value $a_m$ where $(a_1, \ldots, a_m)$ is the set, in array element order, of elements of $ARRAY$ selected to contribute to $r$ by the rules stated in Section 7.4.5. Note that this set is never empty.

Example. \texttt{COPY\_SUFFIX}((1,2,3,4,5), SEGMENT= (F,F,F,T,T)) is

\[
[3 \ 3 \ 3 \ 5 \ 5].
\]

COUNT\_PREFIX(MASK, DIM, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, SEGMENT, EXCLUSIVE

Description. Computes a segmented \texttt{COUNT} scan along dimension DIM of MASK.

Class. Transformational function.

Arguments.

\begin{itemize}
\item \texttt{MASK} must be of type logical. It must not be scalar.
\end{itemize}
DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of MASK.

SEGMENT (optional) must be of type logical and must have the same shape as MASK.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. The result is of type default integer and of the same shape as MASK.

Result Value. Element $r$ of the result has the value $\text{COUNT}(\langle a_1, \ldots, a_m \rangle)$ where $(a_1, \ldots, a_m)$ is the (possibly empty) set of elements of MASK selected to contribute to $r$ by the rules stated in Section 7.4.5.

Example. $\text{COUNT}_\text{PREFIX}(\langle /F, T, T, T, T/ \rangle, \text{SEGMENT} = \langle /F, F, F, T, T/ \rangle)$ is $\begin{bmatrix} 0 & 1 & 2 & 1 & 2 \end{bmatrix}$.

\textbf{COUNT\_SCATTER(MASK,BASE,INDX1, ..., INDXn)}

Description. Scatters elements of MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. Each element of the result is the sum of the corresponding element of BASE and the number of true elements of MASK scattered to that position.

Class. Transformational function.

Arguments.

MASK must be of type logical. It must not be scalar.

BASE must be of type integer. It must not be scalar.

INDX1, ..., INDXn must be of type integer and conformable with MASK. The number of INDX arguments must be equal to the rank of BASE.

Result Type, Type Parameter, and Shape. Same as BASE.

Result Value. The element of the result corresponding to the element $b$ of BASE has the value $b + \text{COUNT}(\langle a_1, a_2, \ldots, a_m \rangle)$, where $(a_1, \ldots, a_m)$ are the elements of MASK associated with $b$ as described in Section 7.4.4.

Example. $\text{COUNT\_SCATTER}(\langle /T, T, T, F/ \rangle, \langle /1, -1, 0/ \rangle, \langle /1, 1, 2, 2/ \rangle)$ is $\begin{bmatrix} 3 & 0 & 0 \end{bmatrix}$.

\textbf{COUNT\_SUFFIX(MASK, DIM, SEGMENT, EXCLUSIVE)}

Optional Arguments. DIM, SEGMENT, EXCLUSIVE

Description. Computes a reverse, segmented COUNT scan along dimension DIM of MASK.
Class. Transformational function.

Arguments.

**MASK**
- must be of type logical. It must not be scalar.

**DIM (optional)**
- must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of MASK.

**SEGMENT (optional)**
- must be of type logical and must have the same shape as MASK.

**EXCLUSIVE (optional)**
- must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. The result is of type default integer and of the same shape as MASK.

Result Value. Element $r$ of the result has the value $\text{COUNT}((/ a_1, \ldots, a_m /))$ where $(a_1, \ldots, a_m)$ is the (possibly empty) set of elements of MASK selected to contribute to $r$ by the rules stated in Section 7.4.5.

Example. $\text{COUNT\_SUFFIX}((/T,F,T,T,T/), \text{SEGMENT}= (/F,F,F,T,T/) )$ is

\[
\begin{bmatrix}
2 & 1 & 1 & 2 & 1
\end{bmatrix}.
\]

**GRADE\_DOWN(ARRAY,DIM)**

Optional Argument. **DIM**

Description. Produces a permutation of the indices of an array, expressed as one-based coordinates, and sorted by descending array element values.

Class. Transformational function.

Arguments.

**ARRAY**
- must be of type integer, real, or character. It must not be scalar.

**DIM (optional)**
- must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of ARRAY. The corresponding actual argument must not be an optional dummy argument.

Result Type, Type Parameter, and Shape. The result is of type default integer. If DIM is present, the result has the same shape as ARRAY. If DIM is absent, the result has shape $(/ \text{SIZE}($SHAPE$(\text{ARRAY}))$, \text{SIZE}$(\text{ARRAY})$)/).

Result Value.

*Case (i):* The result of

\[
S = \text{GRADE\_DOWN}(\text{ARRAY}) \\
+ \text{SPREAD}(\text{LBOUND}(\text{ARRAY}),\text{DIM}=2, \text{NCOPIES}=(\text{SIZE}(\text{ARRAY})-1)
\]

is such that if one computes the rank-one array $B$ of size $\text{SIZE}(\text{ARRAY})$ by
FORALL (K=1:SIZE(B)) B(K)=ARRAY(S(1,K),S(2,K),...,S(N,K))

where N has the value SIZE(SHAPE(ARRAY)), then B is sorted in descending order; moreover, all of the columns of S are distinct, that is, if \( j \neq m \) then ALL(S(:,j) .EQ. S(:,m)) will be false. The sort is stable; if \( j \leq m \) and \( B(j) = B(m) \), then ARRAY(S(1,j),S(2,j),...,S(n,j)) precedes ARRAY(S(1,m),S(2,m),...,S(n,m)) in the array element ordering of ARRAY. The sort is stable; if \( j \neq m \) and \( B(i_1,\ldots,i_k) = B(i_1,\ldots,i_m) \), then

\[
\text{ARRAY}(S(1;i_1,\ldots,i_k))/\text{ARRAY}(S(1;i_1,\ldots,i_m))
\]

in the ordering of ARRAY. The collating sequence for an array of type CHARACTER is that used by the Fortran intrinsic functions, namely ASCII.

Case (ii): The result of

\[
R = \text{GRADE}_\text{DOWN}(\text{ARRAY}, \text{DIM}=K) + \text{LBOUND}(\text{ARRAY}, \text{DIM}=K) - 1
\]

has the property that if one computes the array

\[
B(i_1, i_2, \ldots, i_k, \ldots, i_n) = \\
\text{ARRAY}(i_1, i_2, \ldots, R(i_1, i_2, \ldots, i_k, \ldots, i_n) \ldots, i_n)
\]

then for all \( i_1, \ldots, i_k, \ldots, i_n \) (omit \( i_k \)), the vector \( B(i_1, i_2, \ldots, R(i_1, i_2, \ldots, i_k, \ldots, i_n) \ldots, i_n) \) is sorted in descending order; moreover, \( R(i_1, i_2, \ldots, i_k, \ldots, i_n) \) is a permutation of all the integers between 1 and SIZE(ARRAY, DIM=K), inclusive. The sort is stable; that is, if \( j \neq m \) and

\[
B(i_1, i_2, \ldots, j, \ldots, i_n) = B(i_1, i_2, \ldots, m, \ldots, i_n),
\]

then \( R(i_1, i_2, \ldots, j, \ldots, i_n) \leq R(i_1, i_2, \ldots, m, \ldots, i_n) \). The collating sequence for an array of type CHARACTER is that used by the Fortran intrinsic functions, namely ASCII.

Examples.

Case (i): \( \text{GRADE}_\text{DOWN}(\begin{bmatrix} 30 & 20 & 30 & 40 & -10 \end{bmatrix}) \) is a rank two array of shape \( [1 5] \) with the value \( [4 1 3 2 5] \). (To produce a rank-one result, the optional \( \text{DIM} = 1 \) argument must be used.)

If \( A \) is the array

\[
\begin{bmatrix}
1 & 9 & 2 \\
4 & 5 & 2 \\
1 & 2 & 4
\end{bmatrix}
\]

then \( \text{GRADE}_\text{DOWN}(A) \) has the value

\[
\begin{bmatrix}
1 & 2 & 2 & 3 & 3 & 1 & 2 & 1 & 3 \\
2 & 2 & 1 & 3 & 2 & 3 & 3 & 1 & 1
\end{bmatrix}
\]

Case (ii): If \( A \) is the array

\[
\begin{bmatrix}
1 & 9 & 2 \\
4 & 5 & 2 \\
1 & 2 & 4
\end{bmatrix}
\]

then \( \text{GRADE}_\text{DOWN}(A, \text{DIM} = 1) \) has the value

\[
\begin{bmatrix}
2 & 1 & 3 \\
1 & 2 & 1 \\
3 & 3 & 2
\end{bmatrix}
\]

and \( \text{GRADE}_\text{DOWN}(A, \text{DIM} = 2) \) has the value

\[
\begin{bmatrix}
2 & 3 & 1 \\
2 & 1 & 3 \\
3 & 2 & 1
\end{bmatrix}
\]

\( \text{GRADE}_\text{UP}(\text{ARRAY}, \text{DIM}) \)

Optional Argument. DIM
Description. Produces a permutation of the indices of an array, expressed as one-based coordinates, and sorted by ascending array element values.

Class. Transformational function.

Arguments.

ARRAY must be of type integer, real, or character. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of ARRAY. The corresponding actual argument must not be an optional dummy argument.

Result Type, Type Parameter, and Shape. The result is of type default integer. If DIM is present, the result has the same shape as ARRAY. If DIM is absent, the result has shape $(/ \text{SIZE}(	ext{SHAPE}(\text{ARRAY})), \text{SIZE}(\text{ARRAY}) /)$.

Result Value.

Case (i): The result of
\[
S = \text{GRADE}_\text{UP}(\text{ARRAY}) + \text{SPREAD}(\text{LBOUND}(\text{ARRAY}), \text{DIM}=2, \text{NCOPIES} = \text{SIZE}(\text{ARRAY})) - 1
\]
is such that if one computes the rank-one array $B$ of size $\text{SIZE}(\text{ARRAY})$ by
\[
\text{FORALL} \ (K=1: \text{SIZE}(B)) \ B(K)=\text{ARRAY}(S(1,K), S(2,K), \ldots, S(N,K))
\]
where $N$ has the value $\text{SIZE}(	ext{SHAPE}(\text{ARRAY}))$, then $B$ is sorted in ascending order; moreover, all of the columns of $S$ are distinct, that is, if $j \neq m$ then $\text{ALL}(S(:,j) \ . \text{EQ.} \ S(:,m))$ will be false. The sort is stable; if $j \leq m$ and $B(j) = B(m)$, then $\text{ARRAY}(S(1,j), S(2,j), \ldots, S(n,j))$ precedes $\text{ARRAY}(S(1,m), S(2,m), \ldots, S(n,m))$ in the array element ordering of $\text{ARRAY}$. The collating sequence for an array of type CHARACTER is that used by the Fortran intrinsic functions, namely ASCII.

Case (ii): The result of
\[
R = \text{GRADE}_\text{UP}(\text{ARRAY}, \text{DIM}=K) + \text{LBOUND}(\text{ARRAY}, \text{DIM}=K) - 1
\]
has the property that if one computes the array
\[
B(i_1, i_2, \ldots, i_j, \ldots, i_n) = \text{ARRAY}(i_1, i_2, \ldots, R(i_1, i_2, \ldots, i_j, \ldots, i_n), \ldots, i_n)
\]
then for all $i_1, i_2, \ldots, \text{omit } i_j, \ldots, i_n$, the vector $B(i_1, i_2, \ldots, \ldots, i_n)$ is sorted in ascending order; moreover, $R(i_1, i_2, \ldots, \ldots, i_n)$ is a permutation of all the integers between 1 and $\text{SIZE}(	ext{ARRAY}, \text{DIM}=K)$, inclusive. The sort is stable; that is, if $j \leq m$ and
\[
B(i_1, i_2, \ldots, j, \ldots, i_n) = B(i_1, i_2, \ldots, m, \ldots, i_n),
\]
then $R(i_1, i_2, \ldots, j, \ldots, i_n) \leq R(i_1, i_2, \ldots, m, \ldots, i_n)$. The collating sequence for an array of type CHARACTER is that used by the Fortran intrinsic functions, namely ASCII.

Examples.
Case (i): \( \text{GRADE\_UP}(\begin{bmatrix} 1 & 2 & 3 & 4 \\ 5 & 6 & 7 & 8 \end{bmatrix}) \) is a rank two array of shape \( \begin{bmatrix} 1 & 5 \\ 2 & 4 \end{bmatrix} \) with the value \( \begin{bmatrix} 5 & 2 & 1 & 3 \\ 4 & 3 & 2 & 1 \end{bmatrix} \). (To produce a rank-one result, the optional DIM = 1 argument must be used.)

If \( A \) is the array \( \begin{bmatrix} 1 & 9 & 2 \\ 4 & 5 & 2 \\ 1 & 2 & 4 \end{bmatrix} \),

then \( \text{GRADE\_UP}(A) \) has the value \( \begin{bmatrix} 1 & 3 & 3 & 1 & 2 & 2 & 3 & 2 & 1 \\ 1 & 1 & 2 & 3 & 3 & 1 & 3 & 2 & 2 \end{bmatrix} \).

Case (ii): If \( A \) is the array \( \begin{bmatrix} 1 & 9 & 2 \\ 4 & 5 & 2 \\ 1 & 2 & 4 \end{bmatrix} \),

then \( \text{GRADE\_UP}(A, \text{DIM} = 1) \) has the value \( \begin{bmatrix} 1 & 3 \\ 3 & 2 \\ 2 & 1 \end{bmatrix} \),

and \( \text{GRADE\_UP}(A, \text{DIM} = 2) \) has the value \( \begin{bmatrix} 1 & 3 & 2 \\ 3 & 1 & 2 \\ 1 & 2 & 3 \end{bmatrix} \).

**HPF\_ALIGNMENT(ALIGNEE, LB, UB, STRIDE, AXIS\_MAP, IDENTITY\_MAP, NCOPIES)**

**Optional Arguments.** LB, UB, STRIDE, AXIS\_MAP, IDENTITY\_MAP, NCOPIES

**Description.** Returns information regarding the correspondence of a variable and the align-target (array or template) to which it is ultimately aligned.

**Class.** Mapping inquiry subroutine.

**Arguments.**

**ALIGNEE** may be of any type. It may be scalar or array valued. It must not be an assumed-size array. If it is a member of an aggregate variable group, then it must be an aggregate cover of the group. (See Section 3.8 for the definitions of “aggregate variable group” and “aggregate cover.”) It must not be a pointer that is disassociated or an allocatable array that is not allocated. It is an INTENT (IN) argument.

If ALIGNEE is a pointer, information about the alignment of its target is returned. The target must not be an assumed-size dummy argument or a section of an assumed-size dummy argument.

**LB (optional)** must be of type default integer and of rank one. Its size must be at least equal to the rank of ALIGNEE. It is an INTENT (OUT) argument. The first element of the \( i \)th axis of ALIGNEE is ultimately aligned to the LB(\( i \))th
align-target element along the axis of the align-target associated with the \(i^{th}\) axis of ALIGNEE. If the \(i^{th}\) axis of ALIGNEE is a collapsed axis, \(LB(i)\) is implementation dependent.

**UB (optional)**

must be of type default integer and of rank one. Its size must be at least equal to the rank of ALIGNEE. It is an INTENT (OUT) argument. The last element of the \(i^{th}\) axis of ALIGNEE is ultimately aligned to the \(UB(i)^{th}\) align-target element along the axis of the align-target associated with the \(i^{th}\) axis of ALIGNEE. If the \(i^{th}\) axis of ALIGNEE is a collapsed axis, \(UB(i)\) is implementation dependent.

**STRIDE (optional)**

must be of type default integer and of rank one. Its size must be at least equal to the rank of ALIGNEE. It is an INTENT (OUT) argument. The \(i^{th}\) element of STRIDE is set to the stride used in aligning the elements of ALIGNEE along its \(i^{th}\) axis. If the \(i^{th}\) axis of ALIGNEE is a collapsed axis, STRIDE\((i)\) is zero.

**AXIS\_MAP (optional)**

must be of type default integer and of rank one. Its size must be at least equal to the rank of ALIGNEE. It is an INTENT (OUT) argument. The \(i^{th}\) element of AXIS\_MAP is set to the align-target axis associated with the \(i^{th}\) axis of ALIGNEE. If the \(i^{th}\) axis of ALIGNEE is a collapsed axis, AXIS\_MAP\((i)\) is 0.

**IDENTITY\_MAP (optional)**

must be scalar and of type default logical. It is an INTENT (OUT) argument. It is set to true if the ultimate align-target associated with ALIGNEE has a shape identical to ALIGNEE, the axes are mapped using the identity permutation, and the strides are all positive (and therefore equal to 1, because of the shape constraint); otherwise it is set to false. If a variable has not appeared as an alignee in an ALIGN or REALIGN directive, and does not have the INHERIT attribute, then IDENTITY\_MAP must be true; it can be true in other circumstances as well.

**NCOPIES (optional)**

must be scalar and of type default integer. It is an INTENT (OUT) argument. It is set to the number of copies of ALIGNEE that are ultimately aligned to align-target. For a non-replicated variable, it is set to one.

**Examples.** If ALIGNEE is scalar, then no elements of LB, UB, STRIDE, or AXIS\_MAP are set.

Given the declarations

```plaintext
REAL PI = 3.1415927
DIMENSION A(10,10),B(20,30),C(20,40,10),D(40)
!HPF$ TEMPLATE T(40,20)
```
assuming that the actual mappings are as the directives specify, the results of calling HPF_ALIGNMENT are:

\[
\begin{array}{cccc}
A & B & C & D \\
AXIS_MAP & [1, 2] & [1, 2] & [2, 0, 1] & [1] \\
IDENTITY_MAP & false & true & false & false \\
NCOPIES & 1 & 1 & 1 & 1
\end{array}
\]

where “N/A” denotes a implementation-dependent result. To illustrate the use of NCOPIES, consider:

```plaintext
LOGICAL BOZO(20,20), RONALD_MCDONALD(20)

!HPF$ TEMPLATE EMMETT_KELLY(100,100)

!HPF$ ALIGN RONALD_MCDONALD(I) WITH BOZO(I,*)

!HPF$ ALIGN BOZO(J,K) WITH EMMETT_KELLY(J,5*K)

CALL HPF_ALIGNMENT(RONALD_MCDONALD, NCOPIES = NC) sets NC to 20. Now consider:

LOGICAL BOZO(20,20), RONALD_MCDONALD(20)

!HPF$ TEMPLATE WILLIE_WHISTLE(100)

!HPF$ ALIGN RONALD_MCDONALD(I) WITH BOZO(I,*)

!HPF$ ALIGN BOZO(J,*) WITH WILLIE_WHISTLE(5*J)

CALL HPF_ALIGNMENT(RONALD_MCDONALD, NCOPIES = NC) sets NC to one.
```

**HPF_DISTRIBUTION**(DISTRIBUTEE, AXIS_TYPE, AXIS_INFO, PROCESSORS_RANK, PROCESSORS_SHAPE)

**Optional Arguments.** AXIS_TYPE, AXIS_INFO, PROCESSORS_RANK, PROCESSORS_SHAPE

**Description.** The HPF_DISTRIBUTION subroutine returns information regarding the distribution of the ultimate align-target associated with a variable.

**Class.** Mapping inquiry subroutine.

**Arguments.**

**DISTRIBUTEE** may be of any type. It may be scalar or array valued. It must not be an assumed-size array. If it is a member of an aggregate variable group, then it must be an aggregate...
cover of the group. (See Section 3.8 for the definitions of “aggregate variable group” and “aggregate cover.”) It must not be a pointer that is disassociated or an allocatable array that is not allocated. It is an INTENT (IN) argument.

If DISTRIBUTEE is a pointer, information about the distribution of its target is returned. The target must not be an assumed-size dummy argument or a section of an assumed-size dummy argument.

**AXIS_TYPE** (optional) must be a rank one array of type default character. It may be of any length, although it must be of length at least 9 in order to contain the complete value. Its elements are set to the values below as if by a character intrinsic assignment statement. Its size must be at least equal to the rank of the align-target to which DISTRIBUTEE is ultimately aligned; this is the value returned by HPF TEMPLATE in TEMPLATE_RANK. It is an INTENT (OUT) argument. Its i
\textsuperscript{th} element contains information on the distribution of the i
\textsuperscript{th} axis of that align-target. The following values are defined by HPF (implementations may define other values):

- `'BLOCK'` The axis is distributed BLOCK. The corresponding element of AXIS_INFO contains the block size.
- `'COLLAPSED'` The axis is collapsed (distributed with the "*" specification). The value of the corresponding element of AXIS_INFO is implementation dependent.
- `'CYCLIC'` The axis is distributed CYCLIC. The corresponding element of AXIS_INFO contains the block size.

**AXIS_INFO** (optional) must be a rank one array of type default integer, and size at least equal to the rank of the align-target to which DISTRIBUTEE is ultimately aligned (which is returned by HPF TEMPLATE in TEMPLATE_RANK). It is an INTENT (OUT) argument. The i
\textsuperscript{th} element of AXIS_INFO contains the block size in the block or cyclic distribution of the i
\textsuperscript{th} axis of the ultimate align-target of DISTRIBUTEE; if that axis is a collapsed axis, then the value is implementation dependent.

**PROCESSORS_RANK** (optional) must be scalar and of type default integer. It is set to the rank of the processor arrangement onto which DISTRIBUTEE is distributed. It is an INTENT (OUT) argument.

**PROCESSORS_SHAPE** (optional) must be a rank one array of type default integer and of size at least equal to the value, m, returned in PROCESSORS_RANK. It is an INTENT (OUT) argument. Its first m
elements are set to the shape of the processor arrangement onto which DISTRIBUTEE is mapped. (It may be necessary to call HPF\_DISTRIBUTION twice, the first time to obtain the value of PROCESSORS\_RANK in order to allocate PROCESSORS\_SHAPE.)

**Example.** Given the declarations in the example illustrating HPF\_ALIGNMENT, and assuming that the actual mappings are as the directives specify, the results of HPF\_DISTRIBUTION are:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>AXIS_TYPE</td>
<td>['BLOCK', 'BLOCK']</td>
<td>['CYCLIC', 'BLOCK']</td>
</tr>
<tr>
<td>AXIS_INFO</td>
<td>[10, 10]</td>
<td>[1, 15]</td>
</tr>
<tr>
<td>PROCESSORS_SHAPE</td>
<td>[4, 2]</td>
<td>[2, 2]</td>
</tr>
<tr>
<td>PROCESSORS_RANK</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**HPF\_TEMPLATE(ALIGNEE, TEMPLATE\_RANK, LB, UB, AXIS\_TYPE, AXIS\_INFO, NUMBER\_ALIGNED)**

**Optional Arguments.** LB, UB, AXIS\_TYPE, AXIS\_INFO, NUMBER\_ALIGNED, TEMPLATE\_RANK

**Description.** The HPF\_TEMPLATE subroutine returns information regarding the ultimate align-target associated with a variable; HPF\_TEMPLATE returns information concerning the variable from the point of view of its ultimate align-target, while HPF\_ALIGNMENT returns information from the variable's point of view.

**Class.** Mapping inquiry subroutine.

**Arguments.**

**ALIGNEE** may be of any type. It may be scalar or array valued. It must not be an assumed-size array. If it is a member of an aggregate variable group, then it must be an aggregate cover of the group. (See Section 3.8 for the definitions of “aggregate variable group” and “aggregate cover.”) It must not be a pointer that is disassociated or an allocatable array that is not allocated. It is an INTENT (IN) argument.

If ALIGNEE is a pointer, information about the alignment of its target is returned. The target must not be an assumed-size dummy argument or a section of an assumed-size dummy argument.

**TEMPLATE\_RANK** (optional) must be scalar and of type default integer. It is an INTENT (OUT) argument. It is set to the rank of the ultimate align-target. This can be different from the rank of the ALIGNEE, due to collapsing and replicating.
LB (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of the align-target to which ALIGNEE is ultimately aligned; this is the value returned in TEMPLATE_RANK. It is an INTENT (OUT) argument. The \( i \)th element of LB contains the declared align-target lower bound for the \( i \)th template axis.

UB (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of the align-target to which ALIGNEE is ultimately aligned; this is the value returned in TEMPLATE_RANK. It is an INTENT (OUT) argument. The \( i \)th element of UB contains the declared align-target upper bound for the \( i \)th template axis.

AXIS_TYPE (optional) must be a rank one array of type default character. It may be of any length, although it must be of length at least 10 in order to contain the complete value. Its elements are set to the values below as if by a character intrinsic assignment statement. Its size must be at least equal to the rank of the align-target to which ALIGNEE is ultimately aligned; this is the value returned in TEMPLATE_RANK. It is an INTENT (OUT) argument. The \( i \)th element of AXIS_TYPE contains information about the \( i \)th axis of the align-target. The following values are defined by HPF (implementations may define other values):

'NORMAL' The align-target axis has an axis of ALIGNEE aligned to it. For elements of AXIS_TYPE assigned this value, the corresponding element of AXIS_INFO is set to the number of the axis of ALIGNEE aligned to this align-target axis.

'REPLICATED' ALIGNEE is replicated along this align-target axis. For elements of AXIS_TYPE assigned this value, the corresponding element of AXIS_INFO is set to the number of copies of ALIGNEE along this align-target axis.

'SINGLE' ALIGNEE is aligned with one coordinate of the align-target axis. For elements of AXIS_TYPE assigned this value, the corresponding element of AXIS_INFO is set to the align-target coordinate to which ALIGNEE is aligned.

AXIS_INFO (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of the align-target to which ALIGNEE is ultimately aligned; this is the value returned in TEMPLATE_RANK. It is an INTENT (OUT) argument. See the description of AXIS_TYPE above.

NUMBER_ALIGNED (optional) must be scalar and of type default integer. It is an INTENT (OUT) argument. It is set to the total number
of variables aligned to the ultimate align-target. This is the number of variables that are moved if the align-target is redistributed.

Example. Given the declarations in the example illustrating HPF_ALIGNMENT, and assuming that the actual mappings are as the directives specify, the results of HPF_TEMPLATE are:

<table>
<thead>
<tr>
<th>LB</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1,1]</td>
<td>[1,1]</td>
<td>[1,1]</td>
</tr>
<tr>
<td>[40, 20]</td>
<td>[40, 20]</td>
<td>[40, 20]</td>
</tr>
<tr>
<td>AXIS_TYPE</td>
<td>['NORMAL', 'NORMAL', 'NORMAL', 'NORMAL', 'NORMAL']</td>
<td></td>
</tr>
<tr>
<td>AXIS_INFO</td>
<td>[1, 2]</td>
<td>[3, 1]</td>
</tr>
<tr>
<td>NUMBER_ALIGNED</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>TEMPLATE_RANK</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

IALL(ARRAY, DIM, MASK)

Optional Arguments. DIM, MASK

Description. Computes a bitwise logical AND reduction along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of ARRAY. The corresponding actual argument must not be an optional dummy argument.

MASK (optional) must be of type logical and must be conformable with ARRAY.

Result Type, Type Parameter, and Shape. The result is of type integer with the same kind type parameter as ARRAY. It is scalar if DIM is absent or if ARRAY has rank one; otherwise, the result is an array of rank $n - 1$ and shape $(d_1, d_2, \ldots, d_{DIM-1}, d_{DIM+1}, \ldots, d_n)$ where $(d_1, d_2, \ldots, d_n)$ is the shape of ARRAY.

Result Value.

Case (i): The result of IALL(ARRAY) is the IAND reduction of all the elements of ARRAY. If ARRAY has size zero, the result is equal to a implementation-dependent integer value $x$ with the property that IAND(I, x) = I for all integers I of the same kind type parameter as ARRAY. See Section 7.4.3.
Case (ii): The result of `IALL(ARRAY, MASK=MASK)` is the `IAND` reduction of all the elements of `ARRAY` corresponding to the true elements of `MASK`; if `MASK` contains no true elements, the result is equal to a implementation-dependent integer value `x` (of the same kind type parameter as `ARRAY`) with the property that `IAND(I, x) = I` for all integers `I`.

Case (iii): If `ARRAY` has rank one, `IALL(ARRAY, DIM [,MASK])` has a value equal to that of `IALL(ARRAY [,MASK])`. Otherwise, the value of element 

\[
(s_1, s_2, \ldots, s_{DIM-1}, s_{DIM+1}, \ldots, s_n)
\]

of `IALL(ARRAY, DIM [,MASK])` is equal to `IALL(ARRAY(s_1, s_2, \ldots, s_{DIM-1}, :, s_{DIM+1}, \ldots, s_n) [,MASK = MASK(s_1, s_2, \ldots, s_{DIM-1}, :, s_{DIM+1}, \ldots, s_n)])`

Examples.

Case (i): The value of `IALL((/7, 6, 3, 2/))` is 2.

Case (ii): The value of `IALL(C, MASK = BTEST(C, 0))` is the `IAND` reduction of the odd elements of `C`.

Case (iii): If `B` is the array 

\[
\begin{bmatrix}
2 & 3 & 5 \\
3 & 7 & 7
\end{bmatrix}
\]

then `IALL(B, DIM = 1)` is 

\[
\begin{bmatrix}
2 & 3 & 5
\end{bmatrix}
\]

and `IALL(B, DIM = 2)` is 

\[
\begin{bmatrix}
0 & 3
\end{bmatrix}
\]

`IALL_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)`

Optional Arguments. `DIM, MASK, SEGMENT, EXCLUSIVE`

Description. Computes a segmented bitwise logical AND scan along dimension `DIM` of `ARRAY`.

Class. Transformational function.

Arguments.

`ARRAY` must be of type integer. It must not be scalar.

`DIM` (optional) must be scalar and of type integer with a value in the range `1 \leq DIM \leq n`, where `n` is the rank of `ARRAY`.

`MASK` (optional) must be of type logical and must be conformable with `ARRAY`.

`SEGMENT` (optional) must be of type logical and must have the same shape as `ARRAY`.

`EXCLUSIVE` (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as `ARRAY`.

Result Value. Element `r` of the result has the value `IALL(/(a_1, \ldots, a_m/))` where `(a_1, \ldots, a_m)` is the (possibly empty) set of elements of `ARRAY` selected to contribute to `r` by the rules stated in Section 7.4.5.

Example. `IALL_PREFIX( (/1,3,2,4,5/), SEGMENT= (/F,F,F,T,T/) )` is 

\[
\begin{bmatrix}
1 & 1 & 0 & 4 & 4
\end{bmatrix}
\]
IALL_SCATTER(ARRAY,BASE,INDX1, ..., INDXn, MASK)

Optional Argument. MASK

Description. Scatters elements of ARRAY selected by MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. The jth bit of an element of the result is 1 if and only if the jth bits of the corresponding element of BASE and of the elements of ARRAY scattered to that position are all equal to 1.

Class. Transformational function.

Arguments.

ARRAY must be of type integer. It must not be scalar.

BASE must be of type integer with the same kind type parameter as ARRAY. It must not be scalar.

INDX1, ..., INDXn must be of type integer and conformable with ARRAY. The number of INDX arguments must be equal to the rank of BASE.

MASK (optional) must be of type logical and must be conformable with ARRAY.

Result Type, Type Parameter, and Shape. Same as BASE.

Result Value. The element of the result corresponding to the element b of BASE has the value IALL((a1, a2, ..., am, b)), where (a1, ..., am) are the elements of ARRAY associated with b as described in Section 7.4.4.

Example. IALL_SCATTER((/1, 2, 3, 6/), (/1, 3, 7/), (/1, 1, 2, 2/)) is [0 2 7].

IALL_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a reverse, segmented bitwise logical AND scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range 1 ≤ DIM ≤ n, where n is the rank of ARRAY.

MASK (optional) must be of type logical and must be conformable with ARRAY.
#### SEGMENT (optional)

must be of type logical and must have the same shape as ARRAY.

#### EXCLUSIVE (optional)

must be of type logical and must be scalar.

**Result Type, Type Parameter, and Shape.** Same as ARRAY.

**Result Value.** Element \( r \) of the result has the value \( \text{IALL}((/ a_1, \ldots, a_m /)) \) where \( (a_1, \ldots, a_m) \) is the (possibly empty) set of elements of ARRAY selected to contribute to \( r \) by the rules stated in Section 7.4.5.

**Example.** \( \text{IALL\_SUFFIX}( (/1,3,2,4,5/), \text{SEGMENT} = (/F,F,F,T,T/) ) \) is \[
\begin{bmatrix}
0 & 2 & 2 & 4 & 5
\end{bmatrix}.
\]

### IANY(ARRAY, DIM, MASK)

**Optional Arguments.** DIM, MASK

**Description.** Computes a bitwise logical OR reduction along dimension DIM of ARRAY.

**Class.** Transformational function.

**Arguments.**

- **ARRAY** must be of type integer. It must not be scalar.
- **DIM (optional)** must be scalar and of type integer with a value in the range \( 1 \leq \text{DIM} \leq n \), where \( n \) is the rank of ARRAY. The corresponding actual argument must not be an optional dummy argument.
- **MASK (optional)** must be of type logical and must be conformable with ARRAY.

**Result Type, Type Parameter, and Shape.** The result is of type integer with the same kind type parameter as ARRAY. It is scalar if DIM is absent or if ARRAY has rank one; otherwise, the result is an array of rank \( n - 1 \) and shape \((d_1, d_2, \ldots, d_{\text{DIM}-1}, d_{\text{DIM}+1}, \ldots, d_n)\) where \((d_1, d_2, \ldots, d_n)\) is the shape of ARRAY.

**Result Value.**

**Case (i):** The result of IANY(ARRAY) is the IOR reduction of all the elements of ARRAY. If ARRAY has size zero, the result has the value zero. See Section 7.4.3.

**Case (ii):** The result of IANY(ARRAY, MASK=MASK) is the IOR reduction of all the elements of ARRAY corresponding to the true elements of MASK; if MASK contains no true elements, the result is zero.

**Case (iii):** If ARRAY has rank one, IANY(ARRAY, DIM [,MASK]) has a value equal to that of IANY(ARRAY [,MASK]). Otherwise, the value of element \((s_1, s_2, \ldots, s_{\text{DIM}-1}, s_{\text{DIM}+1}, \ldots, s_n)\) of IANY(ARRAY, DIM [,MASK]) is equal to IANY(ARRAY \((s_1, s_2, \ldots, s_{\text{DIM}-1}, s_{\text{DIM}+1}, \ldots, s_n)\) [,MASK = MASK \((s_1, s_2, \ldots, s_{\text{DIM}-1}, s_{\text{DIM}+1}, \ldots, s_n)\)])
Examples.

Case (i): The value of IANY((9, 8, 3, 2)) is 11.

Case (ii): The value of IANY(C, MASK = BTEST(C, 0)) is the IOR reduction of the odd elements of C.

Case (iii): If B is the array $[2 \ 3 \ 5 \\ 0 \ 4 \ 2]$, then IANY(B, DIM = 1) is $[2 \ 7 \ 7]$ and IANY(B, DIM = 2) is $[7 \ 6]$.

IANY_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a segmented bitwise logical OR scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of ARRAY.

MASK (optional) must be of type logical and must be conformable with ARRAY.

SEGMENT (optional) must be of type logical and must have the same shape as ARRAY.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element $r$ of the result has the value IANY($(a_1, \ldots, a_m)$) where $(a_1, \ldots, a_m)$ is the (possibly empty) set of elements of ARRAY selected to contribute to $r$ by the rules stated in Section 7.4.5.

Example. IANY_PREFIX((1, 2, 3, 2, 5), SEGMENT= (F,F,F,T,T)) is $[1 \ 3 \ 3 \ 2 \ 7]$.

IANY_SCATTER(ARRAY,BASE,INDX1, ..., INDXn, MASK)

Optional Argument. MASK

Description. Scatters elements of ARRAY selected by MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. The $j$th bit of an element of the result is 1 if and only if the $j$th bit of the corresponding element of BASE or of any of the elements of ARRAY scattered to that position is equal to 1.
Class. Transformational function.

Arguments.

ARRAY must be of type integer. It must not be scalar.
BASE must be of type integer with the same kind type parameter as ARRAY. It must not be scalar.
INDX1,...,INDXn must be of type integer and conformable with ARRAY. The number of INDX arguments must be equal to the rank of BASE.
MASK (optional) must be of type logical and must be conformable with ARRAY.

Result Type, Type Parameter, and Shape. Same as BASE.

Result Value. The element of the result corresponding to the element $b$ of BASE has the value $\text{IANY}( (a_1, a_2,..., a_m, b/ ) )$, where $(a_1,..., a_m)$ are the elements of ARRAY associated with $b$ as described in Section 7.4.4.

Example. \text{IANY\_SCATTER}((/1, 2, 3, 6/), (/1, 3, 7/), (/1, 1, 2, 2/)) is \begin{array}{c} 3 \ 7 \ 7 \ 0 \ 3 \end{array}.

\text{IANY\_SUFFIX}(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a reverse, segmented bitwise logical OR scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer. It must not be scalar.
DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of ARRAY.
MASK (optional) must be of type logical and must be conformable with ARRAY.
SEGMENT (optional) must be of type logical and must have the same shape as ARRAY.
EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element $r$ of the result has the value \text{IANY}((/ a_1, ..., a_m /)) where $(a_1,..., a_m)$ is the (possibly empty) set of elements of ARRAY selected to contribute to $r$ by the rules stated in Section 7.4.5.

Example. \text{IANY\_SUFFIX}((/4,2,3,2,5/), SEGMENT= (/F,F,F,T,T/)) is \begin{array}{c} 7 \ 3 \ 3 \ 7 \ 5 \end{array}. 
IPARITY(ARRAY, DIM, MASK)

Optional Arguments. DIM, MASK

Description. Computes a bitwise logical exclusive OR reduction along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of ARRAY. The corresponding actual argument must not be an optional dummy argument.

MASK (optional) must be of type logical and must be conformable with ARRAY.

Result Type, Type Parameter, and Shape. The result is of type integer with the same kind type parameter as ARRAY. It is scalar if DIM is absent or if ARRAY has rank one; otherwise, the result is an array of rank $n - 1$ and shape $(d_1, d_2, \ldots, d_{\text{DIM}-1}, d_{\text{DIM}+1}, \ldots, d_n)$ where $(d_1, d_2, \ldots, d_n)$ is the shape of ARRAY.

Result Value.

Case (i): The result of IPARITY(ARRAY) is the IEOR reduction of all the elements of ARRAY. If ARRAY has size zero, the result has the value zero. See Section 7.4.3.

Case (ii): The result of IPARITY(ARRAY, MASK = MASK) is the IEOR reduction of all the elements of ARRAY corresponding to the true elements of MASK; if MASK contains no true elements, the result is zero.

Case (iii): If ARRAY has rank one, IPARITY(ARRAY, DIM [,MASK]) has a value equal to that of IPARITY(ARRAY [,MASK]). Otherwise, the value of element $(s_1, s_2, \ldots, s_{\text{DIM}-1}, s_{\text{DIM}+1}, \ldots, s_n)$ of IPARITY(ARRAY, DIM [,MASK]) is equal to IPARITY(ARRAY$(s_1, s_2, \ldots, s_{\text{DIM}-1}, \ldots, s_{\text{DIM}+1}, \ldots, s_n)$ [,MASK = MASK$(s_1, s_2, \ldots, s_{\text{DIM}-1}, \ldots, s_{\text{DIM}+1}, \ldots, s_n)$])

Examples.

Case (i): The value of IPARITY([/13, 8, 3, 2/]) is 4.

Case (ii): The value of IPARITY(C, MASK = BTEST(C, 0)) is the IEOR reduction of the odd elements of C.

Case (iii): If B is the array \[
\begin{bmatrix}
2 & 3 & 7 \\
0 & 4 & 2
\end{bmatrix},
\]
then IPARITY(B, DIM = 1) is \[
\begin{bmatrix}
2 & 7 & 5
\end{bmatrix}
\]
and IPARITY(B, DIM = 2) is \[
\begin{bmatrix}
6 & 6
\end{bmatrix}.
\]
IPARITY_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a segmented bitwise logical exclusive OR scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range $1 \leq DIM \leq n$, where $n$ is the rank of ARRAY.

MASK (optional) must be of type logical and must be conformable with ARRAY.

SEGMENT (optional) must be of type logical and must have the same shape as ARRAY.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element $r$ of the result has the value $\text{IPARITY}((/ a_1, \ldots, a_m /))$ where $(a_1, \ldots, a_m)$ is the (possibly empty) set of elements of ARRAY selected to contribute to $r$ by the rules stated in Section 7.4.5.

Example. $\text{IPARITY}_\text{PREFIX}( (/1,2,3,4,5/), \text{SEGMENT}= (/F,F,F,T,T/) )$ is $[ 1 3 0 4 1 ]$.

IPARITY_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)

Optional Argument. MASK

Description. Scatters elements of ARRAY selected by MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. The $j^{th}$ bit of an element of the result is 1 if and only if there are an odd number of ones among the $j^{th}$ bits of the corresponding element of BASE and the elements of ARRAY scattered to that position.

Class. Transformational function.

Arguments.

ARRAY must be of type integer. It must not be scalar.

BASE must be of type integer with the same kind type parameter as ARRAY. It must not be scalar.

INDX1, ..., INDXn must be of type integer and conformable with ARRAY. The number of INDX arguments must be equal to the rank of BASE.
MASK (optional) must be of type logical and must be conformable with ARRAY.

Result Type, Type Parameter, and Shape. Same as BASE.

Result Value. The element of the result corresponding to the element \( b \) of BASE has the value \( \text{IPARITY}(\langle a_1, a_2, \ldots, a_m, b \rangle) \), where \( (a_1, \ldots, a_m) \) are the elements of ARRAY associated with \( b \) as described in Section 7.4.4.

Example. \( \text{IPARITY\_SCATTER}(\langle /1,2,3,6/\rangle, \langle /1,3,7/\rangle, \langle /1,1,2,2/\rangle) \) is \[ \begin{array}{c} 2 \ 6 \ 7 \end{array} \].

**IPARITY\_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)**

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a reverse, segmented bitwise logical exclusive OR scan along dimension \( \text{DIM} \) of ARRAY.

Class. Transformational function.

Arguments.

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARRAY</td>
<td>must be of type integer. It must not be scalar.</td>
</tr>
<tr>
<td>DIM (optional)</td>
<td>must be scalar and of type integer with a value in the range ( 1 \leq \text{DIM} \leq n ), where ( n ) is the rank of ARRAY.</td>
</tr>
<tr>
<td>MASK (optional)</td>
<td>must be of type logical and must be conformable with ARRAY.</td>
</tr>
<tr>
<td>SEGMENT (optional)</td>
<td>must be of type logical and must have the same shape as ARRAY.</td>
</tr>
<tr>
<td>EXCLUSIVE (optional)</td>
<td>must be of type logical and must be scalar.</td>
</tr>
</tbody>
</table>

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element \( r \) of the result has the value \( \text{IPARITY}(\langle a_1, \ldots, a_m \rangle) \) where \( (a_1, \ldots, a_m) \) is the (possibly empty) set of elements of ARRAY selected to contribute to \( r \) by the rules stated in Section 7.4.5.

Example. \( \text{IPARITY\_SUFFIX}(\langle /1,2,3,4,5/\rangle, \text{SEGMENT=} \langle /F,F,F,T,T/\rangle) \) is \[ \begin{array}{c} 0 \ 1 \ 3 \ 1 \ 5 \end{array} \].

**LEADZ(I)**

Description. Return the number of leading zeros in an integer.

Class. Elemental function.

Argument. I must be of type integer.
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**Result Type and Type Parameter.** Same as I.

**Result Value.** The result is a count of the number of leading 0-bits in the integer I. The model for the interpretation of an integer as a sequence of bits is in Section F95:13.5.7 LEADZ(0) is BIT_SIZE(I). For nonzero I, if the leftmost one bit of I occurs in position $k - 1$ (where the rightmost bit is bit 0) then LEADZ(I) is BIT_SIZE(I) - k.

**Examples.** LEADZ(3) has the value BIT_SIZE(3) - 2. For scalar I, LEADZ(I) .EQ. MINVAL((/ (J, J=0, BIT_SIZE(I) ) /), MASK=M ) where M =(/ (BTEST(I,J), J=BIT_SIZE(I)-1, 0, -1), .TRUE. /). A given integer I may produce different results from LEADZ(I), depending on the number of bits in the representation of the integer (BIT_SIZE(I)). That is because LEADZ counts bits from the most significant bit. Compare with ILEN.

**MAXVAL_PREFIX**(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

**Optional Arguments.** DIM, MASK, SEGMENT, EXCLUSIVE

**Description.** Computes a segmented MAXVAL scan along dimension DIM of ARRAY.

**Class.** Transformational function.

**Arguments.**

ARRAY must be of type integer or real. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of ARRAY.

MASK (optional) must be of type logical and must be conformable with ARRAY.

SEGMENT (optional) must be of type logical and must have the same shape as ARRAY.

EXCLUSIVE (optional) must be of type logical and must be scalar.

**Result Type, Type Parameter, and Shape.** Same as ARRAY.

**Result Value.** Element $r$ of the result has the value MAXVAL((/ $a_1, \ldots, a_m$ /)) where $(a_1, \ldots, a_m)$ is the (possibly empty) set of elements of ARRAY selected to contribute to $r$ by the rules stated in Section 7.4.5.

**Example.** MAXVAL_PREFIX((/3,4,-5,2,5/), SEGMENT=(/F,F,F,T,T/)) is

\[
\begin{bmatrix}
3 & 4 & 4 & 2 & 5
\end{bmatrix}
\]
MAXVAL_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)

Optional Argument. MASK

Description. Scatters elements of ARRAY selected by MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. Each element of the result is assigned the maximum value of the corresponding element of BASE and the elements of ARRAY scattered to that position.

Class. Transformational function.

Arguments.

ARRAY must be of type integer or real. It must not be scalar.

BASE must be of the same type and kind type parameter as ARRAY. It must not be scalar.

INDX1, ..., INDXn must be of type integer and conformable with ARRAY. The number of INDX arguments must be equal to the rank of BASE.

MASK (optional) must be of type logical and must be conformable with ARRAY.

Result Type, Type Parameter, and Shape. Same as BASE.

Result Value. The element of the result corresponding to the element b of BASE has the value MAXVAL( (a1, a2, ..., am, b) ), where (a1, ..., am) are the elements of ARRAY associated with b as described in Section 7.4.4.

Example. MAXVAL_SCATTER((/1, 2, 3, 1/), (/4, -5, 7/), (/1, 1, 2, 2/)) is [ 4 3 7 ].

MAXVAL_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a reverse, segmented MAXVAL scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer or real. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range 1 ≤ DIM ≤ n, where n is the rank of ARRAY.

MASK (optional) must be of type logical and must be conformable with ARRAY.
SEGMENT (optional) must be of type logical and must have the same shape as ARRAY.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element \( r \) of the result has the value \( \text{MAXVAL}(\{a_1, \ldots, a_m\}) \) where \( \{a_1, \ldots, a_m\} \) is the (possibly empty) set of elements of ARRAY selected to contribute to \( r \) by the rules stated in Section 7.4.5.

Example. \( \text{MAXVAL\_SUFFIX}(\{3, 4, -5, 2, 5\}, \text{SEGMENT}=\{F, F, F, T, T\}) \) is \[ \begin{bmatrix} 4 & 4 & -5 & 5 & 5 \end{bmatrix}. \]

MINVAL\_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a segmented MINVAL scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer or real. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range \( 1 \leq \text{DIM} \leq n \), where \( n \) is the rank of ARRAY.

MASK (optional) must be of type logical and must be conformable with ARRAY.

SEGMENT (optional) must be of type logical and must have the same shape as ARRAY.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element \( r \) of the result has the value \( \text{MINVAL}(\{a_1, \ldots, a_m\}) \) where \( \{a_1, \ldots, a_m\} \) is the (possibly empty) set of elements of ARRAY selected to contribute to \( r \) by the rules stated in Section 7.4.5.

Example. \( \text{MINVAL\_PREFIX}(\{1, 2, -3, 4, 5\}, \text{SEGMENT}=\{F, F, F, T, T\}) \) is \[ \begin{bmatrix} 1 & 1 & -3 & 4 & 4 \end{bmatrix}. \]

MINVAL\_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)

Optional Argument. MASK

Description. Scatters elements of ARRAY selected by MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. Each element of the result is assigned the minimum value of the corresponding element of BASE and the elements of ARRAY scattered to that position.
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Class. Transformational function.

Arguments.

ARRAY must be of type integer or real. It must not be scalar.

BASE must be of the same type and kind type parameter as ARRAY. It must not be scalar.

INDX1, ..., INDXn must be of type integer and conformable with ARRAY. The number of INDX arguments must be equal to the rank of BASE.

MASK (optional) must be of type logical and must be conformable with ARRAY.

Result Type, Type Parameter, and Shape. Same as BASE.

Result Value. The element of the result corresponding to the element b of BASE has the value MINVAL( (/a1, a2, ..., am, b/) ), where (a1, ..., am) are the elements of ARRAY associated with b as described in Section 7.4.4.

Example. MINVAL_SCATTER((/ 1, -2, -3, 6 /), (/ 4, 3, 7 /), (/ 1, 1, 2, 2 /)) is 

\[
\begin{pmatrix}
-2 & -3 & 7
\end{pmatrix}
\]

MINVAL_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a reverse, segmented MINVAL scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer or real. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range 1 ≤ DIM ≤ n, where n is the rank of ARRAY.

MASK (optional) must be of type logical and must be conformable with ARRAY.

SEGMENT (optional) must be of type logical and must have the same shape as ARRAY.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element r of the result has the value MINVAL((/ a1, ..., am /)) where (a1, ..., am) is the (possibly empty) set of elements of ARRAY selected to contribute to r by the rules stated in Section 7.4.5.

Example. MINVAL_SUFFIX((/ 1, 2, -3, 4, 5 /), SEGMENT= (/F, F, F, T, T/)) is 

\[
\begin{pmatrix}
-3 & -3 & 4 & 5
\end{pmatrix}
\]
PARITY(MASK, DIM)

Optional Argument. DIM

Description. Determine whether an odd number of values are true in MASK along dimension DIM.

Class. Transformational function.

Arguments.

MASK must be of type logical. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of MASK. The corresponding actual argument must not be an optional dummy argument.

Result Type, Type Parameter, and Shape. The result is of type logical with the same kind type parameter as MASK. It is scalar if DIM is absent or if MASK has rank one; otherwise, the result is an array of rank $n - 1$ and shape $(d_1, d_2, \ldots, d_{\text{DIM}-1}, d_{\text{DIM}+1}, \ldots, d_n)$ where $(d_1, d_2, \ldots, d_n)$ is the shape of MASK.

Result Value.

Case (i): The result of PARITY(MASK) is the .NEQV. reduction of all the elements of MASK. If MASK has size zero, the result has the value false. See Section 7.4.3.

Case (ii): If MASK has rank one, PARITY(MASK, DIM) has a value equal to that of PARITY(MASK). Otherwise, the value of element $(s_1, s_2, \ldots, s_{\text{DIM}-1}, s_{\text{DIM}+1}, \ldots, s_n)$ of PARITY(MASK, DIM) is equal to PARITY(MASK($s_1, s_2, \ldots, s_{\text{DIM}-1}, s_{\text{DIM}+1}, \ldots, s_n$))

Examples.

Case (i): The value of PARITY((/T, T, T, F/)) is true.

Case (ii): If B is the array $\begin{bmatrix} T & T & F \\ T & T & T \end{bmatrix}$, then PARITY(B, DIM = 1) is $\begin{bmatrix} F & F & T \end{bmatrix}$ and PARITY(B, DIM = 2) is $\begin{bmatrix} F & T \end{bmatrix}$.

PARITY_PREFIX(MASK, DIM, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, SEGMENT, EXCLUSIVE

Description. Computes a segmented logical exclusive OR scan along dimension DIM of MASK.

