

XcalableMP
<ex-scalable-em-p>
Langugae Specification

Version 1.0

XcalableMP Specification Working Group

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Chapter 1

Intrinsic and Library Procedures

This specification defines various procedures for system inquiry, synchronization, computations, etc. The procedures are provided as intrinsic procedures in XcalableMP Fortran and library procedures in XcalableMP C.

1.1 System Inquiry Procedures

- `xmp_desc_of`
- `xmp_all_node_num`
- `xmp_all_num_nodes`
- `xmp_node_num`
- `xmp_num_nodes`
- `xmp_wtime`
- `xmp_wtick`

1.1.1 `xmp_desc_of`

Format

```
[F]  type(xmp_desc)  xmp_desc_of(xmp_entity)
[C]  xmp_desc_t      xmp_desc_of(xmp_entity)
```

Note that `xmp_desc_of` is an intrinsic function in XcalableMP Fortran or a built-in operator in XcalableMP C.

Synopsis

`xmp_desc_of` returns, in XcalableMP Fortran, or is evaluated to, in XcalableMP C, a descriptor to retrieve informations of the specified global array, template, or node array. The resulting descriptor can be used as an input argument of the inquiry procedures which is described in appendix C.

The type of the descriptor, `type(xmp_desc)`, in XcalableMP Fortran is implementation-dependent, and defined in a Fortran module named `xmp_lib` or a Fortran `include` file named `xmp_lib.h`.

The type of the descriptor, `xmp_desc_t`, in XcalableMP C is implementation-dependent, and defined in a header file named `xmp.h` in XcalableMP C.

Arguments

The argument or operand `xmp_entity` is the name of either a global array, a template or a node array.

1.1.2 `xmp_all_node_num`

Format

```
[F] integer function xmp_all_node_num()  
[C] int             xmp_all_node_num(void)
```

Synopsis

The `xmp_all_node_num` routine returns the node number, within the primary node set, of the node that calls `xmp_all_node_num`.

Arguments

none.

1.1.3 `xmp_all_num_nodes`

Format

```
[F] integer function xmp_all_num_nodes()  
[C] int             xmp_all_num_nodes(void)
```

Synopsis

The `xmp_all_num_nodes` routine returns the number of nodes in the entire node set.

Arguments

none.

1.1.4 `xmp_node_num`

Format

```
[F] integer function xmp_node_num()  
[C] int             xmp_node_num(void)
```

Synopsis

The `xmp_node_num` routine returns the node number, within the current executing node set, of the node that calls `xmp_node_num`.

Arguments

none.

1.1.5 `xmp_num_nodes`

Format

```
[F] integer function xmp_num_nodes()  
[C] int             xmp_num_nodes(void)
```


Synopsis

The `xmp_num_nodes` routine returns the number of the executing nodes.

Arguments

none.

1.1.6 `xmp_wtime`

Format

```
[F] double precision function xmp_wtime()
[C] double                   xmp_wtime(void)
```

Synopsis

The `xmp_wtime` routine returns elapsed wall clock time in seconds since some time in the past. The “time in the past” is guaranteed not to change during the life of the process. There is no requirement that different nodes return “the same time.”

Arguments

none.

1.1.7 `xmp_wtick`

Format

```
[F] double precision function xmp_wtick()
[C] double                   xmp_wtick(void)
```

Synopsis

The `xmp_wtick` routine returns the resolution of the timer used by `xmp_wtime`. It returns a double precision value equal to the number of seconds between successive clock ticks.

Arguments

none.

1.2 Synchronization Procedures

1.2.1 `xmp_test_async`

```
[F] logical function xmp_test_async(async_id)
      integer        async_id

[C] int             xmp_test_async(int async_id)
```

Synopsis

The `xmp_test_async` routine returns `.true.`, in XcalableMP Fortran, or `1`, in XcalableMP C, if an asynchronous communication specified by the argument `async_id` is complete; otherwise, it returns `.false.` or `0`.

