TS 18508 Additional Parallel Features in Fortran

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Contents

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and nongovernmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, the joint technical committee may decide to publish an ISO/IEC Technical Specification (ISO/IEC TS), which represents an agreement between the members of the joint technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/IEC TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/IEC TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

ISO/IEC TS 18508:2015 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC22, *Programming languages, their environments and system software interfaces.*

Introduction

The system for parallel programming in Fortran, as standardized by ISO/IEC 1539-1:2010, defines simple syntax for access to data on another image of a program, synchronization statements for controlling the ordering of execution segments between images, and collective allocation and deallocation of memory on all images.

The existing system for parallel programming does not provide for an environment where a subset of the images can easily work on part of an application while not affecting other images in the program. This complicates development of independent parts of an application by separate teams of programmers. The existing system does not provide a mechanism for a processor to identify what images have failed during execution of a program. This adversely affects the resilience of programs executing on large systems. The synchronization primitives available in the existing system do not provide a convenient mechanism for ordering execution segments on different images without requiring that those images arrive at a synchronization point before either is allowed to proceed. This introduces unnecessary inefficiency into programs. Finally, the existing system does not provide intrinsic procedures for commonly used collective and atomic memory operations. Intrinsic procedures for these operations can be highly optimized for the target computational system, providing significantly improved program performance.

This Technical Specification extends the facilites of Fortran for parallel programming to provide for grouping the images of a program into nonoverlapping teams that can more effectively execute independently parts of a larger problem, for the processor to indicate which images have failed during execution and allow continued execution of the program on the remaining images, for a system of events that can be used for fine grain ordering of execution segments, and for collective and atomic memory operation subroutines that can provide better performance for specific operations involving more than one image.

The facility specified in this Technical Specification is a compatible extension of Fortran as standardized by ISO/IEC 1539-1:2010, ISO/IEC 1539-1:2010/Cor 1:2012, and ISO/IEC 1539-1:2010/Cor 2:2013.

It is the intention of ISO/IEC JTC 1/SC22 that the semantics and syntax specified by this Technical Specification be included in the next revision of ISO/IEC 1539-1 without change unless experience in the implementation and use of this feature identifies errors that need to be corrected, or changes are needed to achieve proper integration, in which case every reasonable effort will be made to minimize the impact of such changes on existing implementations.

This Technical Specification is organized in 8 clauses:

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It also contains the following nonnormative material:

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1 Scope

This Technical Specification specifies the form and establishes the interpretation of facilities that extend the Fortran language defined by ISO/IEC 1539-1:2010, ISO/IEC 1539-1:2010/Cor 1:2012, and ISO/IEC 1539-1:2010/Cor 2:2013. The purpose of this Technical Specification is to promote portability, reliability, maintainability, and efficient execution of parallel programs written in Fortran, for use on a variety of computing systems.

This Technical Specification does not specify formal data consistency or progress models. Some level of asynchronous progress is required to ensure the correct execution of the examples in Annex A that illustrate the semantics described in clauses 7 and 8. Developing the formal data consistency and progress models is left until the integration of these facilities into ISO/IEC 1539-1.

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2 Normative references

The following referenced standards are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 1539-1:2010, *Information technology—Programming languages—Fortran—Part 1:Base language*

ISO/IEC 1539-1:2010/Cor 1:2012, *Information technology—Programming languages—Fortran—Part 1:Base language TECHNICAL CORRIGENDUM 1*

ISO/IEC 1539-1:2010/Cor 2:2013, *Information technology—Programming languages—Fortran—Part 1:Base language TECHNICAL CORRIGENDUM 2*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 1539-1:2010 and the following apply. The intrinsic module ISO_FORTRAN_ENV is extended by this Technical Specification.