Class. Transformational function.

Arguments.
MASK        must be of type logical. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of MASK.

SEGMENT (optional) must be of type logical and must have the same shape as MASK.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as MASK.

Result Value. Element $r$ of the result has the value $\text{PARITY}(\langle a_1, \ldots, a_m \rangle)$ where $(a_1, \ldots, a_m)$ is the (possibly empty) set of elements of MASK selected to contribute to $r$ by the rules stated in Section 7.4.5.

Example. $\text{PARITY}_\text{PREFIX}(\langle T,F,T,T,T \rangle, \text{SEGMENT}=\langle F,F,F,T,T \rangle)$ is $[T \ T \ F \ T \ F]$.

PARITY\_SCATTER(MASK,BASE,INDX1, ..., INDXn)

Description. Scatters elements of MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. An element of the result is true if and only if the number of true values among the corresponding element of BASE and the elements of MASK scattered to that position is odd.

Class. Transformational function.

Arguments.

MASK    must be of type logical. It must not be scalar.

BASE    must be of type logical with the same kind type parameter as MASK. It must not be scalar.

INDX1, ..., INDXn must be of type integer and conformable with MASK. The number of INDX arguments must be equal to the rank of BASE.

Result Type, Type Parameter, and Shape. Same as BASE.

Result Value. The element of the result corresponding to the element $b$ of BASE has the value $\text{PARITY}(\langle a_1, a_2, \ldots, a_m, b \rangle)$, where $(a_1, \ldots, a_m)$ are the elements of MASK associated with $b$ as described in Section 7.4.4.

Example. $\text{PARITY\_SCATTER}(\langle T,T,T,T \rangle, \langle T,F,F \rangle, \langle 1,1,1,2 \rangle)$ is $[F \ T \ F]$. 
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**PARITY SUFFIX(MASK, DIM, SEGMENT, EXCLUSIVE)**

**Optional Arguments.** DIM, SEGMENT, EXCLUSIVE

**Description.** Computes a reverse, segmented logical exclusive OR scan along dimension DIM of MASK.

**Class.** Transformational function.

**Arguments.**

- **MASK**
  - must be of type logical. It must not be scalar.

- **DIM** (optional)
  - must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of MASK.

- **SEGMENT** (optional)
  - must be of type logical and must have the same shape as MASK.

- **EXCLUSIVE** (optional)
  - must be of type logical and must be scalar.

**Result Type, Type Parameter, and Shape.** Same as MASK.

**Result Value.** Element $r$ of the result has the value $\text{PARITY}((/a_1, \ldots, a_m/))$ where $(a_1, \ldots, a_m)$ is the (possibly empty) set of elements of MASK selected to contribute to $r$ by the rules stated in Section 7.4.5.

**Example.** $\text{PARITY SUFFIX}( (/T,F,T,T,T/), \text{SEGMENT}=(/F,F,F,T,T/) )$ is $[F\ T\ T\ F\ T]$.

**POPCNT(I)**

**Description.** Return the number of one bits in an integer.

**Class.** Elemental function.

**Argument.** I must be of type integer.

**Result Type and Type Parameter.** Same as I.

**Result Value.** $\text{POPCNT}(I)$ is the number of one bits in the binary representation of the integer I. The model for the interpretation of an integer as a sequence of bits is in Section F95:13.5.7

**Example.** $\text{POPCNT}(I) = \text{COUNT}( (/ (\text{BTEST}(I,J), J=0, \text{BIT\_SIZE}(I)-1 )/ ))$, for scalar I.
POPPAR(I)

**Description.** Return the parity of an integer.

**Class.** Elemental function.

**Argument.** I must be of type integer.

**Result Type and Type Parameter.** Same as I.

**Result Value.** POPPAR(I) is 1 if there are an odd number of one bits in I and zero if there are an even number. The model for the interpretation of an integer as a sequence of bits is in Section F95:13.5.7

**Example.** For scalar I, POPPAR(I) = MERGE(1,0,BTEST(POPCNT(I),0)).

PRODUCT_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

**Optional Arguments.** DIM, MASK, SEGMENT, EXCLUSIVE

**Description.** Computes a segmented PRODUCT scan along dimension DIM of ARRAY.

**Class.** Transformational function.

**Arguments.**

**ARRAY** must be of type integer, real, or complex. It must not be scalar.

**DIM (optional)** must be scalar and of type integer with a value in the range 1 ≤ DIM ≤ n, where n is the rank of ARRAY.

**MASK (optional)** must be of type logical and must be conformable with ARRAY.

**SEGMENT (optional)** must be of type logical and must have the same shape as ARRAY.

**EXCLUSIVE (optional)** must be of type logical and must be scalar.

**Result Type, Type Parameter, and Shape.** Same as ARRAY.

**Result Value.** Element r of the result has the value PRODUCT((/ a_1, ..., a_m /)) where (a_1, ..., a_m) is the (possibly empty) set of elements of ARRAY selected to contribute to r by the rules stated in Section 7.4.5.

**Example.** PRODUCT_PREFIX( (/1,2,3,4,5/), SEGMENT= (/F,F,F,T,T/) ) is [ 1 2 6 4 20 ].


PRODUCT_SCATTER(ARRAY, BASE, INDX1, ..., INDXn, MASK)

Optional Argument. MASK

Description. Scatters elements of ARRAY selected by MASK to positions of the result indicated by index arrays INDX1, ..., INDXn. Each element of the result is equal to the product of the corresponding element of BASE and the elements of ARRAY scattered to that position.

Class. Transformational function.

Arguments.

ARRAY must be of type integer, real, or complex. It must not be scalar.

BASE must be of the same type and kind type parameter as ARRAY. It must not be scalar.

INDX1, ..., INDXn must be of type integer and conformable with ARRAY. The number of INDX arguments must be equal to the rank of BASE.

MASK (optional) must be of type logical and must be conformable with ARRAY.

Result Type, Type Parameter, and Shape. Same as BASE.

Result Value. The element of the result corresponding to the element b of BASE has the value PRODUCT((a1, a2, ..., am, b)), where (a1, ..., am) are the elements of ARRAY associated with b as described in Section 7.4.4.

Example. PRODUCT_SCATTER((1, 2, 3, 1), (4, -5, 7), (1, 1, 2, 2)) is [8 -15 7].

PRODUCT_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a reverse, segmented PRODUCT scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer, real, or complex. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range 1 ≤ DIM ≤ n, where n is the rank of ARRAY.

MASK (optional) must be of type logical and must be conformable with ARRAY.
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SEGMENT (optional) must be of type logical and must have the same shape as ARRAY.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element \( r \) of the result has the value \( \text{PRODUCT}(\langle a_1, \ldots, a_m \rangle) \) where \( \langle a_1, \ldots, a_m \rangle \) is the (possibly empty) set of elements of ARRAY selected to contribute to \( r \) by the rules stated in Section 7.4.5.

Example. \( \text{PRODUCT\_SUFFIX}(\langle 1,2,3,4,5 \rangle, \text{SEGMENT}=\langle F,F,F,T,T \rangle) \) is \[ \begin{bmatrix} 6 & 6 & 3 & 20 & 5 \end{bmatrix} \].

SORT_DOWN(ARRAY,DIM)

Optional Argument. DIM

Description. Sort by descending value.

Class. Transformational function.

Arguments.  
ARRAY must be of type integer, real, or character. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range \( 1 \leq \text{DIM} \leq n \), where \( n \) is the rank of ARRAY. The corresponding actual argument must not be an optional dummy argument.

Result Type, Type Parameter, and Shape. The result has the same shape, type, and type parameter as ARRAY.

Result Value.  
Case (i): The result of SORT_DOWN(ARRAY), when ARRAY is one-dimensional, is a vector of the same shape as ARRAY, containing the same elements (with the same number of instances) but sorted in descending element order. The collating sequence for an array of type CHARACTER is that used by the Fortran intrinsic functions, namely ASCII.

Case (ii): The result of SORT_DOWN(ARRAY) for a multi-dimensional ARRAY is the result that would be obtained by reshaping ARRAY to a rank-one array \( V \) using array element order, sorting that rank-one array in descending order, as in Case (i), and finally restoring the result to the original shape. That is, it gives the same result as RESHAPE( SORT_DOWN(V), SHAPE = SHAPE(ARRAY) ), where \( V = \text{RESHAPE}( \text{ARRAY}, \text{SHAPE} = \langle / M / \rangle \) and \( M = \text{SIZE}(\text{ARRAY}) \).
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Case (iii): The result of \texttt{SORT\_DOWN(ARRAY, DIM=k)} contains the same elements as \texttt{A}, but each one-dimensional array section of the form \texttt{ARRAY(i_1, i_2, ..., i_{k-1}, ... i_{k+1}, ..., i_n)}, where \( n \) is the rank of \texttt{ARRAY}, has been sorted in descending element order, as in Case(i) above.

Examples.

Case (i): \texttt{SORT\_DOWN( (30, 20, 30, 40, -10/) )}
has the value \[ \begin{bmatrix}
1 & 9 & 2 \\
40 & 30 & 20 & -10
\end{bmatrix}. \]

Case (ii): If \( A \) is the array \[ \begin{bmatrix}
4 & 5 & 2 \\
1 & 2 & 4
\end{bmatrix}, \]
then \texttt{SORT\_DOWN(A)} has the value \[ \begin{bmatrix}
9 & 4 & 2 \\
5 & 2 & 1 \\
4 & 2 & 1
\end{bmatrix}. \]

Case (iii): If \( A \) is the array \[ \begin{bmatrix}
4 & 5 & 2 \\
1 & 2 & 4
\end{bmatrix}, \]
then \texttt{SORT\_DOWN(A, DIM = 1)} has the value \[ \begin{bmatrix}
4 & 9 & 4 \\
1 & 5 & 2 \\
1 & 2 & 2
\end{bmatrix}. \]

\texttt{SORT\_UP(ARRAY,DIM)}

Optional Argument. \texttt{DIM}

Description. Sort by ascending value.

Class. Transformational function.

Arguments.

\texttt{ARRAY} must be of type integer, real, or character. It must not be scalar.

\texttt{DIM (optional)} must be scalar and of type integer with a value in the range \( 1 \leq \texttt{DIM} \leq n \), where \( n \) is the rank of \texttt{ARRAY}. The corresponding actual argument must not be an optional dummy argument.

Result Type, Type Parameter, and Shape. The result has the same shape, type, and type parameter as \texttt{ARRAY}.

Result Value.

Case (i): The result of \texttt{SORT\_UP(ARRAY)}, when \texttt{ARRAY} is one-dimensional, is a vector of the same shape as \texttt{ARRAY}, containing the same elements (with the same number of instances) but sorted in ascending element order. The collating sequence for an array of type \texttt{CHARACTER} is that used by the Fortran intrinsic functions, namely ASCII.
Case (ii): The result of \texttt{SORT_UP(ARRAY)} for a multi-dimensional \texttt{ARRAY} is the result that would be obtained by reshaping \texttt{ARRAY} to a rank-one array \texttt{V} using array element order, sorting that rank-one array in ascending order, as in Case(i), and finally restoring the result to the original shape. That is, it gives the same result as \texttt{RESHAPE(\,SORT_UP(V), SHAPE = SHAPE(ARRAY)\,)}, where \texttt{V} = \texttt{RESHAPE( ARRAY, SHAPE = (/ M /) and M = SIZE(ARRAY)\,)}.

Case (iii): The result of \texttt{SORT_UP(ARRAY, DIM=k)} contains the same elements as \texttt{A}, but each one-dimensional array section of the form \texttt{ARRAY(i_1, i_2, \ldots, i_{k-1}; i_{k+1}, \ldots, i_n)}, where \texttt{n} is the rank of \texttt{ARRAY}, has been sorted in ascending element order, as in Case(i) above.

Examples.

Case (i): \texttt{SORT_UP( (/30, 20, 30, 40, -10/) )} has the value \[
\begin{bmatrix}
-10 & 20 & 30 & 30 & 40 \\
\end{bmatrix}.
\]

Case (ii): If \texttt{A} is the array \[
\begin{bmatrix}
1 & 9 & 2 \\
4 & 5 & 2 \\
1 & 2 & 4 \\
\end{bmatrix},
\]
then \texttt{SORT_UP(A)} has the value \[
\begin{bmatrix}
1 & 2 & 4 \\
1 & 2 & 5 \\
2 & 4 & 9 \\
\end{bmatrix},
\]

Case (iii): If \texttt{A} is the array \[
\begin{bmatrix}
1 & 9 & 2 \\
4 & 5 & 2 \\
1 & 2 & 4 \\
\end{bmatrix},
\]
then \texttt{SORT_UP(A, DIM = 1)} has the value \[
\begin{bmatrix}
1 & 2 & 2 \\
1 & 5 & 2 \\
4 & 9 & 4 \\
\end{bmatrix}.
\]

\texttt{SUM_PREFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)}

Optional Arguments. \texttt{DIM, MASK, SEGMENT, EXCLUSIVE}

Description. Computes a segmented \texttt{SUM} scan along dimension \texttt{DIM} of \texttt{ARRAY}.

Class. Transformational function.

Arguments.

\texttt{ARRAY} must be of type integer, real, or complex. It must not be scalar.

\texttt{DIM} (optional) must be scalar and of type integer with a value in the range \(1 \leq \text{DIM} \leq n\), where \(n\) is the rank of \texttt{ARRAY}.

\texttt{MASK} (optional) must be of type logical and must be conformable with \texttt{ARRAY}.

\texttt{SEGMENT} (optional) must be of type logical and must have the same shape as \texttt{ARRAY}.
EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element \( r \) of the result has the value \( \text{SUM}(//a_1, \ldots, a_m//) \) where \((a_1, \ldots, a_m)\) is the (possibly empty) set of elements of ARRAY selected to contribute to \( r \) by the rules stated in Section 7.4.5.

Example. \( \text{SUM} \text{PREFIX}(//(1,2,3,4,5//), \text{SEGMENT}=(//F,F,F,T,T//)) \) is \[
\begin{bmatrix}
1 & 3 & 6 & 4 & 9
\end{bmatrix}.
\]

**SUM\_SCATTER**\( (\text{ARRAY,BASE,INDX}_1, \ldots, \text{INDX}_n, \text{MASK}) \)

Optional Argument. \text{MASK}

Description. Scatters elements of \text{ARRAY} selected by \text{MASK} to positions of the result indicated by index arrays \text{INDX}_1, \ldots, \text{INDX}_n. Each element of the result is equal to the sum of the corresponding element of \text{BASE} and the elements of \text{ARRAY} scattered to that position.

Class. Transformational function.

Arguments.

\text{ARRAY} must be of type integer, real, or complex. It must not be scalar.

\text{BASE} must be of the same type and kind type parameter as \text{ARRAY}. It must not be scalar.

\text{INDX}_1, \ldots, \text{INDX}_n must be of type integer and conformable with \text{ARRAY}. The number of \text{INDX} arguments must be equal to the rank of \text{BASE}.

\text{MASK} (optional) must be of type logical and must be conformable with \text{ARRAY}.

Result Type, Type Parameter, and Shape. Same as \text{BASE}.

Result Value. The element of the result corresponding to the element \( b \) of \text{BASE} has the value \( \text{SUM}(//(a_1, a_2, \ldots, a_m, b//)) \), where \((a_1, \ldots, a_m)\) are the elements of \text{ARRAY} associated with \( b \) as described in Section 7.4.4.

Example. \( \text{SUM}\_\text{SCATTER}((//1, 2, 3, 1//), ((//4, -5, 7//), ((//1, 1, 2, 2//)))) \) is \[
\begin{bmatrix}
7 & -1 & 7
\end{bmatrix}.
\]
SUM_SUFFIX(ARRAY, DIM, MASK, SEGMENT, EXCLUSIVE)

Optional Arguments. DIM, MASK, SEGMENT, EXCLUSIVE

Description. Computes a reverse, segmented SUM scan along dimension DIM of ARRAY.

Class. Transformational function.

Arguments.

ARRAY must be of type integer, real, or complex. It must not be scalar.

DIM (optional) must be scalar and of type integer with a value in the range \(1 \leq \text{DIM} \leq n\), where \(n\) is the rank of ARRAY.

MASK (optional) must be of type logical and must be conformable with ARRAY.

SEGMENT (optional) must be of type logical and must have the same shape as ARRAY.

EXCLUSIVE (optional) must be of type logical and must be scalar.

Result Type, Type Parameter, and Shape. Same as ARRAY.

Result Value. Element \(r\) of the result has the value \(\text{SUM}(\langle a_1, \ldots, a_m \rangle)\) where \(\langle a_1, \ldots, a_m \rangle\) is the (possibly empty) set of elements of ARRAY selected to contribute to \(r\) by the rules stated in Section 7.4.5.

Example. \(\text{SUM_SUFFIX}(\langle 1,2,3,4,5 \rangle, \text{SEGMENT} = \langle F,F,F,T,T \rangle)\) is \(\begin{bmatrix} 6 & 5 & 3 & 9 & 5 \end{bmatrix}\).
Part III

HPF Approved Extensions

This major section describes the syntax and semantics of features of approved extensions to High Performance Fortran. In most cases, these features build on concepts found in HPF itself; it may therefore be necessary to refer back to Parts I and II for background information.
Section 8

Approved Extensions for Data Mapping

This section describes a set of data mapping features that extend the capabilities provided by the base set as described in Section 3. These extensions can be divided into two categories.

The first set of extensions provides the user greater control over the mapping of the data. These include directives for dynamic remapping of data, which allow the user to redistribute and realign at run time data that has been declared DYNAMIC. The ONTO clause used in the DISTRIBUTE directive is extended to allow direct distribution to subsets of processors. Explicit mapping of pointers and components of derived types are also introduced. Two new distributions are included: the GEN_BLOCK distribution, which generalizes the block distribution, and the INDIRECT distribution, which allows the mapping of individual array elements to be specified through a mapping array.

The programmer can use the second set of extensions to provide the compiler with information useful for generating efficient code. This category includes the RANGE directive, which allows the user to specify the range of distributions that a dynamically distributed array, a pointer, or a dummy argument may have. The SHADOW directive allows the user to specify the amount of additional space required on a processor to accommodate non-local elements in a nearest-neighbor computation.

Since this section deals with extensions, we repeat some of the sections of Sections 3 and 4, providing new rules and extending old ones where necessary. In particular, subsections 8.13, 8.14 and 8.15 extend the corresponding subsections in Section 3 based on the approved extensions described here.

8.1 Extended Model

The fundamental model for allocation of data to abstract processors still remains a two-level mapping as described in Section 3. However, it is extended to allow the dynamic remapping of the data objects as illustrated by the following diagram:
Thus, objects can be remapped at execution time using the executable directives `REALIGN` and `REDISTRIBUTE`. Any object that is the root of an alignment tree (i.e., is not explicitly aligned to another object) can be explicitly redistributed. Redistributing such an object causes all objects ultimately aligned with it also to be redistributed so as to maintain the alignment relationships.

Any object that is not a root of an alignment tree can be explicitly realigned but not explicitly redistributed. Such a realignment does not change the mapping of any other object. Note that such remapping of data may require communication among the processors.

By analogy with the Fortran `ALLOCATABLE` attribute, HPF includes the `DYNAMIC` attribute. It is not permitted to `REALIGN` an array that has not been declared `DYNAMIC`. Similarly, it is not permitted to `REDISTRIBUTE` an array or template that has not been declared `DYNAMIC`.

Saved local variables, variables in common, and variables accessed by use association must not be implicitly remapped (e.g., by having variable distribution formats or being aligned with entities having variable distribution formats). Of these three categories of variables, only variables accessed by use association may have the `DYNAMIC` attribute.

As in Section 3.1, an object is considered to be explicitly mapped if it appears in an HPF mapping directive within the scoping unit in which it is declared; otherwise it is implicitly mapped. The definition of a mapping directive in Section 3.1 is extended as follows: A mapping directive is an `ALIGN`, `DISTRIBUTE`, `INHERIT`, `DYNAMIC`, `RANGE`, or `SHADOW` directive, or any directive that confers an alignment, a distribution, or the `INHERIT`, `DYNAMIC`, `RANGE`, or `SHADOW` attributes.

### 8.2 Syntax of Attributed Forms of Extended Data Mapping Directives

Like other mapping directives, the executable directives `REALIGN` and `REDISTRIBUTE` also come in two forms (statement form and attribute form) but may not be combined with other attributes in a single directive. The `RANGE` and `SHADOW` attributes may be combined with other attributes in a single directive.
8.3. THE REDISTRIBUTE DIRECTIVE

H801 combined-attribute-extended is ALIGN align-attribute-stuff
or DISTRIBUTE dist-attribute-stuff
or INHERIT
or TEMPLATE
or PROCESSORS
or DIMENSION ( explicit-shape-spec-list )
or DYNAMIC
or RANGE range-attr-stuff
or SHADOW shadow-attr-stuff
or SUBSET

Constraint: The SUBSET attribute may be applied only to a processors arrangement.

The SUBSET attribute is discussed in Section 9; the rest are discussed below.

8.3 The REDISTRIBUTE Directive

The REDISTRIBUTE directive is similar to the DISTRIBUTE directive but is considered executable. An object or template may be redistributed at any time, provided it has been declared DYNAMIC (see Section 8.5). Any other objects currently ultimately aligned with an array (or template) when it is redistributed are also remapped to reflect the new distribution, in such a way as to preserve alignment relationships (see Section 3.4). (This can require a lot of computational and communication effort at run time; the programmer must take care when using this feature.)

The DISTRIBUTE directive may appear only in the specification-part of a scoping unit. The REDISTRIBUTE directive may appear only in the execution-part of a scoping unit. The principal difference between DISTRIBUTE and REDISTRIBUTE is that DISTRIBUTE must contain only a specification-expr as the argument to a distribution format such as BLOCK or CYCLIC, whereas in REDISTRIBUTE such an argument may be any integer expression. Another difference is that DISTRIBUTE is an attribute, and so can be combined with other attributes as part of a combined-directive, whereas REDISTRIBUTE is not an attribute (although a REDISTRIBUTE statement may be written in the style of attributed syntax, using “::” punctuation).

The syntax of the REDISTRIBUTE directive is:

H802 redistribute-directive is REDISTRIBUTE distributee dist-directive-stuff
or REDISTRIBUTE dist-attribute-stuff :: distributee-list

Constraint: A distributee that appears in a REDISTRIBUTE directive must have the DYNAMIC attribute (see Section 8.5).

Constraint: A distributee in a REDISTRIBUTE directive may not appear as an alignee in an ALIGN or REALIGN directive.

Constraint: Neither the dist-format-clause nor the dist-target in a REDISTRIBUTE directive may begin with “*”.

Note that, although an object may not have both the INHERIT attribute and the
DISTRIBUTE attribute, any object—whether or not it has the INHERIT attribute—may ap-
pear as a distributee in a REDISTRIBUTE directive, provided that it has the DYNAMIC attribute
and that it does not appear as an alignee in a ALIGN or REALIGN directive.

If a range directive (see Section 8.11) has been used to restrict the set of distribution
formats allowed for a distributee, then the new mapping must match one of the formats
specified in the range directive.

The statement form of a REDISTRIBUTE directive may be considered an abbreviation
for an attributed form that happens to mention only one distributee; for example,

!HPF$ REDISTRIBUTE distributee ( dist-format-list ) ONTO dist-target

is equivalent to

!HPF$ REDISTRIBUTE ( dist-format-list ) ONTO dist-target :: distributee

8.4 The REALIGN Directive

The REALIGN directive is similar to the ALIGN directive but is considered executable. An
array (or template) may be realigned at any time, provided it has been declared DYNAMIC
(see Section 8.5). Unlike redistribution (also in Section 8.5), realigning a data object does
not cause any other object to be remapped. (However, realignment of even a single object,
if it is large, can require a lot of computational and communication effort at run time; the
programmer must take care when using this feature.)

The ALIGN directive may appear only in the specification-part of a scoping unit. The
REALIGN directive is similar but may appear only in the execution-part of a scoping unit.
The principal difference between ALIGN and REALIGN is that ALIGN must contain only a
specification-expr as a subscript or in a subscript-triplet, whereas in REALIGN an expression
as a subscript or in a subscript-triplet need not be a specification-expr. Another difference
is that ALIGN is an attribute, and so can be combined with other attributes as part of a
combined-directive, whereas REALIGN is not an attribute (although a REALIGN statement
may be written in the style of attributed syntax, using ‘::’ punctuation).

The syntax of REALIGN is as follows:

H803  realign-directive is REALIGN alignee align-directive-stuff
      or REALIGN align-attribute-stuff :: alignee-list

Constraint: Any alignee that appears in a REALIGN directive must have the DYNAMIC at-
tribute (see Section 8.5).

Constraint: If the align-target specified in the align-with-clause has the DYNAMIC attribute,
then each alignee must also have the DYNAMIC attribute.

Constraint: An alignee in a REALIGN directive may not appear as a distributee in a
DISTRIBUTE or REDISTRIBUTE directive.

Note that, although an object may not have both the INHERIT attribute and the ALIGN
attribute, any object—whether or not it has the INHERIT attribute—may appear as an
alignee in a REALIGN directive, provided it has the DYNAMIC attribute and that it does not
appear as a distributee in a DISTRIBUTE or REDISTRIBUTE directive.
If a range directive (see Section 8.11) has been used to restrict the set of distribution formats allowed for an \textit{alignee}, then the new mapping must match one of the formats specified in the range directive.

### 8.5 The DYNAMIC Directive

The \texttt{DYNAMIC} attribute specifies that an object may be dynamically realigned or redistributed.

\begin{verbatim}
H804 dynamic-directive is DYNAMIC alignee-or-distributee-list
H805 alignee-or-distributee is alignee or distributee
\end{verbatim}

Constraint: An object in \texttt{COMMON} may not be declared \texttt{DYNAMIC} and may not be aligned to an object (or template) that is \texttt{DYNAMIC}. (To get this kind of effect, modules must be used instead of \texttt{COMMON} blocks.)

Constraint: A component of a derived type may have the \texttt{DYNAMIC} attribute only if it also has the \texttt{POINTER} attribute. (See Section 8.9 for further discussion.)

Constraint: An object with the \texttt{SAVE} attribute may not be declared \texttt{DYNAMIC} and may not be aligned to an object (or template) that is \texttt{DYNAMIC}.

A \texttt{REALIGN} directive may not be applied to an \textit{alignee} that does not have the \texttt{DYNAMIC} attribute. A \texttt{REDISTRIBUTE} directive may not be applied to a \textit{distributee} that does not have the \texttt{DYNAMIC} attribute.

A \texttt{DYNAMIC} directive may be combined with other directives, with the attributes stated in any order, consistent with the Fortran attribute syntax.

Examples:

\begin{verbatim}
!HPF$ DYNAMIC A,B,C,D,E
!HPF$ DYNAMIC:: A,B,C,D,E
!HPF$ DYNAMIC, ALIGN WITH SNEEZY:: X,Y,Z
!HPF$ ALIGN WITH SNEEZY, DYNAMIC:: X,Y,Z
!HPF$ DYNAMIC, DISTRIBUTE(BLOCK, BLOCK) :: X,Y
!HPF$ DISTRIBUTE(BLOCK, BLOCK), DYNAMIC :: X,Y
\end{verbatim}

The first two examples mean exactly the same thing. The next two examples mean exactly the same second thing. The last two examples mean exactly the same third thing.

The three directives

\begin{verbatim}
!HPF$ TEMPLATE A(64,64),B(64,64),C(64,64),D(64,64)
!HPF$ DISTRIBUTE(BLOCK, BLOCK) ONTO P:: A,B,C,D
!HPF$ DYNAMIC A,B,C,D
\end{verbatim}

may be combined into a single directive as follows:

\begin{verbatim}
!HPF$ TEMPLATE, DISTRIBUTE(BLOCK, BLOCK) ONTO P, &
!HPF$ DIMENSION(64,64),DYNAMIC :: A,B,C,D
\end{verbatim}
An ALLOCATABLE object may also be given the DYNAMIC attribute. If an ALLOCATE statement is immediately followed by REDISTRIBUTE and/or REALIGN directives, the meaning in principle is that the array is first created with the statically declared mapping, if any, then immediately remapped. In practice there is an obvious optimization: create the array in the processors to which it is about to be remapped, in a single step. HPF implementors are strongly encouraged to implement this optimization and HPF programmers are encouraged to rely upon it. Here is an example:

```fortran
REAL, ALLOCATABLE(:, :) :: TINKER, EVERS
!HPF$ DYNAMIC :: TINKER, EVERS
REAL, ALLOCATABLE :: CHANCE(:)
!HPF$ DISTRIBUTEBLOCK), DYNAMIC :: CHANCE
...
READ 6, M, N
ALLOCATE(TINKER(N, M, N)*)
!HPF$ REDISTRIBUTE TINKER(CYCLIC, BLOCK)
ALLOCATE(EVERS(N, N))
!HPF$ REALIGN EVERS(: : :) WITH TINKER(M:: M, 1:: M)
ALLOCATE(CHANCE(10000))
!HPF$ REDISTRIBUTE CHANCE(CYCLIC)
```

While CHANCE is by default always allocated with a BLOCK distribution, it should be possible for a compiler to notice that it will immediately be remapped to a CYCLIC distribution. Similar remarks apply to TINKER and EVERS. (Note that EVERS is mapped in a thinly-spread-out manner onto TINKER; adjacent elements of EVERS are mapped to elements of TINKER separated by a stride M. This thinly-spread-out mapping is put in the lower left corner of TINKER, because EVERS(1, 1) is mapped to TINKER(M, 1).)

In Section 5.1, a list is given of operations that, if performed in a do loop, cause the iterations of the loop to interfere with each other, and thereby prevent the loop from being characterized as INDEPENDENT. To that list must be added:

- Any REALIGN or REDISTRIBUTE directive performed in the loop interferes with any access to or any other remapping of the same data.

Rationale. REALIGN and REDISTRIBUTE may change the processor storing a particular array element, which interferes with any assignment or use of that element. Similarly, multiple remapping operations may cause the same element to be stored in multiple locations. (End of rationale.)

### 8.6 Remapping and Subprogram Interfaces

If the dummy argument of any subprogram has the DYNAMIC attribute, then an explicit interface is required for the subprogram (see subsection 8.14). The rules on the interaction of the REALIGN and REDISTRIBUTE directives with a subprogram argument interface are:

1. A dummy argument may be declared DYNAMIC. However, it is subject to the general restrictions concerning the use of the name of an array to stand for its associated template.
The effect of any redistribution of the dummy after the procedure returns to the caller is dependent on the attribute of the actual argument. If the actual argument associated with the dummy has also been declared DYNAMIC, then any explicit remapping of the dummy is visible in the caller after the procedure returns. If a range directive (see Section 8.11) has been used to restrict the set of distribution formats allowed for the actual argument, then the new mapping must match one of the formats specified in the range directive.

A dummy argument whose associated actual argument has the DYNAMIC attribute may be used in REALIGN and REDISTRIBUTE as an alignee or distributee if and only if the associated actual argument is a whole array, not an array section.

If the actual argument associated with the dummy has not been declared DYNAMIC then the original mapping of the actual has to be restored on return. When the subprogram returns and the caller resumes execution, all objects accessible to the caller after the call that are not declared DYNAMIC are mapped exactly as they were before the call.

2. If an array or any section thereof is accessible by two or more paths, it is not HPF-conforming to remap it through any of those paths. For example, if an array is passed as an actual argument, it is forbidden to realign that array, or to redistribute an array or template to which it was aligned at the time of the call, until the subprogram has returned from the call. This prevents nasty aliasing problems. An example:

```fortran
MODULE FOO
REAL A(10,10)
!HPF$ DYNAMIC :: A
END

PROGRAM MAIN
USE FOO
CALL SUB(A(1:5,3:9))
END

SUBROUTINE SUB(B)
USE FOO
REAL B(:,::)
!HPF$ DYNAMIC :: B
...
!HPF$ REDISTRIBUTE A    !Nonconforming
...
END
```

Situations such as this are forbidden, for the same reasons that an assignment to A at the statement marked “Nonconforming” would also be forbidden. In general, in any situation where assignment to a variable would be nonconforming by reason of aliasing, remapping of that variable by an explicit REALIGN or REDISTRIBUTE directive is also forbidden.

Note that it is permitted to remap a host-associated or use-associated variable in a subprogram if it has been declared DYNAMIC and is accessible only through a single
8.7 Mapping to Processor Subsets

This extension allows objects to be directly distributed to processor subsets by allowing a processor subset to be specified where a processor could be named, e.g., in a \texttt{DISTRIBUTE} directive. The specified subset must be a proper subset of the named processor arrangement.

The syntax of the extended \texttt{dist-target} is as follows:

\begin{verbatim}
H806 extended-dist-target  is  processors-name [ ( section-subscript-list ) ]
 or  *  processors-name [ ( section-subscript-list ) ]
 or  *
\end{verbatim}

Constraint: The \texttt{section-subscripts} in the \texttt{section-subscript-list} may not be \texttt{vector-subscripts} and are restricted to be either \texttt{subscripts} or \texttt{subscript-triplets}.

Constraint: In the \texttt{section-subscript-list}, the number of \texttt{section-subscripts} must equal the rank of the \texttt{processor-name}.

Constraint: Within a \texttt{DISTRIBUTE} directive, each \texttt{section-subscript} must be a \texttt{specification-expr}.

Constraint: Within a \texttt{DISTRIBUTE} or a \texttt{REDISTRIBUTE} directive, if both a \texttt{dist-format-list} and a \texttt{dist-target} appear, the number of elements of the \texttt{dist-format-list} that are not “*” must equal the number of \texttt{subscript-triplets} in the named processor arrangement.

Constraint: Within a \texttt{DISTRIBUTE} or a \texttt{REDISTRIBUTE} directive, if a \texttt{dist-target} appears but not a \texttt{dist-format-list}, the rank of each \texttt{distribute} must equal the number of \texttt{subscript-triplets} in the named processor arrangement.

\texttt{Example 1}

\begin{verbatim}
!HPF$ PROCESSORS P(10)
 REAL A(100)
 !HPF$ DISTRIBUTE A(BLOCK) ONTO P(2:5)
\end{verbatim}

\texttt{Example 2}

\begin{verbatim}
!HPF$ PROCESSORS Q(10,10)
 REAL A(100,100)
 !HPF$ DISTRIBUTE B(BLOCK,BLOCK) ONTO Q(5:10,5:10)
\end{verbatim}

In Example 1, the array A is distributed by block across the processors P(2) to P(5) while in the second example, the array B is distributed across the lower right quadrant of the processor array Q.

\textit{Advice to users.} This extension is most useful in conjunction with the tasking construct, see Section 9.4, which allows multiple independent phases of a computation to execute simultaneously on different subsets of processors. A similar situation arises

\texttt{Example 1}
when the code uses multiple data structures which can be computed in parallel where
the computation on each individual object also exhibits parallelism, e.g., the multiple
blocks in a multi-block grid used in some fluid dynamics calculation. Here, the indi-
vidual blocks have to be distributed over subsets of processors to exploit both levels
of parallelism. (End of advice to users.)

8.8 Pointers

8.8.1 Mapped Pointers

As an approved extension to HPF, pointers and targets can be explicitly mapped. Formally,
this implies that the constraints that a distributee and an alignee may not have the POINTER
or TARGET attribute as stated in Sections 3.3 and 3.4 respectively, have to be removed.

As in the case of an allocatable object, the mapping specification for a pointer does
not take effect immediately but plays a role when the pointer becomes pointer associated
with a target either through allocation or through pointer assignment.

When a pointer with an explicit mapping is used in an ALLOCATE statement, the data
is allocated with the specified mapping.

For example:

```fortran
REAL, POINTER, DIMENSION(:) :: A, B
!HPF$ ALIGN B(I) WITH A(I)
!HPF$ DISTRIBUT A(BLOCK)
...
ALLOCATE(A(100))
ALLOCATE(B(50))
...
ALLOCATE(B(200)) ! Nonconforming
```

Pointer A is declared to have a BLOCK distribution while pointer B is declared to be
identically aligned with A. When A is allocated, it is created with a block distribution. When
B is allocated, it is aligned with the first 50 elements of A. Note that the allocation statements
may not occur in the opposite order, since an object may be aligned to another only if it
has already been created or allocated. Also, the second allocation for B is nonconforming,
since a larger object, B here, cannot be aligned with a smaller object, A in this case.

A pointer P with an explicit mapping can be pointer associated with a target T through
a pointer assignment statement under the following conditions:

1. The mapping of T is a specialization of the mapping of P (in particular, T must be a
whole array); and

2. If P is explicitly aligned, its ultimate align target has a fully-specified non-transcrip-
tive distribution; and

3. P and T are either both DYNAMIC or neither is.

Here are some examples:

```fortran
REAL, POINTER, DIMENSION(:,:) :: P
!HPF$ DISTRIBUT P(BLOCK,BLOCK)
```
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REAL, TARGET, DIMENSION (100, 100) :: B, C, D
!HPF$ DISTRIBUT B(BLOCK, BLOCK)
!HPF$ DISTRIBUT C(BLOCK, CYCLIC)
...
P => B       ! Conforming
P => B(1:50, 1:50) ! Nonconforming: target must be a whole array.
P => C       ! Nonconforming: the distribution in the
             ! second dimension does not match
P => D       ! Nonconforming: D is not explicitly mapped
...

The intuitive reason that the pointer assignment \( P \Rightarrow B(1:50, 1:50) \) above is non-conforming is similar to the reason that the example on page 53 (illustrating the difference between \texttt{INHERIT A} and \texttt{DISTRIBUTE A /* ONTO */}) is nonconforming: Suppose for instance that the array \( B \) is distributed over a \( 2 \times 2 \) processor arrangement. Then the section \( B(1:50, 1:50) \) would live entirely on processor \((1,1)\). This mapping is not correctly described by a \( \text{(BLOCK, BLOCK)} \) distribution for \( P \).

The following pointer assignment is valid even though no processor arrangement is specified for the pointer; in this case, the mapping of \( B \) is a specialization of the mapping of \( P \):

\[
\text{REAL, TARGET, DIMENSION}(:) :: P \\
\text{REAL, TARGET, DIMENSION}(100) :: B \\
!HPF$ \text{PROCESSORS PROC(NUMBER_OF_PROCESSORS())} \\
!HPF$ \text{DISTRIBUTE P(BLOCK)} \\
!HPF$ \text{DISTRIBUTE (BLOCK) ONTO PROC :: B} \\
...
P => B       ! Conforming
...
\]

\[
\text{REAL, POINTER, DIMENSION}(:) :: P \\
!HPF$ \text{DISTRIBUTE \* :: P} \\
\text{REAL, TARGET, DIMENSION}(100) :: B, C \\
!HPF$ \text{DISTRIBUTE B(BLOCK), C(CYCLIC)} \\
...
P => B       ! Conforming
P => C       ! Conforming
P => C(1:50) ! Nonconforming: target must be a whole array
...
\]

Here, the \( \ast \) is used to indicate a transcriptive distribution for the pointer \( P \) and thus it can be pointer associated with both targets \( B \) and \( C \) distributed by \texttt{BLOCK} and \texttt{CYCLIC} respectively. However, it still cannot be used to point to an array section such as \( C(1:50) \). To do that, the pointer must have the \texttt{INHERIT} attribute:

\[
\text{REAL, POINTER, DIMENSION}(:) :: P \\
!HPF$ \text{INHERIT :: P} \\
\text{REAL, TARGET, DIMENSION}(100) :: B, C \\
!HPF$ \text{DISTRIBUTE B(BLOCK), C(CYCLIC)}
\]
...  
P => B   ! Conforming  
P => C   ! Conforming  
P => C(1:50) ! Conforming  
...

To allow pointers to have transcriptive distributions, we have to change the constraint for \textit{dist-format-clause} as specified in Section 3.3, to read as follows:

Constraint: If either the \textit{dist-format-clause} or the \textit{dist-target} in a \textit{DISTRIBUTE} directive begins with "*" then every \textit{distributee} must be a dummy argument, \textit{except if the distributee has the \texttt{POINTER} attribute}.

The constraint for \textit{align-spec} as specified in Section 3.4, should be changed to read as follows:

Constraint: If the \textit{align-spec} in an \textit{ALIGN} directive begins with "*" then every \textit{alignee} must be a dummy argument, \textit{except if the alignee has the \texttt{POINTER} attribute}.

The constraint for \textit{inheritee} as specified in Section 4.4.2, should be changed to read as follows:

Constraint: An \textit{inheritee} must be a dummy argument, \textit{except if the alignee has the \texttt{POINTER} attribute}.

When pointers with such transcriptive mappings are used in an \textit{ALLOCATE} statement, the compiler may choose any arbitrary mapping for the allocated data. A range declaration (see Section 8.11) can be used to restrict the set of distribution formats.

If a pointer has the \texttt{DYNAMIC} attribute, then any target associated with the pointer (which must therefore also have the \texttt{DYNAMIC} attribute) may be remapped using a \texttt{REALIGN} or \texttt{REDISTRIBUTE} statement under the following restriction:

A pointer may be used in \texttt{REALIGN} and \texttt{REDISTRIBUTE} as an \textit{alignee}, \textit{align-target}, or \textit{distributee} if and only if it is currently associated with a whole array, not an array section.

Note that when an object is remapped, the new mapping is visible through any pointer that may be associated with the object.

### 8.8.2 Pointers and Subprograms

If a pointer dummy argument is not explicitly mapped, then the actual argument must also not be explicitly mapped.

If a pointer dummy argument has an explicit mapping, then the actual argument must follow the rules for pointer assignment as stated above, with one exception: If the actual argument has the \texttt{DYNAMIC} attribute, it is not necessary that the corresponding dummy argument have the \texttt{DYNAMIC} attribute. That is, item 3 on page 151 is weakened to

3. If a pointer dummy argument has the \texttt{DYNAMIC} attribute, then the corresponding actual argument must also have the \texttt{DYNAMIC} attribute.
A range declaration (see Section 8.11) can be used to restrict the set of distribution formats of the actual.

A pointer dummy argument may have the DYNAMIC attribute. In this case, the actual argument must also have the DYNAMIC attribute. The target associated with the dummy argument may be redistributed under the restrictions stated in the last subsection. Following Fortran rules, if the actual is also visible (through host- or use-association), the target may be redistributed only through the dummy argument. If the dummy argument is redistributed, then the actual argument has the new mapping on return from the procedure. In such a case, the new mapping must match the range restrictions (if any) of the actual.

### 8.8.3 Restrictions on Pointers and Targets

If, on invocation of a procedure P: (a) a dummy argument has the TARGET attribute, and (b) the corresponding actual argument has the TARGET attribute and is not an array section with a vector subscript (and therefore is an object A or a section of an array A), then the program is HPF-conforming only if:

1. No remapping of the actual argument occurs during the call; or
2. the remainder of program execution would be unaffected if

   (a) each pointer associated with any portion of A before the call were to acquire undefined pointer association status on entry to P and, if not reassigned during execution of P, were to be restored on exit to the pointer association status it had before entry.

   (b) each pointer associated with any portion of the dummy argument or with any portion of A during execution of P were to acquire undefined pointer association status on exit from P; and

Advice to users. One way of ensuring that no remapping occurs is to give the dummy argument the INHERIT attribute. (End of advice to users.)

Rationale. These restrictions are made in order to support the following part of the Fortran standard (F95:12.4.1.1) in the face of implicit remapping across the subprogram interface:

If the dummy argument does not have the TARGET or POINTER attribute, any pointers associated with the actual argument do not become associated with the corresponding dummy argument on invocation of the procedure.
If the dummy argument has the TARGET attribute and the corresponding actual argument has the TARGET attribute but is not an array section with a vector subscript:

1. Any pointers associated with the actual argument become associated with the corresponding dummy argument on invocation of the procedure.
2. When execution of the procedure completes, any pointers associated with the dummy argument remain associated with the actual argument.
If the dummy argument has the TARGET attribute and the corresponding actual argument does not have the TARGET attribute or is an array section with a vector subscript, any pointers associated with the dummy argument become undefined when execution of the procedure completes.

(End of rationale.)

Here is an example that illustrates the restrictions of this section:

```fortran
INTEGER, TARGET, DIMENSION (10) :: ACT
INTEGER, POINTER, DIMENSION (:) :: POINTS_TO_ACT, POINTS_TO_DUM
!HPF$ DISTRIBUTED ACT(BLOCK)

POINTS_TO_ACT => ACT
CALL F(ACT)
POINTS_TO_DUM(1) = 1 ! ILLEGAL

CONTAINS
  SUBROUTINE F(DUM)
    INTEGER, TARGET, DIMENSION(10) :: DUM
    !HPF$ DISTRIBUTED DUM(CYCLIC)

    POINTS_TO_DUM => DUM
    POINTS_TO_ACT(1) = 1 ! ILLEGAL
  END SUBROUTINE
END
```

The assignment to POINTS_TO_DUM(1) is illegal because it violates item 2b; the assignment to POINTS_TO_ACT(1) is illegal because it violates item 2a.

### 8.9 Mapping of Derived Type Components

An ALIGN, DISTRIBUTE, or DYNAMIC directive may appear within a derived-type-def wherever a component-def-stmt may appear. Every alignee or distributee within such a directive must be the name of a component defined within that derived-type-def. To allow mapping of the structure components, the rules have to be extended as follows:

```
H807 distributee-extended is object-name
    or template-name
    or component-name
    or structure-component
```

A derived type is said to be an explicitly mapped type if any of its components is explicitly mapped or if any of its components is of an explicitly mapped type.

Constraint: A component of a derived type may be explicitly distributed only if the type of the component is not an explicitly mapped type.
Constraint: An object of a derived type may be explicitly distributed only if the derived type is not an explicitly mapped type.

Constraint: A distributee in a DISTIBUTE directive may not be a structure-component.

Constraint: A distributee in a DISTIBUTE directive which occurs in a derived-type-def must be the component-name of a component of the derived type.

Constraint: A component-name may occur as a distributee in a DISTIBUTE directive occurring within the derived type definition only.

Constraint: A distributee that is a structure-component may occur only in a REDISTRIBUTE directive and every part-ref except the rightmost must be scalar (rank zero). The rightmost part-name in the structure-component must have the DYNAMIC attribute.

H808 alignee-extended is object-name or component-name or structure-component

Constraint: A component of a derived type may be explicitly aligned only if the type of the component is not an explicitly mapped type.

Constraint: An object of a derived type may be explicitly aligned only if the derived type is not an explicitly mapped type.

Constraint: An alignee in an ALIGN directive may not be a structure-component.

Constraint: An alignee in an ALIGN directive that occurs in a derived-type-def must be the component-name of a component of the derived type.

Constraint: A component-name may occur as an alignee only in an ALIGN directive occurring within the derived type definition.

Constraint: An alignee that is a structure-component may occur only in a REALIGN directive and every part-ref except the rightmost must be scalar (rank zero). The rightmost part-name in the structure-component must have the DYNAMIC attribute.

H809 align-target-extended is object-name or template-name or component-name or structure-component

Constraint: A component-name may appear as an align target only in an ALIGN directive occurring within the derived type definition that defines that component.

Constraint: In an align-target that is a structure-component, every part-ref except the rightmost must be scalar (rank zero).

The above constraints imply that components of derived type can be mapped within the derived type definition itself such that when any objects of that type are created the components will be created with the specified mapping.

Consider the following example:
TYPE DT
    REAL C(100)
    !HPF$ DISTRIBUT C(BLOCK) ONTO P
END TYPE DT

TYPE (DT) :: S1
TYPE (DT) :: S2(100)

A derived type with one component, array C, which is specified to be distributed block. Therefore the scalar variable S1 of derived type DT has a structure component S1%C that is distributed block onto the processor arrangement P. Similarly, the component C of each of the elements of the array S2 will also be distributed block onto the processor arrangement P.

An align directive inside a derived type definition may align a component of the derived type with another component of the same derived type or with another object. A structure component can be used as a target to align other objects including components of derived types.

Example:

!HPF$ TEMPLATE T(100)
!HPF$ DISTRIBUTE T(CYCLIC)

TYPE DT
    REAL, DIMENSION(100) :: A, B, C
    !HPF$ ALIGN WITH A :: B
    !HPF$ DISTRIBUTE (BLOCK) :: A
    !HPF$ ALIGN WITH T :: C
END TYPE DT

Here variables of derived type DT will be created such the component B is aligned with A, which is itself distributed block, and such that the component C is aligned with a template T that is external to the derived type definition.

Note that if a derived type component is given a partial mapping, it is up to the compiler to choose the rest of the mapping of that component. However, it is expected that the compiler will choose the same mapping for this component of all variables of such a derived type. For example, consider a modification of the above code in which the distribution of the component A is omitted. B and A are specified to be aligned but no distribution is given for A. In such a situation, it is expected that all variables of the derived type DT will be created such that the component A (and in turn the component B) have the same distribution.

The constraints for the mapping of derived type components allow the mapping of structure variables at only one level. Consider for example the following code in which a derived type contains a components that is itself a derived type:

TYPE SIMPLE
    REAL S(100)
    !HPF$ DISTRIBUTE S(BLOCK)
END TYPE SIMPLE
!HPF$ TEMPLATE, DISTRIBUTE(BLOCK, *) :: HAIRY_TEMPLATE(47,73)

TYPE COMPLICATED
  INTEGER SIZE
  REAL RV(100,100), KV(100,100), QV(47,73)
! Arrays RV, KV, and QV may be mapped
!HPF$ DISTRIBUTE (BLOCK, BLOCK): : RV, KV
!HPF$ ALIGN WITH HAIRY_TEMPLATE : : QV
  TYPE(SIMPLE) SV(100)
! The following directive is not valid because SIMPLE
! is an explicitly mapped type.
!HPF$ DISTRIBUTE SV(BLOCK)
END TYPE COMPLICATED

TYPE(COMPLICATED) LOTSOF(20)

! The following directive is not valid because COMPLICATED
! is an explicitly mapped type.
!HPF$ DISTRIBUTE LOTSOF(BLOCK)

Here, a component of the derived type SIMPLE has been mapped; thus objects of this
type, e.g., SV in type COMPLICATED, cannot be distributed. The array LOTSOF cannot be
distributed for the same reason.

Structure components having the POINTER attribute can be remapped using the
REALIGN or REDISTRIBUTE directive if they have been declared DYNAMIC. For example, the
following code fragment can be used to allocate and map multiple blocks (called SUBGRID
here) of a multi-block grid:

!HPF$ PROCESSORS P( number_of_processors() )

TYPE SUBGRID
  INTEGER SIZE
  INTEGER LO, HI    ! target subset of processors
  REAL, POINTER BL(:)
!HPF$ DYNAMIC BL
END TYPE SUBGRID

TYPE (SUBGRID), ALLOCATABLE :: GRID(:)

READ (*,*) SUBGRID_COUNT
ALLOCATE GRID(SUBGRID_COUNT)
DO I = 1, SUBGRID_COUNT
  READ(*,*) GRID(I)%SIZE
END DO

! Compute processor subsets for each subgrid, setting
! the LO and HI values
  CALL FIGURE_THE_PROCS ( GRID, number_of_processors() )


! Allocate each subgrid and distribute to the computed processors subset
DO I = 1, SUBGRID_COUNT
   ALLOCATE( GRID(I)%BL(GRID(I)%SIZE) )
   !HPF$ REDISTRIBUTE GRID(I)%BL(BLOCK) ONTO P( GRID(I)%LO : GRID(I)%HI )
END DO

Rationale. Components of derived types can be remapped only if they have the
POINTER attribute in addition to the DYNAMIC attribute. This restriction has been
placed to disallow mappings which cannot be directly specified using HPF directives.
Consider, for instance, the following code fragment:

!HPF$ PROCESSORS P(4)

TYPE DT
   REAL C(100)
!HPF$ DISTRIBUTE C(BLOCK) ONTO P
!HPF$ DYNAMIC C ! Nonconforming
END TYPE DT

TYPE (DT) :: S(10)
...
J = 3
...
!HPF$ REDISTRIBUTE S(J)%C(CYCLIC) ONTO P
...
S(:)%C(2) ...