Arguments

The argument `async_id` is an integer expression that specifies an asynchronous communication initiated by a global communication construct with the `async` clause.

1.3 Miscellaneous Procedures

1.3.1 `xmp_gtol`

```
[F] integer function xmp_gtol(d, g_idx, l_idx)
      type(xmp_desc)  d
      integer          g_idx(NDIMS)
      integer          l_idx(NDIMS)
```

```
[C] void          xmp_gtol(xmp_desc_t d, int g_idx[], int l_idx[])
```

Synopsis

The `xmp_gtol` routine translates an index (specified by `g_idx`) of a global array (specified by `d`) into the corresponding index of its local section and sets to an array specified by `l_idx`. If the element of the specified index does not reside in the caller of the routine, the resulting array is set to an unspecified value.

Arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the target global array.
- [F] `g_idx` is a rank-one integer array of the size equal to the rank of the target global array specified by `d`.
- [F] `l_idx` is a rank-one integer array of the size equal to the rank of the target global array specified by `d`.
- [C] `g_idx` is a one-dimensional integer array.
- [C] `l_idx` is a one-dimensional integer array.

1.3.2 [C] `xmp_malloc`

```
void* xmp_malloc(xmp_desc_t d, size_t size)
```

Synopsis

The `xmp_malloc` routine allocates a storage for the local section of a one-dimensional global array of size `size` that is associated with a descriptor specified by `d`, and returns the pointer to it on each node.

Arguments

- `d` is a descriptor, that is, an object of type `xmp_desc_t` that is associated with a pointer to the one-dimensional global array to be allocated.
- `size` is the size of the global array to be allocated.

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Appendix A

Programming Interface for MPI

This chapter describes the programming interface for MPI, which are widely used for parallel programming for cluster computing. Users can introduce MPI functions to XcalableMP using the interface.

XcalableMP provides the following user API functions to mix MPI functions with XcalableMP.

- `xmp_get_mpi_comm`
- `xmp_init_mpi`
- `xmp_finalize_mpi`

A.1 `xmp_get_mpi_comm`

Format

```
[F] integer function xmp_get_mpi_comm()  
[C] MPI_Comm        xmp_get_mpi_comm(void)
```

Synopsis

`xmp_get_mpi_comm` returns the handle of the communicator associated with the executing node set.

Arguments

none.

A.2 `xmp_init_mpi`

Format

```
[F]          xmp_init_mpi()  
[C] void     xmp_init_mpi(int *argc, char ***argv)
```

Synopsis

`xmp_init_mpi` initializes the MPI execution environment.

Arguments

In XcalableMP C, the command-line arguments `argc` and `argv` should be given to `xmp_init_mpi`.

A.3 `xmp_finalize_mpi`

Format

```
[F]      xmp_finalize_mpi()
[C] void xmp_finalize_mpi(void)
```

Synopsis

`xmp_finalize_mpi` terminates the MPI execution environment.

Arguments

none.

Example

```

XcalableMP C
#include <stdio.h>
#include "mpi.h"
#include "xmp.h"
5 #pragma xmp nodes p(4)

int main(int argc, char *argv[]) {
    xmp_init_mpi(&argc, &argv)

10     int rank, size;
    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
    MPI_Comm_size(MPI_COMM_WORLD, &size);

    #pragma xmp task on p(2:3)
15     {
        MPI_Comm comm = xmp_get_mpi_comm(); // get the MPI communicator of p(2:3)

        int rank, size;
        MPI_Comm_rank(comm, &rank);
20     MPI_Comm_size(comm, &size);
    }

    xmp_finalize_mpi();

25     return 0;
}
```

Appendix B

Directive for Thread Parallelism

Thread-level parallelism is needed to program multi-core cluster system. Users can use some features introduced from OpenMP to parallelize loops in thread level with the **threads** clause of the **loop** directive. No direct use of OpenMP directives in XcalableMP code is allowed.

