To: J3
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Subject: Use cases of generic coarray dummy arguments
Date: 2024-December-23
References: 24-139r2, 24-168, 24-187, 24-188r1

1. Introduction

In 24-168 (3), we proposed the following constraint and specification in 24-139r2 to be removed:

C8nn A generic dummy argument shall not be a coarray.

sNN A generic dummy argument cannot be a coarray.

In response to this, a straw vote was taken at the October 2024 meeting on whether to keep or remove these, but the result was very close (24-188r1).

We believe that generic dummy arguments for coarrays are necessary. In this paper, we will introduce two use cases for generic coarray dummy arguments and show that they are indispensable.

2. Use cases

2.1 Example of application: stencil communication

Himeno benchmark solves the Poisson equation by Jacobi's iterative method [1], whose communication pattern is as follows.

```
DO loop=1,nn
   computation
   z+ and z- direction communication (sendp3)
   y+ and y- direction communication (sendp2)
   x+ and x- direction communication (sendp1)
   all reduce
ENDDO
```

In this section, the sendp2 above is introduced (1), expanded to type-generic (2), and changed from a MPI program to a coarray program (3). An example of the generic dummy argument for coarray is shown in (3).

(1) Original subroutine sendp2

List 1 is the original code of the sendp2 above, added inline comments for explanation. Its communication pattern is demonstrated in Figure 1.

<u>List 1: Subroutine sendp2 in the Himeno benchmark</u>

```
module pres
  real(4),dimension(:,:,:),allocatable :: p       ! Main data
end module pres

module others                          ! (Irrelevant names were deleted.)
  integer :: mimax,mjmax,mkmax         ! ! the allocated size of p
  integer :: imax,jmax,kmax            ! ! the size actually used in p
end module others

module comm                            ! (Irrelevant names were deleted.)
  integer :: ndx,ndy,ndz               ! ! 3-D node (image) size
  integer :: npx(2),npy(2),npz(2)      ! ! node numbers of adjacent nodes
  integer :: ijvec,jkvec,ikvec         ! ! representing the shape of communication data
  integer :: mpi_comm_cart             ! ! communicator defined by MPI_Cart_create
end module comm


subroutine sendp2()

  use pres
  use others
  use comm

  implicit none

  include 'mpif.h'

  integer :: ist(mpi_status_size,0:3),ireq(0:3)=(/-1,-1,-1,-1/)
  integer :: ierr
!
  call mpi_irecv(p(1,1,1), &           ! initial address of receive buffer
                 1, &                  ! number of elements
                 ikvec, &              ! representing shape [mimax, 1, mkmax]
                 npy(1), &             ! source node (neighboring in y- direction)
                 2, &                  ! tag
                 mpi_comm_cart, &      ! communicator
                 ireq(3), &            ! communication request (intent(out))
                 ierr)

  call mpi_irecv(p(1,jmax,1), &
                 1, &
                 ikvec, &
                 npy(2), &             ! source node (neighboring in y+ direction)
                 1, &
                 mpi_comm_cart, &
                 ireq(2), &
                 ierr)

  call mpi_isend(p(1,2,1), &           ! initial address of send buffer
                 1, &
                 ikvec, &
                 npy(1), &             ! destination node (neighboring in y- direction)
                 1, &
                 mpi_comm_cart, &
                 ireq(0), &
```

```
                  ierr)

   call mpi_isend(p(1,jmax-1,1), &
                  1, &
                  ikvec, &
                  npy(2), &          ! destination node (neighboring in y+ direction)
                  2, &
                  mpi_comm_cart, &
                  ireq(1), &
                  ierr)

   call mpi_waitall(4, &
                    ireq, &
                    ist, &
                    ierr)

   return
 end subroutine sendp2
```