Here the component C of derived type DT has been declared DYNAMIC. Thus, the array
variable S consists of 10 elements each of which is a structure with a component C
initially distributed block. The REDISTRIBUTE directive remaps the structure com-
ponent C of the Jth element of S so that it is distributed cyclic. Consider now the
mapping of the data object referred to by the expression S(:)%C(2) which picks out
the second element from each of the ten structures that make up the array variable
S. After the redistribution of one of the elements of S (element 3 in this case), each
element of the object will reside on processor P(1) except for the third element, which
will reside on processor P(2). Such a distribution cannot be specified directly using
HPF directives.

The Fortran standard disallows such expressions for components with the POINTER
attribute. In particular, if a part-name in a data reference has the POINTER attribute
then each part-ref to its left must be scalar (F95:6.1.2). Thus, we avoid the above
situation by

• disallowing the remapping of components that do not have the POINTER attribute,
  and

• relying on the Fortran standard to disallow expressions such as the above for
  components with the POINTER attribute.

(End of rationale.)
8.10 New Distribution Formats

This section describes two new distribution formats. The syntax is extended as follows:

H810 extended-dist-format

is BLOCK [ ( int-expr ) ]
or CYCLIC [ ( int-expr ) ]
or GEN_BLOCK ( int-array )
or INDIRECT ( int-array )
or *

Constraint: An int-array appearing in a extended-dist-format of a DISTRIBUTE directive or REDISTRIBUTE directive must be an integer array of rank 1.

Constraint: An int-array appearing in a extended-dist-format of a DISTRIBUTE directive must be a restricted-expr.

Constraint: The size of any int-array appearing with a GEN_BLOCK distribution must be equal to the extent of the corresponding dimension of the target processor arrangement.

Constraint: The size of any int-array appearing with an INDIRECT distribution must be equal to the extent of the corresponding dimension of the distributee to which the distribution is to be applied.

The “generalized” block distribution, GEN_BLOCK, allows contiguous segments of an array, of possibly unequal sizes, to be mapped onto processors. The sizes of the segments are specified by values of a user-defined integer mapping array, one value per target processor of the mapping. That is, the $i$th element of the mapping array specifies the size of the block to be stored on the $i$th processor of the target processor arrangement. Thus, the values of the mapping arrays are restricted to be non-negative numbers and their sum must be greater than or equal to the extent of the corresponding dimension the array being distributed.

The mapping array has to be a restricted expression when used in the DISTRIBUTE directive, but can be an array variable in a REDISTRIBUTE directive. In the latter case, changing the value of the map array after the directive has been executed will not change the mapping of the distributed array.

Let $l$ and $u$ be the lower and upper bounds of the dimension of the distributee, $MAP$ be the mapping array and let $BS(i):BE(i)$ be the resultant elements mapped to the $i$th processor in the corresponding dimension of the target processor arrangements. Then,

\[
BS(1) = l, \\
BE(i) = \min(BS(i) + MAP(i) - 1, u), \\
BS(i) = BE(i - 1) + 1.
\]

Example:

\[
\text{PARAMETER } \{ S = /2, 25, 20, 0, 8, 65/ \}
\]

!HPFS $ PROCESSORS P(6)

  REAL A(100), B(200), new(6)

!HPFS $ DISTRIBUTE A( GEN_BLOCK(S) ) ONTO P
Given the above specification, array elements $A(1:2)$ are mapped on $P(1)$, $A(3:27)$ are mapped on $P(2)$, $A(28:47)$ are mapped on $P(3)$, no elements are mapped on $P(4)$, $A(48:55)$ are mapped on $P(5)$, and $A(56:100)$ are mapped on $P(6)$. The array $B$ is distributed based on the array $new$ whose values are computed at runtime.

Advice to implementors. Accessing elements of an array distributed using the generalized block distribution may require accessing the values of the mapping array at runtime. However, since the size of such an array is equal to that of the processor arrangement, it can in most cases be replicated over all processors.

For dynamic arrays, an independent copy of the mapping array will have to be maintained internally so that a change in the values of the mapping array does not affect the access of the distributed array. (End of advice to implementors.)

There are many scientific applications in which the structure of the underlying domain is such that it does not map directly onto Fortran data structures. For example, in many CFD applications an unstructured mesh (consisting of triangles in 2D or tetrahedra in 3D) is used to represent the underlying domain. The nodes of such a mesh are generally represented by a one-dimensional array while another is used to represent their interconnections. Mapping such arrays using the structured distribution mechanisms, BLOCK and CYCLIC, results in mappings in which unrelated elements are mapped onto the same processor. This in turn leads to massive amounts of unnecessary communication. What is required is a mechanism to map a related set of arbitrary array elements onto the same processor. The INDIRECT distribution provides such a mechanism.

The INDIRECT distribution allows a many-to-one mapping of elements of a dimension of a data array to a dimension of the target processor arrangement. An integer array is used to specify the target processor of each individual element of the array dimension being distributed. That is, the $i$th element of the mapping array provides the processor number onto which the $i$th array element is to be mapped. Since the mapping array maps array elements onto processor elements, the extent of the mapping array must match the extent of the dimension of the array it is distributing. Also, the values of the mapping array must lie between the lower and upper bound of the target dimension of the processor arrangement.

The mapping array has to be a restricted expression when used in the DISTRIBUTE directive, but can be an array variable in a REDISTRIBUTE directive. In the latter case, changing the value of the mapping array after the directive has been executed will not change the mapping of the distributed array.

Example:

```fortran
!HPF$ DYNAMIC B
...
new = ...
!HPF$ REDISTRIBUTE ( B( GEN_BLOCK(new) )

!HPF$ PROCESSORS P(4)
REAL A(100), B(50)
INTEGER map1(100), map2(50)
PARAMETER (map1 = /[1,3,4,3,3,2,1,4, ....])
!HPF$ DYNAMIC B
!HPF$ DISTRIBUTE A( INDIRECT(map1) ) ONTO P
```
!HPF$ DISTRIBUTE map2(BLOCK) ONTO P

map2 = ... 

!HPF$ DISTRIBUTE B(INDIRECT(map2)) ONTO P

Here, the array \( A \) is distributed statically using the constant array \( \text{map1} \). Thus:

\[
\begin{align*}
A(1) & \text{ is mapped onto } P(1), \\
A(2) & \text{ is mapped onto } P(3), \\
A(3) & \text{ is mapped onto } P(4), \\
A(4) & \text{ is mapped onto } P(3), \\
A(5) & \text{ is mapped onto } P(3), \\
A(6) & \text{ is mapped onto } P(2), \\
A(7) & \text{ is mapped onto } P(1), \\
A(5) & \text{ is mapped onto } P(4), \text{ and so on.}
\end{align*}
\]

The array \( B \) is declared dynamic and is redistributed using the mapping array \( \text{map2} \).

Advice to implementors. In general, the \texttt{INDIRECT} distribution is going to be used in the \texttt{REDISTRIBUTE} directive with an array variable as the map array. Also, since the size of the mapping array must be the same as the array being distributed, it will itself be distributed most likely using the \texttt{BLOCK} distribution. This raises several issues. To correctly implement this distribution, the runtime system should maintain a (distributed) copy of the mapping array so that if the program modifies the mapping array, the distribution does not change. Using an array variable as a mapping array implies that the location of each element of the array will not be known until runtime. Thus, a communication may be required to figure out the location of a specific array element. (End of advice to implementors.)

### 8.11 The RANGE Directive

The \texttt{RANGE} attribute is used to restrict the possible distribution formats for an object or template that has the \texttt{DYNAMIC} attribute or a transcriptional distribution format (including pointers).

\[
\begin{align*}
\text{H811} & \quad \texttt{range-directive} & \text{is} & \texttt{RANGE} & \texttt{ranger} & \texttt{range-attr-stuff} \\
\text{H812} & \quad \texttt{ranger} & \text{is} & \texttt{object-name} & \text{or} & \texttt{template-name} \\
\text{H813} & \quad \texttt{range-attr-stuff} & \text{is} & \texttt{range-distribution-list} \\
\text{H814} & \quad \texttt{range-distribution} & \text{is} & \left( \texttt{range-attr-list} \right) \\
\text{H815} & \quad \texttt{range-attr} & \text{is} & \texttt{range-dist-format} & \text{or} & \texttt{ALL} \\
\text{H816} & \quad \texttt{range-dist-format} & \text{is} & \texttt{BLOCK} & \left[ \left( \right) \right] & \text{or} & \texttt{CYCLIC} & \left[ \left( \right) \right] & \text{or} & \texttt{GEN_BLOCK} & \text{or} & \texttt{INDIRECT} & \text{or} & \texttt{*}
\end{align*}
\]
Constraint: At least one of the following must be true:

- The `ranger` has the `DYNAMIC` attribute.
- The `ranger` has the `INHERIT` attribute.
- The `ranger` is specified with a `dist-format-clause` of `*` in a `DISTRIBUTE` or `combined directive`.

Constraint: The length of each `range-attr-list` must be equal to the rank of the `ranger`.

Constraint: The `ranger` must not appear as an alignee in an `ALIGN` or `REALIGN` directive.

Since the length of each `range-attr-list` is the same as the rank of the `ranger`, each `range-attr, R`, in each `range-distribution` corresponds positionally to a dimension `D` of the `ranger`. This dimension `D` in turn either corresponds (though not necessarily positionally) to an axis `A` of the template with which the `ranger` is ultimately aligned, or corresponds to no axis in that template.

With this notation, a `RANGE` attribute on a `ranger` is equivalent to the following restriction:

For at least one `range-distribution` in the `range-distribution-list`, every `range-attr, R`, must either

- be compatible with the distribution format of the corresponding axis `A`, if such a corresponding axis exists, or
- be either `*` or `ALL`, if no such corresponding axis exists.

This compatibility must be maintained by any `DISTRIBUTE` or `REDISTRIBUTE` directive in which the `ranger` appears as a `distributee`, or if the `ranger` has the `POINTER` attribute and is transcriptively distributed, for any target with which the `ranger` becomes associated.

A distribution format of

1. BLOCK is compatible with a `range-dist-format` of BLOCK, BLOCK() or CYCLIC();
2. BLOCK(n) is compatible with a `range-dist-format` of BLOCK(), or CYCLIC();
3. CYCLIC is compatible with a `range-dist-format` of CYCLIC or CYCLIC();
4. CYCLIC(n) is compatible with a `range-dist-format` of CYCLIC();
5. GEN BLOCK(a) is compatible with a `range-dist-format` of GEN BLOCK;
6. INDIRECT(a) is compatible with a `range-dist-format` of INDIRECT;
7. `*` is compatible with a `range-dist-format` of `*`.

All distribution formats are compatible with a `range-dist-format` of `ALL`.

Note that the possibility of a `RANGE` directive of the form

```
!HPF$ RANGE range-attr-stuff-list :: ranger-list
```

is covered by syntax rule H301 for a `combined-directive` using `combined-attribute-extended` as defined in rule H801.

Examples:
Since the ultimate align target of \( X \), the inherited template \( T \) in this case, does not have a second dimension, only a \(*\) or \( \text{ALL} \) can be used in the second dimension of each range/distribution for \( X \).

\[
\text{REAL } A(100, 100, 100)
\]

\[
\text{DISTRIBUTE } A(\text{BLOCK}, *, \text{CYCLIC})
\]

\[
\text{CALL SUB}( A(:, :, 1) ) \quad \text{! Conforming}
\]
\[
\text{CALL SUB}( A(:, :1) ) \quad \text{! Nonconforming}
\]
\[
\text{CALL SUB}( A(1, ::, :) ) \quad \text{! Nonconforming}
\]

--

Given the range directive in the subroutine \( \text{SUB} \), only the first call to \( \text{SUB} \) is conforming. However, all three calls can be made conforming if the range directive above is replaced by the following directive:

\[
\text{!HPF$ RANGE (BLOCK, *), (BLOCK, CYCLIC), (*, CYCLIC) :: } X
\]

### 8.12 The SHADOW Directive

In compiling nearest-neighbor code—for example, in discretizing partial differential equations or implementing convolutions—a standard technique is to allocate storage on each processor for the local array section so as to include additional space for the elements that have to be moved in from neighboring processors. This additional storage is referred to as “shadow edges.” There are conceptually two shadow edges for each array dimension: one at the low end of the local array section and the other at the high end.

In a single routine, the compiler can tell which arrays require shadow edges and allocate this additional space accordingly. However, since the width of the shadow area is dependent on the size of the computational stencil being used, an array may require different shadow widths in different routines. Thus, without interprocedural analysis, an array argument may need to be copied into a space with the appropriate shadow width on each procedure call. A similar data motion would be required to copy the data back to its original location on exit from the subroutine. This unnecessary data motion can be avoided by allowing the user to specify the required shadow width when the array is declared.

The syntax for declaring shadow widths is as follows:
H817  *shadow-directive*       is  *SHADOW*  *shadow-target*  *shadow-attr-stuff*
H818  *shadow-target*        is  *object-name*
      or  *component-name*
H819  *shadow-attr-stuff*   is  (  *shadow-spec-list*  )
H820  *shadow-spec*          is  *width*
      or  *low-width*  :  *high-width*
H821  *width*                is  *int-expr*
H822  *low-width*            is  *int-expr*
H823  *high-width*           is  *int-expr*

Constraint: The *int-expr* representing a *width*, *low-width*, or *high-width* must be a constant *specification-expr* with value greater than or equal to 0.

A *shadow-spec* of *width* is equivalent to a *shadow-spec* of *width*:*width*. Thus, the directives

```
!HPF$  DISTRIBUT (BLOCK) :: A
!HPF$  SHADOW (w) :: A
```

specify that the array *A* is distributed *BLOCK* and is to have a shadow width of *w* on both sides. If *A* is a dummy argument, this gives the compiler enough information to inhibit unnecessary data motion at procedure calls.

Alternatively, different shadow widths can be specified for the low end and high end of a dimension. For example:

```
REAL, DIMENSION (1000) :: A
!HPF$  DISTRIBUT(BLOCK), SHADOW(1:2) :: A
      ....
      FORALL (i = 2, 998)
      A(i) = 0.25 * (A(i) + A(i-1) + A(i+1) + A(i+2))
      END FORALL
```

specifies that only one non-local element is needed at the lower end while two are needed at the high end.

### 8.13 Equivalence and Partial Order on the Set of Mappings

Section 4.5 has to be changed to accommodate the new distributions, the *SHADOW* attribute, and mapping of components of derived types, all introduced as approved extensions. The relevant text now reads as follows; additions are in **bold-face** type.

First, we define a notion of equivalence for *dist-format* specifications:

1. Using the notation \(\equiv\) for the phrase "is equivalent to",
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\[ \begin{align*}
\text{BLOCK} & \equiv \text{BLOCK} \\
\text{CYCLIC} & \equiv \text{CYCLIC} \\
* & \equiv *
\end{align*} \]

\[ \begin{align*}
\text{BLOCK}(n) & \equiv \text{BLOCK}(m) \quad \text{iff } m \text{ and } n \text{ have the same value} \\
\text{CYCLIC}(n) & \equiv \text{CYCLIC}(m) \quad \text{iff } m \text{ and } n \text{ have the same value} \\
\text{CYCLIC} & \equiv \text{CYCLIC}(1) \\
\text{GEN\_BLOCK}(v) & \equiv \text{GEN\_BLOCK}(w) \quad \text{iff the values of corresponding elements of } v \text{ and } w \text{ are equal} \\
\text{INDIRECT}(v) & \equiv \text{INDIRECT}(w) \quad \text{iff the values of corresponding elements of } v \text{ and } w \text{ are equal}
\end{align*} \]

2. Other than this, no two lexically distinct dist-format specifications are equivalent.

This is an equivalence relation in the usual mathematical sense.

Next we define a notion of equivalence for SHADOW attributes (see Section 8.12 for the syntax):

1. The shadow-spec expressions \( w_1 \) and \( w_2 \) are equivalent iff they have the same value.

2. The shadow-spec \( \text{w} \) is equivalent to the shadow-spec \( \text{w};\text{w} \).

3. The shadow-spec \( l_1;h_1 \) is equivalent to the shadow-spec \( l_2;h_2 \) iff \( l_1 \) is equivalent to \( l_2 \) and \( h_1 \) is equivalent to \( h_2 \).

4. Other than this, no two lexically distinct shadow-spec specifications are equivalent.

We then say that two SHADOW attributes are equivalent iff the shadow-spec-list of one is elementwise equivalent to the shadow-spec-list of the other.

Now we define the partial order on mappings: Let \( S \) ("special") and \( G \) ("general") be two data objects.

The mapping of \( S \) is a specialization of the mapping of \( G \) if and only if either

1. \( G \) has the INHERIT attribute, or

2. \( S \) does not have the INHERIT attribute, and the following constraints all hold:

   (a) \( S \) is a named object or structure component, and
   (b) The shapes of the ultimate align targets of \( S \) and \( G \) are the same, and
   (c) Corresponding dimensions of \( S \) and \( G \) are mapped to corresponding dimensions of their respective ultimate align targets, and corresponding elements of \( S \) and \( G \) are aligned with corresponding elements of their respective ultimate align targets, and
   (d) Either

      i. The ultimate align targets of both \( S \) and \( G \) are not explicitly distributed, or
ii. The ultimate align targets of both $S$ and $G$ are explicitly distributed. In this case, the distribution directive specified for the ultimate align target of $G$ must satisfy one of the following conditions:

A. It has no \textit{dist-onto-clause}, or
B. It has a \textit{dist-onto-clause} of \textit{"onto *"}, or
C. It has a \textit{dist-onto-clause} specifying a processor arrangement having the same shape as that explicitly specified in a distribution directive for the ultimate align target of $S$.

and must also satisfy one of the following conditions:

A. It has no \textit{dist-format-clause}, or
B. It has a \textit{dist-format-clause} of \textit{"*"}, or
C. Each \textit{dist-format} is equivalent (in the sense defined above) to the \textit{dist-format} in the corresponding position of the \textit{dist-format-clause} in an explicit distribution directive for the ultimate align target of $S$.

(e) Either $S$ and $G$ both have no \texttt{SHADOW} attribute or they have equivalent \texttt{SHADOW} attributes.

\section*{8.14 Conditions for Omitting Explicit Interfaces}

The requirements in Section 4.6 are extended as follows to account for the possible presence of the \texttt{DYNAMIC} attribute; the addition is in \textbf{bold-face} type:

An explicit interface is required \textit{except} when all of the following conditions hold:

1. Fortran does not require one, \textit{and}
2. No dummy argument is distributed transcriptively or with the \texttt{INHERIT} attribute, \textit{and}
3. \textbf{No dummy argument has the DYNAMIC attribute, and}
4. For each pair of corresponding actual and dummy arguments, either:
   
   (a) They are both implicitly mapped, or
   (b) They are both explicitly mapped and
      
      i. The mapping of the actual argument is a specialization of the mapping of the dummy argument, and
      
      ii. If the ultimate align targets of the actual and dummy arguments are both explicitly distributed, then the \textit{dist-onto-clause} of each must specify processor arrangements with the same shape.

   \textit{and}

5. For each pair of corresponding actual and dummy arguments, either:

   (a) Both are sequential, or
   (b) Both are nonsequential.
8.15 Characteristics of Procedures

The **SHADOW** and **DYNAMIC** attributes, if present, are HPF-characteristics of dummy arguments and procedure return values. To be precise, the definitions in Section 4.7 are rewritten as follows; additions are in **bold-face** type:

- A processor arrangement has one HPF-characteristic: its shape.
- A template has up to three HPF-characteristics:
  1. its shape;
  2. its distribution, if explicitly stated;
  3. the HPF-characteristic (i.e., the shape) of the processor arrangement onto which it is distributed, if explicitly stated.
- A dummy data object has the following HPF-characteristics:
  1. its alignment, if explicitly stated, as well as all HPF-characteristics of its align target;
  2. its distribution, if explicitly stated, as well as the HPF-characteristic (i.e., the shape) of the processor arrangement onto which it is distributed, if explicitly stated;
  3. its **SHADOW** attribute, if explicitly stated.
  4. its **DYNAMIC** attribute, if explicitly stated.
- A function result has the same HPF-characteristics as a dummy data object. Specifically, it has the following HPF-characteristics:
  1. its alignment, if explicitly stated, as well as all HPF-characteristics of its align target;
  2. its distribution, if explicitly stated, as well as the HPF-characteristic (i.e., the shape) of the processor arrangement onto which it is distributed, if explicitly stated;
  3. its **SHADOW** attribute, if explicitly stated.
  4. its **DYNAMIC** attribute, if explicitly stated.
Modern parallel machines achieve their best performance if operations are performed by many processors with each processor accessing its own data. As such, the highest-performing programs will be those for which the computation partitioning and data mapping work in synergy. Three approved extensions provide the means to exploit this symmetry:

1. The **ON** directive partitions computations among the processors of a parallel machine (much as the **DISTRIBUTE** directive partitions the data among the processors).

2. The **RESIDENT** directive asserts that certain data accesses do not require interprocessor data movement for their implementation.

3. The **TASK_REGION** construct provides the means to create independent coarse-grain tasks, each of which can itself execute a data-parallel (or nested task-parallel) computation.

All three constructs are related to the concept of *active processors*, introduced in Section 9.1 below. By assigning computations to processors, the **ON** directive (Section 9.2) defines the active processors. The **RESIDENT** directive (Section 9.3) uses this set and the information given by mapping directives in its assertions of locality. Finally, the **TASK_REGION** construct (Section 9.4) builds its tasks from active processor sets.

### 9.1 Active Processor Sets

*Active processors* are an extension of the idea of processors and processors arrangements as used in HPF 2.0. HPF 2.0 assumes that a (static) set of processors exists, and that the program uses these processors to store data (e.g., through the **DISTRIBUTE** directive) and perform computations (e.g., by execution of **FORALL** statements). Finer divisions of the processor set are seldom mentioned, although they do have uses (e.g., mapping onto processor subsets as in an approved extension, Section 8.7, or in explaining the performance of computations on subarrays). Features such as task parallelism, however, require considering a more dynamic set of processors. In particular, to answer the question “What processor(s) is (are) currently executing?” it is important to define these features.

Simply put, an active processor is one that executes an HPF statement (or group of statements). Active processors perform all operations required to execute the statement(s)
except (perhaps) for the initial access of data and writing of results. Some operations require certain processors to be active, as described below, but for the most part any processor can be active in the execution of any statement. An HPF program begins execution with all processors active. As described in Section 9.2, the ON directive restricts the active processor set for the duration of execution of statements in its scope. Consider this simple example (which has a reasonably intuitive meaning):

```hpflanguage
!HPF$ ON HOME( Z(INDX) )
X(INDX-1) = X(INDX-1) + Y(INDX) * Z(INDX+1)
```

Let X, Y, and Z have the same distribution, which does not replicate data. Following the ON directive, the statement would be executed as follows:

1. The processor owning Z(INDX) is identified as the active processor. On different executions of this ON block, this may be a different processor.

2. The values of X(INDX-1), Y(INDX), and Z(INDX+1) are made available to the active processor. Because of the identical distributions, Y(INDX) is already stored there. Depending on the data distribution and the hardware running the program, retrieving the others might correspond to the active processor loading registers from memory, or it might mean one or two other processors sending messages to the active processor.

3. The active processor performs an addition and a multiplication, using the values sent in the last step.

4. The result is stored to X(INDX-1), which may be on another processor. Again, this may require synchronization or other cross-processor operations.

There are considerable subtleties of this scheme when one of the statements involved is a function or subroutine call. Section 9.2.4 deals with these cases. Advice on the implementation of the ON directive is given in Section 9.2.2 below.

A few additional terms are useful in conjunction with the concept of active processors. If all processors in a set are active, then the set is called an active processor set. The set of all active processors is sometimes called the active processor set. This set is dynamic, and if a statement is executed repeatedly the active processor set may be different each time. In general, an HPF construct can only restrict the active set, not enlarge it. However, if the original active set is partitioned into several independent sets, all partitions may execute simultaneously. This is exactly how the TASK_REGION construct (described in Section 9.4) works.

The universal processor set is the set of all processors available to the HPF program. It is precisely the set of processors that is active when execution of the main program begins.

A processor that is not in the active set is called inactive. (Note that a processor may be inactive with respect to one statement, but active with respect to another. This is common in TASK_REGION constructs.)

It is sometimes necessary to query properties of the active processor set; this is accomplished by the approved extension intrinsics ACTIVE_NUM_PROCS and ACTIVE_PROCS_SHAPE described in Section 12.1.

The data mapped to a processor is said to be resident on it. A replicated object is resident on all of the processors that have a copy of it.
Rationale. It may seem odd at first to concentrate on shrinking the active processor set. However, HPF’s design assumes that all processors are available at the beginning of execution. For example, implementing \texttt{DISTRIBUTE} requires information about the number of processors (in order to determine block sizes, for example) and their identity (in order to allocate the memory and perform data motion). Therefore, the execution model uses a static set of processors that can be subdivided and reunited dynamically. (End of rationale.)

9.1.1 The SUBSET Directive

This subsection explains the interaction of active and inactive processor sets with explicitly mapped data. The rule of thumb is that allocating memory must be done locally; that is, if a processor stores part of an array, then that processor must be active when the array is created. Implications of this rule include:

- Local objects must be stored on a set of active processors, either when their subprogram is invoked or when they are allocated.

- Dummy arguments are always mapped to a set of active processors. Section 9.2.4 explains the mechanism that ensures this.

- Global objects (i.e., objects in \texttt{COMMON} or \texttt{MODULE}s or objects accessed via host association) may be explicitly mapped to inactive processors. However, those processors must have been active when the globals were allocated, whether at program initialization (when all processors were active), or at entry to another subprogram, or on execution of an \texttt{ALLOCATE} statement.

It should be clear from the treatment of local and global objects that declarations may need to refer to two classes of processors arrangements. The first, used mainly for the declaration of global data, consists of arrangements of the universal processor set. These are known as \textit{universal} processors arrangements. Since they always represent the same processors, these serve as a fixed frame of reference, allowing consistent declarations. A \texttt{processors-directive} (Rule H329) defines a universal processors arrangement by default. To accommodate active processors, two slight changes to the rules in Section 3.6 need to be made:

- An HPF compiler is required to accept any \textit{universal} processors arrangement that is scalar, or whose size (i.e., product of the arrangement’s dimensions) is equal to the size of the universal processor set.

- If two \textit{universal} processors arrangements have the same shape, then corresponding elements of the two arrangements are understood to refer to the same abstract processor.

In both cases, the only change is the addition of the word “universal.”

Restricted processors arrangements represent only processors that, at the time the arrangement is declared, are active. They are used for mapping local objects and dummy arguments. To declare a subset processors arrangement, one can use the \texttt{SUBSET} option of \texttt{combined-attribute-extended} (H801), defined on page 145. One can also use the statement form of the \texttt{SUBSET} attribute:


Examples of the two forms are

```hpf
!HPF$ PROCESSORS, SUBSET : : P(NP/4,4)
!HPF$ PROCESSORS Q(ACTIVE_NUM_PROCS())
!HPF$ SUBSET Q
```

As for universal arrangements, there are some modified rules for the use of subset processors arrangements:

- An HPF compiler is required to accept any subset processors arrangement that is scalar, or whose size is equal to the number of active processors, i.e., the number that would be returned by the call `ACTIVE_NUM_PROCS()`.

- If two subset processors arrangements are declared with the same shape and the active processor set has not changed between their declarations, then corresponding elements of the two arrangements are understood to refer to the same abstract processor.

It is important to note that a scalar subset processors arrangement is considered to represent a processor that is active at the time the arrangement is created.

Note that it is permitted for a subset processors arrangements to have fewer than `NUMBER_OF_PROCESSORS()` elements; this reflects the way that the active processor set can shrink. Also note that there is an added condition before two subset processors arrangements are considered identical; this reflects the dynamic nature of the active processor set. Finally, note that a local, subset processors arrangement will be an arrangement of the set of active processors until such time as the active processor set is further restricted by an `ON` directive.

### 9.1.2 Mapping Local Objects and Dummy Arguments

For explicitly mapped local objects without the `SAVE` attribute, the declarations must map all elements of the object onto active processors. This requirement gives rise to several cases:

- If the local object is mapped via a `DISTRIBUTE` directive, then it must be distributed onto a set of active processors. One way, but not the only way, is to use a local, subset processor arrangement as the `dist-target`. If there is no explicit `ONTO` clause, the implementation is free to choose any arrangement of active processors as the `dist-target`.

- A local, universal processors arrangement of size one is always identified with an active processor, and may occur as the `dist-target` for a local object.

- If the local object is mapped by an `ALIGN` directive, then the corresponding elements of the ultimate align target must be distributed exclusively onto active processors. This certainly occurs if the whole of the ultimate align target is distributed onto active processors. It also occurs if the local object is aligned to a section of a target that is distributed onto both active and inactive processors, provided the section that is "hit" by the aligned object is mapped only to active processors. If the align replicates the alignee over one or more axes of the align target, then the distribution of the align target must ensure that all copies of the alignee are mapped to active processors.


In any of these cases, the active processor set is determined at the time that the *DISTRIBUTE* or *ALIGN* becomes instantiated. That is, the mapping directives for *ALLOCATABLE* variables are instantiated when the variable is allocated; other objects have their mapping instantiated when they are declared.

The declaration of subset processors arrangements does not cause processors to become active or inactive; only the execution of *ON* directives does that. In particular, if a program contains no *ON* directives or constructs that modify a program's active processor set, then all processors are always active and all *DISTRIBUTE* directives can use universal arrangements.

Explicitly mapped global objects must have consistent mappings wherever they appear. This will usually (for *COMMON* and *USE* associated objects) be accomplished by distribution onto universal processors arrangements. Notice that the interpretation of an implicit (i.e., missing) *ONTO* clause differs for local and global objects; globals may be distributed onto all processors, while locals must use only active processors. Also note that, since universal processors arrangements are the default for the *PROCESSORS* directive, no modification to the mapping of global objects is needed when active processors are introduced.

Dummy arguments must be explicitly mapped in the same way as local objects, using the rules above. As Section 9.2.4 explains, the effect of this is that dummy arguments are always stored on the active processor set. Other data objects, particularly objects local to the subprogram, can therefore be aligned to the dummy arguments and allocated on the active processor set.

Objects with the *SAVE* attribute must be mapped consistently whenever they come into scope. They are not subject to the restriction of mapping to active processors; where mapping is concerned, they conform to the same rules as global objects.

### 9.1.3 Other Restrictions on Active Processors

In addition to the mapping of locals and dummy arguments, several other constructs are restricted when the active processor set does not match the universal processor set. In general, the intent of these restrictions is to ensure that all processors that are needed for an operation are active when it is performed. In particular, allocating or freeing memory mapped to a processor requires the cooperation of that processor.

For a *REDISTRIBUTE* directive, the active processor set must include:

- All processors that stored any element of the *distributee* before the *REDISTRIBUTE* was encountered, and
- The processors that will store any element of the *distributee* after the *REDISTRIBUTE* is performed.

This implies that all elements of the redistributed object reside on active processors, both before and after the *REDISTRIBUTE* operation. Effectively, this means that all data movement for the *REDISTRIBUTE* will be among active processors. In addition, the processors that owned the *distributee* (or anything aligned to it) beforehand can free the memory, and processors that now own the *distributee* can allocate memory for it.

Similarly, for a *REALIGN* directive, the set of active processors must include all processors that stored elements of the *alignee* before the *REALIGN* and all processors that will store *alignee* elements after the *REALIGN*.

For an *ALLOCATE* statement that creates an explicitly mapped object, the set of active processors must include the processors used by the mapping directive for the allocated object. The allocated object's ultimate align target may fall into one of two classes:
• Distributed with no explicit \texttt{ONTO} clause. (This case includes ultimate align targets with no \texttt{DISTRIBUTE} directive at all.) In this case, the compiler must choose a set of active processors that the object will be stored on.

• Distributed \texttt{ONTO} a section of a processors arrangement. In this case, the specified section must be an arrangement of an active processor set.

For example:

\begin{verbatim}
!HPF$ PROCESSORS P(NUMBER_OF_PROCESSORS())
!HPF$ ON (P(1:4))
  CALL OF_THE_WILD()
  ...

SUBROUTINE OF_THE_WILD()
  INTEGER, ALLOCATABLE, DIMENSION(:) :: A, B, C, D, E, F
!HPF$ PROCESSORS P(NUMBER_OF_PROCESSORS()), ONE_P
!HPF$ PROCESSORS, SUBSET :: Q(ACTIVE_NUM_PROCS())
!HPF$ DISTRIBUTE (BLOCK) :: A, E
!HPF$ DISTRIBUTE (BLOCK) ONTO P(1:4) :: B
!HPF$ DISTRIBUTE (*) ONTO ONE_P :: C
!HPF$ DISTRIBUTE (BLOCK) ONTO Q :: D, F

ALLOCATE (A(100)) ! No explicit ONTO; block size is probably 25
ALLOCATE (B(100)) ! Block size IS 25
ALLOCATE (C(100)) ! On one active processor
ALLOCATE (D(100)) ! On Q(1:4); block size 25
!HPF$ ON HOME(B(1:50)) BEGIN
  ALLOCATE (E(100)) ! No ONTO; E is allocated on Q(1:2)
  ALLOCATE (F(100)) ! Nonconforming since Q(3:4) are inactive
!HPF$ END ON
\end{verbatim}

For a \texttt{DEALLOCATE} statement that destroys an explicitly mapped object, the active processor set must include all processors that own any element of that object. Again, there are two cases for the deallocated object’s ultimate align target:

• Distributed onto a section of a processors arrangement. In this case, the processors that store part of the object must be active when it is deallocated. One way to guarantee this is to ensure that any \texttt{ON} block enclosing the \texttt{DEALLOCATE} statement also encloses the corresponding \texttt{ALLOCATE}.

• Distributed with no explicit \texttt{ONTO} clause. (This case includes ultimate align targets with no \texttt{DISTRIBUTE} directive at all.) In this case, the active processor set must include all the processors that were active when the object was allocated in order to guarantee that the processors that store part of the object are active when it is deallocated. Again, this is ensured if all \texttt{ON} blocks that enclose the deallocation also enclose the allocation operation.

An example may be helpful:
REAL, ALLOCATABLE :: X(:), Y(:)

!HPF$ PROCESSORS P(8)
!HPF$ DISTRIBUTE X(BLOCK) ONTO P(1:4)
!HPF$ DISTRIBUTE Y(CYCLIC)

!HPF$ ON ( P(1:6 )
!HPF$ ON ( P(1:5 )
  ALLOCATE( X(1000), Y(1000)
!HPF$ ON ( P(1:3 )
  ! Point 1
!HPF$ END ON
  ! Point 2
!HPF$ END ON
!HPF$ END ON
!HPF$ END ON
...!
!HPF$ ON ( P(1:4 )
  ! Point 4
!HPF$ END ON
  ! Point 5

At point 1, neither X nor Y can be deallocated, since some of the processors that store their elements might not be active. If the innermost directive were

!HPF$ ON ( P(1:4 )

then X could be safely deallocated because of its explicit ONTO clause; it would still be incorrect to deallocate Y. At points 2 and 3, both X and Y can safely be deallocated. In general, if the deallocation occurs at the same level of ON nesting or at an outer level and the flow of control has not left the outer ON construct, then the deallocation is safe. At point 4 it is correct to deallocate X because its ONTO clause matches the enclosing ON. It is not, however, correct to deallocate Y, since some processors (e.g., P(5)) that were active at the ALLOCATE statement are not active at point 4. This illustrates the care that must be exercised if a DEALLOCATE statement is controlled by an ON clause. One can avoid potential problems by performing the deallocation outside of any ON construct in the same procedure, as at point 5.

It is possible that only a subset of the processors active at allocation time and named in the ONTO clause actually store part of the object:

!HPF$ DISTRIBUTE A(BLOCK(10)) ONTO P(1:4)
  INTEGER, ALLOCATABLE :: A(:)
  ALLOCATE A(10)
!HPF$ ON (P(1))
  DEALLOCATE(A)  ! Correct, because only P(1) owns any part of A

9.2 The ON Directive

The purpose of the ON directive is to allow the programmer to control the distribution of computations among the processors of a parallel machine. In a sense, this is the computational analog of the DISTRIBUTE and ALIGN directives for data. The ON directive does this
by specifying the active processor set for a statement or set of statements. This temporarily
shrinks the active processor set.

If the computations in two ON block executions are not related (for example, if the ON
block executions are two iterations of an INDEPENDENT loop), their ON directives give the
compiler clear instructions for exploiting this potential parallelism.

9.2.1 Syntax of the ON Directive

There are two flavors of the ON directive: a single-statement form and a multi-statement
form. The syntax for these directives is

H902  on-directive is ON on-stuff
H903  on-stuff is home [ , resident-clause ] [ , new-clause ]
H904  on-construct is
directive-origin block-on-directive
    block
    directive-origin end-on-directive
H905  block-on-directive is ON on-stuff BEGIN
H906  end-on-directive is END ON
H907  home is HOME ( variable )
or HOME ( template-elmt )
or ( processors-elmt )
H908  template-elmt is template-name [ ( section-subscript-list ) ]
H909  processors-elmt is processors-name [ ( section-subscript-list ) ]

The nonterminal resident-clause will be defined in Section 9.3. For the present, it suffices
to say that this is a form of the RESIDENT directive mentioned in the introduction.
The home is often called the HOME clause, even in cases where the keyword HOME is not used.
Note that variable is a Fortran syntax term that means (roughly) “a reference, including
an array element, array section, or derived type field”; variable does not include template
or processor elements because they are defined only in directives. Note also that block is a
Fortran syntax term for “a series of statements treated as a group”—for example, the body
of a DO construct.

The on-directive is a kind of executable-directive (see rule H205). This means that an
on-directive can appear wherever an executable statement can.

An on-construct is a Fortran executable-construct. This syntax implies that such con-
structs can be nested, and if so they will be properly nested.

Rationale. Note the use of parentheses in the last option of the home rule (involving
processors-elmt). This prevents the following ambiguity:

    INTEGER X(4)  ! X(I) will be on processor I
    !HPF$ PROCESSORS HOME(4)
    !HPF$ DISTRIBUTE X(BLOCK)
    X = (/ 4,3,2,1 /)
If the parentheses were not required, where should the computation be done?

1. Processor HOME(2) (i.e., the owner of X(2))?  
2. Processor HOME(3) (i.e., use the value of X(2), before the assignment)?  
3. Processor HOME(4) (i.e., use the value of X(2), after the assignment)?

The definition of ON clearly indicates that interpretation 1 is correct. One can get the effect of interpretation 2 by the directive

```fortran
!HPFS$ ON (HOME(X(2)))
```

There is no way to get the effect of interpretation 3. Introducing reserved keywords into Fortran was suggested as a better solution to this problem, but was seen as too large a change to the underlying language. (*End of rationale.*)

### 9.2.2 Semantics of the ON Directive

The ON directive restricts the active processor set for a computation to those processors named in its home. The computation controlled is either the following Fortran statement (for a on-directive or the contained block for a block-on-directive. We refer to the controlled computation as the ON-block.

That is, it advises the compiler to use the named processor(s) to perform the ON block. Like the mapping directives ALIGN and DISTRIBUTE, this is advice rather than an absolute commandment; the compiler may override an ON directive. Also like ALIGN and DISTRIBUTE, the ON directive may affect the efficiency of computation, but not the final results.

*Advice to implementors.* If the compiler may override the user’s advice in an ON directive, then the compiler should also offer the user an option to force all directives to be obeyed. Because dummy arguments and local objects are required to be mapped onto active processors, an HPF compiler that fails to heed the programmer’s advice with respect to the active processor set may also be required to ignore some of the programmer’s advice concerning data mapping. (*End of advice to implementors.*)

The single-statement ON directive sets the active processor set for the first non-comment statement that follows it. It is said to apply to that statement. If the statement is a compound statement (e.g., a DO loop or an IF-THEN-ELSE construct), then the ON directive also applies to all statements nested therein. Similarly, the ON construct applies the initial ON clause to—i.e., sets the active processor set for—all statements up to the matching END ON directive.

The evaluation of any function referred to in the home expression is not affected by the ON directive; these functions are called on all processors active when control reached the directive. Thus,

```fortran
!HPFS$ ON HOME( P(1: (ACTIVE_NUM_PROCS() - 1)) ) ...
```
is a reasonable way to idle one active processor, and is not paradoxically self-referential.

The HOME clause can name a program object, a template, or a processors arrangement. For each of these possibilities, it can specify a single element or multiple elements. This is translated into the processor(s) executing the ON block as follows:

- If the HOME clause names a program object, then every processor owning any part of that object should execute the ON block. For example, if A is an explicitly mapped array, then

  !HPF$ ON HOME ( A(2:4) )

  tells the compiler to perform the statement on the processors owning A(2), A(3), and A(4). If A were distributed BLOCK, this might be one processor; if it were distributed CYCLIC, it would be three processors (assuming that many processors were available). Extra copies of elements created by a SHADOW directive (H817) are not taken into consideration by the HOME clause.

- If the HOME clause names a template element or section, then every processor owning any element of the template element or section should execute the ON block. The example above applies here as well, if A is a template rather than an array.

- If the HOME clause names a processors arrangement, then the processor(s) referenced there should execute the ON block. For example, if P is a processors arrangement, then

  !HPF$ ON ( P(2:4) )

  will execute the following statement on the three processors P(2), P(3), and P(4).

In every case, the ON directive specifies the processor(s) that should perform a computation. More formally, it sets the active processors for the statements governed by the ON directive, as described in Section 9.1. That section also describes how some statements (notably ALLOCATE and dynamic remapping directives) require that particular processors be included in the active set. If one of these constructs occurs in the ON block and the active processor set does not contain all the required processors, then the program is not standard-conforming.

Note that the ON directive only specifies how computation is partitioned among processors; it does not indicate processors that may be involved in data transfer. Also, the ON clause by itself does not guarantee that its body can be executed in parallel with any other operation. However, placing the compilation can have a significant effect on data locality. As later examples will show, the combination of ON and INDEPENDENT can also provide control over the load balance of parallel computations.

Advice to implementors. If the HPF program is compiled into Single-Program-Multiple-Data (SPMD) code, then the ON clause can always be implemented (albeit inefficiently) by having all processors compare their processor id and an id (or list of ids) generated from the HOME clause. (Similar naive implementations can be constructed in other paradigms as well.) If the ON clause will be executed repeatedly, for example in a DO loop, it is worthwhile to invert this process. That is, instead of all processors executing all the HOME clause tests, the compiler should determine the range of loop iterations that will test true on the given processor. (See the “Advice to implementors” in Section 9.2.3 for more details.) For example, consider the following complex case:
DO I = 1, N
   !HPF$ ON HOME( A(MY_FCN(I)) ) BEGIN
...  
   !HPF$ END ON
END DO

Here, the generated code can perform an "inspector" (i.e., a skeleton loop that only evaluates the HOME clause of each iteration) to produce a list of iterations assigned to each processor. This list can be produced in parallel, since MY_FCN must be side-effect free (at least, the programmer cannot rely on any side effects). However, distributing the computation of HOME to all processors may require unstructured communications patterns, possibly negating the advantage of parallelism. In general, more advanced compilers will be able to efficiently invert more complex HOME clauses. It is recommended that the abilities (and limitations) of a particular compiler be documented clearly for users.

Note that processors "screened out" by the naive implementation may still be required to participate in data transfer. If the underlying architecture allows one-sided communication (e.g., shared memory or GET/PUT), this is not a problem. On message-passing machines, a request-reply protocol may be used. This requires the inactive processors to enter a wait loop until the ON block completes, or requires the runtime system to handle requests asynchronously. Again, it is recommended that the documentation tell programmers which cases are likely to be efficient and which inefficient on a particular system. (End of advice to implementors.)

Advice to users. The form of the HOME in an ON directive can be arbitrarily complex. This is a two-edged sword; it can express very complicated computation partitioning, but the implementation of these partitions may not be efficient. More concretely, it may express a perfectly load-balanced computation, but force the compiler to serialize the computation to implement the HOME clauses. Although the amount of overhead for an ON clause will vary based on the HPF code, the compiler, and the hardware, one can expect that compilers will generate very good code based solely on array mappings or a named processors arrangement, and progressively worse code as the complexity of the HOME increases. A rough measure of the complexity of an ON directive is the amount of run-time data used to compute it; for example, a constant offset is fairly simple, while a permutation array is very complex. See Section 9.2.3 below for more concrete examples of this phenomenon.

It should also be noted that the ON clause does not change the semantics of a program, in the same sense that DISTRIBUTE does not change semantics. In particular, an ON clause by itself does not change sequential code into parallel code, because the code in the ON block can still interact with code outside the ON block. (To put it another way, ON does not spawn processes.) (End of advice to users.)

It is legal to nest ON directives, if the set of active processors named by the inner ON directive is included in the set of active processors from the outer directive. The syntax of on-construct automatically ensures that it is properly nested inside other compound statements, and that compound statements properly nest inside of it. As with other Fortran compound statements, transfer of control to the interior of an on-construct from outside the block is prohibited: an on-construct may be entered only by executing the (executable) ON directive.
Transfers within a block may occur. However, HPF also prohibits transfers of control from the interior of an _on-construct_ to outside the _on-construct_, except by "falling through" the _END ON_ directive. Note that this is stricter than in ordinary Fortran. If _ON_ clauses are nested, then the innermost _home_ effectively controls execution of the statement(s). A programmer can think of this as successively restricting the set of processors at each level of _ON_ nesting; clearly, the last restriction must be the strongest. Alternately, the programmer can think of this as a fork-join approach to nested parallelism.

_Rationale_. The restrictions about control flow into and out of an _ON_ block essentially make it a single-entry single-exit region, thus simplifying the semantics considerably. (End of rationale.)

If an _ON_ directive includes a _NEW_ clause, the meaning is the same as a _NEW_ clause in an _INDEPENDENT_ directive. The operation of the program would be identical if the _NEW_ variables were allocated anew, and distributed onto the active processors, on every entry to the _ON_ directive's scope, and deallocated on exit from the _ON_ block. That is, the _NEW_ variables are undefined on entry (i.e., assigned before use in the _ON_ block) and undefined on exit (i.e., not used after the _ON_ block, unless first reassigned). In addition, _NEW_ variables cannot be remapped in the _ON_ clause's scope, whether by REALIGN, REDISTRIBUTE, or by argument association (at subroutine calls). If a variable appears in a _NEW_ clause but does not meet these conditions, then the program is not HPF-conforming. _NEW_ variables are not considered by any nested _RESIDENT_ directives, as detailed in Section 9.3.

The _NEW_ variables are implicitly reallocated and remapped onto the active processors on entry to the _ON_ block. For this reason, there are restrictions on their explicit mappings.

- An _ON_ block _NEW_ variable may not occur as an alignee.
- An _ON_ block _NEW_ variable may occur as a distributee only if there is no _ONTO_ clause.

```fortran
!HPF$ Distribute X(BLOCK, *)
!HPF$ Distribute Y ONTO P             ! Nonconforming due to ONTO clause
!HPF$ Align With X :: Z              ! Nonconforming; ALIGN forbidden
!HPF$ ON (P(1:4), NEW(X, Y, Z), BEGIN
!HPF$ END ON
```

_Rationale_. _NEW_ clauses provide a simple way to create temporary variables. This ability is particularly important when _RESIDENT_ directives come into play, as will be clear below. (End of rationale.)

_Advice to implementors_. Because they are not used outside of the _ON_ blocks, _NEW_ variables need not be kept consistent before and after _ON_ clauses. Therefore, no communication outside of the active processor set, determined by the _ON_ directive, is required to implement them. Scalar _NEW_ variables should be replicated over the active processor set, or allocated in memory areas shared by the active processor set. Note that memory must be dynamically allocated if there is a possibility that multiple instances of the _ON_ block could be active concurrently. This is similar to the requirements for implementing _NEW_ variables in _INDEPENDENT_ loops. (End of advice to implementors.)
9.2.3 Examples of ON Directives

The following are valid examples of ON directives. Most of them illustrate idioms that programmers might want to use, rather than contrived situations. For simplicity, the first several examples assume the following array declarations:

```
REAL A(N), B(N), C(N), D(N)
!HPF$ DISTRIBUTED A(BLOCK), B(BLOCK), C(BLOCK), D(BLOCK)
```

One of the most commonly requested capabilities for HPF is to control how loop iterations were assigned to processors. (Historically, the ON clause first appeared to perform exactly this role in the Kali FORALL construct.) This can be done by the ON directive, as shown in the following examples:

```
!HPF$ INDEPENDENT
DO I = 2, N-1
   !HPF$ ON HOME(A(I))
   A(I) = (B(I) + B(I-1) + B(I+1))/3
END DO

!HPF$ INDEPENDENT
DO J = 2, N-1
   !HPF$ ON HOME(A(J+1)) BEGIN
      A(J) = B(J+1) + C(J+1) + D(J+1)
   !HPF$ END ON
END DO
```

The ON directive in the I loop sets the active processor for each iteration of the loop to be the processor that stores A(I). In other words, it advises the compiler to have each processor run over its own section of the A array (and therefore B as well). The references to B(I-1) and B(I+1) must be fetched from off-processor for the first and last iterations on each processor (except for the boundary processors); note that those processors are not mentioned in the HOME clause. The ON directive in the J loop similarly sets the active set for each iteration, but advises the compiler to shift computations. As a result, each processor does a vector sum of its own sections of B, C, and D, stores the first element of the result on the processor to its left, and stores the rest of the result (shifted by one) in A. It is worth noting that the directives would still be valid (and minimize nonresident data accesses) if the arrays were distributed CYCLIC, although the number of nonresident references would be much higher.

Advice to implementors. It is highly recommended that compilers concentrate on optimizing DO loops with a single ON clause including the entire loop body. Schematically, the code will be:

```
DO i = lb, ub, stride
   !HPF$ ON HOME(array(f(i))) BEGIN
      body
   !HPF$ END ON
END DO
```
where array has some data mapping. Assume the mapping gives processor \( p \) the
elements \( \text{myset}(p) \). (In a BLOCK distribution, for example, \( \text{myset}(p) \) is a contiguous
range of integers.) Then the generated code on processor \( p \) should be

\[
\text{DO } i \in [\text{lb}, \text{ub} : \text{stride}] \cap f^{-1}(\text{myset}(p))
\]

body

\text{END DO}

(This schematic does not show where communication or synchronization must be
placed; that must be derived from analysis of the body.) Moreover, \( f \) is likely to be
the identity function or a linear function with integer coefficients, both of which can
be inverted easily. Given this, techniques for iterating through the set can be found
in several recent conferences. \( \text{End of advice to implementors.} \)

\textbf{Advice to users.} One can expect the \( i \) loop above to generate efficient code for the
computation partitioning. In effect, the compiler will arrange for each processor to
iterate over its own section of array \( A \). The \( J \) loop is slightly more complex, since the
compiler must find the inverse of the \textit{HOME} clause's subscripting function. That is,
the compiler must solve \( K=J+1 \) for \( J \), where \( K \) ranges over the resident elements of
\( A \). Of course, in this case \( J=K-1 \); in general, linear functions can be inverted by the
compiler. (It should be pointed out, however, that complex combinations of \textit{ALIGN}
and \textit{DISTRIBUTE} may make the description of \( K \) unwieldy, and this may add overhead
to the inversion process.) \( \text{End of advice to users.} \)

Sometimes it is advantageous to “split” an iteration between processors. The following
case shows one example of this:

\[
!\text{HPF$ \text{INDEPENDENT}} \\
\text{DO } I = 2, N-1 \\
\quad !\text{HPF$ \text{ON HOME}(A(I))} \\
\quad A(I) = (B(I) + B(I-1) + B(I+1))/3 \\
\quad !\text{HPF$ \text{ON HOME} C(I+1)} \\
\quad C(I+1) = A(I) \times D(I+1) \\
\quad \text{END DO}
\]

Here, the active processor sets for the two statements in the loop body are different.
Due to the first \textit{ON} clause, the reference to \( A(I) \) is resident in the first statement. The
second \textit{ON} clause makes \( A(I) \) nonresident (for some values of \( I \)) there. This maximizes the
data locality in both statements, but does require data movement between the two.