B.1 threads clause

Syntax

```
[F] !$xmp loop [ ( loop-index [, loop-index]... ) ]  
           on { nodes-ref | template-ref } [ reduction-clause ]... [ threads-clause ]  
do-loops
```

```
[C] #pragma xmp loop [ ( loop-index [, loop-index]... ) ]  
           on { nodes-ref | template-ref } [ reduction-clause ]... [ threads-clause ]  
for-loops
```

where *threads-clause* is:

```
threads [ omp-clause ]
```

and *omp-clause* is one of:

```
num_threads( num-thread )  
private( list )  
firstprivate( list )  
lastprivate( list )
```

Description

OpenMP clauses such as **num_threads** can be specified in **threads** clause. The XcalableMP compiler generates internally OpenMP directives from the **loop** directive and the **threads** clause. Note that no **reduction** need to be specified in the **threads** clause because it is inherited from the **reduction** clause in the **loop** directive.

Example

This example calculates the total sum of an array. A **threads** clause is given to the **loop** directive to parallelize the loop statement in both process and thread level. The **reduction**

clause in the loop directive is also applied to the OpenMP directive which is generated by the XcalableMP compiler.

```

XcalableMP C
#include <stdio.h>
#include "xmp.h"
#define N 1024
5 #pragma xmp nodes p(*)
  #pragma xmp template t(0:N-1)
  #pragma xmp distribute t(block) onto p
  #pragma xmp align a[i] with t(i)
10 int main(void) {
    . . . // initialize a[]

    int sum = 0;
    #pragma xmp loop on t(i) reduction(+:sum) threads num_threads(4)
15   for (int i = 0; i < N; i++) {
        sum += a[i];
    }

    return 0;
20 }

```

Appendix C

Interface to Numerical Libraries

This chapter describes the XcalableMP interfaces to existing MPI parallel libraries, which is effective to achieve high productivity and performance of XcalableMP programs.

C.1 Design of the Interface

A recommended design of the interface is as follows:

- Numerical library routines can be invoked by an XcalableMP procedure through an interface procedure (Figure C.1).

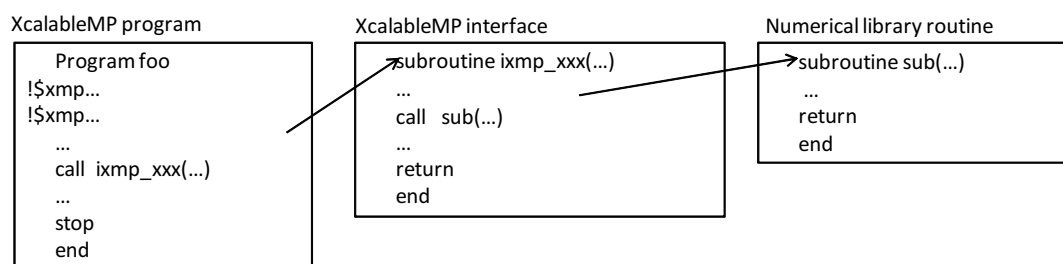


Figure C.1: Invocation of a Library Routine through an Interface Procedure

- When the numerical library routine needs information on a global array, the interface extracts it from the descriptor using some query routines provided by XcalableMP and passes it to the numerical library routine as arguments.
- The interface does not affect the behavior of numerical library routines except for restrictions concerning the XcalableMP specification.

C.2 Inquiry routines

All inquiry routines are specified by integer functions. When these inquiry routines return zero on normal completion, and other implementation-dependent integer on failure. Specifications of some inquiry routines are shown below.

C.2.1 xmp_nodes_ndims

Format

```
[F] integer function xmp_nodes_index(d, ndims)
      type(xmp_desc) d
      integer        ndims
[C]  int            xmp_nodes_ndims(xmp_desc_t d, int *ndims)
```

Synopsis

The `xmp_nodes_ndims` routine provides the rank of the target node array.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the node array.