3.1
active image
An image that has not failed or initiated termination

3.2
asynchronous progress
ability of images to define or reference coarrays without requiring the images on which the data reside to execute any particular statements

3.3
collective subroutine
intrinsic subroutine that is invoked on the active images of the current team to perform a calculation on those images and assign the computed value on one or all of them (8.3)

3.4
established coarray
coarray that is accessible within a CHANGE TEAM construct from outside the construct (5.1)

3.5
team
set of images that can readily execute independently of other images (5.1)

3.5.1
current team
the team specified in the CHANGE TEAM statement of the innermost executing CHANGE TEAM construct, or the initial team if no CHANGE TEAM construct is active (5.1)

3.5.2
initial team
the current team when the program began execution (5.1)

3.5.3
parent team
team from which the current team was formed by executing a FORM TEAM statement (5.1)

3.5.4
team identifier
integer value identifying a team (5.1)

3.6
failed image
an image for which references or definitions of a variable on the image fail when that variable should be accessible; or an image that is not a stopped image and fails to respond during the execution of an image control statement or a reference to a collective subroutine (6.1)

3.7
stopped image

an image that has initiated normal termination

3.8
event variable
scalar variable of type EVENT_TYPE (7.2) in the intrinsic module ISO_FORTRAN_ENV

3.9
team variable
scalar variable of type TEAM_TYPE (5.2) in the intrinsic module ISO_FORTRAN_ENV

4 Compatibility

4.1 New intrinsic procedures

This Technical Specification defines intrinsic procedures in addition to those specified in ISO/IEC 1539-1:2010. Therefore, a Fortran program conforming to ISO/IEC 1539-1:2010 might have a different interpretation under this Technical Specification if it invokes an external procedure having the same name as one of the new intrinsic procedures, unless that procedure is specified to have the EXTERNAL attribute.

4.2 Fortran 2008 compatibility

This Technical Specification specifies an upwardly compatible extension to ISO/IEC 1539-1:2010, as modified by ISO/IEC 1539-1:2010/Cor 1:2012 and ISO/IEC 1539-1:2010/Cor 2:2013.

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5 Teams of images

5.1 Introduction

A team of images is a set of images that can readily execute independently of other images. Syntax and semantics of *image-selector* (R624 in ISO/IEC 1539-1:2010) are extended to determine how cosubscripts are mapped to image indices for both sibling and ancestor team references. Initially, the current team consists of all images and this is known as the initial team. Except for the initial team, every team has a unique parent team. A team is divided into new teams by executing a FORM TEAM statement. Each new team is identified by an integer value known as its team identifier. Information about the team to which the current image belongs can be determined by the processor from the collective value of the team variables on the images of the team.

The current team is the team specified in the CHANGE TEAM statement of the innermost executing CHANGE TEAM construct, or the initial team if no CHANGE TEAM construct is active.

A nonallocatable coarray that is neither a dummy argument, host associated with a dummy argument, declared as a local variable of a subprogram, nor declared in a BLOCK construct is established in the initial team. An allocated allocatable coarray is established in the team in which it was allocated. An unallocated allocatable coarray is not established. An associating coarray is established in the team of its CHANGE TEAM construct. A nonallocatable coarray that is a dummy argument or host associated with a dummy argument is established in the team in which the procedure was invoked. A nonallocatable coarray that is a local variable of a subprogram or host associated with a local variable of a subprogram is established in the team in which the procedure was invoked. A nonallocatable coarray declared in a BLOCK construct is established in the team in which the BLOCK statement was executed. A coarray dummy argument is not established in any ancestor team even if the corresponding actual argument is established in one or more of them.

5.2 TEAM_TYPE

TEAM_TYPE is a derived type with private components. It is an extensible type with no type parameters. Each component is fully default initialized. A scalar variable of this type describes a team. TEAM_TYPE is defined in the intrinsic module ISO_FORTRAN_ENV.

A scalar variable of type TEAM_TYPE is a team variable. The default initial value of a team variable shall not represent any valid team.

5.3 CHANGE TEAM construct

The CHANGE TEAM construct changes the current team to which the executing image belongs.

R501 *change-team-construct* **is** *change-team-stmt*
block
end-change-team-stmt

R502 *change-team-stmt* **is** [*team-construct-name*:] CHANGE TEAM (*team-variable* ■
■ [, *coarray-association-list*] [, *sync-stat-list*])

R503 *coarray-association* **is** *codimension-decl* => *coselector-name*

R504 *end-change-team-stmt* **is** END TEAM [(*sync-stat-list*)] [*team-construct-name*]

R505 *team-variable* **is** *scalar-variable*

C501 (R501) A branch within a CHANGE TEAM construct shall not have a branch target that is outside the construct.