\textbf{Advice to implementors.} If there are several non-nested \textit{ON} clauses in a loop, then
the schematic above needs to be generalized. In essence, the iteration range for each
individual \textit{ON} clause must be generated. A processor will then iterate over the union
of these ranges. Statements guarded by an \textit{ON} directive must now be guarded by an
explicit test. In summary, the code for

\[
\text{DO } i = \text{lb, } \text{ub, } \text{stride} \\
\quad !\text{HPF$ \text{ON HOME}(array_1(f_1(i)))} \\
\quad stmt_1 \\
\quad !\text{HPF$ \text{ON HOME}(array_2(f_2(i)))}
\]
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\[ stmt_2 \]
\[ \text{END DO} \]

on processor \( p \) becomes
\[ set_1 = \{ lb : \text{ab : stride} \cap f_1^{-1}(\text{myset}_1(p)) \} \]
\[ set_2 = \{ lb : \text{ab : stride} \cap f_2^{-1}(\text{myset}_2(p)) \} \]
\[ \text{DO } i \in set_1 \cup set_2 \]
\[ \text{IF } (i \in set_1) \text{ THEN} \]
\[ \text{stmt1} \]
\[ \text{END IF} \]
\[ \text{IF } (i \in set_2) \text{ THEN} \]
\[ \text{stmt2} \]
\[ \text{END IF} \]
\[ \text{END DO} \]

where \( \text{myset}_1(p) \) is the resident set for \( \text{array}_1 \), and \( \text{myset}_2(p) \) is the resident set for \( \text{array}_2 \). (Again, synchronization and communication must be handled by other means.) Code transformations such as loop distribution and loop peeling can be used to eliminate the tests in many cases. They will be particularly profitable if there are data dependences between the \texttt{ON} blocks. (End of advice to implementors.)

Advice to users. Splitting an iteration like this is likely to require either additional tests at runtime or additional analysis by the compiler. Even if the compiler can generate low-overhead scheduling for the individual \texttt{ON} clauses, combining them is not necessarily low-overhead. The locality benefits must be rather substantial for this to pay off, but there are cases where multiple \texttt{ON} clauses are valuable. (All these statements are particularly true if one \texttt{ON} block uses data computed in another one.) (End of advice to users.)

Because \texttt{ON} clauses nest naturally, they can be useful for expressing parallelism along different dimensions. Consider the following examples:

\begin{verbatim}
  REAL X(M,M)
  !HPF$ DISTRIBUTE X(BLOCK,BLOCK)

  !HPF$ INDEPENDENT, NEW(I)
  DO J = 1, M
    !HPF$ ON HOME(X(:,J)) BEGIN
      DO I = 2, M
        !HPF$ ON HOME(X(I,J))
        X(I,J) = (X(I-1,J) + X(I,J)) / 2
      END DO
      !HPF$ END ON
  END DO
\end{verbatim}
The active processor set for each iteration of the J loop is a column of the (presumably universal) processors arrangement. The I loop further subdivides the computation, giving each processor responsibility for computing the elements it owns. Many compilers would have chosen this computation partitioning automatically for such a simple example. However, the compiler might have attempted to fully parallelize the outer loop, executing each inner loop sequentially on one processor. (This might be attractive on a machine with very fast communications.) By inserting the ON clauses, the user has advised against this strategy, thus trading additional locality for restricted parallelism. Notice that the ON directive neither requires nor implies the INDEPENDENT assertion. In both nests, each iteration of the I loop depends on the preceding iteration, but the ON directive can still partition the computation among processors. The ON directive does not automatically make a loop parallel.

Advice to implementors. “Dimension-based” nesting, as above, will probably be a common case. The HOME clauses can be inverted at each level, treating indices from outer loops as run-time invariants. (End of advice to implementors.)

Advice to users. Nested ON directives will tend to have efficient implementations if their HOME clauses refer to different dimensions of the processors arrangements, as in the above example. This minimizes the interaction between the levels of the loops, simplifying the implementation. (End of advice to users.)

Consider the following variation on the above example:

```fortran
!HPF$ DISTRIBUTE Y(BLOCK,*)

!HPF$ INDEPENDENT, NEW(I)
DO J = 1, M
  !HPF$ ON HOME(Y(:,J)) BEGIN
    DO I = 2, M
      !HPF$ ON HOME(Y(I,J))
      Y(I,J) = (Y(I-1,J) + Y(I,J)) / 2
    END DO
  !HPF$ END ON
END DO
```

Note that the ON clauses have not changed, except for the name of the array. The interpretation is similar to the above, except that the outer ON directive assigns each iteration of the J loop to all of the processors. The inner ON directive again implements a simple owner-computes rule. The programmer has directed the compiler to distribute a serial computation across all the processors. There are a few scenarios where this is more efficient than parallelizing the outer loop:

1. Parallelizing the outer loop will generate many nonresident references, since only a part of each column is on any processor. If nonresident references are very expensive (or if M is relatively small), this overhead may outweigh any gain from parallel execution.

2. The compiler may take advantage of the INDEPENDENT directive to avoid inserting any synchronization. This allows a natural pipelined execution. A processor will execute
its part of the I loop for one value of J, then immediately go on to the next J iteration.
Thus, the first processor will start on J=2 while the second receives the data it needs (from processor one) for J=1. (A similar pipeline would develop in the X example above.)

Clearly, the suitability of these ON clauses will depend on the underlying parallel architecture.

Advice to users. This example points out how ON may improve software engineering. While the “value” of HOME(X(I)) will change if X’s mapping changes, its intent will usually stay the same - run the loop “aligned with” the array X. Moreover, the form of the clauses is portable, and they simplify experimenting with alternative computation partitioning. Both qualities are similar to the advantages of DISTRIBUTE and ALIGN over low-level data layout mechanisms. (End of advice to users.)

ON directives are particularly useful when the compiler cannot accurately estimate data locality, for example when the computation uses indirection arrays. Consider three variations of the same loop:

```fortran
REAL X(N), Y(N)
INTEGER IX1(M), IX2(M)
!HPF$ DISTRIBUTE X(BLOCK), Y(BLOCK)
!HPF$ DISTRIBUTE IX(BLOCK), IY(BLOCK)

!HPF$ INDEPENDENT
DO I = 1, N
  !HPF$ ON HOME( X(I) )
  X(I) = Y(IX(I)) - Y(IY(I))
END DO

!HPF$ INDEPENDENT
DO J = 1, N
  !HPF$ ON HOME( IX(J) )
  X(J) = Y(IX(J)) - Y(IY(J))
END DO

!HPF$ INDEPENDENT
DO K = 1, N
  !HPF$ ON HOME( X(IX(K)) )
  X(K) = Y(IX(K)) - Y(IY(K))
END DO
```

In the I loop, each processor runs over its section of the X array. (That is, the active processor for iteration I is the owner of X(I).) Only the reference X(I) is guaranteed to be resident. (If M ≠ N, then IX and IY have a different block size than X, and thus a different mapping.) However, if it is usually the case that X(I), Y(IX(I)), and Y(IY(I)) are located on the same processor, then this choice of active processors may be the best available. (If X(I) and one of the other references are always on the same processor, then the programmer should add the RESIDENT clause as explained in Section 9.3.) In the next loop, iteration J’s
active processor is the owner of IX(J). Because IY has the same distribution as IX, reference IY(J) is always resident as well as IX(J). This is the most common array reference class in the loop, so it minimizes the number of nonresident data references in the absence of any special properties of IX and IY. It may not evenly balance the load among processors; for example, if \( \lceil N=M/2 \rceil \) then half the processors will be idle. As before, if the values in IX or IY ensure that one of the Y references is always resident, a RESIDENT assertion should be added. In the K loop, only reference Y(IX(K)) is guaranteed to be resident (because Y and X have the same distribution). However, the values stored in IX and IY may ensure that Y(IY(K)) and X(K) are always resident. Even if the three REAL values are not always, but merely “usually” on the same processor, this may be a good computation partitioning for both locality and parallelism. However, these advantages must be weighed against the cost of computing this partitioning. Since the HOME clause depends on a (presumably large) array of runtime values, substantial time may be required to determine which iterations are assigned to each processor. It should be clear from this discussion that there is no magic solution for handling complex computation partitionings; the best answer is usually a combination of application knowledge, careful data structure design (including ordering of the elements), and efficient compilation methodology and runtime support.

Advice to implementors. The K loop is the situation that the inspector strategy described above was designed for. If there is an outer loop around any of these examples, and that loop does not modify the distribution of X or the values of IX, then a record of each processor’s iterations can be saved for reuse. The cost is at worst linear in the sizes of the arrays. (*End of advice to implementors.*)

Advice to users. It is unlikely that any current production compiler will generate low-overhead code for K loop. The difference from previous examples is that the HOME clause is not a function that can be easily inverted by the compiler. Some compilers may choose to execute every iteration on all processors, testing the HOME clause at run-time; others may pre-compute a list of iterations for every processor. Of course, the cost of computing the list will be substantial.

In practice, one would make all the arrays the same size to avoid some of the alignment problems above; the example was written this way for pedagogical reasons, not as an example of good data structure design. (*End of advice to users.*)

9.2.4 ON Directives Applied to Subprogram Invocations

The key rule about ON directives when applied to subprogram invocations is that the invocation does not change the active processor set. In effect, the callee inherits the caller’s active processors. Thus,

```plaintext
!HPF$ PROCESSORS P(10)
!HPF$ DISTRIBUTE X(BLOCK) ONTO P

!HPF$ ON ( P(1:3) )
   CALL PERSON_TO_PERSON()
!HPF$ ON ( P(4:7) )
   CALL COLLECT( X )
```

calls PERSON_TO_PERSON on three processors, while it calls COLLECT on four. The actual argument to COLLECT does not reside completely on the active set of processors. This is
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allowed, with appropriate declarations of the corresponding dummy argument as explained below.

The above rule has interesting implications for data distributions within the called routine. In particular, dummy arguments must be declared under the same restrictions as local objects, thus ensuring that the dummy is always stored on the active processor set. This does not imply that the corresponding actual argument is local, however. Consider the possibilities for how a dummy can be explicitly mapped:

- **Prescriptive mapping**: If the actual is not mapped on the active processor set, it will be remapped. This is exactly analogous to remapping a BLOCK-distributed array to CYCLIC via a prescriptive mapping.

- **Descriptive mapping**: The user is asserting that the actual is already mapped onto the set of active processors. If the assertion is true, then the dummy is already stored locally; if not, then the compiler inserts a remapping operation (and reports a warning, following the recommendations in Section 4).

- **Transcriptive mapping**: In this case, a new restriction must be made to allow efficient access to the dummy argument. If a dummy is transscriptively mapped, then the actual argument must be resident on the active processor set at the time of the invocation. This may be checked at run-time.

In summary, a dummy argument is always mapped to the set of active processors, although the actual argument need not be (except in the case of transcriptive mappings).

**Rationale.** The treatment of dummy arguments as local objects is consistent with all previous Fortran (and FORTRAN) standards. Moreover, it has the advantage that it reflects the usual expectations and wishes of programmers. Dummy arguments are not expected to create great inefficiencies in Fortran programs; ensuring that they are always stored locally tends to reinforce that expectation. Also, programmers are used to "pass by reference" behavior, in which arguments are not copied; the restrictions on data mapping to active processor sets allow this implementation when the data is not remapped on subprogram call. One case of this deserves special mention—transcriptive mappings. If the programmer wants to keep the data in place (the usual expectation of INHERIT and related features) and control which processors execute the computation (the meaning of ON), then the basic principles of active sets (set forth in Section 9.1) imply that the data must be resident before the call is made. When remapping occurs due to explicit directives, then surely the user expects a communication cost to accompany the remapping.

It should also be noted that these rules do not invalidate any HPF programs written without using the ON directive. In those programs, the active processor set never changes (at least, not from the view of the language). Therefore, subset and universal processors arrangements can be used interchangeably, and the restriction on use of transcriptive mappings is obeyed automatically. *(End of rationale.)*

**Advice to implementors.** These restrictions imply that accesses to dummy arguments never require one-sided communication if the argument is explicitly mapped and the ON clause is used. Of course, accesses to global data may still run into serious complications. If the compiler itself partitions the computation, it is not restricted by the ON directive rules. *(End of advice to implementors.)*
Advice to users. The idea to remember in calling subprograms from an **ON** block is this: make sure that the actual arguments are stored on the active set. If the subroutine interface uses transcriptive ("take anything") mappings, then this is a requirement. If the subroutine uses any other type of mapping, then having resident actual arguments may avoid the expense of remapping data. (Of course, it does not by itself guarantee that remapping doesn't occur—a prescriptive interface can force a **BLOCK**-to-**CYCLIC** redistribution—but it does ensure that the remapping is between active processors. This allows simpler and more efficient collective communications operations to be generated in the runtime system.) (End of advice to users.)

Let us return to the previous example:

!HPF$ PROCESSORS P(10)
!HPF$ DISTRIBUTED X(BLOCK) ONTO P

!HPF$ ON P(4:7)
CALL COLLECT( X )

If COLLECT were declared as

```fortran
SUBROUTINE COLLECT( A )
!HPF$ DISTRIBUTED A(CYCLIC)
```

then the call will be executed as follows:

1. X will be remapped from **BLOCK** on 10 processors (i.e., all of P) to **CYCLIC** on 4 processors (i.e., P(4:7)). This will be a many-to-many exchange pattern.

2. COLLECT will be called on processors P(4), P(5), P(6), and P(7). Accesses to A within the subroutine will be satisfied from the redistributed array on those processors.

3. A will be remapped back to the distribution of X. This is the inverse of step 1.

Note that the distribution of A is onto 4 processors (the active processor set inside the call), not onto the universal processor set. If the interface is

```fortran
SUBROUTINE COLLECT( A )
!HPF$ DISTRIBUTED A(BLOCK)
```

then the process would be the same, except that there would be a remapping from **BLOCK** on 10 processors to **BLOCK** on 4 processors. That is, the block size would increase by 2.5 times (with related shuffling of data) and then revert to the original. Again, it is important to note that the distribution of A is onto the active processor set rather than onto all of P.

The similar examples

```fortran
REAL X(100,100), Y(100,100)
!HPF$ PROCESSORS P(4), Q(2,2)
!HPF$ DISTRIBUTED X(BLOCK,* ) ONTO P
!HPF$ DISTRIBUTED Y(BLOCK,BLOCK) ONTO Q

INTERFACE
  SUBROUTINE A_CAB( B )
```
REAL B(:)
!HPF$  DISTRIBUT B *(BLOCK)
END INTERFACE

!HPF$  ON ( P(4:7) )
    CALL A_CAB( X( 1:100, 1 )
!HPF$  ON HOME( X(1:100,1) )
    CALL A_CAB( X(1:100,100) )
!HPF$  ON HOME( Y(1:100,1) )
    CALL A_CAB( Y(1:100,1) )
!HPF$  ON HOME( Y(99,1:100) )
    CALL A_CAB( Y(99,1:100) )

can be explained as follows. Calling A_CAB(1:100,1) on P(4:7) will produce a remapping from 10 processors to 4, as in the example above. (The compiler would be expected to produce a warning in this case, as explained in Section 4.) Calling A_CAB(X(1:100,100)) on HOME(X(1:100,1)) produces no such remapping (or warning), because the active processor set does not change; therefore, the descriptive mapping correctly asserts that the data is already on the right processors. The last two examples, calling A_CAB(Y(1:100,1)) and A_CAB( Y(99,1:100) ) on the homes of their arguments, are also accomplished without remapping. In both cases, the actual arguments are mapped BLOCK-wise onto a subset of the processors (a column of Q in the first case, a row of Q in the second). Some compilers may not be able to generate code for these more complex examples, however.

Two examples of transcriptive mapping are also useful:

! Assume
! PROCESSORS P(4)
! is declared in a module
    REAL X(100)
!HPF$  DISTRIBUT X(CYCLIC(5)) ONTO P

INTERFACE
    SUBROUTINE FOR_HELP( C )
        REAL C(:)
!HPF$  INHERIT C
END INTERFACE

!HPF$  ON HOME( X(11:20) )
    CALL FOR_HELP( X(11:20) )
!HPF$  ON ( P(1) )
    CALL FOR_HELP( X(51:60) )  ! Nonconforming

The first example is valid—the actual argument is (trivially) distributed on the active processor set. The second example is invalid—for example, element X(51) is stored on P(3), which is not in the active processor set for the call. The second example would be valid if the ON directive specified P(3:4) or HOME(X(11:20)), both of which map to the same processor set.

Calls to EXTRINSIC subprograms also deserve mention. The “standard” HPF 2.0 description of calling an EXTRINSIC (Section 6) says in part:
A call to an extrinsic procedure must be semantically equivalent to a call of an ordinary HPF procedure. Thus a call to an extrinsic procedure must behave as if the following actions occur:

1. Exactly the same set of processors are visible to the HPF environment before and after the subprogram call.

This constraint is changed to read

- Exactly the same set of active processors are available to the HPF environment before and after the subprogram call.
- Exactly the same universal processor set is visible to the HPF environment before and after the subprogram call.

The intent is the same as in the original language design. Processors where data is stored cannot appear or disappear; nor may the set of processors executing the program change without notice to the program. Similarly, some extrinsic kinds specify “all processors must be synchronized” or “execution of a local procedure on each processor”; such language is understood to mean “all active processors must be synchronized” or “execution of a local procedure on each active processor.”

Rationale. This gives the combination of EXTRINSIC procedures and ON directives a fork-join model of parallelism, which seems to be both natural and semantically clean. (End of rationale.)

If a procedure uses alternate return, then the target of the return must be have the same active processor set as the CALL statement. In effect, this means that labels passed as arguments must refer to statements in the same ON block as the CALL statement.

Rationale. This constraint is similar to the prohibition against jumping out of an ON block, and has the same justification. (End of rationale.)

Explicit use of CALLs in ON directives is often associated with task parallelism. Several examples can be found in Section 9.4. The following example illustrates how processors can be used for a one-dimensional domain decomposition algorithm:

```hpf
!HPF$ PROCESSORS PROCs(NP)
!HPF$ DISTRIBUTE X(BLOCK) ONTO PROCs

! Compute ILO(IP) = lower bound on PROCs(IP)
! Compute IHI(IP) = upper bound on PROCs(IP)
DONE = .FALSE.
DO WHILE (.NOT. DONE)
   !HPF$ INDEPENDENT
   DO IP = 1, NP
      !HPF$ ON (PROCs(IP))
      CALL SOLVE_SUBDOMAIN( IP, X(ILO(IP):IHI(IP)) )
   END DO
   !HPF$ ON HOME(X) BEGIN
```
The RESIDENT clause, Directive, and Construct

The purpose of the RESIDENT clause is to promise that data accessed by a computation are mapped to active processors. That is, RESIDENT asserts that certain references (or all references) in its scope are stored on the active processor set. The compiler can use this information to avoid generating communication or to simplify array address calculations. Note that whether a given data element is resident depends on two facts:

- Where the data is stored (i.e., DISTIBUTE and ALIGN attributes for the object)
- Where the computation is executed (i.e., its active set, as specified by an ON directive)

For these reasons, the RESIDENT clause is added to the ON directive, which is usually the earliest point in the program where the needed facts might be available. The RESIDENT clause can also appear as a stand-alone directive; this is useful when the locality information is not true for an entire ON region. Note that changing the ON directive may invalidate some RESIDENT clauses, or may make more RESIDENT clauses true.
A resident-directive is a kind of executable-directive. Similarly, a resident-construct is a kind of executable-construct.

Any top-level objects in the RESIDENT clause must be explicitly mapped. Similarly, the RESIDENT clause must appear at a point in the program with a declared active processor set (i.e., inside an ON block). Otherwise, the assertion (see below) is a statement about how the compiler works, not about the program.

*Advice to implementors.* RESIDENT removes the need for inactive processors to participate in communication into/out of an ON clause. (End of advice to implementors.)

The RESIDENT directive is an assertion to the compiler that certain object references made within the ON are stored on the active processors if the computation is performed by the specified active processor set. The scope of the assertion is the next Fortran statement if the resident-directive form is used and the enclosed block of code if the resident-construct form is used. If RESIDENT appears as a clause in an ON directive, then the ON and RESIDENT apply to the same statements.

RESIDENT(var) means the *lexical expression* var, when encountered in the execution of statements in the scope of the RESIDENT directive, accesses only data resident on the set of active processors. (That is, the set of processors named by the innermost available ON directive.) If var is accessed by the statement (e.g., it appears on the right-hand side of an assignment statement, or in the evaluation of a conditional expression), then at least one copy of the object and any subobject of the object must be mapped to the active processor set. If var is assigned to by the statement (e.g., it appears on the left hand side of an assignment statement, or in the variable list of a READ statement, or in any other context that may cause its value to change) then all copies of the variable and all subobjects of the variable must reside in the active processor set. The application of RESIDENT to CALL statements and function invocations introduces some complexity into this interpretation; these issues will be dealt with in Section 9.3.2.

Note that RESIDENT is always an assertion relative to the surrounding ON directive. Therefore, if the compiler does not implement the ON directive then it must be careful in interpreting RESIDENT. Similarly, if the compiler overrules the programmer-specified ALIGN and DISTRIBUTE directives, then it may not rely on the RESIDENT clause in general.

Finally, NEW variables are not considered by any nested RESIDENT directives, as detailed below.

*Rationale.* The different treatment of variable reads and writes is due to the implementation requirements. If a variable's value is read (but not written), then it can be taken from any consistent copy. Therefore, RESIDENT only asserts that one of those...
copies is available. Conversely, all copies of a replicated variable must be consistent, so `RESIDENT` asserts that all copies are available if it is updated.

The `RESIDENT` assertion is always relative to the declared data mappings and `ON` clauses because both pieces of information are necessary to determine the locality of data references. Data mapping determines where the data is stored, while `ON` clauses determine where they are used; in essence they determine the endpoints of a data path. `RESIDENT` itself says that the path length is very short; obviously, one cannot measure a path without knowing both endpoints. (*End of rationale.*)

Consider the following:

```hpf
!HPF$ ON HOME(Z(I)), RESIDENT(X,Y,RECORD(I))
X(I) = Y(I+1) + RECORD(I)%FIELD1 + RECORD(I+1)%FIELD2
```

The following facts are asserted by the directive:

- `Z(I)` would be local if it appeared, due to its use in the `HOME` directive.

- All copies of `X(I)` are stored on processors that also store a copy of `Z(I)`, due to the `RESIDENT` clause. This may be true because `X` and `Z` have the same mapping, or because `Z` is replicated over a set of processors that contains the set of processors that store `X(I)`.

- At least one copy of `Y(I+1)` is on the same processor as `Z(I)`, due to the `RESIDENT` clause. This may be true because `Y` is replicated on all processors, because `Z(I)` and `Y(I+1)` are the only elements of their arrays that are mapped to the same processor, or because the directive

  ```hpf
  !HPF$ ALIGN Y(J) WITH Z(J-1)
  ```

  appears elsewhere in the program. (Other situations also make the `RESIDENT` assertion true.)

- At least one copy of all subobjects of `RECORD(I)` is mapped on the same processor as `Z(I)`. In particular, the reference `RECORD(I)%FIELD1` (i.e., a subobject consisting of one component) can be accessed locally. The situations in which this is true are similar to those for `X(I)`. No information is available in this example regarding `RECORD(I+1)%FIELD2`.

If there is no `res-object-list`, then all references to all variables referenced during execution of the `RESIDENT` directive’s body except those declared `NEW` in a surrounding `ON` directive are local in the sense described above. That is, for every usage of any variable’s value, at least one copy of the variable will be mapped to the `ON` processor set. Likewise, for every operation that assigns to a variable, all copies of that variable are mapped to the `ON` processor set. References and assignments to `NEW` variables are always considered resident. If there are no function or subroutine invocations, this is syntactic sugar for listing all variable references within the directive’s scope. (See Section 9.3.2 for a discussion of `RESIDENT` clauses applied to subprogram calls.) It might well have been named the `ALL_RESIDENT` clause; the present form, however, does not add yet another keyword to the directive sublanguage.
Note that if the active set includes more than one processor, then \texttt{RESIDENT} only asserts that the variables are stored on one of the processors. For example, if a statement is executed on a section of the processors arrangement, then communication within that section may be needed for some variables in the \texttt{RESIDENT} clause. Communication with processors outside of the section will not be needed for those variables, however.

\textit{Rationale}. The alternative to this interpretation would be that any variable named in the \texttt{RESIDENT} clause would be local to all processors, i.e., replicated. While that certainly allows more extensive optimizations, it is a less common case. In addition, it does not seem to capture the intent of \texttt{ON} directives applied to CALL statements or compound statements. For example,

\begin{verbatim}
!HPF$ PROCESSORS PROCS(MP,MP)
!HPF$ DISTRIBUTE X(BLOCK,BLOCK) ONTO PROCS
!HPF$ ON HOME(PROCS(1,1:MP)), RESIDENT(X(K,1:N))
CALL FOO( X(K,1:N) )
\end{verbatim}

would presumably call \texttt{FOO} on a row of the processors arrangement, passing elements of \texttt{X} in place. This is what the current definition does; if \texttt{RESIDENT} meant "resident on every processor", the call would force \texttt{X} to be replicated. (\textit{End of rationale}.)

It is not correct to assert that an unmapped object, including of necessity any sequential object, is mapped exclusively to the active processors, unless the programmer knows that all of the processors are active. Thus, when a proper subset of processors is active, no such object can occur in a \texttt{res-object-list} or in the scope of a \texttt{RESIDENT} directive with no \texttt{res-object-list}.

The \texttt{RESIDENT} directive is similar to the \texttt{INDEPENDENT} directive, in that if it is correct it does not change the meaning of the program. If the \texttt{RESIDENT} clause is incorrect, the program is not standard-conforming (and is thus undefined). Like the \texttt{INDEPENDENT} directive, the compiler may use the information in the \texttt{RESIDENT} clause, or ignore it if it is insufficient for the compiler's purposes. If the compiler can detect that the \texttt{RESIDENT} clause is incorrect (i.e., that a \texttt{RESIDENT} variable is definitely nonlocal), it is justified in producing a warning. Unlike the \texttt{INDEPENDENT} directive, however, the truth of the \texttt{RESIDENT} clause depends on the mapping of computations (specified with the \texttt{ON} clause) and the mapping of data (specified with \texttt{DISTRIBUTE} and \texttt{ALIGN} clauses); if the compiler overrides either of these, then it may not be able to use information in the \texttt{RESIDENT} directive.

\textit{Rationale}. Knowing that a reference is local is valuable information for the optimizer. It is in keeping with the spirit of HPF to phrase this as an assertion of fact, which the compiler can use as it pleases. Expressing it as advice to the compiler seems to have disadvantages. Some possible ways this advice could be phrased, and the counter-arguments, are

\begin{itemize}
\item "Don't generate communication for this reference" has great potential for changing the meaning of the program. Some programmers want this capability, but it violates the "correct directives should not change the meaning of a program" principle of HPF. Also, once communication is "turned off" for a reference, it's not clear how to turn it back on.
\end{itemize}
• “Generate communication for this reference” is not a useful directive, since the compiler has to do this anyway.

• “Generate communication for this reference, and place it here” is useful, since it can override the default placement by the compiler. It still has potential for changing program meaning. It also has the potential to create programs as complex as message-passing, as programmers try to move communication out of loops.

(End of rationale.)

9.3.1 Examples of RESIDENT Clauses

As in Section 9.2.3, our aim here is to suggest idioms that may be generally useful to programmers. We begin by expanding on two earlier examples.

RESIDENT is most useful in cases where the compiler cannot detect access patterns. Often this arises due to the use of indirection, as in the following examples:

```hpf
REAL X(N), Y(N)
INTEGER IX1(M), IX2(M)
!HPF$ PROCESSORS P(NP)
!HPF$ DISTRIBUTED (BLOCK) ONTO P :: X, Y
!HPF$ DISTRIBUTED (BLOCK) ONTO P :: IX, IY

!HPF$ INDEPENDENT
DO I = 1, N
   !HPF$ ON HOME (X(I)), RESIDENT (Y(IX(I)))
   X(I) = Y(IX(I)) - Y(IY(I))
END DO

!HPF$ INDEPENDENT
DO J = 1, N
   !HPF$ ON HOME (IX(J)), RESIDENT (Y)
   X(J) = Y(IX(J)) - Y(IY(J))
END DO

!HPF$ INDEPENDENT
DO K = 1, N
   !HPF$ ON HOME (IX(IX(K))), RESIDENT (X(K))
   X(K) = Y(IX(K)) - Y(IY(K))
END DO
```

As we saw in Section 9.2.3, X(I) is always local in the I loop and IX(I) and IY(I) rarely are. The RESIDENT directive above ensures that Y(IX(I)) is local as well. This would most likely be due to some property of the algorithm that generated IX (for example, if IX(I)=I for all I). Note that it is possible for an expression (e.g., Y(IX(I))) to be local even though one of its subexpressions (IX(I)) is not.

The directive gives no information about Y(IY(I)); it might have only one nonlocal value, or all its values might be nonlocal. (We assume that if there were no nonlocal values, then the RESIDENT clause would include Y(IY(I)) as well.) If there are many local elements
referenced by this expression, and they can easily be separated from the local elements, then it may be worthwhile to restructure the loop to make this clear to the compiler. For example, suppose that we knew that only the “first” and “last” X elements on each processor were nonlocal. The loop could then be split thus:

```hpfrange
!HPF$ INDEPENDENT, NEW(LOCALI)
DO I = 1, N
   !HPF$ ON HOME( X(I) ), RESIDENT( Y(IX(I)), Y(IY(I)) )
   BEGIN
      LOCALI = MOD(I,N/NP)
      IF (LOCALI\1 =1 .AND. LOCALI\=0) THEN
         X(I) = Y(IX(I)) - Y(IY(I))
      END IF
   !HPF$ END ON
END DO
!HPF$ INDEPENDENT, NEW(LOCALI)
DO I = 1, NP
   !HPF$ ON (P(I)), RESIDENT( X(LOCALI), Y(IX(LOCALI)) )
   BEGIN
      LOCALI = (I-1)*N/NP
      X(LOCALI) = Y(IX(LOCALI)) - Y(IY(LOCALI))
      LOCALI = I*N/NP
      X(LOCALI) = Y(IX(LOCALI)) - Y(IY(LOCALI))
   !HPF$ END ON
END DO
```

The first loop (inefficiently) processes the local elements of Y(IY(I)), while the second (more efficiently) handles the rest. On most machines, it would pay to rewrite both loops to avoid the division operations, for example by creating a logical mask a priori.

In the J loop, the RESIDENT clause asserts that all accessed elements of Y are local. In this case, that is equivalent to the assertion

```hpfrange
!HPF$ RESIDENT( Y(IX(J)), Y(IY(J)) )
```

Although the original RESIDENT clause only referred to the lexical expression Y, the compiler can infer that the subexpressions are also local. This is because it is impossible for a subobject to be on a different processor than the “parent” object is. This observation can often shorten RESIDENT clauses substantially.

In the K loop, the following references are local:

- Y(IX(K)), because Y has the same distribution as X and X(IX(K)) is local (due to the ON clause).
- X(K), because of the RESIDENT clause.

Note that a reference may be local even if it does not appear explicitly in a RESIDENT clause. One mark of a good compiler will be that it aggressively identifies these elements.

Because it is an assertion of act, the compiler can draw many inferences from a single RESIDENT clause. For example, consider the following case:

```hpfrange
!HPF$ ALIGN Y(I) WITH X(I)
!HPF$ ALIGN Z(J) WITH X(J+1)
```
The compiler is justified in making the following assumptions in compiling the assignment statement (assuming it honors both the ALIGN directives and the ON directive):

- \( X(K) \) requires no communication (because of the HOME clause)
- \( X(INDX(K)) \) requires no communication (because of the RESIDENT clause)
- \( Y(INDX(K)) \) requires no communication (because \( Y \) has the same mapping as \( X \), and \( INDX(K) \) clearly cannot change values between its use in the two references \( X(INDX(K)) \) and \( Y(INDX(K)) \))

The compiler cannot make any assumption about \( INDX(K) \) or \( Z(INDX(K)) \) from the above code. There is no indication how \( INDX \) is mapped relative to \( X \), so the ON directive gives no guidance. Note that the fact that an expression (here, \( X(INDX(K)) \)) is local does not imply that its subexpressions (here, \( INDX(K) \)) are also local. Similarly, \( Z \)’s mapping does not determine if \( Z(INDX(K)) \) would be local; it indicates that \( Z(INDX(K)-1) \) is local, but that isn’t a great help. If the compiler has additional information (for example, \( X \) is distributed by BLOCK and \( INDX(K) \) is not near a block boundary), it might be able to make additional deductions.

**Advice to implementors.** One mark of a good compiler will be that it aggressively propagates RESIDENT assertions. This is likely to significantly reduce communication costs. Note the cases under “Advice to users” below. *(End of advice to implementors.)*

**Advice to users.** One can expect compilers to differ in how aggressive they are in drawing these deductions. Higher-quality compilers will be able to identify more references as local, and use this information to eliminate data movement. All compilers should recognize that if an element of one array is local, then the same element of any other arrays with the same static mapping (i.e., arrays aligned together, or with the same DISTRIBUTE pattern and array size) will also be local. That is, any compiler should recognize \( Y(INDX(K)) \) in the above example as local. Dynamically changing array mappings (i.e., REALIGN and REDISTRIBUTE) will tend to limit such information and information propagation. Also, assignments that might change subexpressions (for example, an assignment to \( K \) or any element of \( INDX \) in the above example) will force the compiler to be conservative in its deductions. *(End of advice to users.)*

### 9.3.2 RESIDENT Directives Applied to Procedure Reference

If a RESIDENT directive applies to procedure reference, then the assertion is more subtle.

- If a *res-object-list* appears in the RESIDENT directive, then no assertion is made about behavior within the called procedure. For example, consider the statements:

  ```fortran
  !HPF$ RESIDENT( A(I), B )
  A(I) = F( A(I), B(LO:HI) )
  ```
The directive declares all variable references in the statement (including the actual arguments) to be local to the current ON processor set. However, the execution of F itself could access elements of arrays named A and B stored on arbitrary processors.

**Rationale.** Propagating assertions about the behavior of lexical entities is difficult to define consistently and usefully. For example, consider the following function called from the code fragment above:

```fortran
REAL FUNCTION F(X, Y)
USE MODULE_DEFINING_A
REAL X, Y(:), B(I)
!HPFS INHERIT Y
!HPFS ALIGN B(:) WITH Y(:)
INTEGER I

Z = 0.0
DO I = 1, SIZE(Y)
   Z = Z + A(I)*X + B(I)*Y(I)
END DO
F = Z
END FUNCTION
```

Assume A is defined as a distributed, global array in module `MODULE_DEFINING_A`. What should the `RESIDENT` clause mean regarding operations in F? The expression A(I) in the `RESIDENT` directive might reasonably mean references only to the array A that is visible in the caller, or it might mean references to any array named A. Note that the A in the caller may be local, the same global array as the A in F (if the caller used `MODULE_DEFINING_A`), or a different global array (if the caller used a different module). Perhaps a limiting case is array B. The array B in function F is local, and thus different from the caller; however, because of the restrictions on ON clauses it is certain that the local B will be mapped to the ON processor set. Thus, the `RESIDENT` assertion is trivially true. To further confuse matters, `RESIDENT` variables might seem to apply to dummy arguments that become associated with those variables. Unfortunately, this implies that the lexical expression B in the caller refers to the lexical expression Y in F, which stretches the definition of “lexical” beyond the breaking point. For all these reasons, it was decided to limit the meaning of named variables in `RESIDENT` clauses to the lexical scope of the directive. *(End of rationale.)*

- If the `RESIDENT` directive does not contain a `res-object-list`, then the directive asserts that all references in the caller *and the called procedures* are local as defined above. For example, consider the statements:

```fortran
!HPFS RESIDENT
A(I) = F( A(I), B(LO:HI) )
```

The directive declares all variable references in the statement (including the actual arguments) to be local to the current ON processor set, and that F itself does not reference or update any nonlocal variables.
9.3. THE RESIDENT CLAUSE, DIRECTIVE, AND CONSTRUCT

Rationale. The RESIDENT assertion is always true for data local to the called procedure. This is true because the called procedure must use a declarative ON clause, which in turn limits the set of processors that can store any local explicitly mapped variables. The above definition extends this assertion to all global explicitly mapped data, producing a very powerful directive. This is similar to the meaning of INDEPENDENT, in that it also makes an assertion about variable accesses in any called procedure in the loop. An alternative semantics for RESIDENT would have been to avoid propagating the assertion interprocedurally (i.e., treat both the variable-list version and the no-list version the same). However, this would not provide enough information to optimize code on certain machines. In particular, it would have made task parallelism quite difficult on message-passing machines. (End of rationale.)

Advice to implementors. RESIDENT without a variable list guarantees that no one-sided communication outside of the ON processor set will be generated by the callee. Such a procedure can be called only on the “active” processors, unless the runtime system has additional constraints (for example, if the runtime system requires all processors to participate in collective communications).

The other forms of RESIDENT provide information that could be propagated interprocedurally. For example, if the actual argument to a subprogram is asserted to be RESIDENT and is passed transitively, then anything that is aligned to it in the callee will also be RESIDENT. If the information is not propagated, the only result will be less optimization. (End of advice to implementors.)

Advice to users. Although the RESIDENT assertion applies interprocedurally, it is by no means certain that all compilers will make use of this information. In particular, separate compilation limits the propagation that can take place. It is therefore good practice to include a RESIDENT clause both in the caller’s ON directive and in the callee. (This assumes that the assertion is true, of course!) This ensures that the compiler has the RESIDENT information available when it is compiling both ends of the procedure call. This is especially useful for RESIDENT clauses without a variable list; knowing that all data accessed is local allows many optimizations that are not otherwise possible. (End of advice to users.)

Locality information is particularly critical interprocedurally. Here, the RESIDENT directive without a res-object-list can be used to good advantage. Consider the following extension of the block-structured example from Section 9.2.4:

```
!HPF$ PROCESSORS PROCS(NP)
!HPF$ DISTRIBUTE X(BLOCK) ONTO PROCS

! Compute ILO(IP) = lower bound on PROCS(IP)
! Compute IHI(IP) = upper bound on PROCS(IP)
DONE = .FALSE.
DO WHILE (.NOT. DONE)
   !HPF$ INDEPENDENT
   DO IP = 1, NP
      !HPF$ ON (PROCS(IP)), RESIDENT
```

CALL SOLVE_SUBDOMAIN( IP, X(ILO(IP):IHI(IP)) )
END DO
!HPF$ ON HOME(X) BEGIN
  CALL SOLVE_BOUNDARIES( X, ILO(1:NP), IHI(1:NP) )
  !HPF$ RESIDENT
  DONE = CONVERGENCE_TEST( X, ILO(1:NP), IHI(1:NP) )
  !HPF$ END ON
END DO

Recall that the INDEPENDENT IP loop performs a computation on each subdomain’s interior, where a subdomain is mapped to a particular processor. The first RESIDENT clause additionally informs the compiler that no subdomain uses data from another processor. Without this information, the compiler would have to assume a worst-case scenario in which each subdomain performed its updates based on non-local read-only data. Any nonlocal data could not be written by another processor without violating the INDEPENDENT directive; however, if the data were not updated (for example, a large lookup table) it could be stored remotely. Particularly on nonshared-memory machines, access to this remote data would be difficult. The RESIDENT clause ensures that this possibility need not be considered. All data required by SOLVE_SUBDOMAIN is stored locally. The second RESIDENT clause asserts that all data for CONVERGENCE_TEST is stored on the same processors that store X. The same cannot be said for SOLVE_BOUNDARIES, which does not fall in the scope of the RESIDENT directive. For example, there might be a processors arrangement other than PROCs with necessary data. Accessing this data might well cause a bottleneck in the computation as described above.

Again, note the usefulness of RESIDENT clauses in giving the compiler information. Few compilers would be able to unravel nontrivial assignments to ILO and IHI, and no current compiler would even attempt to understand the comments in the above code fragment. End of advice to programmers.

9.4 The TASK_REGION Construct

Task parallelism is expressed in HPF by mapping data objects onto subsets of processors and adding assertions that allow concurrent execution of different code blocks on different processor subsets. A data object is mapped to a processor subset by distribution onto a subsection of a processors arrangement. Execution on a subset of processors is specified by using an ON directive. This section introduces a TASK_REGION directive that allows the user to specify that disjoint processor subsets can execute blocks of code concurrently.

A TASK_REGION directive is used to assert that a block of code satisfies the following set of constraints. All lexically outermost ON blocks inside a task region must have a RESIDENT attribute implying that all data accessed inside them is mapped to the corresponding active processor subset. Further, the code inside two such ON blocks must not have interfering I/O. Under these constraints, two such ON blocks can safely execute concurrently if they execute on disjoint processor subsets.

9.4.1 Syntax of the TASK_REGION Construct

A task region is a single entry region delimited by two structured comments:
A task-region-construct is a kind of executable-construct.

There must not be a transfer of control from outside the task-region-construct to inside the task-region-construct. Transfer of control out of the task-region-construct is allowed provided that the transfer does not originate inside an ON block. (The reason for this will be apparent later.)

### 9.4.2 Semantics of the TASK_REGION Construct

We will refer to a block of code enclosed by a TASK_REGION ... END TASK_REGION pair as a task region. The TASK_REGION directives are a way for the programmer to assert that a section of code satisfies a set of conditions. The compiler is expected to use these assertions to generate task-parallel code.

A task region can contain blocks of code that are directed to execute ON processor subsets. All other code executes on a subset that contains all active processors. Every ON block at the outermost nesting level (i.e., not inside another ON block or another task region) inside a task region is defined as a lexical task. Every execution instance of a lexical task is defined as an execution task and will also be referred to as just task when the distinction is clear from the context. An execution task is associated with a set of active processors discussed earlier in this chapter.

The following restrictions must hold inside a task region:

- Every ON block corresponding to a lexical task must have the RESIDENT attribute. This means that, for reading a variable inside an execution task, the corresponding active processors must own at least one copy of the variable, and for writing, they must own all copies of that variable.

- An I/O operation inside an execution task may interfere with an I/O operation inside another execution task if and only if the two tasks execute on identical subsets of processors. Note that two execution tasks can be instances of the same or different lexical tasks. In general, two I/O operations interfere if they access the same file or unit. The conditions for interference of I/O operations are detailed in Section 5.1 in the context of the INDEPENDENT directive.

### 9.4.3 Execution Model and Usage

A task region does not introduce a fundamentally new execution model. However, the assertions implicit in a task region imply that only the specified active processors of an execution task need to participate in its execution, and that other processors can skip its execution. A processor executing a task region participates in the execution of all tasks executing on a processor subset that it belongs to, and does not participate in the execution of tasks executing on processor subsets that it does not belong to. Code outside lexical tasks is executed as normal data parallel code by all active processors of the task region. The
access restrictions for a task region guarantee that the results obtained by this execution
paradigm will be consistent with pure data parallel execution of a task region.

A task region presents a simple yet powerful model to write integrated task and data
parallel programs. We illustrate three basic computation structures in which task parallel-

ism can be effectively exploited with this model.

1. Parallel sections: A task region can be used to divide the available processors into dis-
joint sets for performing independent computations, simulating what is often referred
to as parallel sections. This form of task parallelism is relatively straightforward and
useful in many application scenarios, an example being multiblock applications. The
task region simply contains a sequence of RESIDENT ON blocks on disjoint processor
subsets. Note that the division of processors among subsets can be dynamic, that is,
it can be in terms of other variables computed during execution.

2. Nested parallelism: Task regions can be nested, and in particular, a subroutine call
made from an execution task can further subdivide the active processors using another
task region directive. This allows the exploitation of nested parallelism. An example
is the implementation of dynamic tree structured divide and conquer computations.
As a specific example, quicksort can be implemented by recursively partitioning the
input array of keys around a pivot, and assigning proportionate number of processors
to the two new arrays obtained as a result of partitioning.

3. Data parallel pipelines: Task regions can be used to implement pipelined data parallel
computations. We will illustrate this with a 2 dimensional fast Fourier transform (2D
FFT) computation. The first stage of a 2D FFT reads a two dimensional matrix and
performs a 1 dimensional FFT on each row of the matrix. The second stage performs
a 1 dimensional FFT on each column of the matrix and generates the final output.
In a pipelined data parallel implementation of this form of 2D FFT, the two stages
are mapped on to disjoint subsets of processors. Task and data parallel code for a 2D
FFT, along with a brief description, is included in Section 9.4.5.

9.4.4 Implementation

A task region is simply an assertion about a code block and the exploitation of task parallel-
ism is, at least partially, dependent on the compilation scheme. While the specifics of how
task parallelism is exploited will be strongly dependent on the parallel system architecture,
the compiler, and the underlying communication model, we will point out some important
considerations and illustrate task parallel code generation with an example. We primarily
address distributed memory machines using a message passing communication and synchro-
nization model, but will point out some of the important issues relating to shared memory
implementations.

9.4.4.1 Localized computation and communication

It is of central importance that computation and communication inside an executing task
should not involve any processors other than those directed to execute the task in the
relevant ON clause.

On entry to a lexical task, the compiler has to insert checks so that the inactive pro-
cessors jump to the code following the task. Since an execution task cannot access data
outside of the active processor set, no communication needs to be generated between the
relevant active processors and other processors. In a message passing model, a communica-
tion generation algorithm that only generates necessary messages will naturally achieve the
desired results. However, some communication schemes can involve generation of empty
messages between processors that do not communicate and it is important to ensure that
empty messages are not generated between active processors of an executing task and other
processors.

A communication model that uses barriers for synchronization (in shared or distributed
memory machines) must ensure that all barriers inside an executing task are subset barriers
that only span the active processors. An implementation may also need to include a subset
barrier, on entry to and on exit from, an executing task for consistency of data accesses
inside and outside an executing task. In general, the compilation framework has to ensure
the consistency of data accesses inside and outside an executing task and this can
be done in the context of virtually any synchronization scheme in a shared or distributed
memory environment.

9.4.4.2 Replicated computations

All computations exclusively involving replicated variables should be replicated on all ex-
ecuting processors. A simple alternative is that one processor performs the computation
and broadcasts the results to all processors. While such replication is generally profitable
in HPF anyway, it has additional importance in a task region since the communication
generated by a broadcast can cause additional synchronization that may interfere with task
parallelism.

9.4.4.3 Implications for I/O

In some parallel system implementations, I/O is performed through a single processor of the
system. Task parallelism in the presence of I/O assumes that all processors can perform
I/O independently and this paradigm has to be supported, although it is not necessary
that each processor be able to physically perform all I/O operations independently. One
simple solution is to have a single designated I/O processor that performs all I/O but
is not considered an executing processor and hence does not have any execution related
dependences.

9.4.4.4 SPMD or MIMD code generation

Another issue for the compiler is whether or not the same code image should execute on
all processors. Since different processor groups may need different variables, a naive SPMD
implementation is likely to be wasteful of memory since it must allocate all variables on all
processors. This can be addressed by dynamic memory allocation, but at the cost of added
complexity. Using different code images for different processor subsets is another solution
that also leads to significant added complexity.

9.4.5 Example: 2-D FFT

This section shows the use of task parallelism to build a pipelined data-parallel 2-
dimensional FFT and illustrates the compilation of task parallelism by showing SPMD
code generated from the HPF program.
The basic sequential 2DFFT code is as follows:

```fortran
REAL, DIMENSION(n,n) :: a1, a2

DO WHILE(.true.)
   READ (unit = 1, end = 100) a1
   CALL rowffts(a1)
   a2 = a1
   CALL colffts(a2)
   WRITE (unit = 2) a2
   CYCLE
100  CONTINUE
EXIT
END DO
```

To write a pipelined task and data parallel 2D FFT in HPF, the code is slightly modified and several HPF directives are added. First, variables `a1` and `a2` are distributed onto disjoint subsets of processors, and then a task region is used to create two lexical tasks to perform `rowffts` and `colffts` on different subsets of processors. The assignment `a2 = a1` in the task region specifies the transfer of data between the tasks. A new variable `done1` is introduced to store the termination condition. The modified code is as follows:

```fortran
REAL, DIMENSION(n,n) :: a1,a2
LOGICAL done1
!HPF$  PROCESSORS procs(8)

!HPF$  DISTRIBUTION a1(block,*) ONTO procs(1:4)
!HPF$  DISTRIBUTION a2(*,block) ONTO procs(5:8)

!HPF$  TEMPLATE, DIMENSION(4), DISTRIBUTION(BLOCK) ONTO procs(1:4) :: td1
!HPF$  ALIGN WITH td1(*) :: done1

!HPF$  TASK_REGION
   done1 = .false.
   DO WHILE (.true.)
!HPF$      ON (procs(1:4)) BEGIN, RESIDENT
         READ (unit = iu,end=100) a1
         CALL rowffts(a1)
         GOTO 101
   100     done1 = .true.
   101    CONTINUE
!HPF$  END ON

   IF (done1) EXIT
   a2 = a1

!HPF$  ON (procs(5:8)) BEGIN, RESIDENT
         CALL colffts(a2)
         WRITE(unit = ou) a2
```

```fortran/2/0/0 CONTINUE
```
Finally, we show simplified SPMD code generated for each processor. We assume a message passing model where sends are asynchronous and nonblocking and receives block until the data is available. We use a simple memory model where variable declarations are identical across all processors even though some variables will be referenced only on subsets of the processors. A shadow variable done_copy is created by the compiler to transfer information from processor subset 1 to processor subset 2 about termination of processing. The code is as follows:

```fortran
REAL DIMENSION(n/4,n) :: a1
REAL DIMENSION(n,n/4) :: a2
LOGICAL done1

C Following are compiler generated variables
LOGICAL done1_copy
LOGICAL inset1, inset2

C Following magic compiler function call is to set the variables
C inset1 and inset2 to .true. for subset 1 and subset 2 processors
C respectively, and .false. otherwise.
C
CALL initialize_tasksets(inset1,inset2)

C Code for processor subset 1
IF (inset1)
  done1 = .false.
  DO WHILE (.true.)
    C Read is left unchanged as the code depends on the I/O model
    READ (unit = 1, end=100) a1
    CALL rowffts(a1)
    GOTO 101
  100   done1 = .true.
  101   CONTINUE
    _send(done1,procs(5:8))
    IF (done1) EXIT
    _send(a1,procs(5:8))
  END DO
END IF

C Code for processor subset 2
IF (inset2)
  DO WHILE(.true.)
    _receive(done1_copy,procs(1:4))
```
IF (local_done1) EXIT
  _receive(a2,procs(1:4))
  CALL colffts(a2)

C Write is left unchanged as the code depends on the I/O model.
  WRITE (unit = 2) a2
END DO
END IF

SEND and RECEIVE are communication calls to transfer variables between subsets of processors. Program execution until the end of input is as follows. Subset 1 processors repeatedly read input, compute rowffts, and send the computed output as well as done1 flag, which normally has the value .false., to subset 2 processors. The subset 2 processors receive the flag and the data set, compute colffts and write the results to the output. When the end of input is reached, subset 1 processor set the value flag done1 to .true., send it and terminate execution. Subset 2 processors receive the flag, recognize that the end of input has been reached, and terminate execution.
Section 10

Approved Extension for Asynchronous I/O

This section defines a mechanism for performing Asynchronous I/O from an HPF or Fortran program. These are presented as changes to the Fortran 95 proposed draft standard, X3J3/96-007r1. This extension is a subset of the proposed X3J3 Asynchronous I/O extension, paper X3J3/96-158r2. Briefly, this extension allows direct unformatted data transfers to be performed asynchronously with program execution. The \texttt{WAIT} statement can be used to wait for the data transfers to complete. The \texttt{INQUIRE} statement can be used to determine if the data transfers are complete.