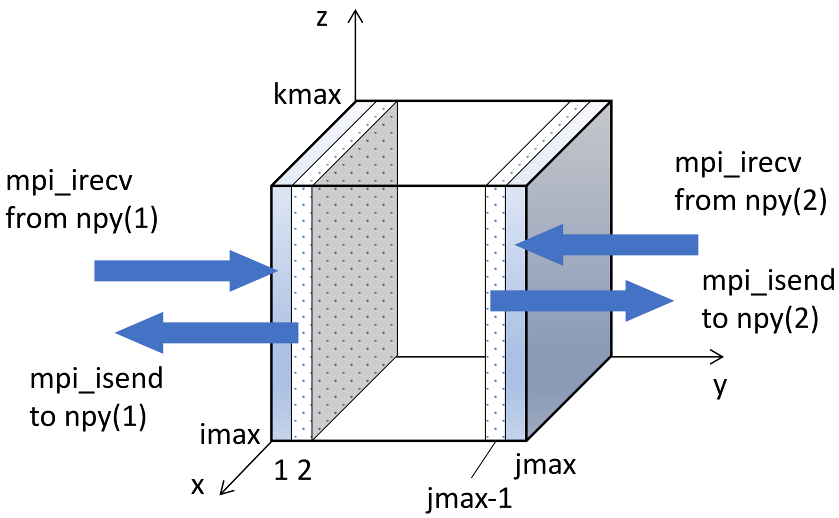


Figure 1. MPI message passing in List 1.

(2) An example of making sendp2 generic

The original data type of Himeno benchmark is REAL(4). List 2 shows a generic version of sendp2, which expanded the data type to all kinds of REAL type supported by the processor.

List 2: Generic subprogram version of sendp2

```
module others
  integer :: mimax,mjmax,mkmax
  integer :: imax,jmax,kmax
end module others

module comm
  integer :: ndx,ndy,ndz
  integer :: npx(2),npy(2),npz(2)
  integer :: ijvec,jkvec,ikvec
  integer :: mpi_comm_cart
end module comm

module himeno_sendp2_mpi
  use comm
  implicit none

contains
  generic subroutine sendp2(p)

    real(*),dimension(mimax,mjmax,mkmax) :: p

    include 'mpif.h'

    integer :: ist(mpi_status_size,0:3),ireq(0:3)=(/-1,-1,-1,-1/)
    integer :: ierr

    call mpi_irecv(p(1,1,1), 1, ikvec, npy(1), &
         2, mpi_comm_cart, ireq(3), ierr)
    call mpi_irecv(p(1,jmax,1), 1, ikvec, npy(2), &
         1, mpi_comm_cart, ireq(2), ierr)
    call mpi_isend(p(1,2,1), 1, ikvec, npy(1), &
         1, mpi_comm_cart, ireq(0), ierr)
    call mpi_isend(p(1,jmax-1,1), 1, ikvec, npy(2), &
         2, mpi_comm_cart, ireq(1), ierr)

    call mpi_waitall(4, ireq, ist, ierr)

    return
  end subroutine sendp2

end module himeno_sendp2_mpi
```

Comparing to List 1, sendp2 was modified as follows.

1. Change sendp2 from an external subprogram to a module subprogram with the GENERIC prefix,
2. Change p from a module variable to a generic dummy argument with REAL(*) type specifier.
3. Change dummy argument p from an allocatable array to an explicit-shape array (optional).

The important point here is that in order to make the subroutine generic, at least one dummy argument that is declared in a generic type declaration statement is necessary (item 2). Item 3 doesn't have much significance in sendp2, but since there is a high-load computational loop in the jacobi subroutine which calls sendp2, higher performance can be expected by making the argument p of jacobi and of all the procedures it calls explicit-shape.

(3) An example of changing sendp2 to use coarray

List 3 shows a coarray version of sendp2 modified from the code in List 2. In this example, the generic dummy argument p must be a coarray because it is referenced as coindexed objects.

<u>List3: A coarray version of sendp2 with a generic coarray dummy argument</u>

```
module others
  integer :: mimax,mjmax,mkmax
  integer :: imax,jmax,kmax
end module others

module comm
  integer :: ndx,ndy,ndz
  integer :: ihalo,jhalo,khalo     !  new variables
end module comm

module himeno_sendp2_coarray
  use comm
  implicit none

contains
  generic subroutine sendp2(p)

    real(*),dimension(mimax,mjmax,mkmax), codimension[ndx,ndy,*] :: p
    integer :: me(3)

    me = this_image(p)

    sync all

    if (me(2)>1) then
       p(:, jhalo, :)[me(1), me(2)-1, me(3)] = p(:, 2      , :)
    end if
    if (me(2)<ndy) then
       p(:, 1     , :)[me(1), me(2)+1, me(3)] = p(:, jmax-1, :)
    endif

    sync all

    return
  end subroutine sendp2

end module himeno_sendp2_coarray
```