C502 (R501) A RETURN statement shall not appear within a CHANGE TEAM construct.

C503 (R501) An *exit-stmt* or *cycle-stmt* within a CHANGE TEAM construct shall not belong to an outer construct.

C504 (R501) If the *change-team-stmt* of a *change-team-construct* specifies a *team-construct-name*, the corresponding *end-change-team-stmt* shall specify the same *team-construct-name*. If the *change-team-stmt* of a *change-team-construct* does not specify a *team-construct-name*, the corresponding *end-change-team-stmt* shall not specify a *team-construct-name*.

C505 (R503) The *coarray-name* in the *codimension-decl* shall not be the same as any *coselector-name* in the *change-team-stmt* or the same as a *coarray-name* in another *codimension-decl* in the *change-team-stmt*.

C506 (R505) A *team-variable* shall be of type TEAM_TYPE (5.2).

C507 (R502) No *coselector-name* shall appear more than once in a *change-team-stmt*.

C508 (R503) A *coselector-name* shall be the name of an accessible coarray.

A coselector name identifies a coarray. The coarray shall be established when the CHANGE TEAM statement begins execution.

The value of *team-variable* shall be the value of a team variable defined by execution of a FORM TEAM statement in the team that executes the CHANGE TEAM statement or be the value of a team variable for the initial team. The values of the *team-variable*s on the active images of the team shall be those of team variables defined by execution of the same FORM TEAM statement on all active images of the team or be the values of team variables for the initial team. The current team for the statements of the CHANGE TEAM *block* is the team specified by the value of the *team-variable*. The current team is not changed by a redefinition of the team variable during execution of the CHANGE TEAM construct. A CHANGE TEAM construct completes execution by executing its END TEAM statement.

A *codimension-decl* in a *coarray-association* associates a coarray with an established coarray during the execution of the block. This coarray is an associating entity (8.1.3.2, 8.1.3.3, 16.5.1.6 of ISO/IEC 1539-1:2010). Its name is an associate name that has the scope of the construct. It has the declared type, dynamic type, type parameters, rank, and bounds of the established coarray. Its corank and cobounds are those specified in the *codimension-decl*.

Within a CHANGE TEAM construct, a coarray that is not an associating entity has the corank and cobounds that it had when it was established.

An allocatable coarray that was allocated when execution of a CHANGE TEAM construct began shall not be deallocated during execution of the construct. An allocatable coarray that is allocated when execution of a CHANGE TEAM construct completes is deallocated if it was not allocated when execution of the construct began.

The CHANGE TEAM and END TEAM statements are image control statements. All active images of the current team shall execute the same CHANGE TEAM statement. When a CHANGE TEAM statement is executed, there is an implicit synchronization of all active images of the team containing the executing image that is identified by *team-variable*. On each active image of the team, execution of the segment following the statement is delayed until all other active images of the team have executed the same statement the same number of times since execution last began in the team that was current before execution of the CHANGE TEAM statement. When a CHANGE TEAM construct completes execution, there is an implicit synchronization of all active images in the current team. On each active image of the team, execution of the segment following the END TEAM statement is delayed until all other active images of the team have executed the same construct the same number of times since execution last began in the team that was current before execution of the corresponding CHANGE TEAM statement.

NOTE 5.1

Deallocation of an allocatable coarray that was not allocated at the beginning of a CHANGE TEAM construct, but is allocated at the end of execution of the construct, occurs even for allocatable coarrays with the SAVE attribute.

5.4 Image selectors

The syntax rule R624 *image-selector* in subclause 6.6 of ISO/IEC 1539-1:2010 is replaced by:

R624	*image-selector*	**is**	*lbracket cosubscript-list* ■
			■ [, *team-identifier*] [, STAT = *stat-variable*] *rbracket*
R624a	*team-identifier*	**is**	TEAM_ID = *scalar-int-expr*
		or	TEAM = *team-variable*

C509 (R624) *stat-variable* shall not be a coindexed object.

If TEAM= appears in a coarray designator, *team-variable* shall be defined with a value that represents the current or an ancestor team. The coarray shall be established in that team or an ancestor of that team and the cosubscripts determine an image index in that team.