To section 9.3.4, rule R905 \textit{connect-spec}, add

\begin{verbatim}
  or ASYNCHRONOUS
\end{verbatim}

Add a new section after 9.3.4.10, entitled “\textit{ASYNCHRONOUS specifier in the OPEN statement}”, containing the following paragraphs:

If the \texttt{ASYNCHRONOUS} specifier is specified for a unit in an \texttt{OPEN} statement, then \texttt{READ} and \texttt{WRITE} statements for that unit may include the \texttt{ASYNCHRONOUS} specifier in the control information list.

The presence of an \texttt{ASYNCHRONOUS} specifier in a \texttt{READ} or \texttt{WRITE} statement permits (but does not require) a processor to perform the data transfer asynchronously. The \texttt{WAIT} statement is used to wait for or inquire as to the status of asynchronous input/output operations.

To section 9.4.1, rule R912 \textit{io-control-spec}, add

\begin{verbatim}
  or ID = scalar-default-int-variable
  or ASYNCHRONOUS
\end{verbatim}

and also add the constraints

\begin{itemize}
  \item Constraint: If either an \texttt{ASYNCHRONOUS} or an \texttt{ID=} specifier is present, then both shall be present.
  \item Constraint: If an \texttt{ASYNCHRONOUS} specifier is present, the \texttt{REC=} specifier shall appear, a \texttt{format} shall not appear, and a \texttt{namelist-group-name} shall not appear.
\end{itemize}
Constraint: If an ASYNCHRONOUS specifier is present, then no function reference may appear in an expression anywhere in the data transfer statement.

At the end of section 9.4.1, add the following paragraphs:

The addition of the ID= specifier results in the initiation of an asynchronous data transfer. Execution of the data transfer statement shall be eventually followed by execution of a WAIT statement specifying the same ID value that was returned to the ID variable in a data transfer statement. This WAIT statement is called the matching WAIT statement. Note that asynchronous data transfer shall be direct and unformatted.

The matching WAIT statement shall be executed in the same instance of the same subprogram in which the asynchronous data transfer statement was executed.

Advice to implementors. The above restriction is to prevent the compiler from performing code motion optimizations across WAIT statements. Any operations involving variables listed in asynchronous input/output lists must be performed after the matching WAIT statement is executed.

(End of advice to implementors.)

No ASYNCHRONOUS specifier nor any ID= specifier shall be specified if the io-unit was not opened with the ASYNCHRONOUS specifier.

In section 9.4.1, in the fourth and fifth paragraphs after the constraints, change both instances of "IOSTAT= or a SIZE=" to "IOSTAT=, SIZE=, or an ID=".

Insert the following text at the end of section 9.4.3 before the final paragraph:

For an asynchronous data transfer, errors may occur either during execution of the data transfer statement or during subsequent data transfer. If these errors occur during the data transfer statement and do not result in termination of the program, then they will be detectable using ERR= and IOSTAT= specifiers in the data transfer statement. If these error conditions occur during subsequent data transfer and do not result in termination of the program, then they will be detectable using ERR= and IOSTAT= specifiers in the matching WAIT statement.

In the paragraph at the end of section 9.4.3, change the first occurrence of “execution” to read “execution or subsequent data transfer.”

To section 9.4.4, add the following paragraphs:

For asynchronous data transfers steps 1–8 correspond to both the asynchronous data transfer statement and the matching WAIT statement. Steps 4–7 may occur asynchronously with program execution. If an implementation does not support asynchronous data transfers then steps 1–8 may be performed by the asynchronous data transfer statement. The matching WAIT statement shall still be executed, the only effect being to return status information.

Any variable that appears as an input-item or output-item in an asynchronous data transfer statement, or that is associated with such a variable, shall not be referenced, become defined, or become undefined until the execution of the
matching \texttt{WAIT} statement. However, it is allowed for a pointer to become associated with such a variable.

Multiple outstanding asynchronous data transfer operations (\texttt{READ} or \texttt{WRITE}) are allowed; however, no two \texttt{WRITE} operations may use the same unit and record number without an intervening \texttt{WAIT}.

\textit{Advice to users.} HPF permits left-to-right definition of the I/O list on a \texttt{READ}, whether or not it is asynchronous. This means that a statement such as

\begin{verbatim}
READ(10,ID=IDNUM,REC=10) I,A(I)
\end{verbatim}

is conforming and has the same input behavior as a synchronous \texttt{READ}. (End of advice to users.)

In section 9, change “and \texttt{INQUIRE} statements” to “, \texttt{INQUIRE}, and \texttt{WAIT} statements”.

In section 9.6.1.14, add the following sentence as the last sentence of the paragraph:

If there are outstanding data transfer operations for the specified unit, the value assigned to the \texttt{NEXTREC=} specifier is computed as if all the outstanding data transfers had already completed, in the order in which they were issued.

To section 9.6.1, rule R924 \texttt{inquire-spec}, add

\begin{verbatim}
 or ID = scalar-default-int-variable  
or PENDING = scalar-default-logical-variable
\end{verbatim}

and also add the constraints

\begin{verbatim}
Constraint: The ID= and PENDING= specifiers shall not appear in an \texttt{INQUIRE} statement if the FILE= specifier is present.
\end{verbatim}

\begin{verbatim}
Constraint: If either an ID= specifier or a PENDING= specifier is present, then both shall be present.
\end{verbatim}

Add a new section after 9.6.1.22, entitled “ID= and PENDING= specifiers in the \texttt{INQUIRE} statement”, containing the following paragraph:

If an ID= specifier is present in an \texttt{INQUIRE} statement, then the variable specified in the PENDING= specifier is assigned the value true if the data transfer identified by the ID= specifier for the specified unit has not yet completed. In all other cases, the variable specified in the PENDING= specifier is set to false.

\section{10.1 The WAIT Statement}

\begin{verbatim}
H1001 wait-stmt  
is WAIT ( \texttt{wait-spec-list} )
\end{verbatim}

\begin{verbatim}
H1002 wait-spec

is UNIT = \texttt{io-unit}
\texttt{or ID} = \texttt{scalar-default-int-expr}
\texttt{or ERR} = \texttt{label}
\texttt{or IOSTAT} = \texttt{label}
\end{verbatim}
Constraint: A wait-spec-list shall contain exactly one UNIT= specifier, exactly one ID= specifier, and at most one of each of the other specifiers.

The \texttt{WAIT} statement terminates an asynchronous data transfer. The IOSTAT= and ERR= specifiers are optional and are described in sections 9.4.1.4 and 9.4.1.5, respectively.

\textit{Advice to implementors.} Implementors may choose to implement any or all asynchronous I/O synchronously. This essentially means using the ID= clause on the data transfer statement to record the results of the transfer, then supplying the results to the matching \texttt{WAIT} statement. (\textit{End of advice to implementors.})
Section 11

Approved Extensions for HPF Extrinsic

This section builds on Section 6 by defining specific interfaces for HPF with different models of parallelism, LOCAL and SERIAL (Section 11.1), and different languages, HPF (Section 11.3), C (Section 11.4), Fortran (Section 11.5), and Fortran 77 (Section 11.6). Library routines useful in the extrinsic models are defined in Section 11.7. These are defined with Fortran bindings. An implementation may choose to define similar routines for use with C. The intent of the HPF extrinsic mechanism is to generalize. These definitions may serve as a model for other interfaces. Some additional extrinsic interfaces are given after Annex E.

In HPF 1.1, specific extrinsic types HPF, HPF_LOCAL, and HPF_SERIAL were defined. There was also a short discussion of F90_LOCAL. In this more general setting, the HPF keywords are retained for compatibility. As defined in Section 6, a model of HPF refers to the global language, HPF_LOCAL is the same as LANGUAGE='HPF',MODEL='LOCAL', and HPF_SERIAL is the same as LANGUAGE='HPF',MODEL='SERIAL'. The F90_LOCAL extrinsic is now addressed by the LANGUAGE='FORTRAN',MODEL='SERIAL' extrinsic kind.

From the caller’s standpoint, an invocation of an extrinsic procedure from a “global” HPF program has the same semantics as an invocation of a regular procedure. The callee may see a different picture. The following sections describe sets of conventions for coding callees in the various extrinsic options. The set of extrinsic options supported by a particular HPF compiler is implementation dependent. They are not limited to those described in this chapter. Furthermore, the language processor used to compile the actual extrinsic subprogram need not be an HPF compiler. More specifically, it need not actually be a compiler for the language noted in the LANGUAGE specification, as long as the executing extrinsic code conforms to the conventions defined for the language. We define these interfaces to promote portability and interoperability, but a given implementation and the programmer are free to create other combinations of models and languages.

11.1 Alternative Extrinsic Models: LOCAL and SERIAL

A global HPF program may be thought of as a set of processors cooperating in a loosely synchronous fashion on a single logical thread of program control. Section 6 defines two additional models that may be invoked from global HPF: LOCAL, where the model is single-processor “node” code, in which all active processors participate, but with only the data that is mapped to a given physical processor directly accessible, and SERIAL, where the
model is a single-processor operating alone, with all necessary data aggregated by the caller before the serial subprogram is invoked. As examples of use, the LOCAL model is useful for programs that drop down into code with explicit message passing for data communications, while the SERIAL model may be needed for calls to system libraries or specialized I/O routines.

Both the LOCAL and the SERIAL models can be invoked from a global HPF program, but in general these models may not be mixed. Calling global HPF from local or serial procedures is not allowed. Furthermore, calling a serial procedure from a local one is not allowed. Section 6.3.1 gives more detail about how various models can interact with each other.

Some additional restrictions are placed on all local and serial subprograms invoked from global HPF:

- The subprogram directly invoked by global HPF must not be recursive.
- The subprogram directly invoked by global HPF must not use any alternate return mechanism.

The behavior of I/O statements in local and serial subprograms is implementation dependent.

### 11.1.1 The LOCAL Model

An extrinsic procedure can be defined as explicit SPMD code by specifying the local procedure code that is to execute on each processor. In this section, we describe the contract between the caller and an EXTRINSIC(MODEL= 'LOCAL') callee. It is important not to confuse the extrinsic procedure, which is conceptually a single procedural entity called from the HPF program, with the individual local procedures that are executed on each node, one apiece. An invocation of an extrinsic procedure results in a separate invocation of a local procedure on each processor. The execution of an extrinsic procedure consists of the concurrent execution of a local procedure on each executing processor. Each local procedure may terminate at any time by executing a RETURN statement. However, the extrinsic procedure as a whole terminates only after every local procedure has terminated; in effect, the processors are synchronized before return to a global HPF caller.

With the exception of returning from a local procedure to the global caller that initiated local execution, there is no implicit synchronization required of the locally executing processors. Variables declared in a local procedure are held in local storage, private to each processor. To access data outside the processor requires either preparatory communication to copy data into the processor before running the local code, or explicit communication operations between the separately executing copies of the local procedure. Individual implementations may provide implementation-dependent means for communicating, for example, through a message-passing library or a shared-memory mechanism. Such communication mechanisms are beyond the scope of this specification. Note, however, that many useful portable algorithms that require only independence of control structure can take advantage of local routines, without requiring a communication facility.

The LOCAL model assumes only that nonsequential array axes are mapped independently to axes of a rectangular processor grid, each array axis to at most one processor axis (no "skew" distributions) and no two array axes to the same processor axis. This restriction suffices to ensure that each physical processor contains a subset of array elements that can
be locally arranged in a rectangular configuration. (Of course, to compute the global indices
of an element given its local indices, or vice versa, may be quite a tangled computation—but
it will be possible.) In the case of cyclic distributions, multiple sections of the array may
be mapped to the local processors.

It is recommended that if, in any given implementation, an extrinsic type does not
obey the conventions described in this section, then its model name or keyword should not
contain the word LOCAL.

11.1.1.1 Conventions for Calling LOCAL Subprograms

The default mapping of scalar dummy arguments, of scalar function results, and of seque-
ncial arrays is such that the argument is replicated on each physical processor. These
mappings may, optionally, be explicit in the interface (except in the case of sequential ar-
rays, which may not be explicitly mapped), but any other explicit mapping is not HPF
conforming. Dummy arguments may not be of explicitly mapped derived types or have
explicitly mapped structure components.

As in the case of non-extrinsic subprograms, actual arguments may be mapped in any
way; if necessary, they are copied automatically to correctly mapped temporaries before
invocation of and after return from the extrinsic procedure.

It should be noted that the conventions for calling local subprograms apply only at
the interface between the GLOBAL and LOCAL models. The conventions do not propagate to
further subprograms called from within the LOCAL model.

11.1.1.2 LOCAL Calling Sequence

Execution of an extrinsic local procedure must be performed as if the actions detailed
below occur prior to the invocation of the local procedure on each processor (see Section
6.3.2 for a related list of conditions and for the meaning of as if). Any actions thus required
are enforced by the compiler of the calling routine, and are not the responsibility of the
programmer, nor do they impact the local procedure.

1. The processors are synchronized. In other words, all actions that logically precede the
call are completed.

2. Each actual argument is remapped, if necessary, according to the directives (explicit
or implicit) in the declared interface for the extrinsic procedure. Thus, HPF map-
ning directives appearing in the interface are binding—the compiler must obey these
directives in calling local extrinsic procedures. (The reason for this rule is that data
mapping is explicitly visible in local routines). Actual arguments corresponding to
sequential arrays and scalar dummy arguments are replicated (by broadcasting, for
example) in all processors. Scalars of derived types with explicitly mapped structure
components or of an explicitly mapped derived type cannot be passed from global
HPF to an extrinsic local procedure.

3. If a variable accessible to the called routine has a replicated representation, then all
copies are updated prior to the call to contain the correct current value according to
the sequential semantics of the source program.

After these actions have occurred, the local procedure is invoked on each processor.
The information available to the local invocation is described below in Section 11.1.1.3.
When control is transferred back to the caller at the conclusion of the extrinsic local procedure, execution must resume as if the following actions have already been performed.

1. All processors are synchronized after the call. In other words, global computation proceeds as if the execution of every copy of the local routine is completed before execution in the caller is resumed.

2. The original distribution of arguments (and of the result of an extrinsic function) is restored, if necessary.

Advice to implementors. An implementation might check, before returning from the local subprogram, to make sure that replicated variables have been updated consistently by the subprogram. However, there is certainly no requirement—perhaps not even any encouragement—to do so. This is the responsibility of the local subprogram, and any checks in the caller are a tradeoff between speed and, for instance, debuggability. (End of advice to implementors.)

11.1.1.3 Information Available to the Local Procedure

The local procedure invoked on each processor is passed a local argument for each global argument passed by the caller to the (global) extrinsic procedure interface. Each global argument is an HPF array or scalar. The corresponding local argument is the part of the global array stored locally, or a local copy of a scalar argument or sequential array replicated across processors. Note that if the HPF array is replicated, each local procedure receives a copy of the entire actual. An array actual argument passed by an HPF caller is called a global array; the subgrid of that global array passed to one copy of a local routine (because it resides in that processor) is called a local array.

If the extrinsic procedure is a function, then the local procedure is also a function. Only scalar-valued extrinsic functions are allowed. All local functions must return the same value.

If a global HPF program calls local subprogram \( A \) with an actual array argument \( X \), and \( A \) receives a portion of array \( X \) as dummy argument \( P \), then \( A \) may call another local subprogram \( B \) and pass \( P \) or a section of \( P \) as an actual argument to \( B \).

The run-time interface must provide enough information that each local function can discover for each local argument the mapping of the corresponding global argument, translate global indices to local indices, and vice-versa. A specific set of procedures that provide this information is listed in the HPF Local Library Section 11.7.1. The manner in which this information is made available to the local routine depends on the implementation and the programming language used for the local routine.

11.1.2 The SERIAL Model

This section defines a set of conventions for writing code in which an instance of a subprogram executes on only one processor (of which there may be more than one).

If a program unit has extrinsic model SERIAL, an HPF compiler should assume that the subprogram is coded to be executed on a single processor. From the point of view of a global HPF caller, the SERIAL procedure behaves the same as an identically coded HPF procedure would. Differences might only arise in implementation-specific behavior (such as the performance).
There is currently no manner in which to specify which processor is to execute an HPF SERIAL procedure.

### 11.1.2.1 SERIAL Calling Sequence

Prior to invocation of a SERIAL procedure from global HPF, the behavior of the program will be as if the following actions take place:

1. The processors are synchronized. All actions that logically precede the call are completed.
2. All actual arguments are remapped to the processor that will actually execute the SERIAL procedure. Each argument will appear to the SERIAL procedure as a sequential argument.

The behavior of the SERIAL procedure will be as if it was executed on only one processor. After the instance of the SERIAL procedure invoked from global HPF has completed, the behavior will be as if the following happens:

1. All processors are synchronized after the call.
2. The original mappings of actual arguments are restored.

### 11.2 Extrinsic Language Bindings

The previous section lays out the rules and considerations for execution models defined for HPF extrinsics. The HPF extrinsic interface is also used to tell the compiler what the language conventions of a called subprogram are. Four language bindings are defined here: HPF, Fortran, F77, and C. A given implementation may support additional interfaces or allow a user to construct custom interfaces. Taken together, these sections define the special extrinsics HPF_LOCAL and HPF_SERIAL.

The key feature of the language interface is an extended set of attributes for dummy arguments in explicit extrinsic interfaces, which can give the programmer control over aspects of argument passing between procedures of different extrinsic types. This mechanism is used extensively in the interfaces to C and Fortran 77, but it is defined in this more general context because it can also apply to other language interfaces.

#### 11.2.1 Control of Arguments

The special data attributes for dummy arguments in routines of certain extrinsic types are MAP_TO, LAYOUT, and PASS_BY. These may only appear in data types statements declaring dummy arguments within explicit interfaces to procedures of appropriate extrinsic types. In particular, all of these attributes have been defined for extrinsic interfaces of type LANGUAGE = 'C' (Section 11.4), and the latter two have been defined for extrinsic interfaces of type LANGUAGE = 'F77' (Section 11.6).

The purpose of this language extension is to increase the flexibility of the EXTRINSIC interface mechanism to facilitate argument passing between procedures written in different programming languages. These three attributes provide a convenient way to pass data between nearly equivalent data type representations and array layouts, as well as to allow for different data passing conventions and options. It should be noted, however, that these
mechanisms are by no means expected to address the problems of full equivalence between
data types and implementations of different languages.

In particular, the MAP_TO attribute is designed to provide a standard, portable mecha-
nism for passing arguments between data types (in different languages) that have substantial
overlap but not necessarily identical ranges of values or an identical machine representation.
The programmer, not the language implementer, retains the responsibility for determining
whether or not any actual argument’s value will be adequately represented in the new data
type, or whether that value may be altered in successive operations involved in conversion
first to the new language, in operations within the extrinsic procedure, and then potentially
in conversion back to the original language. The LAYOUT attribute is used in cases when
the ordering of array elements within one or more processors may need to be changed when
passing them as arguments between procedures of different languages. Finally, the PASS_BY
attribute is designed to offer more detailed control of passing mechanisms for arguments to
allow for differences between language implementations, to choose between distinct passing
options offered in the non-HPF language, and to enable passing implementation-specific
data structures when it is desired to convey HPF mapping information along with data
values to non-HPF procedures.

These attributes are specified by an extension of the syntax rule R503 for attr-spec in
the Fortran standard. Rule R501 for type-declaration-stmt is not changed except to refer
to the extended attr-spec. The first two constraints below are repeated without change
from the Fortran standard for clarity, since they apply generally to all attributes. The
remaining constraints in the Fortran standard following rules R501 through R506 are specific
to attributes already defined in the standard and will also be assumed but not repeated
here.

These changes to Fortran syntax are made in anticipation of such extensions being
considered for addition to the standard language in the next revision, as language interop-
erability is an area of active interest to the full Fortran community.

H1101 type-declaration-stmt-extended is type-spec [ [ , attr-spec-extended ] . . . : ] entity-decl-list
H1102 attr-spec-extended is PARAMETER
or access-spec
or ALLOCATABLE
or DIMENSION ( array-spec )
or EXTERNAL
or INTENT ( intent-spec )
or INTRINSIC
or OPTIONAL
or POINTER
or SAVE
or TARGET
or MAP_TO ( map-to-spec )
or LAYOUT ( layout-spec )
or PASS_BY ( pass-by-spec )
H1103 map-to-spec is scalar-char-initialization-expr
H1104 layout-spec is scalar-char-initialization-expr
H1105 pass-by-spec is scalar-char-initialization-expr
11.2. EXTRINSIC LANGUAGE BINDINGS

Constraint: The same attr-spec-extended shall not appear more than once in a given type-
declaration-stmt.

Constraint: An entity shall not be explicitly given any attribute more than once in a scoping
unit.

Constraint: The attributes MAP_TO, LAYOUT, and PASS_BY may be specified only for dummy
arguments within a scoping unit of an extrinsic type for which these attributes
have been explicitly defined.

The definition of characteristics of a dummy data object as given in F95:12.2.1.1 and
extended in Section 8.15 is further extended to include the dummy data object’s MAP_TO,
LAYOUT, and PASS_BY attributes.

In the MAP_TO attribute, values of map-to-spec are intended to describe how the data
type of the named actual argument is mapped to the data type of the dummy argument in
the extrinsic procedure. An example is given in Section 11.4.2.1

For a given extrinsic type that allows the MAP_TO attribute, the set of permitted values
for the map-to-spec will be specified. If the range of permitted values of the type and
mapped-to type differ, and the value of the actual argument or some subobject of the
actual argument is not within the permitted range of the mapped-to type, the value of the
associated dummy argument or subobject becomes undefined. Conversely, if the value of
the dummy argument or some subobject of the dummy is not within the permitted range of
values of the associated actual argument, and the associated actual argument is a variable,
the value of the associated actual argument or subobject of the actual becomes undefined.

If there is a mismatch between the precision, representation method, range of permitted
values, or storage sequence between the type of the dummy argument and the permitted
mapped-to type of the dummy argument, the compiler shall ensure that, for the duration
of the reference to the extrinsic, the dummy argument is represented in a manner that is
compatible with the expectations of the callee for an object of the permitted mapped-to
type. Upon return from the procedure, the compiler shall ensure that the value of an actual
argument that is a variable is restored to the specified type and kind.

Advice to users. This rule was created to ensure the portability of interoperability.
However, it should be noted that for large objects, a significant overhead may be
incurred if there is a mismatch between the representation method used for the data
type versus the representation method used for the permitted mapped-to type. (End
of advice to users.)

In the LAYOUT attribute, any permitted values of layout-spec for a given extrinsic inter-
face are intended to describe how the data layout of the named actual argument is mapped
to the data layout of the dummy argument in the extrinsic procedure. An example is given
in Section 11.6.3. If no LAYOUT attribute is specified for a dummy array argument, the
data layout shall be the same as if it were being passed to an HPF procedure of the same
model, unless another default layout is defined for the given extrinsic type.

In the PASS_BY attribute, any permitted values of pass-by-spec for a given extrinsic
interface indicate a choice of mechanism used to associate the named actual argument with
the dummy argument in the extrinsic procedure. Examples are given in Sections 11.6.3
and 11.4.2.1. If no PASS_BY attribute is specified, the argument association mechanism is implementation dependent, based on the compiler's knowledge of the extrinsic language processor.

11.3 HPF Bindings

HPF is the default language assumption. It requires no MAP_TO, LAYOUT, or PASS_BY attributes in explicit interface definitions. All required subprogram binding information can be accomplished via the standard Fortran explicit interface.

The rules stated in section 14.7 of the Fortran standard will apply to variables defined in Fortran-based SERIAL and LOCAL scoping units. In particular, if the definition status, association status, or allocation status of a variable is defined upon execution of a RETURN statement or an END statement in a Fortran subprogram, such a variable in an SERIAL or LOCAL subprogram will be defined upon execution of a RETURN statement or an END statement.

Any I/O performed within an extrinsic subprogram of a different model, and the correspondence between file names and unit numbers used in global HPF and those used in local or serial subprogram code will be implementation defined.

11.3.1 Additional Special Considerations for HPF_LOCAL

There are some considerations about what HPF features may be used in writing a local, per-processor procedure.

Scalars of an explicitly mapped derived type cannot be passed to an \texttt{HPF LOCAL} subroutine.

The attributes (type, kind, rank, optional, intent) of the dummy arguments must match the attributes of the corresponding dummy arguments in the explicit interface. A dummy argument of an \texttt{EXTRINSIC('HPF', 'LOCAL')} routine may not be a procedure name.

A dummy argument of an \texttt{EXTRINSIC('HPF', 'LOCAL')} routine may not have the \texttt{POINTER} attribute.

A nonsequential dummy array argument of an \texttt{EXTRINSIC('HPF', 'LOCAL')} routine must have assumed shape. Note that, in general, the shape of a dummy array argument differs from the shape of the corresponding actual argument, unless there is a single executing processor.

Explicit mapping directives for dummy arguments may appear in a local procedure. Such directives are understood as applying to the global array whose local sections are passed as actual arguments or results on each processor. If such directives appear, corresponding mapping directives must be visible to every global HPF caller. This may be done by providing an interface block in the caller, or by placing the local procedure in a module of extrinsic kind \texttt{HPF LOCAL} that is then used by the global HPF program unit that calls the local procedure.

An \texttt{EXTRINSIC('HPF', 'LOCAL')} routine may not be invoked, either directly or indirectly, in the body of a \texttt{FORALL} construct or in the body of an \texttt{INDEPENDENT} loop.

A local procedure may have several \texttt{ENTRY} points. A global HPF caller must contain a separate extrinsic interface for each entry point that can be invoked from the HPF program.

### 11.3.2 Argument Association

If a dummy argument of an \texttt{EXTRINSIC('HPF', 'LOCAL')} routine is a scalar, then the corresponding dummy argument of the local procedure must be a scalar of the same type and type parameters. Only scalars of intrinsic types, or of derived types that are not explicitly mapped, may be passed from a global to an \texttt{HPF LOCAL} routine. When the extrinsic procedure is invoked, the local procedure is passed an argument that consists of a local copy of the scalar. This copy will be a valid HPF scalar.

If a dummy argument of an \texttt{EXTRINSIC('HPF', 'LOCAL')} routine is an array, then the corresponding dummy argument in the specification of the local procedure must be an array of the same rank, type, and type parameters.

If the array is sequential in the extrinsic interface, the corresponding actual argument will be passed by replication on all processors, just as scalar arguments are passed. Each local dummy argument will be associated with a full copy of the actual array argument. The dummy argument in the extrinsic interface and the corresponding dummy argument in the specification of the local procedure may be declared with the same explicit shape. All sequential dummy arguments passed by replication to an \texttt{EXTRINSIC('HPF', 'LOCAL')} procedure must either be \texttt{INTENT(IN)} arguments or should be updated consistently across processors.

If the dummy argument is a nonsequential array, then, when the extrinsic procedure is invoked, the local dummy argument is associated with the local array that consists of the subgrid of the global array that is stored locally. This local array will be a valid HPF array.

If an \texttt{EXTRINSIC('HPF', 'LOCAL')} routine is a function, then the local procedure is a function that returns a scalar of the same type and type parameters as the HPF extrinsic function. The value returned by each local invocation must be the same.
Each physical processor has at most one copy of each HPF variable. Consider the following extrinsic interface:

\[
\text{INTERFACE}
\text{EXTRINSIC('HPF','LOCAL')}\text{ FUNCTION MATZOH(X,Y) RESULT(Z)}\text{ REAL, DIMENSION(:,:) :: X} \text{ REAL, DIMENSION(:) :: Y} \text{ REAL Z} \text{ !HPF$ ALIGN WITH X(:,*) :: Y(:)} \text{ ! note that this asserts that size(Y) = size(X,1)} \text{ !HPF$ DISTRIBUTE X(BLOCK, CYCLIC)}
\text{END FUNCTION}
\text{END INTERFACE}
\]

The corresponding local HPF procedure is specified as follows.

\[
\text{EXTRINSIC('HPF','LOCAL')}\text{ FUNCTION MATZOH(XX,YY) RESULT(ZZ)} \text{ REAL, DIMENSION(:,:) :: XX} \text{ REAL, DIMENSION(5:) :: YY ! assumed shape with lower bound of 5} \text{ REAL ZZ} \text{ NX1 = SIZE(XX, 1)} \text{ LX1 = LBOUND(XX, 1)} \text{ UX1 = UBOUND(XX, 1)} \text{ NX2 = SIZE(XX, 2)} \text{ LX2 = LBOUND(XX, 2)} \text{ UX2 = UBOUND(XX, 2)} \text{ NY = SIZE(YY, 1)} \text{ LY = LBOUND(YY, 1)} \text{ UY = UBOUND(YY, 1)} \text{ ...}
\text{END FUNCTION}
\]

Assume that the function is invoked with an actual (global) array \(X\) of shape \(3 \times 3\) and an actual vector \(Y\) of length 3 on a 4-processor machine, using a 2 \(\times\) 2 processor arrangement (assuming one abstract processor per physical processor).

Then each local invocation of the function \(\text{MATZOH}\) receives the following actual arguments:

<table>
<thead>
<tr>
<th>Processor (1,1)</th>
<th>Processor (1,2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X(1,1))</td>
<td>(X(1,2))</td>
</tr>
<tr>
<td>(X(1,3))</td>
<td></td>
</tr>
<tr>
<td>(X(2,1))</td>
<td>(X(2,2))</td>
</tr>
<tr>
<td>(X(2,3))</td>
<td></td>
</tr>
<tr>
<td>(Y(1))</td>
<td>(Y(1))</td>
</tr>
<tr>
<td>(Y(2))</td>
<td>(Y(2))</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Processor (2,1)</th>
<th>Processor (2,2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X(3,1))</td>
<td>(X(3,2))</td>
</tr>
<tr>
<td>(X(3,3))</td>
<td></td>
</tr>
<tr>
<td>(Y(3))</td>
<td>(Y(3))</td>
</tr>
</tbody>
</table>

Here are the values to which each processor would set \(\text{NX1}, \text{LX1}, \text{UX1}, \text{NX2}, \text{LX2}, \text{UX2}, \text{NY}, \text{LY}, \text{and UY}:\)
### 11.3. HPF BINDINGS

<table>
<thead>
<tr>
<th>Processor (1,1)</th>
<th>Processor (1,2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NX1 = 2, LX1 = 1, UX1 = 2</td>
<td>NX1 = 2, LX1 = 1, UX1 = 2</td>
</tr>
<tr>
<td>NX2 = 2, LX2 = 1, UX2 = 2</td>
<td>NX2 = 1, LX2 = 1, UX2 = 1</td>
</tr>
<tr>
<td>NY = 2, LY = 5, UY = 6</td>
<td>NY = 2, LY = 5, UY = 6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Processor (2,1)</th>
<th>Processor (2,2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NX1 = 1, LX1 = 1, UX1 = 1</td>
<td>NX1 = 1, LX1 = 1, UX1 = 1</td>
</tr>
<tr>
<td>NX2 = 2, LX2 = 1, UX2 = 2</td>
<td>NX2 = 1, LX2 = 1, UX2 = 1</td>
</tr>
<tr>
<td>NY = 1, LY = 5, UY = 5</td>
<td>NY = 1, LY = 5, UY = 5</td>
</tr>
</tbody>
</table>

An actual argument to an extrinsic procedure may be a pointer. Since the corresponding dummy argument may not have the `POINTER` attribute, the dummy argument becomes associated with the target of the HPF global pointer. In no way may a local pointer become pointer associated with a global HPF target. Therefore, an actual argument may not be of a derived-type containing a pointer component.

*Rationale.* It is expected that global pointer variables will have a different representation from that of local pointer variables, at least on distributed memory machines, because of the need to carry additional information for global addressing. This restriction could be lifted in the future. *(End of rationale.)*

Other inquiry intrinsics, such as `ALLOCATED` or `PRESENT`, should also behave as expected. Note that when a global array is passed to a local routine, some processors may receive an empty set of elements.

#### 11.3.3 Special Considerations for HPF_SERIAL

There are restrictions that apply to an HPF_SERIAL subprogram.

No `specification-directive`, `realign-directive`, or `redistribute-directive` is permitted to be appear in an HPF_SERIAL subprogram or interface body.

*Rationale.* An HPF mapping directive would likely be meaningless in an HPF_SERIAL subprogram. Note, however, the `independent-directive` may appear in an HPF_SERIAL subprogram, since it may provide meaningful information to a compiler about a DO loop or a FORALL statement or construct. *(End of rationale.)*

Any dummy data objects and any function result variables of an HPF_SERIAL procedure will be considered to be sequential.

An HPF_SERIAL subprogram must not contain a definition of a common block that has the same name as a common block defined in an HPF or HPF_LOCAL program unit. In addition, an HPF_SERIAL subprogram must not contain a definition of the blank common block if an HPF or HPF_LOCAL program unit has a definition of the blank common block.

A dummy argument or function result variable of an HPF_SERIAL procedure that is referenced in global HPF must not have the `POINTER` attribute. A subobject of a dummy argument or function result of an HPF_SERIAL procedure that is referenced in global HPF, must not have the `POINTER` attribute.

A dummy argument of an HPF_SERIAL procedure that is referenced in global HPF and any subobject of such a dummy argument must not have the `TARGET` attribute.

A dummy procedure argument of an HPF_SERIAL procedure must be an HPF_SERIAL procedure.
PROGRAM MY_TEST
  INTERFACE
    EXTRINSIC('HPF', 'SERIAL') SUBROUTINE GRAPH_DISPLAY(DATA)
      INTEGER, INTENT(IN) :: DATA(:,:)
    END SUBROUTINE GRAPH_DISPLAY
  END INTERFACE
  
  INTEGER, PARAMETER :: X_SIZE = 1024, Y_SIZE = 1024
  INTEGER DATA_ARRAY(X_SIZE, Y_SIZE)
  !HPF$ DISTRIBUTED DATA_ARRAY(BLOCK, BLOCK)
  
  ! Compute DATA_ARRAY
  ...
  CALL DISPLAY_DATA(DATA_ARRAY)
  END PROGRAM MY_TEST

! The definition of a graphical display subroutine.
! In some implementation-dependent fashion,
! this will plot a graph of the data in DATA.

EXTRINSIC('HPF', 'SERIAL') SUBROUTINE GRAPH_DISPLAY(DATA)
  INTEGER, INTENT(IN) :: DATA(:, :)
  INTEGER :: X_IDX, Y_IDX
  
  DO Y_IDX = LBOUND(DATA, 2), UBOUND(DATA, 2)
    DO X_IDX = LBOUND(DATA, 1), UBOUND(DATA, 1)
      ...
    END DO
  END DO
  
  END SUBROUTINE GRAPH_DISPLAY

11.4 C Language Bindings

A common problem faced by Fortran users is the need to call procedures written in other languages, particularly those written in C or ones that have interfaces that can be described by C prototypes. Although many Fortran implementations provide methods that solve this problem, these solutions are rarely portable.

This section defines a method of specifying interfaces to procedures defined in C that removes most of the common obstacles to interoperability, while retaining portability.

11.4.1 Specification of Interfaces to Procedures Defined in C

If a user wishes to specify that a procedure is defined by a C procedure, this is specified with an extrinsic-spec-arg of LANGUAGE = ' C', or an extrinsic-kind-keyword of C, as specified in Section 6.

For C subprograms for which EXTRINSIC (LANGUAGE = ' C') has been specified, the constraints associated with the syntax for attr-spec-extended (H1102) are extended as fol-
11.4. C LANGUAGE BINDINGS

11.4.1 Constraints on C LANGUAGE = 'C' Functions and Procedures

- **Constraint:** A `LANGUAGE = 'C'` function shall have a scalar result of type integer, real or double precision.

- **Constraint:** A dummy argument of a `LANGUAGE = 'C'` procedure shall not be an assumed-shape array, shall not have the `POINTER` attribute, shall not have the `TARGET` attribute, nor shall it have a subobject that has the `POINTER` attribute.

- **Constraint:** The bounds of a dummy argument shall not be specified by specification expressions that are not constant specification expressions, nor shall the character length parameter of a dummy argument of such a procedure be specified by a specification expression that is not a constant specification expression.

- **Constraint:** A `dummy-arg-list` of a `LANGUAGE = 'C'` subroutine shall not have a `dummy-arg` that is `*` or a dummy procedure.

The value of the `scalar-char-initialization-expr` in the `EXTERNAL_NAME` specifier gives the name of the procedure as defined in C. This value need not be the same as the procedure name specified by the `function-stmt` or `subroutine-stmt`. If `EXTERNAL_NAME` is not specified, it is as if it were specified with a value that is the same as the procedure name in lower case letters.

*Advice to users.* Note that the `EXTERNAL_NAME` specifier does not necessarily specify the name by which a binder knows the procedure. It specifies the name by which the procedure would be known if it were referenced by a C program, and the HPF compiler is required to perform any transformations of that name that the C compiler would perform.

The `EXTERNAL_NAME` specifier also allows the user to specify a name that might not be permitted by an HPF compiler, such as a name beginning with an underscore, or as a way of enforcing the distinction between upper and lower case characters in the name. *(End of advice to users.)*

The `extrinsic-spec-arg` of `LANGUAGE = 'C'` helps a compiler identify a procedure that is defined in C so that it can take appropriate steps to ensure that the procedure is invoked in the manner required by the C compiler.

*Advice to implementors.* A vendor may feel compelled to provide support for more than one C compiler, if different C compilers available for a system provide different procedure calling conventions or different data type sizes. For instance, a vendor’s compiler may provide support for a value of `GNU_C` in the `LANGUAGE=` specifier, or it may provide support through the use of compiler switches. *(End of advice to implementors.)*

### 11.4.2 Specification of Data Type Mappings for C

The extrinsic dummy argument feature, consisting of the `MAP_TO`, `LAYOUT`, and `PASS_BY` attributes, is the principal feature that facilitates referencing procedures defined in C from within Fortran programs. Together, these attributes allow the user to specify conversions required to associate the actual arguments specified in the procedure reference with the
formal arguments defined by the referenced procedure. In particular, the MAP_TO attribute indicates the type of the C data to which the HPF data shall be converted by the compiler; the PASS_BY attribute indicates whether a C pointer to the dummy argument needs to be passed; the LAYOUT attribute indicates for an array whether the array element order needs to be changed from Fortran's array element ordering to C's.

For C, the constraints associated with attr-spec-extended, map-to-spec, layout-spec, and pass-by-spec (H1102–H1105) are further extended as follows.

Constraint: The MAP_TO attribute shall be specified for all dummy arguments and function result variables of a LANGUAGE = 'C' explicit interface.

Constraint: The map-to-spec associated with a dummy argument shall be compatible with the type of the dummy argument. (See below for compatibility rules.)

Constraint: A LAYOUT attribute shall only be specified for a dummy argument that is an array.

Constraint: A LAYOUT attribute shall not be specified for an assumed-size array.

If the compiler is capable of representing letters in both upper and lower case, the value specified for a map-to-spec, layout-spec or pass-by-spec is without regard to case. Any blanks specified for a map-to-spec, layout-spec or pass-by-spec shall be ignored by the compiler for the purposes of determining its value.

An implementation shall provide a module, ISO_C, that shall define a derived type, C_VOID_POINTER. The components of the C_VOID_POINTER type shall be private.

Advice to users. The C_VOID_POINTER type provides a method of using void * pointers in a program, but does not give the user any way of manipulating such a pointer in the Fortran part of the program, since I/O cannot be performed on an object with private components outside the module that defines the type, neither can the components or structure constructor of such a structure be used outside of the module that defines the type. (End of advice to users.)

The values permitted for a map-to-spec for LANGUAGE = 'C' are 'INT', 'LONG', 'SHORT', 'SIGNED_CHAR', 'FLOAT', 'DOUBLE', 'LONG_DOUBLE', 'CHAR', 'CHAR_PTR', 'VOID_PTR', or a comma-separated list, delimited by parentheses, of any of these values. The HPF types with which these are compatible are shown in the table below.

A map-to-spec that is a parenthesized list of values is compatible with a dummy argument of derived type if each value in the list is compatible with the corresponding component of the derived type.

When the PASS_BY attribute is used, the values permitted for a pass-by-spec are 'VAL', '*', or '**'. If no PASS_BY attribute is specified, then PASS_BY (‘VAL’) is assumed. If a pass-by-spec of VAL is specified, the dummy argument shall not have the INTENT(OUT) or INTENT(INOUT) attribute specified. If a value of '*' or '**' is specified for the pass-by-spec, an associated actual argument shall be a variable.

The value of the map-to-spec specified for a dummy argument in the interface body of a procedure for which a LANGUAGE=specifier whose value is C appears shall be such that at least one of the permitted mapped-to types is the same as the C data type of the corresponding formal argument in the C definition of the procedure (or a type that is compatible with one of the permitted mapped-to types). The C data type of a function in the C definition
of a procedure shall be one of the permitted mapped-to types (or a type that is equivalent to the permitted mapped-to types) specified for the function result variable in the interface body of a function with the LANGUAGE= specifier whose value is C. If a subroutine has been specified with a LANGUAGE= specifier whose value is C, the C definition of the procedure shall be specified with a data type of void.

The permitted mapped-to types for scalar dummy arguments of intrinsic type or of the derived type C_VOID_PTR, are shown in the following table.

<table>
<thead>
<tr>
<th>MAP_TO</th>
<th>Compatible With</th>
<th>'VAL'</th>
<th>C Type if PASS_BY</th>
</tr>
</thead>
<tbody>
<tr>
<td>'INT'</td>
<td>INTEGER</td>
<td>int</td>
<td>int*</td>
</tr>
<tr>
<td>'LONG'</td>
<td>INTEGER</td>
<td>long</td>
<td>long*</td>
</tr>
<tr>
<td>'SHORT'</td>
<td>INTEGER</td>
<td>short</td>
<td>short*</td>
</tr>
<tr>
<td>'SIGNED_CHAR'</td>
<td>INTEGER</td>
<td>signed char</td>
<td>signed char*</td>
</tr>
<tr>
<td>'FLOAT'</td>
<td>REAL</td>
<td>float</td>
<td>float*</td>
</tr>
<tr>
<td>'DOUBLE'</td>
<td>REAL</td>
<td>double</td>
<td>double*</td>
</tr>
<tr>
<td>'LONG_DOUBLE'</td>
<td>REAL</td>
<td>double</td>
<td>double*</td>
</tr>
<tr>
<td>'CHAR'</td>
<td>CHARACTER(1)</td>
<td>char</td>
<td>char*</td>
</tr>
<tr>
<td>'CHAR_PTR'</td>
<td>CHARACTER</td>
<td>char*</td>
<td>char*</td>
</tr>
<tr>
<td>'VOID_PTR'</td>
<td>C_VOID_PTR</td>
<td>void*</td>
<td>void**</td>
</tr>
</tbody>
</table>

The permitted mapped-to types of an array are the same as the permitted mapped-to types of a scalar variable of that type followed by a left bracket ([), followed by the extent of the corresponding dimension of the dummy argument, followed by a right bracket (]), for each dimension of the array. If no value is specified for the LAYOUT attribute, the corresponding dimensions of the dummy argument are determined from right to left; if the value C_ARRAY is specified for the LAYOUT attribute, the corresponding dimensions of the dummy argument are determined from left to right.

The value permitted for a LANGUAGE = 'C' layout-spec is C_ARRAY.

The permitted mapped-to types of a scalar variable of derived type are the structures whose corresponding members are of one of the permitted mapped-to types of the components of the derived type.

If there is a mismatch between the precision, representation method, range of permitted values or storage sequence between the type of the dummy argument and the permitted mapped-to type of the dummy argument, the compiler shall ensure that, for the duration of the reference to a procedure defined with a LANGUAGE= specifier whose value is C, the dummy argument is represented in a manner that is compatible with the expectations of the C processor for an object of the permitted mapped-to type. Upon return from the procedure, the compiler shall ensure that the value of an actual argument that is a variable is restored to the specified type and kind.

If the range of permitted values of the type and mapped-to type differ and the value of the actual argument or some subobject of the actual argument is not within the permitted range of the mapped-to type, the value of the associated dummy argument or subobject becomes undefined. Conversely, if the value of the dummy argument or some subobject of the dummy is not within the permitted range of values of the associated dummy argument, and the associated actual argument is a variable, the value of the associated actual argument or subobject of the actual becomes undefined.
Advice to users. These rules were created to ensure the portability of interoperability. However, it should be noted that for large objects, a significant overhead may be incurred if there is a mismatch between the representation method used for the data type versus the representation method used for the permitted mapped-to type. (End of advice to users.)

Advice to users. In some cases, this may cause the value of the actual argument to change without the value being modified by the procedure referenced. For example,

```
PROGRAM P

INTERFACE

EXTRINSIC(LANGUAGE='C') SUBROUTINE C_SUB(R,I)
  REAL(KIND(1.0D0)), MAP_TO('FLOAT'), PASS_BY('*') :: R
  INTEGER, MAP_TO('INT'), PASS_BY('*') :: I
END SUBROUTINE C_SUB

END INTERFACE

REAL(KIND(0.0D0)) RR

RR = 1.0D0 + 1.0D-10
I = 123456789
PRINT *, RR
CALL C_SUB(RR, I)
PRINT *, RR
END PROGRAM P

void c_sub(float *r, int *i)
{
}
```

might print

```
1.000000000100000000
1.000000000000000000
```

although the value of *r is not modified in c_sub. Similarly, the value of I might become undefined after the reference to c_sub, although *i is not modified.

Although it is good practice to avoid specifying a mapped-to type of float for a dummy argument of any type other than default real, or a mapped-to type of double for a dummy argument of any type other than double precision real, selecting an appropriate dummy argument type for objects requiring a mapped-to type int or long might not be so simple. (End of advice to users.)

If no layout-spec is specified for a dummy array argument, the array element order shall be the same as that specified by Fortran. If the value of layout-spec specified is C_ARRAY, the array element order of the array shall be transposed for the duration of the reference to the procedure.
11.4.2.1 Examples of Data Type Mappings

Some examples should help to clarify what sorts of C procedure definitions would be permitted given an interface body in a Fortran program. For example, the following interface body

```fortran
INTERFACE
    EXTRINSIC('C') SUBROUTINE C_SUB(I, R, DARR, STRUCT)
    INTEGER, MAP_TO('INT') :: I
    REAL, MAP_TO('FLOAT'), PASS_BY('*') :: R
    REAL(KIND(1.0D0)), MAP_TO('DOUBLE') :: DARR(10)
    TYPE DT
        SEQUENCE
        INTEGER :: I, J
    END TYPE DT
    TYPE(DT), MAP_TO('(INT, LONG)'), PASS_BY('*') :: STRUCT
END SUBROUTINE C_SUB
END INTERFACE
```

could correspond to a C procedure that has the prototype

```c
void c_sub(int i, float r*, double darr[10], struct {int i, long j} *)
```

In the following example of the LAYOUT attribute,

```fortran
PROGRAM P
    INTERFACE
        EXTRINSIC('C') SUBROUTINE C_SUB(A, B)
        INTEGER, MAP_TO('INT') :: A(2,2)
        INTEGER, MAP_TO('INT'), LAYOUT('C_ARRAY') :: B(2,2)
    END SUBROUTINE C_SUB
END INTERFACE

INTEGER :: AA(2,2), BB(2,2)
CALL C_SUB(AA, BB)
END PROGRAM P

void c_sub(int a[2][2], b[2][2])
```

the correspondence between elements of AA and a, and elements of BB and b is

- AA(1,1) a[0][0] BB(1,1) b[0][0]
- AA(2,1) a[0][1] BB(2,1) b[1][0]
- AA(1,2) a[1][0] BB(1,2) b[0][1]
- AA(2,2) a[1][1] BB(2,2) b[1][1]

11.5 Fortran Language Bindings

When the language specified in an extrinsic definition is Fortran, the rules are basically the same as those for HPF because HPF is based on the Fortran standard. There are a few issues to consider in this case:
• Only Fortran constructs should be used. Features such as asynchronous I/O or the HPF library may not be supported.

• It is recommended that Fortran language processors to be used for this purpose be extended to support the HPF_LOCAL distribution query routines and the associated HPF_LOCAL_LIBRARY.

• Assuming the intent is to compile the extrinsic routines with a Fortran processor, these routines should be in separate files rather than incorporated into files with HPF source code.

• The programmer should expect any HPF directives may be ignored.

11.6 Fortran 77 Language Bindings

For language interface purposes, Fortran 77 is still essentially a subset of ANSI/ISO standard Fortran, so most considerations relating to HPF calling Fortran also apply to HPF calling Fortran 77 extrinsic procedures. However, two chief differences between Fortran and Fortran 77 complicate the specification of any EXTRINSIC(LANGUAGE='F77'), interface from HPF, especially for the local model:

• Arguments are usually passed differently. Fortran 77 implementations typically pass arguments between subprograms by address (reference). That is, no other information about the actual argument is passed — for example, data type, size, distribution, etc. In contrast, HPF implementations often pass by variables by descriptor in order to make such information available to the subprogram.

• Very different information about how array elements are to be assigned to specific memory locations is available to Fortran 77 and HPF programmers.

In Fortran 77, the declaration of an array prescribes exactly the mapping of array elements to the linear sequence of storage locations. In HPF, the mapping of array elements to different processors may be controlled (e.g., with DISTRIBUTION and ALIGN directives) and queried (e.g., with HPF_ALIGNMENT, HPF_DISTRIBUTION, and HPF_TEMPLATE) but there is absolutely no information about how array elements on a given processor are organized within local, serial memory. Even in Fortran 90, assumed shape dummy arrays, for example, do not have to follow the same storage and sequence association rules as Fortran 77 arrays do.

Indeed, different HPF compilers may organize the data locally in different manners — perhaps including border cells for “stencil” optimizations, or global padding to ensure equal-size subgrids on all processors. Certainly, different HPF compilers are not bound to organize local data in any particular manner, and some may choose imaginative orderings in such cases as SMP’s, for example.

11.6.1 Special Considerations for F77_LOCAL

The EXTRINSIC(F77_LOCAL) interface extends the HPF_LOCAL and FORTRAN_LOCAL extrinsic interfaces to meet the needs of Fortran 77 programmers.

This EXTRINSIC type uses the syntax for calling extrinsic subprograms described above. It can be described more precisely as an EXTRINSIC(LANGUAGE='F77',MODEL='LOCAL')
interface. The basic conventions for transferring control between global and local routines described previously in Section 11.1 also apply.

However, the differences in argument passing and data distribution between these two languages, as well as the different possible motivations for using such an interface, can be better addressed by allowing additional options for passing data and distribution information. These options are provided with the help of LAYOUT and PASS_BY attributes.

### 11.6.2 Argument Passing to F77_LOCAL Procedures

A typical Fortran 77 implementation passes arguments by reference, usually by passing the base address of the location of the first data element, and such arguments may also be assumed to be sequence associated. These facts make it most practical for the default method of passing a distributed data structure from HPF to an F77_LOCAL procedure by passing the base address of that section of local memory that has been allocated to it. To allow for sequence association of actual and dummy arguments, data should also be reordered or compressed or both, if necessary, on all processors. This is the safest method of passing distributed data to an EXTRINSIC(F77_LOCAL) procedure, and hence it should be the default one. However, it tends to have the greatest performance costs.