Output arguments

- `ndims` is the rank of the node array.

C.2.2 xmp_nodes_index

Format

```
[F] integer function xmp_nodes_index(d, index)
      type(xmp_desc) d
      integer        dim
      integer        index
[C]  int            xmp_nodes_index(xmp_desc_t d, int dim, int *index)
```

Synopsis

The `xmp_nodes_index` routine provides the indices of the executing node in the target node array.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)` in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the node array.
- `dim` is a target dimension of the node array.

Output arguments

- `index` is the index of the target dimension of the node array.

C.2.3 xmp_nodes_size

Format

```
[F] integer function xmp_nodes_size(d, dim, size)
      type(xmp_desc) d
      integer        dim
      integer        size
[C]  int            xmp_nodes_size(xmp_desc_t d, int dim, int *size)
```

Synopsis

The `xmp_nodes_size` routine provides the size of each dimension of the target node array.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the node array.
- `dim` is a target dimension of the node array.

Output arguments

- `size` is a extent of the target dimension of the node array.

C.2.4 `xmp_nodes_attr`

Format

```
[F] integer function xmp_nodes_attr(d, attr)
      type(xmp_desc)  d
      integer         attr
[C]  int              xmp_nodes_attr(xmp_desc_t d, int *attr)
```

Synopsis

The `xmp_nodes_attr` routine provides the attribute of the target node array. This routine outputs one of:

```
XMP_ENTIRE_NODES      (Entire nodes)
XMP_EXECUTING_NODES   (Executing nodes)
XMP_PRIMARY_NODES     (Primary nodes)
XMP_EQUIVALENCE_NODES (Equivalence nodes)
```

Each output integer value for the attribute is implementation-dependent.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the node array.

Output arguments

- `attr` is the attribute of the target node array.

C.2.5 `xmp_template_fixed`

Format

```
[F] integer function xmp_template_fixed(d, fixed)
      type(xmp_desc)  d
      logical         fixed
[C]  int              xmp_template_fixed(xmp_desc_t d, _Bool *fixed)
```

Synopsis

The `xmp_template_fixed` routine provides the logical value which shows whether the template is fixed or not.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.

Output arguments

- `fixed` is a logical scalar. When the template is fixed, `fixed` is true.

C.2.6 `xmp_template_ndims`

Format

```
[F] integer function xmp_template_ndims(d, ndims)
      type(xmp_desc) d
      integer         ndims
[C] int              xmp_template_ndims(xmp_desc_t d, int *ndims)
```

Synopsis

The `xmp_template_ndims` routine provides the rank of the target template

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.

Output arguments

- `ndims` is the rank of the template.

C.2.7 `xmp_template_lbound`

Format

```
[F] integer function xmp_template_lbound(d, dim, lbound)
      type(xmp_desc) d
      integer         dim
      integer         lbound
[C] int              xmp_template_lbound(xmp_desc_t d, int dim, int *lbound)
```

Synopsis

The `xmp_template_lbound` routine provides the lower bound of each dimension of the template. When the lower bound is not fixed, this routine the implementation-dependent negative integer value that indicates `XMP_UNDEFINED`.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.
- `dim` is a target dimension of the template.

Output arguments

- `lbound` is lower bound of target dimension of the template.

C.2.8 `xmp_template_ubound`

Format

```
[F] integer function xmp_template_ubound(d, dim, ubound)
      type(xmp_desc) d
      integer        dim
      integer        ubound
[C]  int            xmp_template_ubound(xmp_desc_t d, int dim, int *ubound)
```

Synopsis

The `xmp_template_ubound` routine provides the upper bound of each dimension of the template. When the upper bound is not fixed, this routine returns `XMP_UNDEFINED`.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.
- `dim` is a target dimension of the template.

Output arguments

- `ubound` is upper bound of target dimension of the template.