If TEAM_ID = appears in a coarray designator and the current team is not the initial team, the *scalar-int-expr* shall be defined with the value of a team identifier for one of the teams that were formed by execution of the FORM TEAM statement for the current team. The coarray shall be established in an ancestor of the current team and the cosubscripts determine an image index in the team identified by TEAM_ID. If TEAM_ID= appears in a coarray designator and the current team is the initial team, the value of *scalar-int-expr* is ignored.

NOTE 5.2

The image selector in `b[i]` identifies the current team. The image selector in `b[i,team_id=1]` identifies a sibling team. The image selector in `b[i,TEAM=ancestor]` identifies the team `ancestor`.

NOTE 5.3

The use of a STAT=specifier in an image selector allows a test to be made for a failed image in a reference where the use of a processor- dependent result could cause error termination or an incorrect execution path. Where there is no such possibility, it may be preferable to rely on the STAT=specifier in the next image control statement.

NOTE 5.4

In the following code, the vector *a* of length N*P is distributed over P images. Each image has an array A(0:N+1) holding its own values of *a* and halo values from its two neighbors. The images are divided into two teams that execute independently but periodically exchange halo data. Before the data exchange, all images (of the initial team) must be synchronized and for the data exchange the coindices of the initial team are needed.

```
USE, INTRINSIC :: ISO_FORTRAN_ENV, ONLY: TEAM_TYPE
TYPE(TEAM_TYPE) :: INITIAL, BLOCK
REAL :: A(0:N+1)[*]
INTEGER :: ME, P2
INITIAL = GET_TEAM()
ME = THIS_IMAGE()
P2 = NUM_IMAGES()/2
FORM TEAM(1+(ME-1)/P2,BLOCK)
CHANGE TEAM(BLOCK,B[*]=>A)
```

NOTE 5.4 (cont.)

```
      DO
         ! Iterate within team
           :
         ! Halo exchange across team boundary
         SYNC TEAM(INITIAL)
         IF(ME==P2  ) B(N+1) = A(1)[ME+1,TEAM=INITIAL]
         IF(ME==P2+1)   B(0) = A(N)[ME-1,TEAM=INITIAL]
         SYNC TEAM(INITIAL)
      END DO
   END TEAM
```

5.5 FORM TEAM statement

R506	*form-team-stmt*	**is**	FORM TEAM (*team-id*, *team-variable* ■ ■ [, *form-team-spec-list*])
R507	*team-id*	**is**	*scalar-int-expr*
R508	*form-team-spec*	**is**	NEW_INDEX = *scalar-int-expr*
		or	*sync-stat*

C510 (R506) No specifier shall appear more than once in a *form-team-spec-list*.

The FORM TEAM statement defines *team-variable* for a new team. The value of *team-id* specifies the new team to which the executing image will belong. The value of *team-id* shall be positive and is the same for all images that are members of the same team.

The value of the *scalar-int-expr* in a NEW_INDEX= specifier specifies the image index that the executing image will have in the team specified by *team-id*. It shall be positive and less than or equal to the number of images in the team. Each image with the same value for *team-id* shall have a different value for the NEW_INDEX= specifier. If the NEW_INDEX= specifier does not appear, the image index that the executing image will have in the team specified by *team-id* is a processor-dependent value that shall be positive and not greater than the number of images in the team.

The FORM TEAM statement is an image control statement. If the FORM TEAM statement is executed on one image, the same statement shall be executed on all active images of the current team. When a FORM TEAM statement is executed, there is an implicit synchronization of all active images in the current team. On these images, execution of the segment following the statement is delayed until all other active images in the current team have executed the same statement the same number of times since execution last began in this team. If an error condition other than detection of a failed image occurs, the team variable becomes undefined.

NOTE 5.5

Executing the statement

```
      FORM TEAM ( 2-MOD(ME,2), ODD_EVEN )
```

with `ME` an integer with value THIS_IMAGE() and `ODD_EVEN` of type TEAM_TYPE, divides the current team into two teams according to whether the image index is even or odd.

NOTE 5.6

When executing on P^2 images with corresponding coarrays on each image representing parts of a larger array spread over a P by P square, the following code establishes teams for the rows with image indices equal to the column indices.