A second argument passing option is to pass distributed array data “as is” from a global HPF procedure to the local F77 ones, not guaranteeing sequence association of the dummy arguments in order to avoid unwanted local data motion that might be required to compress or reorder the elements of an array local to a processor. In other words, it should be possible to do no more data motion than if the same argument were being passed to another HPF procedure. The guarantee of a sequence associated dummy argument is sacrificed for the possible gains in performance available because the local components of the actual argument are not reordered or compressed. The local programmer must be able to use the implementation-dependent ordering created by the global HPF program.

A third option that can be useful to permit HPF_LOCAL-style local programming from an EXTRINSIC(F77_LOCAL) procedure call is to pass an array via a descriptor or handle, as is typically done in HPF implementations or for Fortran 90 assumed shape arrays. The local procedure may not access elements of this dummy argument directly but may only pass it on to special utility routines, perhaps to obtain local or global distribution information.

The following attributes suffice to support the above three alternate form of passing data to an EXTRINSIC(F77_LOCAL) procedure:

- **LAYOUT('F77_ARRAY')** indicates that the rectangular configuration should be FORTRAN 77 sequence associated in local, serial memory.

  For example, many compilers add border elements for “stencil” optimizations or pad array allocations on particular processors so that all processors allocate equal amounts of memory for each array. Local reordering eliminates such padding and provides FORTRAN 77 sequence association for actual data values.

  Any local reordering is in addition to any global remapping that may be dictated by DISTRIBUTION or ALIGN directives in the INTERFACE block.

  If no LAYOUT attribute is specified, then LAYOUT('F77_ARRAY') is assumed.

- **LAYOUT('HPF_ARRAY')** indicates that an array argument is passed just as it would be to a global HPF procedure, with no local reordering of the data.
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This option is desirable when the programmer decides that the overhead of local reordering should be eliminated or that certain characteristics of the global HPF compiler's ordering (border cells, equal-size allocations among processors, etc.) should be preserved at the local level. It forces the local programmer to access the local data in whatever implementation-dependent style the global HPF compiler employs.

Furthermore, each argument in the INTERFACE block can also have its PASS_BY attribute specified to indicate whether the data is passed by reference, for Fortran 77-style access, or via a special handle, perhaps a descriptor used for HPF variable passing, that permits the global HPF caller to pass special mapping information for use within the local Fortran 77 procedure.

- PASS_BY('**') indicates that the local procedure should be able to access the dummy argument locally as an F77-style variable, passed by reference.
- PASS_BY('HPF_HANDLE') indicates that the local procedure should receive a reference to a global descriptor that can be used with special inquiry routines to obtain useful distribution information.

Thus, the default dummy argument attributes are LAYOUT('F77_ARRAY'), a guarantee of sequence association, and PASS_BY('**'), an indication that data is being passed via a pointer to its location.

Advice to implementors.

In addition to providing argument passing and data reordering options, a good EXTRINSIC(F77_LOCAL) implementation should address the problem of declaring arbitrary sized local subgrids and accessing their elements without being able to describe them as assumed-shape arrays, as in HPF. Dealing with the local results of global data distributions within each local procedure initiated by an extrinsic procedure call can also be difficult without Fortran 90 array inquiry functions and the inquiry subroutines in the HPF Library. Special inquiry routines, callable globally or locally, such as the proposed library of Fortran 77 function interfaces in Annex G are recommended as supplements to the EXTRINSIC(F77_LOCAL) procedure interface in order to permit more flexible and efficient use of a broad range of possible global HPF data distributions.

(End of advice to implementors.)

11.6.3 F77_LOCAL Programming Examples

11.6.3.1 LAYOUT('F77_ARRAY') and PASS_BY('**')

This example illustrates F77_LOCAL programming using the default LAYOUT('F77_ARRAY') and PASS_BY('**') attributes, and the use of inquiry routines from the local level using the LAYOUT('HPF_ARRAY') attribute.

- HPF caller

PROGRAM EXAMPLE
! Declare the data array and a verification copy
INTEGER, PARAMETER :: NX = 100, NY = 100
REAL, DIMENSION(NX,NY) :: X, Y
!HPF$ DISTRIBUTEBLOCK, BLOCK :: X, Y

! The global sum will be computed
! by forming partial sums on the processors
REAL PARTIAL_SUM(NUMBER_OF_PROCESSORS())
!HPF$ DISTRIBUTEBLOCK, BLOCK :: PARTIAL_SUM(BLOCK)

! Local subgrid parameters are declared per processor
! for a rank-two array
INTEGER, DIMENSION(NUMBER_OF_PROCESSORS(),2) :::
& LB, UB, NUMBER
!HPF$ DISTRIBUTEBLOCK, * :: LB, UB, NUMBER

! Define interfaces
INTERFACE
EXTRINSIC(F77_LOCAL) SUBROUTINE LOCAL1
& ( LB1, UB1, LB2, UB2, X, X_DESC )
INTEGER, DIMENSION::* :: LB1, UB1, LB2, UB2
REAL, DIMENSION(:,,:),LAYOUT('HPF_ARRAY') :: X
REAL, DIMENSION(:,,:),LAYOUT('HPF_ARRAY'), &
& PASS_BY('HPF_HANDLE') :: X_DESC
!HPF$ DISTRIBUTEBLOCK :: LB1, UB1, LB2, UB2
!HPF$ DISTRIBUTEBLOCK, BLOCK :: X, X_DESC
END

EXTRINSIC(F77_LOCAL) SUBROUTINE LOCAL2(N,X,R)
INTEGER N(:)
REAL X(:,:), R(:)
! Defaults:
! LAYOUT('F77_ARRAY') sequential, column-major storage
! PASS_BY('*') pass by reference (local address)
!HPF$ DISTRIBUTEBLOCK
!HPF$ DISTRIBUTE XBLOCK, BLOCK)
!HPF$ DISTRIBUTE R(BLOCK)
END

END INTERFACE

! Determine result using only global HPF

! Initialize values
FORALL (I=1:NX, J=1:NY) X(I,J) = I + (J-1) * NX
! Determine and report global sum
PRINT *, 'Global HPF result: ', SUM(X)

! Determine result using local subroutines

! Initialize values (assume stride = 1)
CALL HPF_SUBGRID_INFO(Y, IERR, LB=lb, UB=UB)
IF (IERR.NE.0) STOP 'ERROR!'
CALL LOCAL1(LB(:,1), UB(:,1), LB(:,2), UB(:,2), Y, Y)

! DETERMINE AND REPORT GLOBAL SUM
NUMBER = UB - LB + 1
CALL LOCAL2(NUMBER(:,1) * NUMBER(:,2), Y, PARTIAL_SUM)
PRINT *, 'F77_LOCAL result #1: ', SUM(PARTIAL_SUM)

END

* FORTRAN 77 callee

SUBROUTINE LOCAL1(LB1, UB1, LB2, UB2, X, DESCRX)

REAL X ( LB1 : UB1 , LB2 : UB2 )
INTEGER DESCRX ( * )

! Get the global extent of the first axis
! This is an HPF_LOCAL type of inquiry routine with an 'F77_' prefix
CALL F77_GLOBAL_SIZE(NX, DESCRX, 1)

! Initialize elements of the array
DO J = LB2, UB2
  DO I = LB2, UB2
    X(I,J) = I + (J-1) * NX
  END DO
END DO
END

END

SUBROUTINE LOCAL2(N,X,R)

! Here, the correspondence to the global indices is not important
! Only the total size of the subgrid is passed in
REAL X(N)

R = 0.
DO I = 1, N
  R = R + X(I)
END DO
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11.6.3.2 LAYOUT(‘HPF_ARRAY’) and PASS_BY(‘HPF_HANDLE’)

This example performs only the initialization of the above example. It illustrates use of the
LAYOUT(‘F77_ARRAY’) attribute to pass an HPF distributed array without remapping, as
well as use of PASS_BY(‘HPF_HANDLE’) to pass an HPF-style descriptor or handle for use
in the F77_LOCAL subgrid inquiry function. It also illustrates the addressing of data in
terms of “embedding arrays.”

- HPF caller

PROGRAM EXAMPLE

INTEGER, PARAMETER :: NX = 100, NY = 100
REAL, DIMENSION(NX, NY) :: Y
!HPF$ DISTRIBUT(BLOCK,BLOCK) :: Y

! Local subgrid parameters are declared per processor
! for a rank-two array
INTEGER, DIMENSION(NUMBER_OF_PROCESSORS(),2) :::
  & LB, UB, LB_EMBED, UB_EMBED
!HPF$ DISTRIBUT(BLOCK,*): LB, UB, LB_EMBED, UB_EMBED

! Define interfaces

INTERFACE

EXTRINSIC(F77_LOCAL) SUBROUTINE LOCAL1( 
  & LB1, UB1, LB_EMBED1, UB_EMBED1,
  & LB2, UB2, LB_EMBED2, UB_EMBED2, X, X_DESC )
INTEGER, DIMENSION(:,:):=
  & LB1, UB1, LB_EMBED1, UB_EMBED1,
  & LB2, UB2, LB_EMBED2, UB_EMBED2
! By default, X is passed by reference
REAL, DIMENSION(:,:), LAYOUT(‘HPF_ARRAY’) :: X
! X_DESC is passed by its descriptor or ‘handle’
REAL, DIMENSION(:,:), LAYOUT(‘HPF_ARRAY’),
  & PASS_BY(‘HPF_HANDLE’) :: X_DESC
!HPF$ DISTRIBUT(BLOCK) :: LB1, UB1, LB_EMBED1, UB_EMBED1
!HPF$ DISTRIBUT(BLOCK) :: LB2, UB2, LB_EMBED2, UB_EMBED2
!HPF$ DISTRIBUT(BLOCK,BLOCK) :: X
END

END INTERFACE
! Initialize values
! ( Assume stride = 1 and no axis permutation )

CALL HPF_SUBGRID_INFO( Y, IERR,
& LB=LB, LB_EMBED=LB_EMBED,
& UB=UB, UB_EMBED=UB_EMBED)
IF (IERR.NE.0) STOP 'ERROR!

CALL LOCAL1(
& LB(:,1), UB(:,1), LB_EMBED(:,1), UB_EMBED(:,1),
& LB(:,2), UB(:,2), LB_EMBED(:,2), UB_EMBED(:,2), Y, Y )

END

• Fortran 77 callee

SUBROUTINE LOCAL1(
& LB1, UB1, LB_EMBED1, UB_EMBED1,
& LB2, UB2, LB_EMBED2, UB_EMBED2, X, X_DESC )

! The subgrid has been passed in its 'embedded' form
REAL X ( LB_EMBED1 : UB_EMBED1 , LB_EMBED2 : UB_EMBED2 )

! This argument is used only as input to inquiry functions
INTEGER X_DESC

! Get the global extent of the first axis
! This is an HPF_LOCAL type of inquiry routine with an 'F77_' prefix
CALL F77_GLOBAL_SIZE(NX,X_DESC,1)

! Otherwise, initialize elements of the array
! Loop only over actual array elements
DO J = LB2, UB2
  DO I = LB2, UB2
    X(I,J) = I + (J-1) * NX
  END DO
END DO
END

11.7 The Extrinsic Library

Following are Fortran bindings for routines useful in intrinsic subprograms.

11.7.1 HPF Local Routine Library

Local HPF procedures can use any HPF intrinsic or library procedure.
Advice to implementors. The arguments to such procedures will be local arrays. Depending on the implementation, the actual code for the intrinsic and library routines used by local HPF procedures may or may not be the same code used when called from global HPF code. (End of advice to implementors.)

In addition, local library procedures `GLOBAL_ALIGNMENT`, `GLOBAL_DISTRIBUTION`, and `GLOBAL_TEMPLATE` are provided to query the global mapping of an actual argument to an extrinsic function. Other local library procedures are provided to query the size, shape, and array bounds of an actual argument. These library procedures take as input the name of a dummy argument and return information on the corresponding global HPF actual argument. They may be invoked only by a local procedure that was directly invoked by global HPF code. If module facilities are available, they reside in a module called `HPF_LOCAL_LIBRARY`; a local routine that calls them should include the statement

```
USE HPF_LOCAL_LIBRARY
```

or some functionally appropriate variant thereof.

The HPF local routine library identifies each physical processor by an integer in the range 0 to `n` − 1, where `n` is the value returned by the global `HPF_LIBRARY` function `NUMBER_OF_PROCESSORS`. Processor identifiers are returned by `ABSTRACT_TO_PHYSICAL`, which establishes the one-to-one correspondence between the abstract processors of an HPF processors arrangement and the physical processors. Also, the local library function `MY_PROCESSOR` returns the identifier of the calling processor.

In all cases, when an argument of one of the procedures of the local HPF library is required to be a local dummy argument associated with a global HPF actual argument, such association is not considered to be transitive. That is, the local dummy argument must be a dummy argument of a procedure which was referenced from global HPF, not from another local subprogram.

### 11.7.1.1 Accessing Dummy Arguments by Blocks

The mapping of a global HPF array to the physical processors places one or more blocks, which are groups of elements with consecutive indices, on each processor. The number of blocks mapped to a processor is the product of the number of blocks of consecutive indices in each dimension that are mapped to it. For example, a rank-one array `X` with a `CYCLIC(4)` distribution will have blocks containing four elements, except for a possible last block having `1 + SIZE(X)` mod 4 elements. On the other hand, if `X` is first aligned to a template or an array having a `CYCLIC(4)` distribution, and a non-unit stride is employed (as is `HPF$ ALIGN X(I) WITH T(3*I)`), then its blocks may have fewer than four elements.

In this case, when the align stride is three and the template has a block-cyclic distribution with four template elements per block, the blocks of `X` have either one or two elements each. If the align stride were five, then all blocks of `X` would have exactly one element, as template blocks to which no array element is aligned are not counted in the reckoning of numbers of blocks.

The portion of a global array argument associated with a dummy argument in an `HPF_LOCAL` subprogram may be accessed in a block-by-block fashion. Three of the local library routines, `LOCAL_BLK_CNT`, `LOCAL_LINDEX`, and `LOCAL_UINDEX`, allow easy access to the local storage of a particular block. Their use for this purpose is illustrated by the following example, in which the local data are initialized one block at a time:
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EXTRINSIC(HPF_LOCAL) SUBROUTINE NEWKI_DONT_HEBLOCK(X)
REAL X(:, :, :)
INTEGER BL(3)
INTEGER, ALLOCATABLE LIND1(:,), LIND2(:,), LIND3(:,)
INTEGER, ALLOCATABLE UIND1(:,), UIND2(:,), UIND3(:,)

BL = LOCAL_BLKCNT(X)

ALLOCATE LIND1(BL(1))
ALLOCATE LIND2(BL(2))
ALLOCATE LIND3(BL(3))

ALLOCATE UIND1(BL(1))
ALLOCATE UIND2(BL(2))
ALLOCATE UIND3(BL(3))

LIND1 = LOCAL_LINDEX(X, DIM = 1)
UIND1 = LOCAL_UINDEX(X, DIM = 1)

LIND2 = LOCAL_LINDEX(X, DIM = 2)
UIND2 = LOCAL_UINDEX(X, DIM = 2)

LIND3 = LOCAL_LINDEX(X, DIM = 3)
UIND3 = LOCAL_UINDEX(X, DIM = 3)

DO IB1 = 1, BL(1)
  DO IB2 = 1, BL(2)
    DO IB3 = 1, BL(3)
      FORALL (I1 = LIND1(IB1) : UIND1(IB1), &
        I2 = LIND2(IB2) : UIND2(IB2), &
        I3 = LIND3(IB3) : UIND3(IB3) ) &
        X(I1, I2, I3) = IB1 + 10*IB2 + 100*IB3
    ENDDO
  ENDDO
ENDDO
END SUBROUTINE NEWKI_DONT_HEBLOCK

GLOBAL_ALIGNMENT(ARRAY, ...)

This has the same interface and behavior as the HPF inquiry subroutine HPF_ALIGNMENT, but it returns information about the global HPF array actual argument associated with the local dummy argument ARRAY, rather than returning information about the local array.

GLOBAL_DISTRIBUTION(ARRAY, ...)

This has the same interface and behavior as the HPF inquiry subroutine HPF_DISTRIBUTION, but it returns information about the global HPF array actual argument associated with the
local dummy argument \texttt{ARRAY}, rather than returning information about the local array.

\textbf{GLOBAL\_TEMPLATE(ARRAY, \ldots)}

This has the same interface and behavior as the HPF inquiry subroutine \texttt{HPF\_TEMPLATE}, but it returns information about the \textit{global} HPF array actual argument associated with the local dummy argument \texttt{ARRAY}, rather than returning information about the local array.

\textbf{GLOBAL\_SHAPE(SOURCE)}

\textbf{Description.} Returns the shape of the global HPF actual argument associated with an array or scalar dummy argument of an HPF\_LOCAL procedure.

\textbf{Class.} Inquiry function.

\textbf{Argument.}

\texttt{SOURCE} may be of any type. It may be array valued or a scalar. It must be a dummy argument of an HPF\_LOCAL procedure which is argument associated with a global HPF actual argument.

\textbf{Result Type, Type Parameter and Shape.} The result is a default integer array of rank one whose size is equal to the rank of \texttt{SOURCE}.

\textbf{Result Value.} The value of the result is the shape of the global actual argument associated with the actual argument associated with \texttt{SOURCE}.

\textbf{Examples.} Assuming \texttt{A} is declared by the statement

\begin{verbatim}
INTEGER A(3:100, 200)
\end{verbatim}

and is argument associated with \texttt{B}, the value of \texttt{GLOBAL\_SHAPE(B)} is $[98, 200]$. If \texttt{B} is argument associated with the section, \texttt{A(5:10, 10)}, the value of \texttt{GLOBAL\_SHAPE(B)} is $[6]$.

\textbf{GLOBAL\_SIZE(ARRAY, DIM)}

\textbf{Optional argument.} \texttt{DIM}

\textbf{Description.} Returns the extent along a specified dimension of the global HPF actual array argument associated with a dummy array argument of an HPF\_LOCAL procedure.

\textbf{Class.} Inquiry function.

\textbf{Argument.}

\texttt{ARRAY} may be of any type. It must not be a scalar. It must be a dummy argument of an HPF\_LOCAL procedure which is argument associated with a global HPF actual argument.

\texttt{DIM} (optional) must be scalar and of type integer with a value in the range $1 \leq \texttt{DIM} \leq n$, where $n$ is the rank of \texttt{ARRAY}. 


**Result Type, Type Parameter and Shape.** Default integer scalar.

**Result Value.** The result has a value equal to the extent of dimension \( \text{DIM} \) of the actual argument associated with the actual argument associated with \( \text{ARRAY} \) or, if \( \text{DIM} \) is absent, the total number of elements in the actual argument associated with the actual argument associated with \( \text{ARRAY} \).

**Examples.** Assuming \( A \) is declared by the statement

\[
\text{INTEGER } A(3:10, 10)
\]

and is argument associated with \( B \), the value of \( \text{GLOBAL\_SIZE}(B, 1) \) is 8. If \( B \) is argument associated with the section, \( A(5:10, 2:4) \), the value of \( \text{GLOBAL\_SIZE}(B) \) is 18.

**ABSTRACT_TO_PHYSICAL(ARRAY, INDEX, PROC)**

**Description.** Returns processor identification for the physical processor associated with a specified abstract processor relative to a global actual argument array.

**Class.** Subroutine.

**Arguments.**

**ARRAY** may be of any type; it must be a dummy array that is associated with a global HPF array actual argument. It is an \( \text{INTENT(IN)} \) argument.

**INDEX** must be a rank-1 integer array containing the coordinates of an abstract processor in the processors arrangement onto which the global HPF array is mapped. It is an \( \text{INTENT(IN)} \) argument. The size of \( \text{INDEX} \) must equal the rank of the processors arrangement. The value of the \( i^{th} \) element must be in the range 1 to \( e_i \), where \( e_i \) is the extent of the \( i^{th} \) dimension of the processors arrangement.

**PROC** must be scalar and of type integer. It is an \( \text{INTENT(OUT)} \) argument. It receives the identifying value for the physical processor associated with the abstract processor specified by \( \text{INDEX} \).

**PHYSICAL_TO_ABSTRACT(ARRAY, PROC, INDEX)**

**Description.** Returns coordinates for an abstract processor, relative to a global actual argument array, corresponding to a specified physical processor.

**Class.** Subroutine.

**Arguments.**

**ARRAY** may be of any type; it must be a dummy array that is associated with a global HPF array actual argument. It is an \( \text{INTENT(IN)} \) argument.
PROC must be scalar and of type default integer. It is an INTENT(IN) argument. It contains an identifying value for a physical processor.

INDEX must be a rank-1 integer array. It is an INTENT(OUT) argument. The size of INDEX must equal the rank of the processor arrangement onto which the global HPF array is mapped. INDEX receives the coordinates within this processors arrangement of the abstract processor associated with the physical processor specified by PROC. The value of the \( i^{th} \) element will be in the range 1 to \( e_i \), where \( e_i \) is the extent of the \( i^{th} \) dimension of the processors arrangement.

This procedure can be used only on systems where there is a one-to-one correspondence between abstract processors and physical processors. On systems where this correspondence is one-to-many an equivalent, system-dependent procedure should be provided.

LOCAL_TO_GLOBAL(ARRAY, L_INDEX, G_INDEX)

Description. Converts a set of local coordinates within a local dummy array to an equivalent set of global coordinates within the associated global HPF actual argument array.

Class. Subroutine.

Arguments.

ARRAY may be of any type; it must be a dummy array that is associated with a global HPF array actual argument. It is an INTENT(IN) argument.

L_INDEX must be a rank-1 integer array whose size is equal to the rank of ARRAY. It is an INTENT(IN) argument. It contains the coordinates of an element within the local dummy array ARRAY. The value of the \( i^{th} \) element must be in the range 1 to \( e_i \), where \( e_i \) is the extent of the \( i^{th} \) dimension of ARRAY.

G_INDEX must be a rank-1 integer array whose size is equal to the rank of ARRAY. It is an INTENT(OUT) argument. It receives the coordinates within the global HPF array actual argument of the element identified within the local array by L_INDEX. The value of the \( i^{th} \) element will be in the range 1 to \( e_i \), where \( e_i \) is the extent of the \( i^{th} \) dimension of the global HPF actual argument array associated with ARRAY.

GLOBAL_TO_LOCAL(ARRAY, G_INDEX, L_INDEX, LOCAL, NCOPIES, PROCS)

Optional arguments. L_INDEX, LOCAL, NCOPIES, PROCS
**Description.** Converts a set of global coordinates within a global HPF actual argument array to an equivalent set of local coordinates within the associated local dummy array.

**Class.** Subroutine.

**Arguments.**

- **ARRAY** may be of any type; it must be a dummy array that is associated with a global HPF array actual argument. It is an INTENT(IN) argument.

- **G_INDEX** must be a rank-1 integer array whose size is equal to the rank of ARRAY. It is an INTENT(IN) argument. It contains the coordinates of an element within the global HPF array actual argument associated with the local dummy array ARRAY. The value of the $i^{th}$ element must be in the range 1 to $e_i$, where $e_i$ is the extent of the $i^{th}$ dimension of the global HPF actual argument array associated with ARRAY.

- **L_INDEX (optional)** must be a rank-1 integer array whose size is equal to the rank of ARRAY. It is an INTENT(OUT) argument. It receives the coordinates within a local dummy array of the element identified within the global actual argument array by **G_INDEX**. (These coordinates are identical on any processor that holds a copy of the identified global array element.) The value of the $i^{th}$ element will be in the range 1 to $e_i$, where $e_i$ is the extent of the $i^{th}$ dimension of ARRAY.

- **LOCAL (optional)** must be scalar and of type LOGICAL. It is an INTENT(OUT) argument. It is set to .TRUE. if the local array contains a copy of the global array element and to .FALSE. otherwise.

- **NCOPIES (optional)** must be scalar and of type integer. It is an INTENT(OUT) argument. It is set to the number of processors that hold a copy of the identified element of the global actual array.

- **PROCS (optional)** must be a rank-1 integer array whose size is at least the number of processors that hold copies of the identified element of the global actual array. The identifying numbers of those processors are placed in **PROCS**. The order in which they appear is implementation dependent.

### MY_PROCESSOR()

**Description.** Returns the identifying number of the calling physical processor.

**Class.** Pure function.
**Result Type, Type Parameter, and Shape.** The result is scalar and of type default integer.

**Result Value.** Returns the identifying number of the physical processor from which the call is made. This value is in the range $0 \leq \text{MY\_PROCESSOR} \leq n - 1$ where $n$ is the value returned by \texttt{NUMBER\_OF\_PROCESSORS}.

**\texttt{LOCAL\_BLKCNT(ARRAY, DIM, PROC)}**

**Optional arguments.** \texttt{DIM}, \texttt{PROC}.

**Description.** Returns the number of blocks of elements in each dimension, or of a specific dimension of the array on a given processor.

**Class.** Pure function.

**Arguments.**

- **ARRAY** may be of any type; it must be a dummy array that is associated with a global HPF array actual argument.

- **DIM (optional)** must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of \texttt{ARRAY}. The corresponding actual argument must not be an optional dummy argument.

- **PROC (optional)** must be scalar and of type integer. It must be a valid processor number.

**Result Type, Type Parameter, and Shape.** The result is of type default integer. It is scalar if \texttt{DIM} is present; otherwise the result is an array of rank one and size $n$, where $n$ is the rank of \texttt{ARRAY}.

**Result Value.**

- **Case (i):** The value of \texttt{LOCAL\_BLKCNT(ARRAY, DIM, PROC)} is the number of blocks of the ultimate align target of \texttt{ARRAY} in dimension \texttt{DIM} that are mapped to processor \texttt{PROC} and which have at least one element of \texttt{ARRAY} aligned to them.

- **Case (ii):** \texttt{LOCAL\_BLKCNT(ARRAY, DIM)} returns the same value as \texttt{LOCAL\_BLKCNT(ARRAY, DIM, PROC=MY\_PROCESSOR())}.

- **Case (iii):** \texttt{LOCAL\_BLKCNT(ARRAY)} has a value whose $i^{th}$ component is equal to \texttt{LOCAL\_BLKCNT(ARRAY, i)}, for $i = 1, \ldots, n$, where $n$ is the rank of \texttt{ARRAY}.

**Examples.** Given the declarations

```fortran
REAL A(20,20), B(10)
!HPF$ TEMPLATE T(100,100)
!HPF$ ALIGN B(J) WITH A(*,J)
!HPF$ ALIGN A(I,J) WITH T(3*I, 2*J)
```
SECTION 11. APPROVED EXTENSIONS FOR HPF EXTRINSICS

!HPF$ PROCESORS PR(5,5)
!HPF$ DISTRIBUTE T(CYCLIC(3), CYCLIC(3)) ONTO PR
!HPF$ CALL LOCAL.Compute(A, B)
... ...
...
EXTRINSIC(HPF_LOCAL) SUBROUTINE LOCAL.Compute(X, Y)
USE HPF_LOCAL_LIBRARY
REAL X(:,), Y(:)
INTEGER NBY(1), NBX(2)
NBX = LOCAL_BLKCNT(X)
NBY = LOCAL_BLKCNT(Y)

the values returned on the physical processor corresponding to PR(2,4) in NBX is $\begin{bmatrix} 4 & 3 \end{bmatrix}$
and in NBY is $\begin{bmatrix} 1 \end{bmatrix}$.

LOCAL_LINDEX(ARRAY, DIM, PROC)

Optional argument. PROC.

Description. Returns the lowest local index of all blocks of an array dummy argument in a given dimension on a processor.

Class. Pure function.

Arguments.

ARRAY may be of any type; it must be a dummy array that is associated with a global HPF array actual argument.

DIM must be scalar and of type integer with a value in the range $1 \leq \text{DIM} \leq n$, where $n$ is the rank of ARRAY.

PROC (optional) must be scalar and of type integer. It must be a valid processor number.

Result Type, Type Parameter, and Shape. The result is a rank-one array of type default integer and size $b$, where $b$ is the value returned by LOCAL_BLKCNT(ARRAY, DIM [, PROC])

Result Value.

Case (i): The value of LOCAL_LINDEX(ARRAY, DIM, PROC) has a value whose $i^{th}$ component is the local index of the first element of the $i^{th}$ block in dimension DIM of ARRAY on processor PROC. The value of the $j^{th}$ element will be in the range 1 to $e_i$, where $e_i$ is the extent of the $i^{th}$ dimension of ARRAY.

Case (ii): LOCAL_LINDEX(ARRAY, DIM) returns the same value as LOCAL_LINDEX(ARRAY, DIM, PROC=MY_PROCESSOR()).
Examples. With the same declarations as in the example under LOCAL_BITCNT, on
the physical processor corresponding to PR(2, 4) the value returned by
LOCAL_LINDEX(X, DIM=1) is \[ \begin{bmatrix} 1 & 2 & 3 & 4 \end{bmatrix} \];
the value of LOCAL_LINDEX(X, DIM=2) is \[ \begin{bmatrix} 1 & 3 & 4 \end{bmatrix} \].

**LOCAL_UINDEX(ARRAY, DIM, PROC)**

Optional argument. PROC.

Description. Returns the highest local index of all blocks of an array dummy
argument in a given dimension on a processor.

Class. Pure function.

Arguments.

ARRAY may be of any type; it must be a dummy array that is
associated with a global HPF array actual argument.

DIM must be scalar and of type integer with a value in the
range \[ 1 \leq \text{DIM} \leq n \], where \( n \) is the rank of ARRAY.

PROC (optional) must be scalar and of type integer. It must be a valid
processor number.

Result Type, Type Parameter, and Shape. The result is a rank-one
array of type default integer and size \( b \), where \( b \) is the value returned by
LOCAL_BITCNT(ARRAY, DIM [, PROC])

Result Value.

Case (i): The value of LOCAL_UINDEX(ARRAY, DIM, PROC) has a value whose \( i^{th} \)
component is the local index of the last element of the \( i^{th} \) block in di-

dimension DIM of ARRAY on processor PROC. The value of the \( j^{th} \) element
will be in the range 1 to \( e_j \), where \( e_j \) is the extent of the \( i^{th} \) dimension of
ARRAY.

Case (ii): LOCAL_UINDEX(ARRAY, DIM) returns the same value as
LOCAL_UINDEX(ARRAY, DIM, PROC=MY_PROCESSOR()).

Examples. With the same declarations as in the example under LOCAL_BITCNT, on
the physical processor corresponding to PR(2, 4) the value returned by
LOCAL_UINDEX(X, DIM=1) is \[ \begin{bmatrix} 1 & 2 & 3 & 4 \end{bmatrix} \];
the value of LOCAL_UINDEX(X, DIM=2) is \[ \begin{bmatrix} 2 & 3 & 4 \end{bmatrix} \].

11.7.2 Library Access from Serial Extrinsics

A SERIAL subprogram may contain references to any HPF_LIBRARY procedure or HPF intrin-
sic function, except HPF_ALIGNMENT, HPF_DISTRIBUTION or HPF_TEMPLATE. Within a SERIAL
scope the HPF_LOCAL_LIBRARY module must not be used.

References to the intrinsic functions NUMBER_OF_PROCESSORS and PROCESSORS_SHAPE
will return the same value as if the function reference appeared in global HPF.
Section 12

Approved Extensions to the HPF Intrinsic and Library Procedures

This chapter describes intrinsic and library routines that have been approved as extensions to HPF Version 2.0.

The extended intrinsic procedures include a transpose function that generalizes the Fortran TRANSPOSE intrinsic function. Certain algorithms require access to multidimensional arrays along different axes. In modern machines, it will usually be best to make the array axis along which an inner loop runs the first axis, so that in local memory the elements will be contiguous. A generalized transpose is required to do this data rearrangement, which is not simply a data remapping. In many cases, the result of the transpose will be assigned to a variable whose first axis is distributed with a dist-format of (*).

For this sort of operation, FORALL is adequate when the rank and the particular set of axes to be exchanged are known; for example:

```fortran
FORALL(I1 = 1:SIZE(ARRAY,1))
  FORALL(I2 = 1:SIZE(ARRAY,2))
    FORALL(I3 = 1:SIZE(ARRAY,3))
      RESULT(I3,I1,I2) = ARRAY(I1,I2,I3)
  ENDFORALL
ENDFORALL
ENDFORALL
```

If, however, the relation between input and result axes is to be variable, FORALL is an inconvenient idiom. Thus we have generalized the TRANSPOSE intrinsic function, allowing as arguments an input array (which is to be transposed) of any nonzero rank, and an integer rank-one array (giving the axis permutation) whose size is the rank of the first input array.

The default value for the order argument makes this an extension of the existing Fortran one-argument TRANSPOSE function.

Two new intrinsic inquiry functions, ACTIVE_NUM_PROCS and ACTIVE_PROCS_SHAPE are useful for determining the size and the shape of the processor subset executing the program, as modified by ON constructs.

The extended library consists of mapping inquiry subroutines. Extended versions of HPF_ALIGNMENT and HPF_TEMPLATE allow an additional, optional, DYNAMIC output argument. This allows a program to determine whether an object, or its align ultimate target, has the DYNAMIC attribute. There is a new version of HPF_DISTRIBUTION, and two new mapping
inquiry subroutines that are especially useful for determining mappings produced by the general block and indirect distribution forms.

12.1 Specifications of Extended Intrinsic Procedures

**ACTIVE_NUM_PROCS**(DIM)

**Optional Argument.** DIM

**Description.** Returns the total number of processors currently executing the program or the number of processors currently executing the program along a specified dimension of the processor array, as determined by the innermost ON block.

**Class.** Processors inquiry function.

**Arguments.**

DIM (optional) must be scalar and of type integer with a value in the range \(1 \leq \text{DIM} \leq n\) where \(n\) is the rank of the processor array.

**Result Type, Type Parameter, and Shape.** Default integer scalar.

**Result Value.** The result has a value equal to the extent of dimension DIM of the processor array determined by the innermost containing ON block or, if DIM is absent, the total number of elements of this processor array. The result is always greater than zero. Outside of any ON block, the result is the same as that returned by **NUMBER_OF_PROCESSORS()**.

**Examples.** The program fragment

```fortran
INTEGER X(16, 3)
!hpf$ TEMPLATE T(16, 8)
!hpf$ PROCESSORS PROCS(4, 4)
!hpf$ ALIGN X(I, J) WITH T(I, 3*J-1)
!hpf$ DISTRIBUTE T(CYCLIC(2), BLOCK) ONTO PROCS
!hpf$ ON (PROCS(:,:)) BEGIN
!hpf$ ON HOME(X(2:12:10, :) BEGIN
PRINT *, ACTIVE_NUM_PROCS()
PRINT *, ACTIVE_NUM_PROCS(DIM=1)
PRINT *, ACTIVE_NUM_PROCS(DIM=2)
!hpf$ END ON
!hpf$ END ON
```

prints 6, 2 and 3 regardless of the size or shape of the hardware processor array on which the program is running,
ACTIVE_PROCS_SHAPE()

**Description.** Returns the shape of the currently active processor array, as determined by the innermost ON block.

**Class.** Processors inquiry function.

**Arguments.** None

**Result Type, Type Parameter, and Shape.** The result is a default integer array of rank one whose size is equal to the rank of the processor array determined by the innermost containing ON block.

**Result Value.** The value of the result is the shape of the processor array determined by the innermost containing ON block. Outside of any ON block, the result is the same as that returned by PROCESSORS_SHAPE().

**Examples.** The program fragment

```plaintext
INTEGER X(16, 3)
!hpf$ TEMPLATE T(16, 8)
!hpf$ PROCESSORS PROCS(4, 4)
!hpf$ ALIGN X(I, J) WITH T(I, 3*J-1)
!hpf$ DISTRIBUTE T(CYCLIC(2), BLOCK) ONTO PROCS
!hpf$ ON (PROCS(:, :) BEGIN
  PRINT *, ACTIVE_PROCS_SHAPE()
!hpf$ ON HOME(X(2:12:10, :) BEGIN
  PRINT *, ACTIVE_PROCS_SHAPE()
!hpf$ END ON
!hpf$ END ON
```

prints 4, 4 and 2, 3 regardless of the size or shape of the hardware processor array on which the program is running.

TRANSPOSE(ARRAY,ORDER)

**Optional Argument.** ORDER

**Description.** Permute the axes (a generalized transpose) of an array.

**Class.** Transformational function.

**Arguments.**

- ARRAY may be of any type, and must be array valued.
- ORDER (optional) must be of type integer, rank one, and of size equal to the rank of ARRAY. Its elements must be a permutation of \((1, 2, \ldots, n)\), where \(n\) is RANK(ARRAY).
Result Type, Type Parameters, and Shape. The result is an array of the same rank, type, and type parameters as ARRAY. Its shape satisfies the relation $RS(ORDER) == AS$, where $RS$ is the shape of the result and $AS$ is $SHAPE(ARRAY)$. If $ORDER$ is absent, it defaults to $(n, n - 1, \ldots, 1)$, where $n$ is $RANK(ARRAY)$.

Result value. Element $(j_1, j_2, \ldots, j_n)$ of the result is $ARRAY(j_{order(1)}, j_{order(2)}, \ldots, j_{order(n)})$.

Examples. For an array of rank two, $TRANSPOSE(ARRAY)$ is the usual matrix transpose.

If $ARRAY$ has shape $[1 \ 2 \ 3]$ and $ARRAY(1, :, :)$ is $[[111 \ 112 \ 113]$

$[121 \ 122 \ 123]$

and $ORDER$ is $[3 \ 1 \ 2]$ then the shape of the result is $[2 \ 3 \ 1]$;

if $R$ is the result then $R(:, :, 1)$ is equal to $ARRAY(1, :, :).$ The rule is that axis $i$ of $ARRAY$ becomes axis $ORDER(i)$ of the result.

### 12.2 Specifications of Extended Library Procedures

HPF_ALIGNMENT(ALIGNEE, LB, UB, STRIDE, AXIS_MAP, IDENTITY_MAP, DYNAMIC, NCOPIES)

Optional Arguments. LB, UB, STRIDE, AXIS_MAP, IDENTITY_MAP, DYNAMIC, NCOPIES

Description. Returns information regarding the correspondence of a variable and the align-target (array or template) to which it is ultimately aligned.

Class. Mapping inquiry subroutine.

Arguments.

ALIGNEE may be of any type. It may be scalar or array valued. It must not be an assumed-size array. It must not be a pointer that is disassociated or an allocatable array that is not allocated. It is an INTENT (IN) argument.

If ALIGNEE has the pointer attribute, information about the alignment of its target is returned. The target must not be an assumed-size dummy argument or a section of an assumed-size dummy argument.

LB (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of ALIGNEE. It is an INTENT (OUT) argument. The first element of the $i^{th}$ axis of ALIGNEE is ultimately aligned to the LB($i$)$^{th}$ align-target element along the axis of the align-target associated with the $i^{th}$ axis of ALIGNEE. If the $i^{th}$ axis of ALIGNEE is a collapsed axis, LB($i$) is implementation dependent.
UB (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of ALIGNEE. It is an INTENT (OUT) argument. The last element of the \(i\)th axis of ALIGNEE is ultimately aligned to the UB\(i\)th align-target element along the axis of the align-target associated with the \(i\)th axis of ALIGNEE. If the \(i\)th axis of ALIGNEE is a collapsed axis, UB\(i\) is implementation dependent.

STRIDE (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of ALIGNEE. It is an INTENT (OUT) argument. The \(i\)th element of STRIDE is set to the stride used in aligning the elements of ALIGNEE along its \(i\)th axis. If the \(i\)th axis of ALIGNEE is a collapsed axis, STRIDE\(i\) is zero.

AXIS_MAP (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of ALIGNEE. It is an INTENT (OUT) argument. The \(i\)th element of AXIS_MAP is set to the align-target axis associated with the \(i\)th axis of ALIGNEE. If the \(i\)th axis of ALIGNEE is a collapsed axis, AXIS_MAP\(i\) is 0.

IDENTITY_MAP (optional) must be scalar and of type default logical. It is an INTENT (OUT) argument. It is set to true if the ultimate align-target associated with ALIGNEE has a shape identical to ALIGNEE, the axes are mapped using the identity permutation, and the strides are all positive (and therefore equal to 1, because of the shape constraint); otherwise it is set to false. If a variable has not appeared as an alignee in an ALIGN or REALIGN directive, and does not have the INHERIT attribute, then IDENTITY_MAP must be true; it can be true in other circumstances as well.

DYNAMIC (optional) must be scalar and of type default logical. It is an INTENT (OUT) argument. It is set to true if ALIGNEE has the DYNAMIC attribute; otherwise it is set to false.

NCOPIES (optional) must be scalar and of type default integer. It is an INTENT (OUT) argument. It is set to the number of copies of ALIGNEE that are ultimately aligned to align-target. For a non-replicated variable, it is set to one.

If ALIGNEE is scalar, then no elements of LB, UB, STRIDE, or AXIS_MAP are set.

Examples.

```
REAL PI = 3.1415927
DIMENSION A(10,10),B(20,30),C(20,40,10),D(40)
!HPF$ TEMPLATE T(40,20)
!HPF$ DYNAMIC A
```
assuming that the actual mappings are as the directives specify, the results of calling HPF_ALIGNMENT are:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB</td>
<td>[4, 2]</td>
<td>[1, 1]</td>
<td>[20, N/A, 1]</td>
<td>[1]</td>
</tr>
<tr>
<td>UB</td>
<td>[31, 20]</td>
<td>[20, 30]</td>
<td>[1, N/A, 10]</td>
<td>[40]</td>
</tr>
<tr>
<td>STRIDE</td>
<td>[3, 2]</td>
<td>[1, 1]</td>
<td>[-1, 0, 1]</td>
<td>[1]</td>
</tr>
<tr>
<td>AXIS_MAP</td>
<td>[1, 2]</td>
<td>[1, 2]</td>
<td>[2, 0, 1]</td>
<td>[1]</td>
</tr>
<tr>
<td>IDENTITY_MAP</td>
<td>false</td>
<td>true</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>DYNAMIC</td>
<td>true</td>
<td>false</td>
<td>false</td>
<td>false</td>
</tr>
<tr>
<td>NCOPIES</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

where “N/A” denotes a implementation-dependent result. To illustrate the use of NCOPIES, consider:

```
LOGICAL BOZO(20,20), RONALD_MCDONALD(20)
!HPF$ TEMPLATE EMMETT_KELLY(100,100)
!HPF$ ALIGN RONALD_MCDONALD(I) WITH BOZO(I,*)
!HPF$ ALIGN BOZO(J,K) WITH EMMETT_KELLY(J,5*K)
```

Then CALL HPF_ALIGNMENT(RONALD_MCDONALD, NCOPIES = NC) sets NC to 20. Now consider:

```
LOGICAL BOZO(20,20), RONALD_MCDONALD(20)
!HPF$ TEMPLATE WILLIE_WHISTLE(100)
!HPF$ ALIGN RONALD_MCDONALD(I) WITH BOZO(I,*)
!HPF$ ALIGN BOZO(J,*) WITH WILLIE_WHISTLE(5*J)
```

Then CALL HPF_ALIGNMENT(RONALD_MCDONALD, NCOPIES = NC) sets NC to one.

**HPF_DISTRIBUTION** (DISTRIBUTEE, AXIS_TYPE, AXIS_INFO, PROCESSORS_RANK, PROCESSORS_SHAPE, PLB, PUB, PSTRIDE, LOW_SHADOW, HIGH_SHADOW)

**Optional Arguments.** AXIS_TYPE, AXIS_INFO, PROCESSORS_RANK, PROCESSORS_SHAPE, PLB, PUB, PSTRIDE, LOW_SHADOW, HIGH_SHADOW.

**Description.** The HPF_DISTRIBUTION subroutine returns information regarding the distribution of the ultimate align-target associated with a variable.

**Class.** Mapping inquiry subroutine.

**Arguments.**
DISTRIBUTEE may be of any type. It may be scalar or array valued. It must not be sequential. It must not be a pointer that is disassociated or an allocatable array that is not allocated. It is an INTENT (IN) argument.

AXIS_TYPE (optional) must be a rank one array of type default character. It may be of any length, although it must be of length at least 9 in order to contain the complete value. Its elements are set to the values below as if by a character intrinsic assignment statement. Its size must be at least equal to the rank of the align-target to which DISTRIBUTEE is ultimately aligned; this is the value returned by HPF TEMPLATE in TEMPLATE_RANK. It is an INTENT (OUT) argument. Its $i^{th}$ element contains information on the distribution of the $i^{th}$ axis of that align-target. The following values are defined by HPF (implementations may define other values):

'BLOCK' The axis is distributed BLOCK. The corresponding element of AXIS_INFO contains the block size.

'GEN_BLOCK' The axis is distributed BLOCK(array). The value of the corresponding element of AXIS_INFO is implementation dependent.

'COLLAPSED' The axis is collapsed (distributed with the "*" specification). The value of the corresponding element of AXIS_INFO is implementation dependent.

'CYCLIC' The axis is distributed CYCLIC. The corresponding element of AXIS_INFO contains the block size.

'INDIRECT' The axis is distributed INDIRECT(map-array). The value of the corresponding element of AXIS_INFO is implementation dependent.

AXIS_INFO (optional) must be a rank one array of type default integer, and size at least equal to the rank of the align-target to which DISTRIBUTEE is ultimately aligned (which is returned by HPF TEMPLATE in TEMPLATE_RANK). It is an INTENT (OUT) argument. The $i^{th}$ element of AXIS_INFO contains the block size in the block or cyclic distribution of the $i^{th}$ axis of the ultimate align-target of DISTRIBUTEE; if that axis is a collapsed axis, then the value is implementation dependent.

PROCESSORS_RANK (optional) must be scalar and of type default integer. It is set to the rank of the processor arrangement onto which DISTRIBUTEE is distributed. It is an INTENT (OUT) argument.
PROCESSORS_SHAPE (optional) must be a rank one array of type default integer and
of size at least equal to the value, $m$, returned in PROCESSORS_RANK. It is an INTENT (OUT) argument. Its first $m$
elements are set to the shape of the processor arrangement onto which DISTRIBUTEE is mapped. (It may be
necessary to call HPF DISTRIBUTION twice, the first time to obtain the value of PROCESSORS_RANK in order to allocate PROCESSORS_SHAPE.)

PLB (optional) must be a rank one array of type default integer and
of size at least equal to the rank of the ultimate align-target of DISTRIBUTEE. It is an INTENT (OUT) argument. The $i$th element is set to the smallest processor index ONTO which the $i$th axis of the ultimate align-target of DISTRIBUTEE is mapped; if that axis is collapsed, then the corresponding element of PLB is implementation dependent. The value returned is in the range 1 to $e_i$ where $e_i$ is the extent of processor arrangement axis onto which the selected axis of the ultimate align-target of DISTRIBUTEE is mapped.

PUB (optional) must be a rank one array of type default integer and
of size at least equal to the rank of the ultimate align-target of DISTRIBUTEE. It is an INTENT (OUT) argument. The $i$th element is set to the largest processor index ONTO which the $i$th axis of the ultimate align-target of DISTRIBUTEE is mapped; if that axis is collapsed, then the corresponding element of PUB is implementation dependent. The value returned is in the range 1 to $e_i$ where $e_i$ is the extent of processor arrangement axis onto which the selected axis of the ultimate align-target of DISTRIBUTEE is mapped.

PSTRIDE (optional) must be a rank one array of type default integer and
of size at least equal to the rank of DISTRIBUTEE. It is an INTENT (OUT) argument. The $i$th element is set to the interprocessor stride in the ONTO clause with which the $i$th axis of DISTRIBUTEE is mapped; if that axis is collapsed, then the corresponding element of PSTRIDE is set to zero.

LOW_SHADOW (optional) must be a rank one array of type default integer, and size
at least equal to the rank of the align-target to which DISTRIBUTEE is ultimately aligned (which is returned by HPF TEMPLATE in TEMPLATE_RANK). It is an INTENT (OUT) argument. The $i$th element of LOW_SHADOW contains the low-side shadow width in the block or cyclic distribution of the $i$th axis of the ultimate align-target of DISTRIBUTEE; if that axis is a collapsed axis, then the value is implementation dependent.
HIGH_SHADOW (optional) must be a rank one array of type default integer, and size at least equal to the rank of the align-target to which DISTRIBUTEE is ultimately aligned (which is returned by HPF TEMPLATE in TEMPLATE_RANK). It is an INTENT (OUT) argument. The i\textsuperscript{th} element of HIGH_SHADOW contains the high-side shadow width in the block or cyclic distribution of the i\textsuperscript{th} axis of the ultimate align-target of DISTRIBUTEE; if that axis is a collapsed axis, then the value is implementation dependent.

Example. Given the declarations in the example illustrating HPF ALIGNMENT and assuming that the actual mappings are as the directives specify, the results of HPF DISTRIBUTION are:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>['BLOCK', 'BLOCK']</td>
<td>['CYCLIC', 'BLOCK']</td>
<td>[ ]</td>
</tr>
<tr>
<td>[10, 10]</td>
<td>[1, 15]</td>
<td>[ ]</td>
</tr>
<tr>
<td>[4, 2]</td>
<td>[2, 2]</td>
<td>[ ]</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>[1, 2]</td>
<td>[3, 2]</td>
<td>[ ]</td>
</tr>
<tr>
<td>[-1,1]</td>
<td>[1, 1]</td>
<td>[ ]</td>
</tr>
</tbody>
</table>

HPF TEMPLATE(ALIGNEE, TEMPLATE_RANK, LB, UB, AXIS_TYPE, AXIS_INFO, NUMBER_ALIGNED, DYNAMIC)

Optional Arguments. LB, UB, AXIS_TYPE, AXIS_INFO, NUMBER_ALIGNED, TEMPLATE_RANK, DYNAMIC

Description. The HPF TEMPLATE subroutine returns information regarding the ultimate align-target associated with a variable; HPF TEMPLATE returns information concerning the variable from the point of view of its ultimate align-target, while HPF ALIGNMENT returns information from the variable’s point of view.

Class. Mapping inquiry subroutine.

Arguments.

ALIGNEE may be of any type. It may be scalar or array valued. It must not be an assumed-size array. It must not be a pointer that is disassociated or an allocatable array that is not allocated. It is an INTENT (IN) argument.

If ALIGNEE has the pointer attribute, information about the alignment of its target is returned. The target must not be an assumed-size dummy argument or a section of an assumed-size dummy argument.

TEMPLATE_RANK (optional) must be scalar and of type default integer. It is an INTENT (OUT) argument. It is set to the rank of the ultimate align-target. This can be different from the rank of the ALIGNEE, due to collapsing and replicating.
LB (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of the align-target to which ALIGNEE is ultimately aligned; this is the value returned in TEMPLATE_RANK. It is an INTENT (OUT) argument. The i\textsuperscript{th} element of LB contains the declared align-target lower bound for the i\textsuperscript{th} template axis.

UB (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of the align-target to which ALIGNEE is ultimately aligned; this is the value returned in TEMPLATE_RANK. It is an INTENT (OUT) argument. The i\textsuperscript{th} element of UB contains the declared align-target upper bound for the i\textsuperscript{th} template axis.

AXIS\_TYPE (optional) must be a rank one array of type default character. It may be of any length, although it must be of length at least 10 in order to contain the complete value. Its elements are set to the values below as if by a character intrinsic assignment statement. Its size must be at least equal to the rank of the align-target to which ALIGNEE is ultimately aligned; this is the value returned in TEMPLATE_RANK. It is an INTENT (OUT) argument. The i\textsuperscript{th} element of AXIS\_TYPE contains information about the i\textsuperscript{th} axis of the align-target. The following values are defined by HPF (implementations may define other values):

- `NORMAL' The align-target axis has an axis of ALIGNEE aligned to it. For elements of AXIS\_TYPE assigned this value, the corresponding element of AXIS\_INFO is set to the number of the axis of ALIGNEE aligned to this align-target axis.