C.2.9 `xmp_dist_format`

Format

```
[F] integer function xmp_dist_format(d, dim, format)
      type(xmp_desc) d
      integer        dim
      integer        format
[C]  int            xmp_dist_format(xmp_desc_t d, int dim, int *format)
```

Synopsis

The `xmp_dist_format` routine provides the distribution format of each dimension of the target template. This routine outputs one of:

```
      XMP_NOT_DISTRIBUTED (Not distributed)
      XMP_BLOCK           (Block distribution)
      XMP_CYCLIC         (Cyclic distribution)
      XMP_GBLOCK         (Gblock distribution)
```

Each output integer value for the distribution format is implementation-dependent.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.
- `dim` is a target dimension of the template.

Output arguments

- `format` is the distribution format of target dimension of the template.

C.2.10 `xmp_dist_blocksize`

Format

```
[F] integer function xmp_dist_blocksize(d, dim, blocksize)
      type(xmp_desc) d
      integer        dim
      integer        blocksize
[C]  int            xmp_dist_blocksize(xmp_desc_t d, int dim, int *blocksize)
```

Synopsis

The `xmp_dist_blocksize` routine provides the blocking extent of each dimension of the target template.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.
- `dim` is a target dimension of the template.

Output arguments

- `blocksize` is the blocking extent of the target dimension of the template.

C.2.11 `xmp_dist_gblockmap`

Format

```
[F] integer function xmp_dist_gblockmap(d, dim, n, map)
      type(xmp_desc) d
      integer        dim
      integer        n
      integer        map(n)
[C]  int            xmp_dist_gblockmap(xmp_desc_t d, int dim, int n, int *map[])
```

Synopsis

The `xmp_dist_gblockmap` routine provides a mapping array. When `dim` dimension of the global array is distributed by `gblock` and a mapping array is fixed, this routine returns zero. When a mapping array is not fixed, this routine returns `XMP_UNDEFINED`.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.
- `dim` is a target dimension of the template.
- `n` is an extent of the mapping array. `n` must be more than the size of the corresponding dimension of the node array that the template maps.

Output arguments

- `map` is a one-dimensional integer array. The i -th element of `map` is the value of the i -th element of the target mapping array.

C.2.12 `xmp_dist_nodes`

Format

```
[F] integer function xmp_dist_nodes(d, dn)
      type(xmp_desc) d
      type(xmp_desc) dn
[C]  int             xmp_dist_nodes(xmp_desc_t d, xmp_desc_t *dn)
```

Synopsis

The `xmp_dist_nodes` routine provides an object which of type `type(xmp_desc)` is associated with the node array.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.

Output arguments

- `dn` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the node array.

C.2.13 `xmp_dist_axis`

Format

```
[F] integer function xmp_dist_axis(d, dim, axis)
      type(xmp_desc) d
      integer         dim
      integer         axis
[C]  int             xmp_dist_axis(xmp_desc_t d, int dim, int *axis)
```

Synopsis

The `xmp_dist_axis` routine provides the dimension of the node array associated with each dimension of the template. When no dimension of a node array maps a dimension of a template, this routine returns `XMP_UNDEFINED`.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.
- `dim` is a target dimension of the template.

Output arguments

- `axis` is the dimension of the node array associated with target dimension of the template.

C.2.14 xmp_align_axis

Format

```
[F] integer function xmp_align_axis(d, dim, axis)
      type(xmp_desc) d
      integer        dim
      integer        axis
[C] int             xmp_align_axis(xmp_desc_t d, int dim, int *axis)
```

Synopsis

The `xmp_dist_axis` routine provides the dimension of the template associated with each dimension of the global array. When no dimension of a template maps a dimension of a global array, this routine returns `XMP_UNDEFINED`.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the global array.
- `dim` is a target dimension of the global array.

Output arguments

- `axis` is the dimension of the template associated with target dimension of the global array.