NOTE 5.6 (cont.)

```
USE, INTRINSIC :: ISO_FORTRAN_ENV
TYPE(TEAM_TYPE) :: ROW
REAL :: A[P,*]
INTEGER :: ME(2)
ME(:) = THIS_IMAGE(A)
FORM TEAM(ME(1),ROW,NEW_INDEX=ME(2))
```

5.6 SYNC TEAM statement

R509 *sync-team-stmt* **is** SYNC TEAM (*team-variable* [, *sync-stat-list*])

The SYNC TEAM statement is an image control statement. The values of the *team-variable*s on the active images of the team shall be those defined by execution of the same FORM TEAM statement on all active images of the team or shall be the values of team variables for the initial team. Execution of a SYNC TEAM statement performs a synchronization of the executing image with each of the other active images of the team specified by *team-variable*. Execution on an image, M, of the segment following the SYNC TEAM statement is delayed until each active other image of the specified team has executed a SYNC TEAM statement specifying the same team as many times as has image M since execution last began in this team. The segments that executed before the SYNC TEAM statement on an image precede the segments that execute after the SYNC TEAM statement on another image.

NOTE 5.7

A SYNC TEAM statement performs a synchronization of images of a particular team whereas a SYNC ALL statement performs a synchronization of all images of the current team.

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6 Failed images

6.1 Introduction

A failed image is one for which references or definitions of a variable on the image fail when that variable should be accessible; or an image that is not a stopped image and fails to respond during the execution of an image control statement or a reference to a collective subroutine. A failed image remains failed for the remainder of the program execution. The conditions that cause an image to fail are processor dependent.

Defining a coindexed object on a failed image has no effect other than defining the *stat-variable*, if one appears, with the value STAT_FAILED_IMAGE (6.4). The value of an expression that includes a reference to a coindexed object on a failed image is processor dependent. Execution continues after such a reference.

When an image fails during the execution of a segment, a data object on a non-failed image becomes undefined if it might be defined or undefined by execution of a statement of the segment other than an invocation of an atomic subroutine.

If the *lock-variable* in a LOCK statement was locked by a failed image and was not unlocked by that image, it becomes unlocked.

The CRITICAL statement described in subclause 8.1.5 of ISO/IEC 1539-1:2010 is extended as described in 6.3.

NOTE 6.1

A failed image is usually associated with a hardware failure of a cpu, memory system, or interconnection network. A failure that occurs while a coindexed reference or definition, or collective action, is in progress might leave variables on other images that would be defined by that action in an undefined state. Similarly, failure while using a file might leave that file in an undefined state.

NOTE 6.2

Continued execution after the failure of image 1 in the initial team might be difficult because of the lost connection to standard input. However, the likelihood of a given image failing is small. With a large number of images, the likelihood of some image other than image 1 in the initial team failing is significant and it is for this circumstance that STAT_FAILED_IMAGE is designed.

NOTE 6.3

In addition to detecting that an image has failed by having the variable in a STAT=specifier or a STAT argument of a call to a collective or atomic subroutine assigned the value STAT_FAILED_IMAGE, an image can get the indices of failed images in a specified team by invoking the intrinsic function FAILED_IMAGES.

6.2 FAIL IMAGE statement

R601 *fail-image-stmt* **is** FAIL IMAGE

Execution of a FAIL IMAGE statement causes the executing image to behave as if it has failed. Neither normal nor error termination is initiated, but no further statements are executed by that image.

NOTE 6.4

The FAIL IMAGE statement allows a program to test a recovery algorithm without experiencing an actual failure.

NOTE 6.4 (cont.)

On a processor that does not have the ability to detect that an image has failed, execution of a FAIL IMAGE statement might provide a simulated failure environment that provides debug information.

In a piece of code that executes about once a second, invoking this subroutine on an image

```
SUBROUTINE FAIL
   REAL :: X
   CALL RANDOM_NUMBER(X)
   IF (X<0.001) FAIL IMAGE
END SUBROUTINE FAIL
```

will cause that image to have an independent 1/1000 chance of failure every second if the random number generators on different images are independent.