- `REPLICATED' ALIGNEE is replicated along this align-target axis. For elements of AXIS\_TYPE assigned this value, the corresponding element of AXIS\_INFO is set to the number of copies of ALIGNEE along this align-target axis.

- `SINGLE' ALIGNEE is aligned with one coordinate of the align-target axis. For elements of AXIS\_TYPE assigned this value, the corresponding element of AXIS\_INFO is set to the align-target coordinate to which ALIGNEE is aligned.

AXIS\_INFO (optional) must be of type default integer and of rank one. Its size must be at least equal to the rank of the align-target to which ALIGNEE is ultimately aligned; this is the value returned in TEMPLATE_RANK. It is an INTENT (OUT) argument. See the description of AXIS\_TYPE above.

NUMBER\_ALIGNED (optional) must be scalar and of type default integer. It is an INTENT (OUT) argument. It is set to the total number
of variables aligned to the ultimate align-target. This is the number of variables that are moved if the align-target is redistributed.

**DYNAMIC (optional)** must be scalar and of type default logical. It is an INTENT (OUT) argument. It is set to true if the align-target has the DYNAMIC attribute, and to false otherwise.

**Example.** Given the declarations in the example illustrating HPF_ALIGNMENT, and assuming that the actual mappings are as the directives specify, the results of HPF_TEMPLATE are:

```
A  C  D
LB [1, 1] [1, 1] [1, 1]
UB [40, 20] [40, 20] [40, 20]
AXIS_TYPE ['NORMAL', 'NORMAL', 'NORMAL', 'NORMAL']
AXIS_INFO [1, 2] [3, 1] [1, 4]
NUMBERAligned 3 3 3
TEMPLATE_RANK 2 2 2
DYNAMIC false false false
```

**HPF_MAP_ARRAY(ARRAY, TEMPLATE_DIM, MAP_ARRAY)**

**Description.** Returns the map array used in the indirect distribution of axis TEMPLATE_DIM of the ultimate align-target associated with ARRAY.

**Class.** Mapping inquiry subroutine.

**Arguments.**

- **ARRAY** may be of any type. It must not be scalar. It must not be sequential. It must not be a pointer that is disassociated or an allocatable array that is not allocated. It is an INTENT(IN) argument.

- **TEMPLATE_DIM** must be scalar and of type default integer. Its value must be between one and the rank of the ultimate align-target of ARRAY. It is an INTENT(IN) argument.

- **MAP_ARRAY** must be of type default integer and of rank one. Its size must be no smaller than the extent of the PROCESSORS_DIM^h axis of the processors arrangement onto which is distributed the ultimate align-target associated with ARRAY. It is an INTENT(OUT) argument.

  The i-th element of MAP_ARRAY is set to the processor index to which the i-th element of the ultimate align-target of ARRAY along axis TEMPLATE_DIM is mapped. If axis TEMPLATE_DIM of the ultimate align-target of ARRAY is collapsed, then all elements of the result have the value one.
Example. Given the declarations

```fortran
DIMENSION A(2)
!HPF$ TEMPLATE T(4,8)
!HPF$ ALIGN A(I,*) WITH T(2*I,5)
!HPF$ PROCESSORS PROCS(2,2)
!HPF$ DISTRIBUTE T(INDIRECT( (/1,2,2,1/ ) ), BLOCK( (/3,5/) )) ONTO PROCS
```

assuming that the actual mappings are as the directives specify, Then after calling

```fortran
HPF_MAP_ARRAY(A,TEMPLATE_DIM=1, MAP_ARRAY=M), M has the value [ 1 2 2 1 ].
```

After calling `HPF_MAP_ARRAY(A,TEMPLATE_DIM=2, MAP_ARRAY=M), M` has the value

```fortran
[ 1 1 1 2 2 2 2 2 2 ].
```

**HPF_NUMBER_MAPPED(ARRAY, PROCESSORS_DIM, NUMBER_MAPPED)**

**Description.** Returns the number of elements of the ultimate `align-target` of `ARRAY` mapped to the each element of axis `PROCESSORS_DIM` of the processors arrangement onto which the ultimate `align-target` of `ARRAY` is distributed.

**Class.** Mapping inquiry subroutine.

**Arguments.**

**ARRAY**

May be of any type. It must not be scalar. It must not be sequential. It must not be a pointer that is disassociated or an allocatable array that is not allocated.

**PROCESSORS_DIM**

Must be scalar and of type default integer. Its value must be between one and the rank of the processors arrangement onto which the ultimate `align-target` of `ARRAY` is distributed.

**NUMBER_MAPPED**

Must be of type default integer and of rank one. Its size must be no smaller than the extent of axis `PROCESSORS_DIM` of the processors arrangement onto which the ultimate `align-target` of `ARRAY` is distributed. The `ith` element of `NUMBER_MAPPED` is set to the number of elements of an axis of the ultimate `align-target` of `ARRAY` that are mapped to the `ith` processor of axis `PROCESSORS_DIM` of the processors arrangement onto which the ultimate `align-target` of `ARRAY` is distributed. If axis `PROCESSORS_DIM` of the processors arrangement onto which the ultimate `align-target` of `ARRAY` is distributed is associated with a `BLOCK` distributed axis, then `MAP_ARRAY` is set to the array of block sizes used to distribute that axis.

**Example.** Given the declarations
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```
DIMENSION A(2,40)
!HPF$ TEMPLATE T(4,8,4,16)
!HPF$ ALIGN A(I,* ) WITH T(2*I, 5, *, *)
!HPF$ PROCESSORS PROCES(2,2,3)
!HPF$ DISTRIBUTE T(INDIRECT((/2,2,1,2/)), BLOCK((/3,5/)), *, BLOCK) &
!HPF$ ONTO PROCES

assuming that the actual mappings are as the directives specify; after calling

HPF_NUMBER_MAPPED(A,PROCESSORS_DIM=1, NUMBER_MAPPED = M) M has the value [ 1  3 ];

after calling HPF_NUMBER_MAPPED(A,PROCESSORS_DIM=2, NUMBER_MAPPED = M) M has the

value [ 3  5 ]; after calling HPF_NUMBER_MAPPED(A,PROCESSORS_DIM=3, NUMBER_MAPPED =

M) M has the value [ 6  6  4 ].
```
Part IV

Annexes

This major section organizes descriptions of the syntax and semantics of features of the High Performance Fortran language, version 2.0 (described in Parts I and II) and its approved extensions (described in Part III) for reference use. It is not a part of the HPF language specification proper.
Annex A

Syntax Rules

This Appendix collects the formal syntax definitions of this High Performance Fortran Language Specification.

A.2 Notation and Syntax

A.2.2 Syntax of Directives

H201  *hpf-directive-line* is *directive-origin hpf-directive*

H202  *directive-origin* is *

H203  *hpf-directive* is *specification-directive*

H204  *specification-directive* is *processors-directive*

H205  *executable-directive* is *independent-directive*

Constraint: An *hpf-directive-line* cannot be commentary following another statement on the same line.

Constraint: A *specification-directive* may appear only where a *declaration-construct* may appear.

Constraint: An *executable-directive* may appear only where an *executable-construct* may appear.

Constraint: An *hpf-directive-line* follows the rules of either Fortran free form (F95:3.3.1.1) or fixed form (F95:3.3.2.1) comment lines, depending on the source form of the surrounding Fortran source form in that program unit. (F95:3.3)
H206  specification-directive-extended is  processors-directive
   or  subset-directive
   or  align-directive
   or  distribute-directive
   or  inherit-directive
   or  template-directive
   or  combined-directive
   or  sequence-directive
   or  dynamic-directive
   or  range-directive
   or  shadow-directive

H207  executable-directive-extended is  independent-directive
   or  realign-directive
   or  redistribute-directive
   or  on-directive
   or  resident-directive

H208  executable-construct-extended is  action-stmt
   or  case-construct
   or  do-construct
   or  if-construct
   or  where-construct
   or  on-construct
   or  resident-construct
   or  task-region-construct

A.3  Data Mapping

A.3.2  Syntax of Data Alignment and Distribution Directives

H301  combined-directive is  combined-attribute-list :: combined-decl-list

H302  combined-attribute is  ALIGN align-attribute-stuff
   or  DISTIBUTE dist-attribute-stuff
   or  INHERIT
   or  TEMPLATE
   or  PROCESSORS
   or  DIMENSION ( explicit-shape-spec-list )

H303  combined-decl is  hpf-entity [ ( explicit-shape-spec-list ) ]
   or  object-name

H304  hpf-entity is  processors-name
   or  template-name

Constraint: The same kind of combined-attribute must not appear more than once in a given combined-directive.

Constraint: If the DIMENSION attribute appears in a combined-directive, any entity to which it applies must be declared with the HPF TEMPLATE or PROCESSORS type spec-
ifier.

A.3.3 The DISTRIBUTE Directive

H305 distribute-directive is DISTRIBUTE distributee dist-directive-stuff
H306 dist-directive-stuff is dist-format-clause [ dist-onto-clause ]
H307 dist-attribute-stuff is dist-directive-stuff
or dist-onto-clause
H308 distributee is object-name
or template-name
H309 dist-format-clause is ( dist-format-list )
or * ( dist-format-list )
or *
H310 dist-format is BLOCK [ ( scalar-int-expr ) ]
or CYCLIC [ ( scalar-int-expr ) ]
or *
H311 dist-onto-clause is ONTO dist-target
H312 dist-target is processors-name
or * processors-name
or *

Constraint: An object-name mentioned as a distributee must be a simple name and not a subobject designator or a component-name.

Constraint: An object-name mentioned as a distributee may not appear as an alignee.

Constraint: An object-name mentioned as a distributee may not have the POINTER attribute.

Constraint: An object-name mentioned as a distributee may not have the TARGET attribute.

Constraint: If the distributee is scalar, the dist-format-list (and its surrounding parentheses) must not appear. In this case, the statement form of the directive is allowed only if a dist-format-clause of "*" is present.

Constraint: If a dist-format-list is specified, its length must equal the rank of each distributee to which it applies.

Constraint: If both a dist-format-list and a dist-target appear, the number of elements of the dist-format-list that are not "*" must equal the rank of the specified processor arrangement.

Constraint: If a dist-target appears but not a dist-format-list, the rank of each distributee must equal the rank of the specified processor arrangement.

Constraint: If either the dist-format-clause or the dist-target in a DISTRIBUTE directive begins with "*" then every distributee must be a dummy argument.

Constraint: Any scalar-int-expr appearing in a dist-format of a DISTRIBUTE directive must be a specification-expr.
A.3.4 The ALIGN Directive

H313  \textit{align-directive} is \texttt{ALIGN alignee align-directive-stuff}

H314  \textit{align-directive-stuff} is \((\text{align-source-list})\) align-with-clause

H315  \textit{align-attribute-stuff} is \([ (\text{align-source-list}) ]\) align-with-clause

H316  \textit{alignee} is \textit{object-name}

H317  \textit{align-source} is :

or \(\ast\)

or \textit{align-dummy}

H318  \textit{align-dummy} is \texttt{scalar-int-variable}

Constraint: An \textit{object-name} mentioned as an \textit{alignee} must be a simple name and not a subobject designator or a \texttt{component-name}.

Constraint: An \textit{object-name} mentioned as an \textit{alignee} may not appear as a \texttt{distributee}.

Constraint: An \textit{object-name} mentioned as an \textit{alignee} may not have the \texttt{POINTER} attribute.

Constraint: An \textit{object-name} mentioned as an \textit{alignee} may not have the \texttt{TARGET} attribute.

Constraint: If the \textit{alignee} is scalar, the \textit{align-source-list} (and its surrounding parentheses) must not appear. In this case the statement form of the directive is not allowed.

Constraint: If the \textit{align-source-list} is present, its length must equal the rank of each \textit{alignee} to which it applies.

Constraint: An \textit{align-dummy} must be a named variable.

Constraint: An \textit{align-dummy} must be a named variable.

H319  \textit{align-with-clause} is \texttt{WITH align-spec}

H320  \textit{align-spec} is \textit{align-target} \([ (\text{align-subscript-list}) \] \)

or \(\ast\) \textit{align-target} \([ (\text{align-subscript-list}) \] \)

H321  \textit{align-target} is \textit{object-name}

or \textit{template-name}

H322  \textit{align-subscript} is \texttt{int-expr}

or \textit{align-subscript-use}

or \textit{subscript-triplet}

or \(\ast\)

H323  \textit{align-subscript-use} is \([ [\texttt{int-level-two-expr}] \texttt{add-op} \]

\texttt{align-add-operand}

or \textit{align-subscript-use} \texttt{add-op int-add-operand}

H324  \textit{align-add-operand} is \([ \texttt{int-add-operand} \ast ]\) \textit{align-primary}

or \textit{align-add-operand} \ast \texttt{int-mult-operand}

H325  \textit{align-primary} is \textit{align-dummy}

or \((\text{align-subscript-use})\)
H326  `int-add-operand`  is  `add-operand`
H327  `int-mult-operand`  is  `mult-operand`
H328  `int-level-two-expr`  is  `level-2-expr`

Constraint: An object-name mentioned as an align-target must be a simple name and not a subobject designator or a component-name.

Constraint: An align-target may not have the OPTIONAL attribute.

Constraint: If the align-spec in an ALIGN directive begins with "*" then every alignee must be a dummy argument.

Constraint: In an align-directive any int-expr, int-level-two-expr, int-add-operand or int-mult-operand must be a specification expression.

Constraint: Any subscript or stride in a subscript-triplet that is an align-subscript in an align-directive must be a specification expression.

Constraint: Each align-dummy may appear at most once in an align-subscript-list.

Constraint: An align-subscript-use expression may contain at most one occurrence of an align-dummy.

Constraint: A scalar-int-variable that is used as an align-dummy may not appear anywhere in the align-spec except where explicitly permitted to appear by virtue of the grammar shown above. Paraphrased, one may construct an align-subscript-use only by starting with an align-dummy and then doing additive and multiplicative things to it with integer specification expressions that contain no align-dummy.

Constraint: A subscript within an align-subscript may not contain occurrences of any align-dummy.

Constraint: An int-add-operand, int-mult-operand or int-level-two-expr must be of type integer.

A.3.6 The PROCESSORS Directive

H329  `processors-directive`  is  `PROCESSORS  processors-decl-list`
H330  `processors-decl`  is  `processors-name`
            `[ ( explicit-shape-spec-list ) ]`

A.3.7 The TEMPLATE Directive

H331  `template-directive`  is  `TEMPLATE  template-decl-list`
H332  `template-decl`  is  `template-name`
            `[ ( explicit-shape-spec-list ) ]`
A.3.8 Storage and Sequence Association

H333 sequence-directive is SEQUENCE [ [ :: ] association-name-list ]
or NO SEQUENCE [ [ :: ] association-name-list ]

H334 association-name is object-name
or / [ common-block-name ] /

Constraint: An object name or COMMON block name may appear at most once in a sequence-directive within any scoping unit.

Constraint: Only one sequence directive with no association-name-list is permitted in the same scoping unit.

A.4 Data Mapping in Subprogram Interfaces

A.4.4 Alignment

H401 inherit-directive is INHERIT inheritee-list

H402 inheritee is object-name

Constraint: An inheritee must be a dummy argument.

Constraint: An inheritee must not be an alignee.

Constraint: An inheritee must not be a distributee.

A.5 INDEPENDENT and Related Directives

A.5.1 The INDEPENDENT Directive

H501 independent-directive is INDEPENDENT [ , new-clause ]
[ , reduction-clause ]

H502 new-clause is NEW ( variable-name-list )

H503 reduction-clause is REDUCTION ( reduction-variable-list )

H504 reduction-variable is array-variable-name
or scalar-variable-name
or structure-component

Constraint: The first non-comment line following an independent-directive must be a do-stmt, forall-stmt, or a forall-construct.

Constraint: If the first non-comment line following an independent-directive is a do-stmt, then that statement must contain a loop-control option containing a do-variable.

Constraint: If either the NEW clause or the REDUCTION clause is present, then the first non-comment line following the directive must be a do-stmt.

Constraint: A variable named in the NEW or the REDUCTION clause and any component or element thereof must not:
• Be a dummy argument;
• Have the SAVE or TARGET attribute;
• Occur in a COMMON block;
• Be storage associated with another object as a result of appearing in an EQUIVALENCE statement;
• Be use associated;
• Be host associated; or
• Be accessed in another scoping unit via host association.

Constraint: A variable that occurs as a reduction-variable may not appear in a new-clause in the same independent-directive, nor may it appear in either a new-clause or a reduction-clause in the range (i.e., the lexical body) of the following do-stmt, forall-stmt, or forall-construct to which the independent-directive applies.

Constraint: A structure-component in a reduction-variable may not contain a subscript-section-list.

Constraint: A variable that occurs as a reduction-var must be of intrinsic type. It may not be of type CHARACTER.

H505 reduction-stmt is variable = variable mult-op mult-operand
or variable = add-operand * variable
or variable = variable add-op add-operand
or variable = level-2-expr + variable
or variable = variable and-op and-operand
or variable = and-operand and-op variable
or variable = variable or-op or-operand
or variable = or-operand or-op variable
or variable = variable equiv-op equiv-operand
or variable = equiv-operand equiv-op variable
or variable = reduction-function ( variable , expr )
or variable = reduction-function ( expr , variable )

H506 reduction-function is MAX
or MIN
or IAND
or IOR
or IEOR

Constraint: The two occurrences of variable in a reduction-stmt must be textually identical.

A.6 Extrinsic Program Units

A.6.2 Declaration of Extrinsic Program Units

H601 function-stmt is [ prefix ] FUNCTION function-name
( [ dummy-arg-name-list ]
[ RESULT ( result-name ) ]

Constraint: A dummy argument in a function may only appear in a function-stmt.
subroutine-stmt is [ prefix ] SUBROUTINE subroutine-name
    [ ( [ dummy-arg-list ] ) ]
prefix is prefix-spec [ prefix-spec ] ...
prefix-spec is type-spec
    or RECURSIVE
    or PURE
    or ELEMENTAL
    or extrinsic-prefix

Constraint: Within any HPF external-subprogram, every internal-subprogram must be of the same extrinsic kind as its host and any internal-subprogram whose extrinsic kind is not given explicitly is assumed to be of that extrinsic kind.

program-stmt is [ extrinsic-prefix ] PROGRAM program-name
module-stmt is [ extrinsic-prefix ] MODULE module-name
block-data-stmt is [ extrinsic-prefix ] BLOCK DATA
    [ block-data-name ]

Constraint: Every module-subprogram of any HPF module must be of the same extrinsic kind as its host, and any module-subprogram whose extrinsic kind is not given explicitly is assumed to be of that extrinsic kind.

Constraint: Every internal-subprogram of any HPF main-program or module-subprogram must be of the same extrinsic kind as its host, and any internal-subprogram whose extrinsic kind is not given explicitly is assumed to be of that extrinsic kind.

extrinsic-prefix is EXTRINSIC ( extrinsic-spec )
extrinsic-spec is extrinsic-spec-arg-list
    or extrinsic-kind-keyword
extrinsic-spec-arg is language
    or model
    or external-name
language is [ LANGUAGE = ]
    scalar-char-initialization-expr
model is [ MODEL = ]
    scalar-char-initialization-expr
external-name is [ EXTERNAL_NAME = ]
    scalar-char-initialization-expr

Constraint: In an extrinsic-spec-arg-list, at least one of language, model, or external-name must be specified and none may be specified more than once.

Constraint: If language is specified without LANGUAGE=, language must be the first item in the extrinsic-spec-arg-list. If model is specified without MODEL=, language without LANGUAGE= must be the first item and model must be the second item in the
extrinsic-spec-arg-list. If external-name is specified without EXTERNAL\NAME=, language without LANGUAGE= must be the first item and model without MODEL= must be the second item in the extrinsic-spec-arg-list.

Constraint: The forms with LANGUAGE=, MODEL=, and EXTERNAL\NAME= may appear in any order except as prohibited above.

Note that these rules for extrinsic-spec-arg-list are as if EXTRINSIC were a procedure with an explicit interface with a dummy-arg-list of LANGUAGE, MODEL, EXTERNAL\NAME, each of which were OPTIONAL.

Constraint: In language, values of scalar-char-initialization-expr may be:

- 'HPF', referring to the HPF language; if a model is not explicitly specified, the model is implied to be 'GLOBAL';
- 'FORTRAN', referring to the ANSI/ISO standard Fortran language; if a model is not explicitly specified, the model is implied to be 'SERIAL';
- 'F77', referring to the former ANSI/ISO standard FORTRAN 77 language; if a model is not explicitly specified, the model is implied to be 'SERIAL';
- 'C', referring to the ANSI standard C programming language; if a model is not explicitly specified, the model is implied to be 'SERIAL'; or
- an implementation-dependent value with an implementation-dependent implied model.

Note that, for most implementations, 'C' will only be allowed for function-stmts and subroutine-stmts occurring in an interface-body.

Constraint: If language is not specified it is the same as that of the host scoping unit.

Constraint: In model, values of scalar-char-initialization-expr may be:

- 'GLOBAL', referring to the global model,
- 'LOCAL', referring to the local model,
- 'SERIAL', referring to the serial model, or
- an implementation-dependent value.

Constraint: If model is not specified or implied by the specification of a language, it is the same as that of the host scoping unit.

Constraint: All languages and models whose names begin with the three letters HPF are reserved for present or future definition by this specification and its successors.

Constraint: In external-name, the value of scalar-char-initialization-expr is a character string whose use is determined by the extrinsic kind. For example, an extrinsic kind may use the external-name to specify the name by which the procedure would be known if it were referenced by a C procedure. In such an implementation, a user would expect the compiler to perform any transformations of that name that the C compiler would perform. If external-name is not specified, its value is implementation-dependent.
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H614  extrinsic-kind-keyword is HPF
     or HPF_LOCAL
     or HPF_SERIAL

Constraint: \texttt{EXTRINSIC}(HPF) is equivalent to \texttt{EXTRINSIC}('HPF', 'GLOBAL'). In the absence of an extrinsic-prefix an HPF compiler interprets a compilation unit as if it were of extrinsic kind HPF. Thus, for an HPF compiler, specifying \texttt{EXTRINSIC}(HPF) or \texttt{EXTRINSIC}('HPF', 'GLOBAL') is redundant. Such explicit specification may, however, be required for use with a compiler that supports multiple extrinsic kinds.

Constraint: \texttt{EXTRINSIC}(HPF\_LOCAL) is equivalent to \texttt{EXTRINSIC}('HPF', 'LOCAL'). A main-program whose extrinsic kind is HPF\_LOCAL behaves as if it were a subroutine of extrinsic kind HPF\_LOCAL that is called with no arguments from a main program of extrinsic kind HPF whose executable part consists solely of that call.

Constraint: \texttt{EXTRINSIC}(HPF\_SERIAL) is equivalent to \texttt{EXTRINSIC}('HPF', 'SERIAL'). A main-program whose extrinsic kind is HPF\_SERIAL behaves as if it were a subroutine of extrinsic kind HPF\_SERIAL that is called with no arguments from a main program of extrinsic kind HPF whose executable part consists solely of that call.

Constraint: All extrinsic-kind-keywords whose names begin with the three letters HPF are reserved for present or future definition by this specification and its successors.

A.8  Approved Extensions for Data Mapping

A.8.2  Syntax of Attributed Forms of Extended Data Mapping Directives

H801  combined-attribute-extended is ALIGN align-attribute-stuff
     or DISTRIBUT\_dist-agent-stuff
     or INHERIT
     or TEMPLATE
     or PROCESSORS
     or DIMENSION ( explicit-shape-spec-list )
     or DYNAMIC
     or RANGE range-attrib-stuff
     or SHADOW shadow-attrib-stuff
     or SUBSET

Constraint: The SUBSET attribute may be applied only to a processors arrangement.

A.8.3  The REDISTRIBUTE Directive

H802  redistribute-directive is REDISTRIBUTE distributee dist-directive-stuff
     or REDISTRIBUTE dist-attribute-stuff :: distributee-list
Constraint: A `distributee` that appears in a `REDISTRIBUTE` directive must have the `DYNAMIC` attribute (see Section 8.5).

Constraint: A `distributee` in a `REDISTRIBUTE` directive may not appear as an `alignee` in an `ALIGN` or `REALIGN` directive.

Constraint: Neither the `dist-format-clause` nor the `dist-target` in a `REDISTRIBUTE` directive may begin with “*”.

### A.8.4 The REALIGN Directive

H803 `realign-directive` is `REALIGN alignee align-directive-stuff`

or `REALIGN align-attribute-stuff :: alignee-list`

Constraint: Any `alignee` that appears in a `REALIGN` directive must have the `DYNAMIC` attribute (see Section 8.5).

Constraint: If the `align-target` specified in the `align-with-clause` has the `DYNAMIC` attribute, then each `alignee` must also have the `DYNAMIC` attribute.

Constraint: An `alignee` in a `REALIGN` directive may not appear as a `distributee` in a `DISTRIBUTE` or `REDISTRIBUTE` directive.

### A.8.5 The DYNAMIC Directive

H804 `dynamic-directive` is `DYNAMIC alignee-or-distributee-list`

H805 `alignee-or-distributee` is `alignee`

or `distributee`

Constraint: An object in `COMMON` may not be declared `DYNAMIC` and may not be aligned to an object (or template) that is `DYNAMIC`. (To get this kind of effect, modules must be used instead of `COMMON` blocks.)

Constraint: A component of a derived type may have the `DYNAMIC` attribute only if it also has the `POINTER` attribute. (See Section 8.9 for further discussion.)

Constraint: An object with the `SAVE` attribute may not be declared `DYNAMIC` and may not be aligned to an object (or template) that is `DYNAMIC`.

### A.8.7 Mapping to Processor Subsets

H806 `extended-dist-target` is `processors-name [ ( section-subscript-list ) ]`

or `* processors-name [ ( section-subscript-list ) ]`

or `*`

Constraint: The `section-subscripts` in the `section-subscript-list` may not be `vector-subscripts` and are restricted to be either `subscripts` or `subscript-triplets`.

Constraint: In the `section-subscript-list`, the number of `section-subscripts` must equal the rank of the `processor-name`. 
Constraint: Within a **DISTRIBUTE** directive, each *section-subscript* must be a *specification-expr*.

Constraint: Within a **DISTRIBUTE** or a **REDISTRIBUTE** directive, if both a *dist-format-list* and a *dist-target* appear, the number of elements of the *dist-format-list* that are not "*" must equal the number of *subscript-triplets* in the named processor arrangement.

Constraint: Within a **DISTRIBUTE** or a **REDISTRIBUTE** directive, if a *dist-target* appears but not a *dist-format-list*, the rank of each *distributee* must equal the number of *subscript-triplets* in the named processor arrangement.

Constraint: If either the *dist-format-clause* or the *dist-target* in a **DISTRIBUTE** directive begins with "*" then every *distributee* must be a dummy argument, *except if the distributee has the POINTER attribute*.

Constraint: If the *align-spec* in an **ALIGN** directive begins with "*" then every *alignee* must be a dummy argument, *except if the alignee has the POINTER attribute*.

Constraint: An *inheritee* must be a dummy argument, *except if the alignee has the POINTER attribute*.

### A.8.9 Mapping of Derived Type Components

**H807**  
*distributee-extended* is  
*object-name*  
*or*  
*template-name*  
*or*  
*component-name*  
*or*  
*structure-component*

Constraint: A component of a derived type may be explicitly distributed only if the type of the component is not an explicitly mapped type.

Constraint: An object of a derived type may be explicitly distributed only if the derived type is not an explicitly mapped type.

Constraint: A *distributee* in a **DISTRIBUTE** directive may not be a *structure-component*.

Constraint: A *distributee* in a **DISTRIBUTE** directive which occurs in a *derived-type-def* must be the *component-name* of a component of the derived type.

Constraint: A *component-name* may occur as a *distributee* in a **DISTRIBUTE** directive occurring within the derived type definition only.

Constraint: A *distributee* that is a *structure-component* may occur only in a **REDISTRIBUTE** directive and every *part-ref* except the rightmost must be scalar (rank zero). The rightmost *part-name* in the *structure-component* must have the **DYNAMIC** attribute.

**H808**  
*alignee-extended* is  
*object-name*  
*or*  
*component-name*  
*or*  
*structure-component*
Constraint: A component of a derived type may be explicitly aligned only if the type of the component is not an explicitly mapped type.

Constraint: An object of a derived type may be explicitly aligned only if the derived type is not an explicitly mapped type.

Constraint: An alignee in an ALIGN directive may not be a structure-component.

Constraint: An alignee in an ALIGN directive that occurs in a derived-type-def must be the component-name of a component of the derived type.

Constraint: A component-name may occur as an alignee only in an ALIGN directive occurring within the derived type definition.

Constraint: An alignee that is a structure-component may occur only in a REALIGN directive and every part-ref except the rightmost must be scalar (rank zero). The rightmost part-name in the structure-component must have the DYNAMIC attribute.

H809 align-target-extended is object-name
or template-name
or component-name
or structure-component

Constraint: A component-name may appear as an align target only in an ALIGN directive occurring within the derived type definition that defines that component.

Constraint: In an align-target that is a structure-component, every part-ref except the rightmost must be scalar (rank zero).

A.8.10 New Distribution Formats

H810 extended-dist-format is BLOCK [ ( int-exp ) ]
or CYCLIC [ ( int-exp ) ]
or GEN_BLOCK ( int-array )
or INDIRECT ( int-array )
or *

Constraint: An int-array appearing in a extended-dist-format of a DISTRIBUTE directive or REDISTRIBUTE directive must be an integer array of rank 1.

Constraint: An int-array appearing in a extended-dist-format of a DISTRIBUTE directive must be a restricted-expr.

Constraint: The size of any int-array appearing with a GEN_BLOCK distribution must be equal to the extent of the corresponding dimension of the target processor arrangement.

Constraint: The size of any int-array appearing with an INDIRECT distribution must be equal to the extent of the corresponding dimension of the distributee to which the distribution is to be applied.
A.8.11 The RANGE Directive

H811  range-directive  is  RANGE  ranger  range-attr-stuff
H812  ranger  is  object-name
      or  template-name
H813  range-attr-stuff  is  range-distribution-list
H814  range-distribution  is  (  range-attr-list  )
H815  range-attr  is  range-dist-format
      or  ALL
H816  range-dist-format  is  BLOCK  [  (  )  ]
      or  CYCLIC  [  (  )  ]
      or  GEN_BLOCK
      or  INDIRECT
      or  *

Constraint: At least one of the following must be true:

- The ranger has the DYNAMIC attribute.
- The ranger has the INHERIT attribute.
- The ranger is specified with a dist-format-clause of * in a DISTRIBUTE or combined directive.

Constraint: The length of each range-attr-list must be equal to the rank of the ranger.

Constraint: The ranger must not appear as an alignee in an ALIGN or REALIGN directive.

A.8.12 The SHADOW Directive

H817  shadow-directive  is  SHADOW  shadow-target  shadow-attr-stuff
H818  shadow-target  is  object-name
      or  component-name
H819  shadow-attr-stuff  is  (  shadow-spec-list  )
H820  shadow-spec  is  width
      or  low-width  :  high-width
H821  width  is  int-expr
H822  low-width  is  int-expr
H823  high-width  is  int-expr

Constraint: The int-expr representing a width, low-width, or high-width must be a constant specification-expr with value greater than or equal to 0.
A.9. Approved Extensions for Data and Task Parallelism

A.9.1 Active Processor Sets

H901 subset-directive is SUBSET processors-name

A.9.2 The ON Directive

H902 on-directive is ON on-stuff
H903 on-stuff is home [ , resident-clause ] [ , new-clause ]
H904 on-construct is directive-origin block-on-directive
    block
    directive-origin end-on-directive

H905 block-on-directive is ON on-stuff BEGIN
H906 end-on-directive is END ON
H907 home is HOME ( variable )
or HOME ( template-elmt )
or ( processors-elmt )
H908 template-elmt is template-name [ ( section-subscript-list ) ]
H909 processors-elmt is processors-name [ ( section-subscript-list ) ]

A.9.3 The RESIDENT Clause, Directive, and Construct

H910 resident-clause is RESIDENT resident-stuff
H911 resident-stuff is [ ( res-object-list ) ]
H912 resident-directive is RESIDENT resident-stuff
H913 resident-construct is directive-origin block-resident-directive
    block
    directive-origin end-resident-directive

H914 block-resident-directive is RESIDENT resident-stuff BEGIN
H915 end-resident-directive is END RESIDENT
H916 res-object is object

A.9.4 The TASK_REGION Construct

H917 task-region-construct is
    directive-origin block-task-region-directive
    block
    directive-origin end-task-region-directive

H918 block-task-region-directive is TASK_REGION
H919 end-task-region-directive is END TASK_REGION
A.10 Approved Extension for Asynchronous I/O

or ASYNCHRONOUS
or ID = scalar-default-int-variable
or ASYNCHRONOUS

Constraint: If either an ASYNCHRONOUS or an ID= specifier is present, then both shall be present.

Constraint: If an ASYNCHRONOUS specifier is present, the REC= specifier shall appear, a format shall not appear, and a namelist-group-name shall not appear.

Constraint: If an ASYNCHRONOUS specifier is present, then no function reference may appear in an expression anywhere in the data transfer statement.

or ID = scalar-default-int-variable
or PENDING = scalar-default-logical-variable

Constraint: The ID= and PENDING= specifiers shall not appear in an INQUIRE statement if the FILE= specifier is present.

Constraint: If either an ID= specifier or a PENDING= specifier is present, then both shall be present.

A.10.1 The WAIT Statement

H1001 wait-stmt  is  WAIT ( wait-spec-list )
H1002 wait-spec is  UNIT = io-unit
or ID = scalar-default-int-expr
or ERR = label
or IOSTAT = label

Constraint: A wait-spec-list shall contain exactly one UNIT= specifier, exactly one ID= specifier, and at most one of each of the other specifiers.

A.11 Approved Extensions for HPF Extrinsic

A.11.2 Extrinsic Language Bindings

H1101 type-declaration-stmt-extended is  type-spec [ [ , attr-spec-extended ] ... :: ] entity-decl-list
H1102 attr-spec-extended is PARAMETER
or access-spec
or ALLOCATABLE
or DIMENSION ( array-spec )
or EXTERNAL
or INTENT ( intent-spec )
or INTRINSIC
or OPTIONAL
or POINTER
or SAVE
or TARGET
or MAP_TO ( map-to-spec )
or LAYOUT ( layout-spec )
or PASS_BY ( pass-by-spec )

H1103 map-to-spec is scalar-char-initialization-expr
H1104 layout-spec is scalar-char-initialization-expr
H1105 pass-by-spec is scalar-char-initialization-expr

Constraint: The same attr-spec-extended shall not appear more than once in a given type-
declaration-stmt.

Constraint: An entity shall not be explicitly given any attribute more than once in a scoping
unit.

Constraint: The attributes MAP_TO, LAYOUT, and PASS_BY may be specified only for dummy
arguments within a scoping unit of an extrinsic type for which these attributes
have been explicitly defined.
Annex B

Syntax Cross-reference

This Appendix cross-references symbols used in the formal syntax rules. Rule identifiers beginning with “H” refer to syntax rules of this High Performance Fortran Language Specification; the full rule may be found in Appendix A. Rule identifiers beginning with “R” refer to syntax rules of the Fortran Language Standard (“Fortran 95”).

B.1 Nonterminal Symbols That Are Defined

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B.1. NONTERMINAL SYMBOLS THAT ARE DEFINED

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2 attr-spec R503
3 attr-spec-extended H1102 H1101
4 block R801 H904 H913 H917
5 block-data-stmt H607
6 block-on-directive H905 H904
7 block-resident-directive H914 H913
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22 dist-onto-clause H311 H306 H307
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31 end-on-directive H906 H904
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33 end-subroutine-stmt R1224
34 end-task-region-directive H919 H917
35 entity-decl R504 H1101
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37 equiv-op-and R717 H505
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### B.3. TERMINAL SYMBOLS

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Annex C

HPF 1.1 Subset

As part of the definition of the previous version of the High Performance Fortran language, HPF 1.1, a subset language was formally defined, based on the Fortran 77 language. The goal was to permit more rapid implementations of a useful subset of HPF that did not require full implementation of the new ANSI/ISO standard Fortran (“Fortran 90”).

No subset language is defined as part of the current version, HPF 2.0. This Annex is included in the HPF 2.0 language document as a convenient summary of the HPF 1.1 Subset, which has served as a minimum requirement for HPF implementations.

C.1 Fortran 90 Features in the HPF 1.1 Subset

The features of the HPF 1.1 subset languages are listed below. For reference, the section numbers from the Fortran 90 standard are given along with the related syntax rule numbers:

- All FORTRAN 77 standard conforming features, except for storage and sequence association.

- The Fortran 90 definitions of MIL-STD-1753 features:
  - DO WHILE statement (8.1.4.1.1 / R821)
  - END DO statement (8.1.4.1.1 / R825)
  - IMPLICIT NONE statement (5.3 / R540)
  - INCLUDE line (3.4)
  - scalar bit manipulation intrinsic procedures: IOR, IAND, NOT, IEOR, ISHFT, ISHFTC, BTEST, IBSET, IBCLR, IBITS, MVBITS (13.13)
  - binary, octal and hexadecimal constants for use in DATA statements (4.3.1.1 / R407 and 5.2.9 / R533)

- Arithmetic and logical array features:
  - array sections (6.2.2.3 / R618–621)
    - subscript triplet notation (6.2.2.3.1)
    - vector-valued subscripts (6.2.2.3.2)
  - array constructors limited to one level of implied DO (4.5 / R431)
– arithmetic and logical operations on whole arrays and array sections (2.4.3, 2.4.5, and 7.1)
– array assignment (2.4.5, 7.5, 7.5.1.4, and 7.5.1.5)
– masked array assignment (7.5.3)
  * WHERE statement (7.5.3 / R738)
  * block WHERE . . ELSEWHERE construct (7.5.3 / R739)
– array-valued external functions (12.5.2.2)
– automatic arrays (5.1.2.4.1)
– ALLOCATABLE arrays and the ALLOCATE and DEALLOCATE statements (5.1.2.4.3, 6.3.1 / R622, and 6.3.3 / R631)
– assumed-shape arrays (5.1.2.4.2 / R516)

- Intrinsic procedures:
  The list of intrinsic functions and subroutines below is a combination of (a) routines which are entirely new to Fortran and (b) routines that have always been part of Fortran, but have been extended here to new argument and result types. The new or extended definitions of these routines are part of the subset. If a FORTRAN 77 routine is not included in this list, then only the original FORTRAN 77 definition is part of the subset.

  For all of the intrinsics that have an optional argument DIM, only actual argument expressions for DIM that are initialization expressions are part of the subset. The intrinsics with this constraint are marked with \(\|$\) in the list below.

  – the argument presence inquiry function: PRESENT (13.10.1)
  – all the numeric elemental functions: ABS, AIMAG, AINT, ANINT, CEILING, CMPLX, CONJG, DBLE, DIM, DPROD, FLOOR, INT, MAX, MIN, MOD, MODULO, NINT, REAL, SIGN (13.10.2)
  – all mathematical elemental functions: ACOS, ASIN, ATAN, ATAN2, COS, COSH, EXP, LOG, LOG10, SIN, SINH, SQRT, TAN, TANH (13.10.3)
  – all the bit manipulation elemental functions: BTEST, IAND, IBCLR, IBITS, IBSET, IEOR, IOR, ISHFT, ISHFTC, NOT (13.10.10)
  – all the vector and matrix multiply functions: DOT_PRODUCT, MATMUL (13.10.13)
  – all the array reduction functions: ALL\(\|$\), ANY\(\|$\), COUNT\(\|$\), MAXVAL\(\|$\), MINVAL\(\|$\), PRODUCT\(\|$\), SUM\(\|$\) (13.10.14)
  – all the array inquiry functions: ALLOCATED, LBOUND\(\|$\), SHAPE, SIZE\(\|$\), UBOUND\(\|$\) (13.10.15)
  – all the array construction functions: MERGE, PACK, SPREAD\(\|$\), UNPACK (13.10.16)
  – the array reshape function: RESHAPE (13.10.17)
  – all the array manipulation functions: CSHIFT\(\|$\), RSHIFT\(\|$\), TRANSPOSE (13.10.18)
  – all array location functions: MAXLOC\(\|$\), MINLOC\(\|$\) (13.10.19)
  – all intrinsic subroutines: DATE_AND_TIME, MVBITS, RANDOM_NUMBER, RANDOM_SEED, SYSTEM_CLOCK (3.11)
Declarations:

- Type declaration statements, with all forms of type-spec except kind-selector and TYPE(type-name), and all forms of attr-spec except access-spec, TARGET, and POINTER. (5.1 / R501-503, R510)
- attribute specification statements: ALLOCATABLE, INTENT, OPTIONAL, PARAMETER, SAVE (5.2)

Procedure features:

- INTERFACE blocks with no generic-spec or module-procedure-stmt (12.3.2.1)
- optional arguments (5.2.2)
- keyword argument passing (12.4.1 /R1212)

Syntax improvements:

- long (31 character) names (3.2.2)
- lower case letters (3.1.7)
- use of "_" in names (3.1.3)
- "!" initiated comments, both full line and trailing (3.3.2.1)

C.2 HPF 1.1 Directives and Language Extensions in the HPF 1.1 Subset

The following HPF 1.1 directives and language extensions to Fortran 90 were included in the HPF 1.1 Subset:

- The basic data distribution and alignment directives: ALIGN, Distribute, PROCESSORS, and TEMPLATE.
- The forall-statement (but not the forall-construct).
- The INDEPENDENT directive.
- The SEQUENCE and NO SEQUENCE directives.
- The system inquiry intrinsic functions NUMBER_OF_PROCESSORS and PROCESSORS_SHAPE.
- The computational intrinsic functions ILEN, and the HPF extended Fortran intrinsics MAXLOC and MINLOC, with the restriction that any actual argument expression corresponding to an optional DIM argument must be an initialization expression.

For a discussion of the rationale by which features were chosen for the HPF 1.1 Subset, please consult HPF Language Specification Version 1.1.
Annex D

Previous HPFF Acknowledgments

The current HPF 2.0 document would not have been possible without the contributions of the previous series of HPFF meetings. Following are the acknowledgments for those efforts.

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Technical development for HPF 1.0 was carried out by subgroups, and was reviewed by the full committee. Many people served in positions of responsibility:

- Ken Kennedy, Convener and Meeting Chair;
- Charles Koelbel, Executive Director and Head of the FORALL Subgroup;
- Mary Zosel, Head of the Fortran 90 and Storage Association Subgroup;
- Guy Steele, Head of the Data Distribution Subgroup;
- Rob Schreiber, Head of the Intrinsics Subgroup;
- Bob Knighten, Head of the Parallel I/O Subgroup;
- Marc Snir, Head of the Extrinsics Subgroup;
- Joel Williamson and Marina Chen, Heads of the Subroutine Interface Subgroup; and
- David Loveman, Editor.

Geoffrey Fox convened the first HPFF meeting with Ken Kennedy and later led a group to develop benchmarks for HPF. Clemens-August Thole organized a group in Europe and was instrumental in making this an international effort. Charles Koelbel produced detailed meeting minutes that were invaluable to subgroup heads in preparing successive revisions to the draft proposal. Guy Steele developed \texttt{Bt\TeX} macros for a variety of tasks, including formatting BNF grammar, Fortran code and pseudocode, and commentary material; the document would have been much less aesthetically pleasing without his efforts.

Many companies, universities, and other entities supported their employees’ attendance at the HPFF meetings, both directly and indirectly. The following organizations were represented at two or more meetings by the following individuals (not including those present at the first HPFF meeting in January of 1992, for which there is no accurate attendee list): Alliant Computer Systems Corporation
Amoco Production Company ......................... Jerrold Wagener, Rex Page
Applied Parallel Research ......................... John Levesque, Rony Sawdayi, Gene Wagenbruth
Archipel ........................................Jean-Laurent Philippe
CONVEX Computer Corporation .................. Joel Williamson
Cornell Theory Center ................................ David Presberg
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United Technologies Corporation ................ Richard Shapiro
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University of Southampton ........................ John Merlin
University of Vienna ................................ Barbara Chapman, Hans Zima
Yale University ................................... Marina Chen, Alok Majumdar

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Ken Kennedy, Robert Knighten, Charles Koelbel, David Loveman, Piyush Mehrotra, John
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contributed shorter passages and examples and corrected errors.

Because public input was encouraged on electronic mailing lists, it is impossible to
identify all who contributed to discussions; the entire mailing list was over 500 names long.
Following are some of the active participants in the HPFF process not mentioned above:
D.1. HPFF ACKNOWLEDGMENTS

The following organizations made the language draft available by anonymous FTP access and/or mail servers: AT&T Bell Laboratories, Cornell Theory Center, GMD-ITI (Sankt Augustin), Oak Ridge National Laboratory, Rice University, Syracuse University, and Thinking Machines Corporation. These outlets were instrumental in distributing the document.

The High Performance Fortran Forum also received a great deal of volunteer effort in nontechnical areas. Theresa Chatman and Ann Redelfs were responsible for most of the meeting planning and organization, including the first HPFF meeting, which drew over 125 people. Shaun Bontron, Rachele Harless, Rhonda Perales, Seryu Patel, and Daniel Swint helped with many logistical details. Danny Powell spent a great deal of time handling the financial details of the project. Without these people, it is unlikely that HPF would have been completed.

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Duane Carbon Richard Carpenter Brice Cassenti
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Ruth Lovey Doug MacDonald Raymond Man
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Dale Nielsen Kraytov Nikolay Steve O’Neale
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HPFF operated on a very tight budget (in reality, it had no budget when the first meeting was announced). The first meeting in Houston was entirely financed from the conferences budget of the Center for Research on Parallel Computation, an NSF Science and Technology Center. DARPA and NSF have supported research at various institutions that have made a significant contribution towards the development of High Performance Fortran. Their sponsored projects at Rice, Syracuse, and Yale Universities were particularly influential in the HPFF process. Support for several European participants was provided by ESPRIT through projects P6643 (PPPE) and P6516 (PREPARE).

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- Ken Kennedy, Convener and Meeting Chair;
- Mary Zosel, Executive Director and head of CCI Group 2;
- Richard Shapiro, Head of CCI Group 1;
- Ian Foster, Head of Tasking Subgroup;
- Alok Choudhary, Head of Parallel I/O Subgroup;
- Chuck Koelbel, Head of Irregular Distributions Subgroup;
- Rob Schreiber, Head of Implementation Subgroup;
- Joel Saltz, Head of Benchmarks Subgroup;
- David Loveman, Editor, assisted by Chuck Koelbel, Rob Schreiber, Guy Steele, and Mary Zosel, section editors.

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Bibliography


Annex E

Policy and Mechanism for Recognized Extrinsic Interfaces

HPF defines certain extrinsics such as HPF\_LOCAL and HPF\_SERIAL as interfaces that HPFF believes are useful to the HPF community. But there are many more such extrinsic interfaces beyond those maintained by HPFF. HPFF has adopted a policy of formally recognizing certain extrinsic interface definitions, where the interface, and its addition to the HPF document is considered to be a service to the HPF community. Examples are language bindings to HPF or library packages.

E.1 Extrinsic Policy

To be considered for HPFF recognition, a proposed extrinsic must demonstrate the following things. It should be noted, however, that meeting these criteria does not guarantee acceptance of a proposed interface by HPFF.

- conformance to HPF rules for calling extrinsics,
- significant new functionality,
- existing practice such as users, implementations, etc.,
- institutional backing with evidence of ongoing support,
- coherent documentation,
- non-proprietary interface definition, and
- copyright goes to HPFF for interface, with permission to use (royalty free).

If a proposed extrinsic is accepted by HPFF, then:

- HPFF will recognize the interface and reference it in documentation, but HPFF does not assume responsibility for the extrinsic or its interface.
- The sponsor of the extrinsic must continue to conform to the HPF interface rules for extrinsics. The interface HPFF approves must not change without HPFF approval.
- The sponsor must assume responsibility for any CCI requests concerning the extrinsic.
A list of recognized extrinsic interfaces will be included in HPF documentation, with the following guidelines:

- There should be a single page introduction to the extrinsic which contains:
  - the name of the extrinsic,
  - a brief abstract of functionality,
  - a brief and informal description of the interface,
  - information about platform and system availability, and
  - reference and contacts for formal documentation, continued responsibility, and additional information (e.g., compiler availability).

- There should be about two pages with short examples of usage.

- A short paper with the formal definition of the interface and an informal description of the functionality of the extrinsic.

E.2 Extrinsic Interface Mechanism

The HPF www-home page will have instructions for submission of an extrinsic interface. For HPFF consideration, the sponsor prepares a proposal that includes:

- a statement of what significant new functionality is provided,
- a description of existing practice,
- a statement of institutional backing with evidence of ongoing support,
- a copy of the complete documentation or a reference to an online version of the documentation,
- a draft of the text (described above) that would be included in the HPFF documentation, and
- a statement justifying the claim that the interface follows HPF conventions for calling extrinsics.

If the proposed extrinsic interface is approved by HPFF, the sponsor then submits:

- a formal statement for HPFF records that the interface definition is non-proprietary and that the copyright of the interface belongs HPFF,
- the formal contact for CCI and continued maintenance of the interface, and
- a copy of the interface documentation formatted for HPFF use, including a copy in the current document and web mark-up languages.
Annex F

HPF_CRAFT

HPF_CRAFT is a hybrid language, combining an SPMD execution model with high performing HPF features. The model combines the multi-threaded execution of HPF_LOCAL and the HPF syntax. The goal of HPF_CRAFT is to attain the potential performance of an SPMD programming model with access to HPF features and a well-defined extrinsic interface to HPF.

F.1 Introduction

HPF_CRAFT is a hybrid language, combining an SPMD execution model with high performing and portable HPF features. The model combines the multi-threaded execution of HPF_LOCAL and the HPF syntax and features. The goal of HPF_CRAFT is to attain the potential performance of an SPMD programming model with access to HPF features and a well-defined extrinsic interface to HPF. It is built on top of the HPF_LOCAL extrinsic environment.

SPMD features and a multi-threaded model allow the user to take advantage of the performance and opportunity for low level access of a more general purpose programming model. Including HPF data distribution features gives the programmer access to high performing aspects of both models, but with the added responsibility of working with a more low-level execution model. HPF_CRAFT is best suited for platforms that support one way communication features, but is consistent with HPF and easily targeted for platforms that have HPF and can support SPMD programming styles.

The HPF features included in HPF_CRAFT are a subset of the full HPF language chosen for their performance and their broad portability and ease of use. HPF_CRAFT contains additional features to support SPMD programming styles. There are some differences from HPF, however. For example, I/O causes differences; in HPF_CRAFT different processors are allowed to read from different files at the same time, in HPF the processors must all read from the same file. The differences in the models are principally caused by the multi-threaded execution model and the introduction of HPF_LOCAL data rules.

HPF_CRAFT allows for the notion of private data. Data defaults to a mapping in which data items are allocated so that each processor has a unique copy. The values of the individual data items and the flow of control may vary from processor to processor within HPF_CRAFT. This behavior is consistent with the behavior of HPF_LOCAL. In HPF_CRAFT a processor may be individually named and code executed based upon which processor it is executing on. HPF_CRAFT also allows for the notion of private loops. A
private loop is executed in entirety by each processor.

The rules governing the interface to HPF_CRAFT subprograms are similar to those for the HPF_LOCAL interface. Dummy arguments use a hybrid of the interfaces between HPF and itself and that of HPF and HPF_LOCAL. Explicitly mapped dummy arguments behave just as they do in HPF, while default (private) dummy arguments use the HPF_LOCAL calling convention.

HPF_CRAFT will be initially made available on Cray MPP systems and may also be available on Cray vector architectures. Future versions of HPF_CRAFT are possible on other vendor’s architectures as well.

HPF_CRAFT is being implemented for Cray Research by The Portland Group, Inc. For Cray systems, HPF_CRAFT may be obtained through the Cray Research Inc. Orderdesk, Cray Research Inc.

orerdsk@cray.com
(612) 683-5907

Additional formal documentation, requests, and suggestions can be made to

The Portland Group
9150 SW Pioneer Ct., Suite H
Wilsonville, OR 97070
(503) 682-2806
trs@pgroup.com

F.2 Examples of Use

HPF_CRAFT is intended for use in circumstances where greater control and performance are desired for MIMD style architectures. Since data may be declared to be private, local control is made more available and since processor information is available message passing and direct memory access programming styles can be seamlessly integrated with explicitly mapped data.

The following examples show some of the capabilities of HPF_CRAFT that are different from those of HPF. Others, such as integrated message passing and synchronization primitives are not shown. Much of HPF can also be used within HPF_CRAFT.

Example 1 illustrates the difference between the default distribution for data and the distribution of mapped data.

Example 1

```fortran
INTEGER PRIVATE_A(100, 20), PRIVATE_B(12, 256), PRIVATE_C
INTEGER MAPPED_A(100, 20), MAPPED_B(12, 256), MAPPED_C
!HPF$ DISTRIBUTED MAPPED_A(BLOCK, BLOCK), MAPPED_B(BLOCK, *), MAPPED_C
```

In the above example, given 8 processors, there would be $8 \times 100 \times 20$ (or 16,000) elements in the array PRIVATE_A. Each processor contains an entire array named PRIVATE_A. The elements of PRIVATE_A on processor 1 cannot be referenced using implicit syntax by any
other processor. There are only 100 * 20 (or 2000) elements of array MAPPED\_A, however, and these elements are distributed about the machine in a (BLOCK, BLOCK) fashion.

The difference between the PRIVATE\_A declaration in HPF\_CRAFT and that in HPF is the most instructive. In HPF\_CRAFT each processor contains one copy of the array, and the values of the elements of the array may vary from processor to processor. HPF implementations are permitted to make one copy of the array per processor the default, but the values of these copies must remain coherent across all processors. In HPF there is no way to write a conforming program in which different processors have different values for the same array.

Example 2 shows the usefulness of the ON clause for the INDEPENDENT loop as well as giving an example of how private data may be used.

! Example 2

```
PRIVATE\_C = 0

!HPF$ INDEPENDENT (I, J) ON MAPPED\_B(I, J)
DO J=1,256
   DO I=1,12
      MAPPED\_B(I, J) = MAPPED\_B(I, J) + 5
      PRIVATE\_C = PRIVATE\_C + MAPPED\_B(I, J)
   ENDDO
   PRIVATE\_C = PRIVATE\_C + MAPPED\_B(I, J)
ENDDO
```

In this example, each iteration is executed on the processor containing the data that is mapped to it. The user was allowed to specify this.

In addition, the private variable PRIVATE\_C is used to compute a total for each processor. At the end of execution of the loop, the values of PRIVATE\_C may be different on each processor depending upon the values in the elements of the array on each processor. This data may be used as is, or it can be quickly summed using a barrier or an ATOMIC UPDATE.

Example 3 shows the final total value being combined into the variable MAPPED\_C whose value is available to all processors.

! Example 3

```
MAPPED\_C = 0

!HPF$ ATOMIC UPDATE
MAPPED\_C = MAPPED\_C + PRIVATE\_C
```

Example 4 shows how the language allows private data to vary from processor to processor.

! Example 4

```
IF (MY\_PE() .EQ. 5) THEN
   PRIVATE\_C = some-big-expression
ENDIF
```
In this example, `PRIVATE` on processor 5 will have the result of `some-big-expression`. Each processor can do distinctly different work and communicate through mapped data.

The code fragment in Example 5 is from an application and shows a few features of the language.