C.2.15 xmp_align_offset

Format

```
[F] integer function xmp_align_offset(d, dim, offset)
      type(xmp_desc) d
      integer        dim
      integer        offset
[C] int             xmp_align_offset(xmp_desc_t d, int dim, int *offset)
```

Synopsis

The `xmp_align_offset` routine provides the offset of each dimension of the target global array. When there is no offset, this routine returns `XMP_UNDEFINED`.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the global array.
- `dim` is a target dimension of the global array.

Output arguments

- `offset` is the offset of target dimension of the global array.

C.2.16 xmp_align_replicated

Format

```
[F] integer function xmp_align_replicated(d, dim, replicated)
      type(xmp_desc) d
      integer        dim
      integer        replicated
[C] int             xmp_align_replicated(xmp_desc_t d, int dim, int *replicated)
```

Synopsis

The `xmp_align_replicated` routine provides the logical value which shows whether the target dimension of the template that aligns the global array is replicated or not. When the dimension of the template is replicated, this routine returns true.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the global array.
- `dim` is a target dimension of the global array.

Output arguments

- `replicated` is a logical scalar.

C.2.17 xmp_align_template

Format

```
[F] integer function xmp_align_template(d, dt)
      type(xmp_desc) d
      type(xmp_desc) dt
[C] int             xmp_align_template(xmp_desc_t d, xmp_desc_t *dn)
```

Synopsis

The `xmp_align_template` routine provides an object which of type `type(xmp_desc)` is associated with the template.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the global array.

Output arguments

- `dt` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the template.

C.2.18 xmp_array_ndims

Format

```
[F] integer function xmp_array_ndims(d, ndims)
      type(xmp_desc) d
      integer        ndims
[C]  int            xmp_array_ndims(xmp_desc_t d, int *ndims)
```

Synopsis

The `xmp_array_ndims` routine provides the rank of the target global array

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the global array.

Output arguments

- `ndims` is the rank of the global array.

C.2.19 xmp_array_lshadow

Format

```
[F] integer function xmp_array_lshadow(d, dim, lshadow)
      type(xmp_desc) d
      integer        dim
      integer        lshadow
[C]  int            xmp_array_lshadow(xmp_desc_t d, int dim, int *lshadow)
```

Synopsis

The `xmp_array_lshadow` routine provides the size of lower shadow of each dimension of the target global array.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the global array.
- `dim` is a target dimension of the global array.

Output arguments

- `lshadow` is the size of lower shadow of target dimension of the global array.

C.2.20 xmp_array_ushadow

Format

```
[F] integer function xmp_array_ushadow(d, dim, ushadow)
      type(xmp_desc) d
      integer        dim
      integer        ushadow
[C]  int            xmp_array_ushadow(xmp_desc_t d, int dim, int *ushadow)
```

Synopsis

The `xmp_array_ushadow` routine provides the size of upper shadow of each dimension of the target global array.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the global array.
- `dim` is a target dimension of the global array.

Output arguments

- `ushadow` is the size of upper shadow of target dimension of the global array.

C.2.21 `xmp_array_lbound`

Format

```
[F] integer function xmp_array_lbound(d, dim, lbound)
      type(xmp_desc) d
      integer        dim
      integer        lbound
[C] int             xmp_array_lbound(xmp_desc_t d, int dim, int *lbound)
```

Synopsis

The `xmp_array_lbound` routine provides the lower bound of each dimension of the global array. When the lower bound is not fixed, this routine returns `XMP_UNDEFINED`.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the global array.
- `dim` is a target dimension of the global array.

Output arguments

- `lbound` is lower bound of target dimension of the global array.

C.2.22 `xmp_array_ubound`

Format

```
[F] integer function xmp_array_ubound(d, dim, ubound)
      type(xmp_desc) d
      integer        dim
      integer        ubound
[C] int             xmp_array_ubound(xmp_desc_t d, int dim, int *ubound)
```

Synopsis

The `xmp_array_ubound` routine provides the upper bound of each dimension of the global array. When the upper bound is not fixed, this routine returns `XMP_UNDEFINED`.