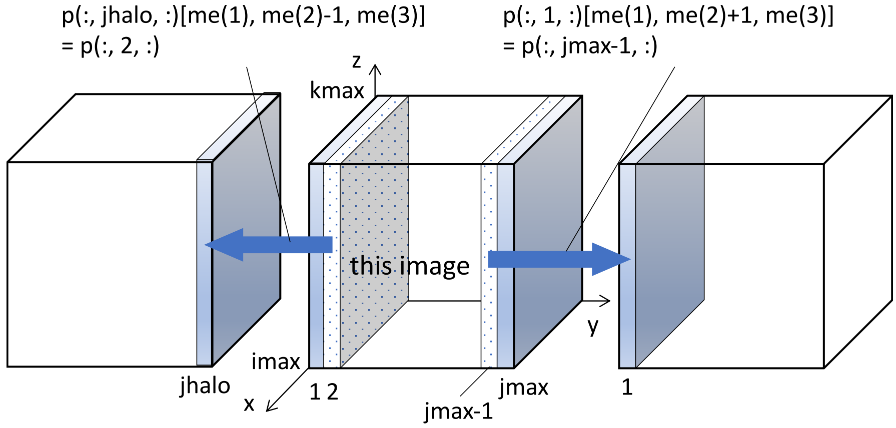


Figure 2. Coarray assignment in List 3.

Figure 2. shows the communication caused by the two coarray assignment statements in List 3. Instead of the message passing used in Lists 1 and 2, one-sided communication is used in List 3. The newly-appeared variable jhalo is the index of the halo in the y+ direction on the image [me(1), me(2)-1, me(3)]. This is a pre-calculated value, and if the data is equally allocated to all images, it will be the same value as jmax.

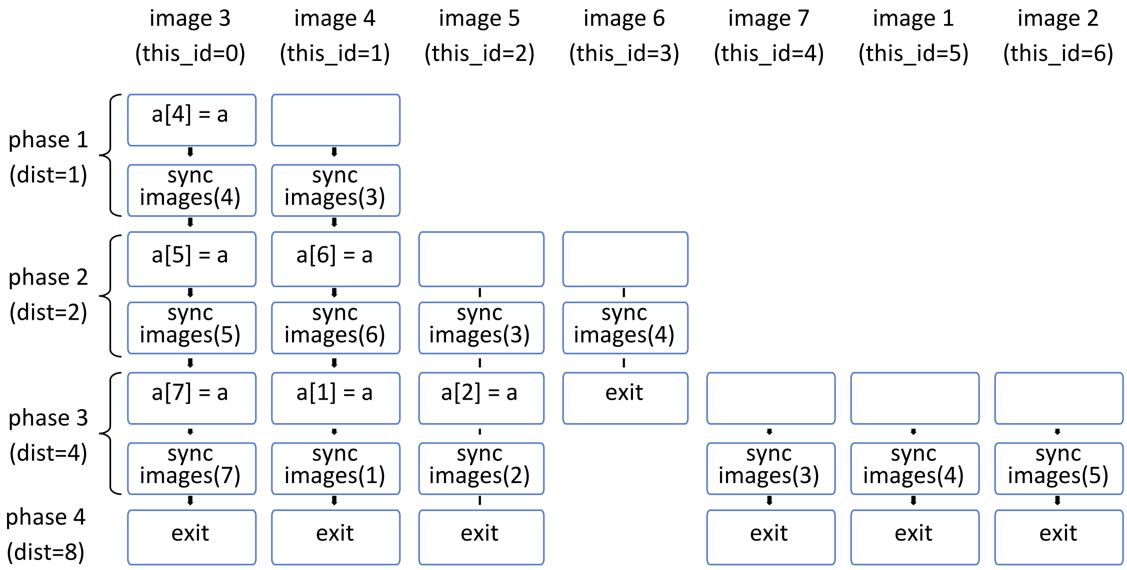
2.2 Example of creating a library procedure: CO_BROADCAST

Generic subprograms are suitable to write Fortran intrinsic procedures and intrinsic module procedures with generic names, at least for the entry layers of those procedures. The same can be said for highly generic user-defined procedures. This is because generic subprograms can achieve both high performance and high productivity for developing highly generic procedures. And then, coarray dummy arguments are necessary to use coarray one-to-one communication.

List 4 shows an example of writing the CO_BROADCAST intrinsic subroutine assuming the argument is coarray. Using generic type declaration, dummy argument A can be any intrinsic type with any kind supported by the processor and any rank. For the sake of simplicity, A cannot be a derived type and arguments STAT and ERRMSG are omitted. Figure 3 displays the communication and synchronization in this program. We assume that the function MAX_RANK proposed in 24-187 is included in the module ISO_FORTRAN_ENV.