6.3 CRITICAL construct

The syntax rule R811 in subclause 8.1.5 of ISO/IEC 1539-1:2010 is replaced by:

R811 *critical-stmt* **is** [*critical-construct-name* :] CRITICAL [(*sync-stat-list*)]

If an image fails during the execution of a CRITICAL construct, the execution of the construct is regarded by other images as complete. If the CRITICAL statement of a CRITICAL construct has a STAT= specifier, and an image fails while executing that construct, the specified variable will become defined with the value STAT_FAILED_IMAGE on the next image to execute the construct.

6.4 STAT_FAILED_IMAGE

If the processor has the ability to detect that an image has failed, the value of the default integer scalar constant STAT_FAILED_IMAGE is positive; otherwise, the value of STAT_FAILED_IMAGE is negative. If the processor has the ability to detect that an image involved in execution of an image control statement, a reference to a coindexed object, or a collective or atomic subroutine has failed and does so, and no error condition other than a failed image image is detected, the value of STAT_FAILED_IMAGE is assigned to the variable specified in a STAT=specifier in an execution of an image control statement or a reference to a coindexed object, or the STAT argument in an invocation of a collective or atomic procedure. If more than one nonzero status value is valid for the execution of a statement, the status variable is defined with a value other than STAT_FAILED_IMAGE. If the STAT= specifier of an execution of a CHANGE TEAM, END TEAM, FORM TEAM, SYNC ALL, SYNC IMAGES, or SYNC TEAM statement is assigned the value STAT_FAILED_IMAGE, the intended action shall have taken place for all active images involved.

STAT_FAILED_IMAGE is defined in the intrinsic module ISO_FORTRAN_ENV. The values of the named constants IOSTAT_INQUIRE_INTERNAL_UNIT, STAT_FAILED_IMAGE, STAT_LOCKED, STAT_LOCKED_OTHER_IMAGE, STAT_STOPPED_IMAGE, and STAT_UNLOCKED shall be distinct.

7 Events

7.1 Introduction

An image can post an event to notify another image that it can proceed to work on tasks that use common resources. An image can wait on events posted by other images and can query if images have posted events.

7.2 EVENT_TYPE

EVENT_TYPE is a derived type with private components. It is an extensible type with no type parameters. Each component is fully default initialized. EVENT_TYPE is defined in the intrinsic module ISO_FORTRAN_ENV.

A scalar variable of type EVENT_TYPE is an event variable. An event variable has a count that is updated by execution of a sequence of EVENT POST or EVENT WAIT statements. The effect of each change is as if the atomic subroutine ATOMIC_ADD were executed with a variable that stores the event count as its ATOM argument. A coarray that is of type EVENT_TYPE may be referenced or defined during the execution of a segment that is unordered relative to the execution of another segment in which that coarray of type EVENT_TYPE is defined. The event count is type integer with kind ATOMIC_INT_KIND, where ATOMIC_INT_KIND is a named constant defined in the intrinsic module ISO_FORTRAN_ENV. The initial value of the event count of an event variable is zero.

C701 A named variable of type EVENT_TYPE shall be a coarray. A named variable with a noncoarray subcomponent of type EVENT_TYPE shall be a coarray.

C702 An event variable shall not appear in a variable definition context except as the *event-variable* in an EVENT POST or EVENT WAIT statement, as an *allocate-object* in an ALLOCATE statement without a SOURCE= *alloc-opt*, as an *allocate-object* in a DEALLOCATE statement, or as an actual argument in a reference to a procedure with an explicit interface if the corresponding dummy argument has INTENT (INOUT).

C703 A variable with a nonpointer subobject of type EVENT_TYPE shall not appear in a variable definition context except as an *allocate-object* in an ALLOCATE statement without a SOURCE= *alloc-opt*, as an *allocate-object* in a DEALLOCATE statement, or as an actual argument in a reference to a procedure with an explicit interface if the corresponding dummy argument has INTENT (INOUT).

NOTE 7.1

The restrictions against changing an event variable except via EVENT POST and EVENT WAIT statements ensure the integrity of its value and facilitate efficient implementation, particularly when special synchronization is needed for correct event handling.

7.3 EVENT POST statement

The EVENT POST statement provides a way to post an event. It is an image control statement.