```plaintext
! Example 5

!HPF$ GEOMETRY G(*, CYCLIC)
   REAL FX(100,100), FY(100,100), FZ(100,100)
!HPF$ DISTIBUTE (G) :: FX,FY,FZ
   REAL FXP(100,16,100), FYP(100,16,100)
!HPF$ DISTIBUTE FXP(*,*), BLOCK FYP(*,*), BLOCK
   INTEGER CELL, ATOM, MAP(1000), NACELL(1000)

!HPF$ INDEPENDENT (CELL) ON FX(1,CELL)
   DO CELL=1,100
      JCELL0 = 16*(CELL-1)
      DO NABOR = 1, 13
         JCELL = MAP(JCELL0+NABOR)
      END DO
      DO ATOM=1, NACELL(CELL)
         FX(ATOM, CELL) = FX(ATOM, CELL) + FXP(ATOM, NABOR, JCELL)
         FY(ATOM, CELL) = FY(ATOM, CELL) + FYP(ATOM, NABOR, JCELL)
      END DO
   ENDDO
ENDDO
ENDDO
```

The `GEOMETRY` directive allows the user to generically specify a mapping and use it to apply to many arrays (they need not have the same extents.)

Example 5 has a single `INDEPENDENT` loop which is the outer loop. It executes 100 iterations total. Within this loop the private value of `JCELL0` is set for each processor (ensuring that it is a local computation everywhere.) Nested inside the `INDEPENDENT` loop is a private loop; this loop executes 13 times per processor. Inside this loop `JCELL` is computed locally on each processor, minimizing unnecessary communication. Finally the innermost loop is also private.

F.3  External Interface

This section describes the behavior when an `HPF_CRAFT` routine is called from `HPF`.

The calling convention and argument passing rules for `HPF_CRAFT` are a hybrid of those for `HPF` calling `HPF_LOCAL` and `HPF` calling `HPF`. Explicit interfaces are required. Where dummy arguments are private (default) storage, the `HPF` calling `HPF_LOCAL` conventions are used. Where dummy arguments are explicitly mapped, the calling convention matches `HPF` calling `HPF`.

There are a number of constraints on `HPF_CRAFT` routines that are called from `HPF`. The following is a list of restrictions placed on `HPF_CRAFT` routines called from `HPF`:

- Recursive `HPF_CRAFT` routines cannot be called from `HPF`.
• HPF_CRAFT routines called from HPF may only enter the routine at a single place (no alternate entries).

• An HPF_CRAFT supprogram may not be invoked directly or indirectly from within the body of a FORALL construct or within the body of an INDEPENDENT DO loop that is inside an HPF program.

• The attributes (type, kind, rank, optional, intent) of the dummy arguments in a supprogram called by HPF must match the attributes of the corresponding dummy arguments in the explicit interface.

• A dummy argument of an HPF_CRAFT supprogram called by HPF

  – must not be a procedure name.
  – must not have the POINTER attribute.
  – must not be sequential, unless it is also PE_PRIVATE.
  – must have assumed shape even when it is explicit shape in the interface.
  – if scalar, it must be mapped so that each processor has a copy of the argument.

• The default mapping of scalar dummy arguments and of scalar function results when an HPF program calls an HPF_CRAFT routine is that it is replicated on each processor.

If a dummy argument of an EXTRINSIC(’HPF_CRAFT’) routine interface block is an array and the dummy argument of the HPF_CRAFT supprogram has the default private mapping, then the corresponding dummy argument in the specification of the HPF_CRAFT procedure must be an array of the same rank, type, and type parameters. When the extrinsic procedure is invoked, the dummy argument is associated with the local array that consists of the subgrid of the global array that is stored locally.

If the dummy argument of the HPF_CRAFT supprogram is explicitly mapped, it must have the same mapping as the dummy argument of the EXTRINSIC(’HPF_CRAFT’) supprogram. Note that this restriction does not require actual and dummy arguments to match and is no more stringent than saying that mappings of dummy arguments in interface blocks must match those in the actual routine.

F.4 Execution Model

HPF_CRAFT is built upon the fundamental execution model of HPF_LOCAL, augmented with data mapping and work distribution features from HPF. It is also augmented with explicit low-level control features, many taken from Cray Research’s CRAFT language.

In HPF_CRAFT there is a single task on each processor and all tasks begin executing in parallel, with data defaulting to a private distribution, the same default distribution used in HPF_LOCAL. Each processor gets a copy of the data storage unless specified otherwise by the user. Consequently I/O works identically to I/O in HPF_LOCAL and message passing libraries are easily integrated.

Simply stated, the execution model is that of HPF_LOCAL.

To provide correct behavior when explicitly mapped data is involved, this model defines implicit barrier points at which the execution model requires that all processors must stop and wait for the execution of all other processors before continuing. These barriers add
ANNEX F. HPF_CRAFT

additional semantics to the HPF_LOCAL behavior. An implementation may remove any of these barriers that are deemed unnecessary, but every processor must participate in the barriers at each one of these points.

The points where there are implicit barriers are conceptually after those instances in which the processors in the HPF_CRAFT program are executing cooperatively, as if in an HPF program (e.g., after an INDEPENDENT loop). An HPF_CRAFT program treats operations on explicitly mapped objects as if they were operations in an HPF program and it treats operations on private data as if they were executed within the HPF_LOCAL framework. It is occasionally useful for an advanced programmer to indicate to the compilation system where barriers are not needed; HPF_CRAFT has syntax to allow this capability.

F.5 HPF_CRAFT Functional Summary

HPF_CRAFT contains a number of features not available in HPF, and restricts the usage of many of the features currently available. The following is a concise list of the differences.

- INDEPENDENT has been extended to better support an ON clause.
- There are new rules defining the interaction of explicitly mapped and private data.
- Parallel inquiry intrinsics IN_PARALLEL() and IN_INDEPENDENT() have been added.
- Serial regions (MASTER / END MASTER) have been added.
- Explicit synchronization primitives are provided.
- The ATOMIC UPDATE, SYMMETRIC, and GEOMETRY directives have been added.
- Many other compiler information directives have been added to assist the compiler in producing good quality code.

F.5.1 Data Mapping Features

Data mapping features provided are those that have been found useful most often. When data is explicitly mapped, only one copy of the data storage is created unless the explicit mapping directs otherwise. The value of explicitly mapped replicated data items must be consistent between processors as is the case in HPF. Storage and sequence association for explicitly mapped arrays is not guaranteed in HPF_CRAFT. For private data, storage and sequence association follows the Fortran 90 rules.

A new directive is included for completeness: PE_PRIVATE, which specifies that the data should conform to the default behavior. The values of private variables may vary on different processors.

F.5.2 Subprogram Interfaces

The behavior and requirements of an HPF_CRAFT program at subprogram interfaces may be divided into three cases. Each case is also available using some combination of HPF and HPF_LOCAL. For dummy arguments that are explicitly mapped, the behavior is identical to that of HPF. All processors must cooperate in a subprogram invocation that remaps or explicitly maps data. In other words, if an explicit interface is required (by the HPF rules) or the subprogram declares explicitly mapped data, the subprogram must be called on all
processors. Processors need not cooperate if there are only reads to non-local data. The
INHERIT attribute may only be applied to explicitly mapped data.

Data that has the default private mapping (case two) the behavior of an HPF.CRAFT
subprogram at subprogram interfaces is identical to that of HPF.LOCAL. Data is passed
individually on every processor and the processors need not interact in any way.

When a subprogram is passed actual arguments that are a combination of both explic-
itly mapped data and private data, the explicitly mapped data follows the HPF rules and
the private data follows the HPF.LOCAL rules.

In case three, the user has the option of passing data with explicitly mapped actual
arguments to dummy arguments that are not explicitly mapped (i.e., private.) The mapping
rules for this data are identical to the mapping rules when HPF calls an HPF.LOCAL
subprogram. The data remains “in-place.” All HPF arrays are logically carved up into
pieces; the HPF.CRAFT procedure executing on a particular physical processor sees an
array containing just those elements of the global array that are mapped to that physical
processor. There is implicit barrier synchronization after an INDEPENDENT loop. Transfer
of control into or out of an INDEPENDENT loop is prohibited.

Finally, it is undefined behavior when an actual argument is private and the dummy
argument is explicitly mapped. A definition could be supplied for this interaction, but
it is the same solution that one might propose for a calling sequence when HPF.LOCAL
subprograms call HPF subprograms.

F.5.3 The INDEPENDENT Directive

The INDEPENDENT directive is part of HPF.CRAFT with the same semantics as in HPF.
However, within INDEPENDENT loops the values of private data may vary from processor to
processor. INDEPENDENT applied to FORALL has identical syntax and semantics as in HPF.

An HPF independent loop option may have a NEW clause. The NEW clause is not
required by HPF.CRAFT for default (not explicitly mapped) data. In HPF.CRAFT data
defaults to private so values may differ from processor to processor.

Private data has slightly different behavior than data specified in the NEW clause. The
value of a private datum on each processor can be used beyond a single iteration of the
loop. Private data may be used to compute local sums, for example. The values of data
items named in a NEW clause may not be used beyond a single iteration. The NEW clause
asserts that the INDEPENDENT directive would be valid if new objects were created for the
variables named in the clause for each iteration of the loop. The semantics of the NEW clause
are identical in HPF.CRAFT and HPF.

The semantics of an INDEPENDENT applied to loops containing private data references
changes with respect to the private data. The change can be summarized to say that instead
of indicating that iterations have no dependencies upon one-another, with respect to the
private data, iterations on different processors have no dependencies upon one-another.

F.5.4 The ON Clause

In addition to the version of INDEPENDENT available from HPF, a new version of INDEPENDENT
is included that incorporates the ON clause. There are a number of differences between the
versions of INDEPENDENT with and without the ON clause.

The new version of the INDEPENDENT directive may be applied to the first of a group of
tightly nested loops and may apply to more than one of them. This more easily facilitates
the use of the ON clause. The current INDEPENDENT directive applies only to a single loop nest. The INDEPENDENT directive is extended so that multiple loop nests can be named. The general syntax for these new independent loops is as follows:

```plaintext
!HPF$ INDEPENDENT (l_1,l_2,...,l_n) ON array-name(h_1(l_1),h_2(l_2),...,h_n(l_n))
DO l_1 = L_1, U_1, S_1
   DO l_2 = L_2, U_2, S_2
      ...
   DO l_n = L_n, U_n, S_n
      ...
END DO
...
END DO
```

The syntax and semantics of INDEPENDENT with the ON clause are different from its syntax and semantics without the ON clause. With the ON clause the directive states that there are no cross-processor dependencies, but there may be dependencies between iterations on a processor. There is an implicit barrier synchronization after an INDEPENDENT loop. Transfer of control into or out of an INDEPENDENT loop is prohibited.

The iteration space of an INDEPENDENT nest must be rectangular. That is, the lower loop bound, the upper loop bound, and the step expression for each loop indicated by the INDEPENDENT induction list must be invariant with regard to the INDEPENDENT nest. Each index expression of array-name in the ON clause (the functions h_i above, ) must be one of the following two forms:

```
[ a * loop_control_variable + ] b
[ a * loop_control_variable - ] b
```

where a and b must be integer values; they can be expressions, constants, or variables. The values of a and b must be invariant with regard to the INDEPENDENT loop nest. For example, specifying A(I,J,K) is valid. Specifying A(3,I+J,K) is not valid. Specifying A(I,J,K) is not valid because I appears twice. Division is prohibited in any index expression of the ON clause.

**F.5.5 Array Syntax**

Array syntax is treated identically in HPF_CRAFT as in HPF for explicitly mapped objects. For private objects the behavior is identical to that of HPF_LOCAL. When private objects and explicitly mapped objects are combined the rules are as follows:

```
result = rhs_1 op_1 rhs_2 op_2 ... op_m rhs_n
```

- If `result` is explicitly mapped and all `rhs` arrays are explicitly mapped, the work is distributed as in HPF.
- If `result` is private and all `rhs` arrays are private the computation is done on all processors as an HPF_LOCAL program would do it.
- If `result` is private and all `rhs` arrays are explicitly mapped, the work is distributed as in HPF and the values of the results are broadcast to the `result` on each processor.
• If result is explicitly mapped and not all rhs arrays are explicitly mapped, the results of the operation are undefined, unless all corresponding elements of all private rhs arrays have the same values.

• If result is private and some, but not all rhs arrays are explicitly mapped, the value is computed on each processor and saved to the local result.

All processors must participate in any array syntax statement in which the value of an explicitly mapped array is modified, and there is implicit barrier synchronization after the statement executes.

F.5.6 Treatment of FORALL and WHERE Statements
The FORALL and WHERE statements are treated exactly as in HPF when data is explicitly mapped. When private data is modified, the statement is executed separately on each processor. Finally, when data in a FORALL or WHERE are mixed, the rules for array syntax apply. If any explicitly mapped data item is modified in a FORALL-stmt or WHERE-stmt then arrays in the forall-header or where-header must be explicitly mapped. In a FORALL construct, if any explicitly mapped array is modified, all modified arrays must be explicitly mapped. There is an implicit barrier synchronization after FORALL and WHERE statements if any arrays in the forall-header or where-header are explicitly mapped.

F.5.7 Synchronization Primitives
A number of synchronization primitives are provided. These primitives include:

Barriers (test, set, wait)
Locks (test, set, clear)
Critical Sections
Events (test, set, wait, clear)

Barriers provides an explicit mechanism for a task to indicate its arrival at a program point and to wait there until all other tasks arrive. A task may test and optionally wait at an explicit barrier point. In the following example, a barrier is used to make sure that block3 is not entered by any task until all tasks have completed execution of block1.

```
block1
CALL SET_BARRIER()
block2
CALL WAIT_BARRIER()
block3
```

The following example performs a similar function as above. However, while waiting for all tasks to arrive at the barrier, the early tasks perform work within a loop.

```
block1
CALL SET_BARRIER()
DO WHILE (.NOT. TEST_BARRIER())
block2
END DO
block3
```
Locks are used to prevent the simultaneous access of data by multiple tasks.

The \texttt{SET\_LOCK(lock)} intrinsic sets the mapped integer variable \textit{lock} atomically. If the lock is already set, the task that called \texttt{SET\_LOCK} is suspended until the lock is cleared by another task and then sets it. Individual locks may be tested or cleared using \texttt{result = TEST\_LOCK(lock)} and \texttt{CLEAR\_LOCK(lock)} respectively.

A critical section protects access to a section of code rather than to a data object. The \texttt{CRITICAL} directive marks the beginning of a code region in which only one task can enter at a time. The \texttt{END\_CRITICAL} directive marks the end of the critical section. Transfer of control into or out of a critical section is prohibited.

\begin{verbatim}
!HPF$ CRITICAL
    GLOBAL\_SUM = GLOBAL\_SUM + LOCAL\_SUM
!HPF$ END\_CRITICAL
\end{verbatim}

Events are typically used to record the state of a program's execution and to communicate that state to another task. Because they do not set locks, as do the lock routines described earlier, they cannot easily be used to enforce serial access of data. They are suited to work such as signalling other tasks when a certain value has been located in a search procedure. There are four routines needed to perform the event functions, and each requires a mapped argument.

The \texttt{SET\_EVENT(event)} routine sets or \textit{posts} an event; it declares that an action has been accomplished or a certain point in the program has been reached. A task can post an event at any time, whether the state of the event is cleared or already posted. The \texttt{CLEAR\_EVENT(event)} routine clears an event, the \texttt{WAIT\_EVENT(event)} routine waits until a particular event is posted, and the \texttt{result = TEST\_EVENT(event)} function returns a logical value indicating whether a particular event has been posted.

\subsection{F.5.8 Barrier Removal}

You can explicitly remove an implicit barrier after any \texttt{INDEPENDENT} loop, or after any array syntax statement that modifies explicitly mapped arrays, by using the \texttt{NO\_BARRIER} directive.

\begin{verbatim}
!HPF$ NO\_BARRIER
\end{verbatim}

\subsection{F.5.9 Serial Regions}

It is often useful to enter a region where only one task is executing. This is particularly useful for certain types of I/O. To facilitate this, two directives are provided. In addition, one may optionally attach a \texttt{COPY} clause to the \texttt{END\_MASTER} directive which specifies the private data items whose values should be broadcast to all processors. The syntax of this directive is:

\begin{verbatim}
!HPF$ MASTER
    sequential region
    ...
!HPF$ END\_MASTER [, COPY( var_1 [, var_2, ..., var_n ])]
\end{verbatim}
where \texttt{var} is \texttt{SYMMETRIC} private data to be copied to the same named private data on other processors.

If a routine is called within a serial region, the routine executes serially; there is no way to get back to parallel execution within the routine. All explicitly mapped data is accessible from within routines called in a serial region, but a routine called from within a serial region cannot allocate explicitly mapped data or remap data. All processors must participate in the invocation of the serial region. Transfer of control into or out of a serial region is not permitted.

\textbf{F.5.10 Libraries}

The HPF Local Routine Library is available in HPF\_CRAFT. The HPF\_LOCAL extrinsic environment contains a number of libraries that are useful for local SPMD programming and a number of libraries that allow the user to determine global (rather than local) state information. These library procedures take as input the name of a dummy argument and return information on the corresponding global HPF actual argument. They may only be invoked by an HPF\_CRAFT procedure that was directly invoked by global HPF code. They may be called only for private data. The libraries reside in a module called HPF\_LOCAL\_LIBRARY.

The HPF Library is available to HPF\_CRAFT when called with data that is explicitly mapped and all processors are participating in the call. In addition, as in HPF\_LOCAL, the entire HPF Library is available for use with private data. Mixing private and explicitly mapped data in calls to the HPF library produces undefined behavior.

\textbf{F.5.11 Parallel Inquiry Intrinsics}

These intrinsic functions are provided as an extension to HPF. They return a logical value that provides information to the programmer about the state of execution in a program.

\begin{verbatim}
IN_PARALLEL()
IN_INDEPENDENT()
\end{verbatim}

\textbf{F.5.12 Task Identity}

\texttt{MY\_PE()} may be used to return the local processor number. The physical processors are identified by an integer in the range of 0 to \( n-1 \) where \( n \) is the value returned by the global HPF\_LIBRARY function \texttt{NUMBER\_OF\_PROCESSORS}. Processor identifiers are returned by \texttt{ABSTRACT\_TO\_PHYSICAL}, which establishes the one-to-one correspondence between the abstract processors of an HPF processors arrangement and the physical processors. Also, the local library function \texttt{MY\_PROCESSOR} returns the identifier of the task executing the call.

\textbf{F.5.13 Parallelism Specification Directives}

These directives allow a user to assert that a routine will only be called from within a parallel region, a serial region, or from within both regions. Without these directives an implementation might be required to generate two versions of code for each routine, depending upon implementation strategies. The directives simply make the generated code size smaller and remove a test.

\begin{verbatim}
!HPF$ PARALLEL\_ONLY
!HPF$ SERIAL\_ONLY
\end{verbatim}
!HPF$ PARALLEL_AND_SERIAL

The default is PARALLEL_ONLY.

F.5.14 The SYMMETRIC Directive

SYMMETRIC variables are private data that are guaranteed to be at the same storage location on every processor. The feature is beneficial to implementations that provide one-way communication functionality. One task can either get or put data into another task’s symmetric data location, without involving the other task. There is an implicit barrier synchronization after SYMMETRIC data is allocated.

REAL PRIV1(100), PRIV2
!HPF$ SYMMETRIC PRIV1, PRIV2

F.5.15 The RESIDENT Directive

The RESIDENT directive can be specified at the loop level and at the routine level. It is an assertion that the references to particular variables in the routine (or loop) are only references to data that are local to the task making the assertion. In the following loop, all references to arrays A, B, and C are local to the task executing each iteration.

REAL A(100), B(100), C(100)
INTEGER IX(100)
!HPF$ DISTRIBUTE A(BLOCK), B(BLOCK), C(BLOCK)
!HPF$ RESIDENT A

... !HPF$ INDEPENDENT (I) ON B(I) RESIDENT(C)
DO I = 1, 100
   A(IX(I)) = B(I) + C(IX(I))
END DO

F.5.16 The ATOMIC UPDATE Directive

In HPF_CRAFT, the ATOMIC UPDATE directive tells the compiler that a particular data item or the elements of a particular array for a specified operation must be updated atomically. This can be used within loops or in array syntax and applies to both the elements of an array with an assignment of a permutation and the elements of an array within a loop.

In the following example, all references to R(IX(I)) occur atomically, thus eliminating the possibility that different iterations might try to modify the same element concurrently.

REAL R(200), S(1000)
INTEGER IX(1000)
!HPF$ DISTRIBUTE R(BLOCK), S(BLOCK), IX(BLOCK)

!HPF$ INDEPENDENT (I) ON S(I)
DO I = 1, 1000
   !HPF$ ATOMIC UPDATE
\[ R(IX(I)) = R(IX(I)) + S(I) \]

END DO

**F.5.17 The GEOMETRY Directive**

The **GEOMETRY** directive is similar to a **typedef** in C, only it is for data mapping. It allows the user to conveniently change the mappings of many arrays at the same time. It is similar in many ways to the **TEMPLATE** directive, but since it is bound to no particular extent it is sometimes easier to apply.

!HPF$ GEOMETRY geom(d_1, d_2, \ldots, d_n) 
!HPF$ DISTRIBUTE (geom) [::] var_1[, var_2, \ldots, var_m]

Where \( d_i \) indicates one of the allowable distribution formats.

!HPF$ GEOMETRY GBB(BLOCK, CYCLIC)

REAL A(300,300), B(400,400)

!HPF$ DISTRIBUTE (GBB) :: A, B

! if GBB changes then both A and B change
Annex G

The FORTRAN 77 Local Library

The HPF standard now describes an EXTRINSIC(LANGUAGE='F77',MODEL='LOCAL') interface, or EXTRINSIC(F77 LOCAL) to use the keyword identification (see Section 11.6 for its description), similar in characteristics to the EXTRINSIC(LANGUAGE='HPF',MODEL='LOCAL') and EXTRINSIC(LANGUAGE='FORTRAN',MODEL='LOCAL') interfaces. This section describes a set of library routines to make it easier to make use of the F77 LOCAL interface when passing distributed array data. These library routines can facilitate, for example, a portable blend of global data parallel code with preexisting FORTRAN 77-based code using explicit message passing calls for interprocessor communication. The FORTRAN 77 Local Library interface described in this section was originally developed as part of Thinking Machines TMHPF and is now supported by Sun Microsystems Inc. For suggestions, requests, or corrections concerning this interface, please contact

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G.1 Introduction

The basic constraints for the local model (Section 11.1) together with the F77_LOCAL-specific argument passing options (Section 11.6) define the nature of the F77_LOCAL interface: how control is to be transferred from a global HPF procedure to a set of local procedures described by an EXTRINSIC(F77_LOCAL) procedure interface and how data can be passed between these two types of procedures: by reference or by descriptor, and with or without temporary local reordering of data to satisfy FORTRAN 77 provisions for sequential, contiguous storage of array data in Fortran array element order. These alternative methods of argument passing can be obtained by use of the two special-purpose attributes for extrinsic dummy arguments defined for LANGUAGE='F77' routines: LAYOUT('F77 ARRAY') (the default) vs. LAYOUT('HPF ARRAY'), and PASS_BY('*') (the default) vs. PASS_BY('HPF HANDLE'). However, to take advantage of the option allowing one to pass global HPF array “handles” to local FORTRAN 77 procedures and then obtain information locally about how the local portion of a given parallel array is actually distributed requires special inquiry routines
comparable to the HPF Local Library of functions. Since this library is not only described as a module, but uses many features such as array-valued functions and optional arguments not available in FORTRAN 77 code, it is recommended that a modified FORTRAN 77 interface to this library be provided in the manner described below. Furthermore, there is the problem of describing local portions of parallel arrays in the FORTRAN 77 code used in each local routine called from a global HPF one. Since assumed-shape syntax may not be used, explicit shape arrays are required. But it is common for global distribution of arbitrary sized arrays to result in local portions of arrays that do not have constant shapes on all processors, and the actual extents in each processor cannot necessarily be predicted in advance. In order to allow programmers to obtain axis extent information at run time from the HPF global caller, a special HPF-callable subgrid inquiry subroutine is provided. A FORTRAN 77 callable version of the same routine is also described below, for flexibility in programming.

G.2 Summary

- One HPF-callable subgrid inquiry subroutine
  
  HPF_SUBGRID_INFO

- A set of FORTRAN 77-callable inquiry subroutines
  
  F77_SUBGRID_INFO
  F77_GLOBAL_ALIGNMENT
  F77_GLOBAL_DISTRIBUTION
  F77_GLOBAL_TEMPLATE
  F77_ABSTRACT_TO_PHYSICAL
  F77_PHYSICAL_TO_ABSTRACT
  F77_LOCAL_TO_GLOBAL
  F77_GLOBAL_TO_LOCAL
  F77_LOCAL_BLKCNT
  F77_LOCAL_LINDEX
  F77_LOCAL_UINDEX
  F77_GLOBAL_SHAPE
  F77_GLOBAL_SIZE
  F77_SHAPE
  F77_SIZE
  F77_MY_PROCESSOR

G.3 Global HPF Subgrid Inquiry Routine

The F77_LOCAL library interface includes only one global HPF subroutine, HPF_SUBGRID_INFO, whose implementation should be added as an extension to the standard HPF Library module. Its purpose is to provide per-processor information about the local subgrids of distributed arrays. This information is often critical when passing such arrays to local procedures written in FORTRAN 77, where array argument shapes must be stated explicitly.
G.3. **GLOBAL HPF SUBGRID INQUIRY ROUTINE**

in the local procedure (except in the last dimension; there are “assumed size” but no “assumed shape” arrays), but may be expressed in terms of arguments passed at run time (“adjustable shape arrays”). Thus the subgrid parameters obtained from this subgrid inquiry routine can be passed as arguments to the local routines and used there to describe the extents of the locally visible portions of global HPF arrays, as the example in Section G.5 will demonstrates.

**HPF_SUBGRID_INFO (ARRAY, IERR, DIM, LB, UB, STRIDE, LB_EMBED, UB_EMBED, AXIS_MAP)**

**Description.** Gives local information about local subgrid allocation onto each processor of a distributed array; callable from a global HPF routine.

**Class.** Inquiry subroutine.

**Arguments.**

**ARRAY**

is a nonsequential array of any type, size, shape, or mapping. It is an **INTENT (IN)** argument.

**IERR**

is a scalar integer of default kind. It is an **INTENT (OUT)** argument. Its return value is zero upon successful return and nonzero otherwise. Errors result if local subgrids cannot be expressed as array sections of **ARRAY**.

If any of the optional arguments **LB_EMBED**, **UB_EMBED**, or **AXIS_MAP** is present, then a nonzero value is also returned if the compiler does not organize the local data in serial memory by sequence associating a larger “embedding” array (see Section G.3.1 below for more explanation). If **DIM** is not present, values are returned for all axes.

**DIM (optional)**

is a scalar integer of default kind. It is an **INTENT (IN)** argument. **DIM** indicates the axis along which return values are desired. If **DIM** is not present, values are returned for all axes.

**LB (optional)**

is an **INTENT (OUT)**, default integer array. If this argument is present, and if the value returned in **IERR** is zero, the values returned in array **LB** are the lower bounds in global coordinates of each processor’s subgrid, along one (if **DIM** is present) or each dimension of **ARRAY**.

**UB (optional)**

is an **INTENT (OUT)**, default integer array. If this argument is present, and if the value returned in **IERR** is zero, the values returned in array **UB** are the upper bounds in global coordinates of each processor’s subgrid, along one (if **DIM** is present) or each dimension of **ARRAY**.

**STRIDE (optional)**

is an **INTENT (OUT)**, default integer array. If this argument is present, and if the value returned in **IERR** is zero, the values returned in array **STRIDE** are the strides in local memory between elements of each processor’s subgrid, along one (if **DIM** is present) or each dimension of **ARRAY**.
LB_EMBED (optional) is an INTENT (OUT), default integer array. If this argument is present, and if the value returned in IERR is zero, the values returned in array LB_EMBED are the lower bounds in global coordinates of the actual global array elements allocated on each processor, possibly a superset of the user-visible subgrid, along one (if DIM is present) or each dimension of ARRAY.

UB_EMBED (optional) is an INTENT (OUT), default integer array. If this argument is present, and if the value returned in IERR is zero, the values returned in array UB_EMBED are the upper bounds in global coordinates of the actual global array elements allocated on each processor, possibly a superset of the user-visible subgrid, along one (if DIM is present) or each dimension of ARRAY.

AXIS_MAP (optional) is a rank 2, INTENT (OUT), default integer array. If this argument is present, its shape must be at least \([n, r]\), where \(n\) is the number of processors and \(r\) is the rank of ARRAY.

If the value returned in IERR is zero, the values returned in AXIS_MAP(\(i, 1:r\)) represent the numbers of the axes of the subgrid on processor \(i\) from fastest varying to slowest varying, and form a permutation of the sequence \(1, 2, \ldots, r\).

For the last six arguments, LB, UB, STRIDE, LB_EMBED, UB_EMBED, and AXIS_MAP, each array has a first axis of extent at least \(n\), where \(n\) is the number of processors, and the first \(n\) indices of that axis of each array must be distributed (perhaps via an explicit CYCLIC or BLOCK distribution) one index per processor. If a second dimension is needed, it should be a collapsed axis of extent at least equal to the rank of ARRAY.

If HPF_SUBGRID_INFO is called, and the elements of ARRAY that are local to any particular processor are not representable as an array section of the global user array, then a nonzero value is returned for IERR. Otherwise, if any of the optional arguments LB, UB, or STRIDE is present, then the lower bounds, upper bounds, or strides, respectively, that describe the local array sections are returned in terms of one-based, global coordinates.

G.3.1 Subgrid Inquiries Involving Embedding Arrays

In the common case in which the elements of each local subgrid of the global array argument are distributed across processors, with no overlap, and allocated in local memory like a local FORTRAN 77 array, as a contiguous sequence of elements in Fortran array element order, these three last optional arguments would not be required.

However, some implementations may choose less common layouts in local memory, that involve “embedding” these elements in a larger array section of equal rank that is sequence-associated in serial memory. For example, alignment of axes of arrays in different orders may result in a permuting embedding of the subgrid. Or axes of subgrids map be padded with ghost cells, either for stencil optimizations or to achieve same-size subgrids on all nodes.
In variations such as these, we may still view the subgrid as being “embedded” in a sequence associated array which may be accessible in F77_LOCAL operations, if the permutation of axes, shape of any embedding array, and offsets into that array can be obtained at runtime. The last three arguments of HPF_SUBGRID_INFO are provided to allow programmers to obtain this information when it is appropriate, with the help of the IERR flag to signal when this is not the case.

In this mapping, local memory has been allocated for a larger array section, with coordinates (LB_EMBED : UB_EMBED : STRIDE). The coordinates of the actual computational elements are limited to the subset (LB : UB : STRIDE). The sequence association is generalized to an arbitrary mapping of axes. Here, AXIS_MAP numbers the axes from fastest varying to slowest varying. If LB_EMBED, UB_EMBED, or AXIS_MAP is specified in a call to HPF_SUBGRID_INFO but ARRAY does not satisfy the assumptions of this mapping model, then a nonzero value is returned for IERR.

### G.4 Local FORTRAN 77 Inquiry Routines

Here the F77-callable inquiry subroutines are described briefly. These provide essentially the same capability as the combination of the HPF intrinsic array inquiry functions such as SHAPE and SIZE, together with the HPF LOCAL LIBRARY inquiry routines. The subroutine F77_SUBGRID_INFO serves as a local counterpart to the globally callable subroutine HPF_SUBGRID_INFO described above. In all of the following:

- ARRAY is a dummy argument passed in from a global HPF caller using the LAYOUT ('HPF_ARRAY') attribute and declared within the FORTRAN 77 local subroutine as a scalar integer variable. It is an INTENT (IN) argument.

- DIM is a scalar integer of default kind. It is an INTENT (IN) argument. This argument specifies a particular axis of the global array associated with ARRAY or, if DIM = -1, inquiry is for all axes.

- An “inquiry result” is an INTENT (OUT) argument. If DIM = -1, it is a rank-one array of size equal to at least the rank of the global array associated with ARRAY, returning information associated with all axes. If DIM is positive, the “inquiry result” is a scalar, returning information only for the axis indicated by DIM.

- The arguments are defined in the same way as for the corresponding HPF or HPF_LOCAL routines unless otherwise noted. See the description of HPF_SUBGRID_INFO above and Section 11.7.1 for full specifications of the similarly-named HPF_LOCAL_LIBRARY procedures.

### F77_SUBGRID_INFO (ARRAY, IERR1, IERR2, DIM, LB, UB, STRIDE, LB_EMBED, UB_EMBED, AXIS_MAP)

**Description.** This is a FORTRAN 77-callable version of the HPF subroutine HPF_SUBGRID_INFO.

**Arguments.**

- **IERR1** is a scalar integer of default kind. It is an INTENT (OUT) argument. Its return value is zero if LB, UB, and STRIDE were determined successfully and nonzero otherwise.
IERR2 is a scalar integer of default kind. It is an INTENT (OUT) argument. Its return value is zero if LB_EMBED and UB_EMBED were determined successfully and nonzero otherwise.

LB, UB, STRIDE, LB_EMBED, UB_EMBED, AXIS_MAP are “inquiry results” of default integer type. They are the lower and upper bounds and strides of the array sections describing the local data (in terms of global indices), the lower and upper bounds of the embedding arrays (again, in terms of global indices), and the axes of the embedding arrays to which the axes of ARRAY are mapped.

F77_GLOBAL_ALIGNMENT (ALIGNEE, LB, UB, STRIDE, AXIS_MAP, IDENTITY_MAP, DYNAMIC, NCOPIES)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL subroutine GLOBAL_ALIGNMENT. All but the first are INTENT (OUT) arguments whose return values are as specified by the corresponding HPF routine.

Arguments.

ALIGNEE is a dummy argument passed in from global HPF. It is an INTENT (IN) argument.

LB, UB, STRIDE, AXIS_MAP are integer arrays of rank one. Their size must be at least equal to the rank of the global HPF array associated with ALIGNEE.

IDENTITY_MAP, DYNAMIC are scalar logicals.

NCOPIES is a scalar integer of default kind.

F77_GLOBAL_DISTRIBUTION (DISTRIBUTEE, AXIS_TYPE, AXIS_INFO, PROCESSORS_RANK, PROCESSORS_SHAPE)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL subroutine GLOBAL_DISTRIBUTION. All but the first are INTENT (OUT) arguments whose return values are as specified by the corresponding HPF routine.

Arguments.

DISTRIBUTEE is a dummy argument passed in from global HPF. It is an INTENT (IN) argument.

AXIS_TYPE is a CHARACTER*9 array of rank one. Its size must be at least equal to the rank of the global HPF array associated with DISTRIBUTEE.

AXIS_INFO is a default integer array of rank one. Its size must be at least equal to the rank of the global HPF array associated with DISTRIBUTEE.

PROCESSORS_RANK is a scalar of default integer type.
PROCESSORS_SHAPE is an integer array of rank one. Its size must be at least equal to the value returned by PROCESSORS_RANK.

F77_GLOBAL_TEMPLATE (ALIGNEE, TEMPLATE_RANK, LB, UB, AXIS_TYPE, AXIS_INFO, NUMBER_ALIGNED, DYNAMIC)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL subroutine GLOBAL_TEMPLATE. All but the first are INTENT (OUT) arguments whose return values are as specified by the corresponding HPF routine.

Arguments.

ALIGNEE is a dummy argument passed in from global HPF. It is an INTENT (IN) argument.

TEMPLATE_RANK is a scalar integer of default kind.

LB, UB, AXIS_INFO are integer arrays of rank one. Their size must be at least equal to the rank of the align-target to which the global HPF array associated with ALIGNEE is ultimately aligned.

AXIS_TYPE is a CHARACTER*10 array of rank one. Its size must be at least equal to the rank of the align-target to which the global HPF array associated with ALIGNEE is ultimately aligned.

NUMBER_ALIGNED is a scalar integer of default kind.

DYNAMIC is a scalar logical.

F77_ABSTRACT_TO_PHYSICAL(ARRAY, INDEX, PROC)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL subroutine ABSTRACT_TO_PHYSICAL.

Arguments.

INDEX is a rank-one, INTENT (IN), integer array.

PROC is a scalar, INTENT (OUT), integer.

F77_PHYSICAL_TO_ABSTRACT(ARRAY, PROC, INDEX)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL subroutine PHYSICAL_TO_ABSTRACT.

Arguments.

PROC is a scalar, INTENT (IN), integer.

INDEX is a rank-one, INTENT (OUT), integer array.
ANNEX G. THE FORTRAN 77 LOCAL LIBRARY

F77_LOCAL_TO_GLOBAL(ARRAY, L_INDEX, G_INDEX)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL subroutine LOCAL_TO_GLOBAL.

Arguments.

L_INDEX is a rank-one, INTENT (IN), integer array.

G_INDEX is a rank-one, INTENT (OUT), integer array.

F77_GLOBAL_TO_LOCAL(ARRAY, G_INDEX, L_INDEX, LOCAL, NCOPIES, PROCS)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL subroutine GLOBAL_TO_LOCAL.

Arguments.

G_INDEX is a rank-one, INTENT (IN), integer array.

L_INDEX is a rank-one, INTENT (OUT), integer array.

LOCAL is a scalar, INTENT (OUT), logical.

NCOPIES is a scalar, INTENT (OUT), integer.

PROCS is a rank-one, integer array whose size is at least the number of processors that hold copies of the identified element.

F77_LOCAL_BLKCNT(L_BLKCNT, ARRAY, DIM, PROC)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL function LOCAL_BLKCNT.

Arguments.

L_BLKCNT is an “inquiry result” of type integer.

PROC is a scalar integer of default kind. It must be a valid processor number or, if PROC = -1, the value returned by F77_MYPROCESSOR() is implied.

F77_LOCAL_LINDEX(L_INDEX, ARRAY, DIM, PROC)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL function LOCAL_LINDEX.

Arguments.

L_INDEX is a rank-one, integer array of size equal to at least the value returned by F77_LOCAL_BLKCNT.

DIM may not be -1.

PROC is a scalar integer of default kind. It must be a valid processor number or, if PROC = -1, the value returned by F77_MYPROCESSOR() is implied.
F77_LOCAL_UINDEX(L_UINDEX, ARRAY, DIM, PROC)

**Description.** This is a FORTRAN 77-callable version of the HPF_LOCAL function LOCAL_UINDEX.

**Arguments.**

- **L_UINDEX** is a rank-one, integer array of size equal to at least the value returned by F77_LOCAL_BLKCONT.
- **DIM** may not be -1.
- **PROC** is a scalar integer of default kind. It must be a valid processor number or, if PROC = -1, the value returned by F77_MY_PROCESSOR() is implied.

F77_GLOBAL_SHAPE(SHAPE, ARRAY)

**Description.** This is a FORTRAN 77-callable version of the HPF_LOCAL function GLOBAL_SHAPE.

**Arguments.**

- **SHAPE** is a rank-one, integer array of size equal to at least the rank of the global array associated with ARRAY. Its return value is the shape of that global array.

F77_GLOBAL_SIZE(SIZE, ARRAY, DIM)

**Description.** This is a FORTRAN 77-callable version of the HPF_LOCAL function GLOBAL_SIZE.

**Arguments.**

- **SIZE** is a scalar integer equal to the extent of axis DIM of the global array associated with ARRAY or, if DIM = -1, the total number of elements in that global array.

F77_SHAPE(SHAPE, ARRAY)

**Description.** This is a FORTRAN 77-callable version of the HPF intrinsic SHAPE, as it would behave as called from HPF_LOCAL.

**Arguments.**

- **SHAPE** is a rank-one, integer array of size equal to at least the rank of the subgrid associated with ARRAY. Its return value is the shape of that subgrid.
F77_SIZE(SIZE, ARRAY, DIM)

Description. This is a FORTRAN 77-callable version of the HPF intrinsic SIZE, as it would behave as called from HPF_LOCAL.

Arguments.

SIZE is a scalar integer equal to the extent of axis DIM of the subgrid associated with ARRAY or, if DIM = -1, the total number of elements in that subgrid.

F77_MY_PROCESSOR(MY_PROC)

Description. This is a FORTRAN 77-callable version of the HPF_LOCAL function MY_PROCESSOR.

Arguments.

MY_PROC is a scalar, INTENT (OUT), integer. Its value is the identifying number of the physical processor from which this call is made.

G.5 Programming Example Using HPF_SUBGRID_INFO

G.5.1 HPF Caller

PROGRAM EXAMPLE

! Declare the data array and a verification copy
INTEGER, PARAMETER :: NX = 100, NY = 100
REAL, DIMENSION(NX,NY) :: X, Y
!HPF$ DISTRIBUTEBLOCK,BLOCK:: X, Y
! The global sum will be computed
! by forming partial sums on the processors
REAL PARTIAL_SUM(NUMBER_OF_PROCESSORS())
!HPF$ DISTRIBUTEPARTIAL_SUM(BLOCK)
! Local subgrid parameters are declared per processor
! for a rank-two array
INTEGER, DIMENSION(NUMBER_OF_PROCESSORS(),2) ::
& LB, UB, NUMBER
!HPF$ DISTRIBUTEBLOCK,*:: LB, UB, NUMBER
! Define interfaces
INTERFACE
EXTRINSIC(F77_LOCAL) SUBROUTINE LOCAL
& ( LB1, UB1, LB2, UB2, NX, X )
! Arrays LB1, UB1, LB2, UB2, and X are passed by default
! as LAYOUT('F77_ARRAY') and PASS_BY('*)
INTEGER, DIMENSION(:) :: LB1, UB1, LB2, UB2
INTEGER NX
REAL X(:,:)
!HPF$ DISTRIBUTEBLOCK:: LB1, UB1, LB2, UB2
!HPF$ DISTRIBUTEBLOCK,BLOCK::X
END

EXTRINSICF77_LOCALSUBROUTINELocal2N,X,R

!Arrays N, X, and R are passed by default
!as LAYOUT('F77_ARRAY') and PASS_BY('*')
INTEGERN(:)
REALX(:,:),R(:)

!HPF$ DISTRIBUTEN(BLOCK)
!HPF$ DISTRIBUTEX(BLOCK,BLOCK)
!HPF$ DISTRIBUTERR(BLOCK)
END

END INTERFACE

!Determine result using only global HPF
!Initialize values
FORALL(I=1:NX,J=1:NY)X(I,J) = I*(J-1)*NX
!Determine and report global sum
PRINT*, 'GLOBAL HPF RESULT: ',SUMX

!Determine result using local subroutines
!Initialize values (assume stride = 1)
CALL HPF_SUBGRID_INFO(Y,IERR,LB=LB,UB=UB)
IF (IERR .NE. 0) STOP 'ERROR!
CALL LOCAL1(LB(:,1),UB(:,1),LB(:,2),UB(:,2),NX,Y)
!Determine and report global sum
NUMBER = UB - LB + 1
CALL LOCAL2(NUMBER(:,1)*NUMBER(:,2), Y, PARTIAL_SUM)
PRINT*, 'F77_LOCAL RESULT #1: ',SUM(PARTIAL_SUM)
END

G.5.2 FORTRAN 77 Caller

SUBROUTINELocal1(LB1,UB1,LB2,UB2,NX,X)
!The global actual arguments passed to LB1, UB1, LB2, and UB2
!have only one element apiece and so can be treated as scalars
!in the local Fortran 77 procedures
INTEGERLB1,UB1,LB2,UB2
!NX contains the global extent of the first dimension
!of the global array associated with local array X
INTEGERNX
!Note that X may have no local elements.
REALX(LB1:UB1, LB2:UB2)
!Initialize the elements of the array, if any
DOJ = LB2, UB2
DOI = LB2, UB2
X(I,J) = I*(J-1)*NX
ENDDO
ENDDO
END
SUBROUTINE LOCAL2(N,X,R)
! Here, the rank of the original array is unimportant
! Only the total number of local elements is needed
! INTEGER N
REAL X(N), R
! If N is zero, local array X has no elements, but R
! still computes the correct local sum
R = 0.
DO I = 1, N
   R = R + X(I)
END DO
END

G.6 Programming Example Using F77-Callable Inquiry Subroutines

This example performs only the initialization of the above example. It illustrates use of the F77-callable inquiry routines on descriptors passed from HPF, as well as the addressing of uncompressed local subgrid data in terms of “embedding arrays.”

G.6.1 HPF Caller

PROGRAM EXAMPLE
INTEGER, PARAMETER :: NX = 100, NY = 100
REAL, DIMENSION(NX,NY) :: X
!HPF$ DISTRIBUTEBLOCK BLOCK) :: X
! Local subgrid parameters are declared per processor
! for a rank-two array
INTEGER, DIMENSION(NUMBER_OF_PROCESSORS(),2) :::
& LB, UB, LB_EMBED, UB_EMBED
!HPF$ DISTRIBUTEBLOCK:*) :: LB, UB, LB_EMBED, UB_EMBED
! Define interfaces
INTERFACE
EXTRINSIC(F77_LOCAL) SUBROUTINE LOCAL1(
& LB1, UB1, LB_EMBED1, UB_EMBED1,
& LB2, UB2, LB_EMBED2, UB_EMBED2, X, X_DESC )
INTEGER, DIMENSION(:) :::
& LB1, UB1, LB_EMBED1, UB_EMBED1,
& LB2, UB2, LB_EMBED2, UB_EMBED2
! X is passed twice, both times without local reordering.
! First, it is passed by reference for accessing array elements.
REAL, DIMENSION(:,:), LAYOUT('HPF_ARRAY'),
& PASS_BY('') :: X
! It is also passed by descriptor for use in F77 LOCAL
! LIBRARY subroutines only.
REAL, DIMENSION(:,:), LAYOUT('HPF_ARRAY'),
& PASS_BY('HPF_HANDLE') :: X_DESC
!HPF$ DISTRIBUTEBLOCK) :: LB1, UB1, LB_EMBED1, UB_EMBED1
!HPF$ DISTRIBUTEBLOCK::LB2, UB2, LB_EMBED2, UB_EMBED2
!HPF$ DISTRIBUTE(BLOCK,BLOCK)::X
END INTERFACE

! Initialize values
! (Assume stride /= 1 and no axis permutation)
CALL HPF_SUBGRID_INFO(X, IERR,
& LB=LB, LB_EMBED=LB_EMBED,
& UB=UB, UB_EMBED=UB_EMBED)
IF (IERR.NE.0) STOP 'ERROR!'
CALL LOCAL1(
& LB(:,1), UB(:,1), LB_EMBED(:,1), UB_EMBED(:,1),
& LB(:,2), UB(:,2), LB_EMBED(:,2), UB_EMBED(:,2), X, X)
END

G.6.2 FORTRAN 77 Callee

SUBROUTINE LOCAL1(
& LB1, UB1, LB_EMBED1, UB_EMBED1,
& LB2, UB2, LB_EMBED2, UB_EMBED2, X, X_DESC )
INTEGER LB1, UB1, LB_EMBED1, UB_EMBED1
INTEGER LB2, UB2, LB_EMBED2, UB_EMBED2

! The subgrid has been passed in its 'embedded' form
REAL X ( LB_EMBED1 : UB_EMBED1, LB_EMBED2 : UB_EMBED2 )
! Locally X_DESC is declared as an INTEGER
INTEGER X_DESC

! Get the global extent of the first axis
! This is an HPF_LOCAL type of inquiry routine with an
! 'F77_' prefix
CALL F77_GLOBAL_SIZE(NX,X,1)
! Otherwise, initialize elements of the array
! Loop only over actual array elements
DO J = LB2, UB2
  DO I = LB2, UB2
    X(I,J) = I + (J-1) * NX
  END DO
END DO
END