<u>List 4: CO_BROADCAST specialized for coarrays as dummy arguments</u>

```
GENERIC SUBROUTINE co_broadcast_coarray(a, source_image)
  USE iso_fortran_env
  IMPLICIT NONE
  TYPE(INTEGER(*),REAL(*),COMPLEX(*),LOGICAL(*),CHARACTER(kind=*)), &
         RANK(0:MAX_RANK(1)), INTENT(INOUT):: a[*]
  INTEGER, INTENT(IN):: source_image
  INTEGER:: n_images, dist, i
  INTEGER:: this_img, that_img, this_id, that_id

  n_images = num_images()
  this_img = this_image()
  this_id = modulo(this_img - source_image, n_images)

  SYNC ALL
  dist = 1
  DO
     IF (this_id < dist) THEN        ! This image is a sender.

        !-- find receiver or exit the loop
        that_id = this_id + dist
        IF (that_id >= n_images) EXIT     ! This image exits the loop.
        that_img = modulo(this_img + dist - 1, n_images) + 1

        !-- send the data
        a[that_img] = a

        !-- 1-by-1 synchronization
        SYNC IMAGES (that_img)

     ELSE IF (this_id < 2 * dist) THEN  ! This image is a receiver.

        !-- find sender
        that_id = this_id - dist
        that_img = modulo(this_img - dist - 1, n_images) + 1

        !-- 1-by-1 synchronization
        SYNC IMAGES (that_img)

     END IF
     dist = 2 * dist
  END DO
  SYNC ALL

END SUBROUTINE co_broadcast_coarray
```



Assumed that the number of images is 7, and the value of source_image is 3.

Figure 3. Broadcast communication and synchronization pattern

Subroutine co_broadcast_coarray in List 4 assumes that the actual argument corresponding to a is a coarray. If not, a coarray communication buffer, for example as shown in List 5. In this case, dynamic coarray allocation and round-trip full data copying may cause a significant overhead cost. So, the processor should select co_broadcast_coarray if the actual argument is coarray, and co_broadcast_noncoarray otherwise.

<u>List 5: CO_BROADCAST for non-coarrays using the subroutine in List 4.</u>

```
GENERIC SUBROUTINE co_broadcast_noncoarray(a, source_image)
  IMPLICIT NONE
  TYPE(INTEGER(*),REAL(*),COMPLEX(*),LOGICAL(*),CHARACTER(kind=*)), &
          RANK(0:MAX_RANK), INTENT(INOUT):: a
  INTEGER, INTENT(IN):: source_image
  TYPE(REAL), ALLOCATABLE, DIMENSION(:):: tmp[:]

  ALLOCATE (tmp(SIZE(a))[*])
  tmp(:) = RESHAPE(a, [SIZE(a)])
  CALL co_broadcast_coarray(tmp, source_image)
  a = RESHAPE(tmp, SHAPE(a))
  RETURN
END SUBROUTINE co_broadcast_noncoarray
```

3. Discussions

In this section, the need for a generic coarray dummy argument is discussed.

3.1 Execution performance

Coarray one-to-one communication has the potential to achieve high performance through zero-copy communication by implementing it as one-sided communication using DMA (Direct Memory Access) and RDMA (Remote DMA) provided by communication layers such as GASNet [2]. In order to apply such high performance to dummy arguments, it must be declared as a coarray to receive the global address and other information (if any) from the corresponding coarray actual argument. This is true regardless of whether the subprogram is generic or not.

3.2 Programming and maintenance

It is doubtful whether adding such a constraint that only apply to generic subprograms, and not to non-generic subprograms, will lead to simplification. We think a typical programmer would first design an algorithm for a specific type/kind/rank and then expend it to a generic type/kind/rank. If the programmer encounters the constraint when expanding it to generic, they must either give up to make it generic, or go back to reconsider the algorithm.

We don't think the idea of "setting it to constraint for now and then releasing it later" is appropriate in this case. Programs that get around the constraint in strange ways will become established as assets.

Acknowledgments

We would like to thank to John Reid for his detailed review of the program codes.

References

[1] Himeno benchmark. https://i.riken.jp/en/supercom/documents/himenobmt/

[2] Iwashita, H., Nakao, M. (2021). Coarrays in the Context of XcalableMP. In: Sato, M. (eds) XcalableMP PGAS Programming Language. Springer, Singapore. https://doi.org/10.1007/978-981-15-7683-6_3