R701 *event-post-stmt* **is** EVENT POST (*event-variable* [, *sync-stat-list*])

R702 *event-variable* **is** *scalar-variable*

C704 (R702) An *event-variable* shall be of type EVENT_TYPE (7.2).

Successful execution of an EVENT POST statement atomically increments the count of the event variable by 1.

If an error condition occurs during execution of an EVENT POST statement, the count does not change.

If the segment that precedes an EVENT POST statement is unordered with respect to the segment that precedes another EVENT POST statement for the same event variable, the order of execution of the EVENT POST statements is processor dependent.

NOTE 7.2

It is expected that an image will continue executing after posting an event without waiting for an EVENT WAIT statement to execute on the image of the event variable.

7.4 EVENT WAIT statement

The EVENT WAIT statement provides a way to wait until events are posted. It is an image control statement.

R703	*event-wait-stmt*	**is**	EVENT WAIT (*event-variable* [, *wait-spec-list*])
R704	*wait-spec*	**is**	*until-spec*
		or	*sync-stat*
R705	*until-spec*	**is**	UNTIL_COUNT = *scalar-int-expr*

C705 (R703) An *event-variable* in an *event-wait-stmt* shall not be coindexed.

C706 (R703) An *until-spec* shall not appear more than once in an *event-wait-stmt*.

Execution of an EVENT WAIT statement causes the following sequence of actions:

(1) the threshold value is set to *scalar-int-expr* if the UNTIL_COUNT specifier appears and *scalar-int-expr* has a positive value, and to 1 otherwise,

(2) the executing image waits until the count of the event variable is greater than or equal to its threshold value or an error condition occurs, and

(3) if no error condition occurs, the count of the event variable is atomically decremented by its threshold value.

If an EVENT WAIT statement using an event variable is executed with a threshold of k, the segments preceding at least k EVENT POST statements using that event variable will precede the segment following the EVENT WAIT statement. The segment following a different EVENT WAIT statement using the same event variable can be ordered to succeed segments preceding other EVENT POST statements using that event variable.

A failed image might cause an error condition for an EVENT WAIT statement.

NOTE 7.3

An unreasonably long wait on an EVENT WAIT statement in the presence of failed images may be because it was intended that the event be posted by an image that has failed.

NOTE 7.4

The segment that follows the execution of an EVENT WAIT statement is ordered with respect to all segments that precede EVENT POST statements that caused prior changes in the sequence of values of the event variable.

NOTE 7.5

Event variables of type EVENT_TYPE are restricted so that EVENT WAIT statements can only wait on an event variable on the executing image. This enables more efficient implementation of this concept.

8 Intrinsic procedures

8.1 General

Detailed specifications of the generic intrinsic procedures ATOMIC_ADD, ATOMIC_AND, ATOMIC_CAS, ATOMIC_FETCH_ADD, ATOMIC_FETCH_AND, ATOMIC_FETCH_OR, ATOMIC_FETCH_XOR, ATOMIC_OR, ATOMIC_XOR, CO_BROADCAST, CO_MAX, CO_MIN, CO_REDUCE, CO_SUM, EVENT_QUERY, FAILED_IMAGES, GET_TEAM, IMAGE_STATUS, STOPPED_IMAGES, and TEAM_ID are provided in 8.4. The types and type parameters of the arguments to these intrinsic procedures are determined by these specifications. The "Argument" paragraphs specify requirements on the actual arguments of the procedures. All of these intrinsic procedures are pure.

The intrinsic procedures ATOMIC_DEFINE, ATOMIC_REF, IMAGE_INDEX, MOVE_ALLOC, NUM_IMAGES, and THIS_IMAGE described in clause 13 of ISO/IEC 1539-1:2010, as modified by ISO/IEC 1539-1:2010/Cor 1:2012, are extended as described in 8.5.

8.2 Atomic subroutines

An atomic subroutine is an intrinsic subroutine that performs an action on its ATOM argument or the count of its EVENT argument atomically. For any two executions of atomic subroutines in unordered segments by different images on the same atomic object, the effect is as if one of the executions is performed before the other in a single segment on a separate image, without access to the object in either execution interleaving with access to the object in the other. Which is executed first is indeterminate. The sequence of atomic actions within ordered segments is specified in 2.3.5 of ISO/IEC 1539-1:2010. If two variables are updated by atomic actions in segments P_1 and P_2, and the changes to them are observed by atomic accesses from a segment Q which is unordered relative to either P_1 or P_2, the changes need not be observed in segment Q in the same order as they are made in segments P_1 and P_2, even if segments P_1 and P_2 are ordered.