Input arguments

- `d` is a descriptor, that is, an object of type `type(xmp_desc)`, in XcalableMP Fortran, or `xmp_desc_t`, in XcalableMP C, that is associated with the global array.
- `dim` is a target dimension of the global array.

Output arguments

- `ubound` is upper bound of target dimension of the global array.

C.3 Example

This section shows the interface to ScaLAPACK as an example of the XcalableMP interface to numerical libraries.

ScaLAPACK is a linear algebra library for distributed-memory. Communication processes in the ScaLAPACK routines depends on BLACS (Basic Linear Algebraic Communication Subprograms). ScaLAPACK library routines invoked from XcalableMP procedures also depend on BLACS.

Example 1 This example shows an implementation of the interface for the ScaLAPACK driver routine `pdgesv`.

```

----- XcalableMP Fortran -----
subroutine ixmp_pdgesv(n,nrhs,a,ia,ja,da,ipiv,b,ib,jb,db,ictxt,info)

use xmp_lib

5 integer n,nrhs,ia,ja,ib,jb,ictxt,info,desca(9),descb(9),ierr
double precision a,b
type(xmp_desc) da,db,dta,dtb
integer lbound_a1,ubound_a1,lbound_a2,ubound_a2
integer blocksize_a1,blocksize_a2
10 ...
ierr=xmp_array_lbound(da,1,lbound_a1)
ierr=xmp_array_ubound(da,1,ubound_a1)
ierr=xmp_array_lbound(da,2,lbound_a2)
ierr=xmp_array_ubound(da,2,ubound_a2)
15 ierr=xmp_align_template(da,dta)
ierr=xmp_dist_blocksize(dta,1,blocksize_a1)
ierr=xmp_dist_blocksize(dta,2,blocksize_a2)
...
desca(1)=1
20 desca(2)=ictxt
desca(3)=ubound_a1-lbound_a1+1
desca(4)=ubound_a2-lbound_a2+1
desca(5)=blocksize_a1
desca(6)=blocksize_a2
25 ...
call pdgesv(n,nrhs,a,ia,ja,desca,ipiv,b,ib,jb,descb,info)

return
```

```
end
```

30

Example 2 This example shows an XcalableMP procedure using the interface of Example 1.

```

                                XcalableMP Fortran
program xmptdgesv

use xmp_lib

5   double precision a(1000,1000)
   double precision b(1000)
   integer ipiv(2*1000,2)
!$xmp nodes p(2,2)
!$xmp template t(1000,1000)
10  !$xmp template t1(2*1000,2)
!$xmp distribute t(block,block) onto p
!$xmp distribute t1(block,block) onto p
!$xmp align a(i,j) with t(i,j)
!$xmp align ipiv(i,j) with t1(i,j)
15  !$xmp align b(i) with t(i,*)
   ...
   integer i,j,ictxt
   integer m=1000,n=1000,nprow=2,npcol=2
   integer ictxt=-1,iwhat=0
20  integer nrhs=1,ia=1,ja=1,ib=1,jb=1,info
   character*1 order
   ...
   order="C"
   ...
25  call blacs_get(ictxt,iwhat,ictxt)
   call blacs_gridinit(ictxt,order,nprow,npcol)
   ...
!$xmp loop (i,j) on t(i,j)
30  do j=1,n
     do i=1,m
       a(i,j) = ...
     end do
   end do
   ...
35  !$xmp loop on t(i,*)
   do i=1,m
     b(i)= ...
   end do
   ...
40  call ixmp_pdgesv(n,nrhs,a,ia,ja,xmp_desc_of(a),ipiv,
*      b,ib,jb,xmp_desc_of(b),ictxt,info)
   ...
   call blacs_gridexit(ictxt)
   ...
45  stop
```

end