For invocation of an atomic subroutine with an argument OLD, the determination of the value to be assigned to OLD is part of the atomic operation even though the assignment of that value to OLD is not. For invocation of an atomic subroutine, evaluation of an INTENT(IN) argument is not part of the atomic action.

If the STAT argument is present in an invocation of an atomic subroutine and no error condition occurs, the argument is assigned the value zero.

If the STAT argument is present in an invocation of an atomic subroutine other than ATOMIC_REF and an error condition occurs, any ATOM or OLD argument becomes undefined. The STAT argument is assigned the value STAT_FAILED_IMAGE if a coindexed ATOM or EVENT argument is determined to be located on a failed image; otherwise, the STAT argument is assigned a processor-dependent positive value that is different from STAT_FAILED_IMAGE.

If a condition occurs that would assign a nonzero value to a STAT argument but the STAT argument is not present, error termination is initiated.

NOTE 8.1

> The properties of atomic subroutines support their use for designing customized synchronization mechanisms. The programmer needs to account for all possible orderings of sequences of atomic subroutine executions that can arise as a consequence of the above rules; the orderings can turn out to be different on different images even in the same program run.

8.3 Collective subroutines

A collective subroutine is one that is invoked on each active image of the current team to perform a calculation on those images and that assigns the computed value on one or all of them. If it is invoked by one image, it shall be invoked by the same statement on all active images of the current team in execution segments that are not ordered with respect to each other. From the beginning to the end of execution as the current team, the sequence of invocations of collective subroutines shall be the same on all active images of the current team. A call to a collective subroutine shall appear only in a context that allows an image control statement.

If the A argument to a collective subroutine is a whole coarray the corresponding ultimate arguments on all active images of the current team shall be corresponding coarrays as described in 2.4.7 of ISO/IEC 1539-1:2010.

Collective subroutines have the optional arguments STAT and ERRMSG. If the STAT argument is present in the invocation on one image it shall be present on the corresponding invocations on all active images of the current team.

If the STAT argument is present in an invocation of a collective subroutine and its execution is successful, the argument is assigned the value zero.

If the STAT argument is present in an invocation of a collective subroutine and an error condition occurs, the argument is assigned a nonzero value and the A argument becomes undefined. If execution involves synchronization with an image that has initiated normal termination, the argument is assigned the value of STAT_STOPPED_IMAGE in the intrinsic module ISO_FORTRAN_ENV; otherwise, if all images of the current team are active, the argument is assigned a processor-dependent positive value that is different from the value of STAT_STOPPED_IMAGE or STAT_FAILED_IMAGE in the intrinsic module ISO_FORTRAN_ENV. Otherwise, if an image of the current team has been detected as failed, the argument is assigned the value of the constant STAT_FAILED_IMAGE.

If a condition occurs that would assign a nonzero value to a STAT argument but the STAT argument is not present, error termination is initiated.

If an ERRMSG argument is present in an invocation of a collective subroutine and an error condition occurs during its execution, the processor shall assign an explanatory message to the argument. If no error condition occurs, the processor shall not change the value of the argument.

NOTE 8.2

The argument A becomes undefined if an error condition occurs during execution of a collective subroutine because it is intended that implementations be able to use A as scratch space.

NOTE 8.3

All of the collective subroutines have an argument A with INTENT(INOUT) that holds the original data on entry and the result on return. If it is desired to retain the original data, this is readily obtained by making a copy before entry. Here is an example:

```
REDUCTION = ORIGINAL
CALL CO_MIN(REDUCTION)
```

NOTE 8.4

There is no separate synchronization at the beginning and end of an invocation of a collective subroutine, which allows overlap with other actions. However, each collective subroutine involves transfer of data between images. A transfer from an image cannot occur before the collective subroutine has been invoked on that image. The rules of Fortran do not allow the value of an associated argument such as A to be changed except via the argument. This includes action taken by another image that has not started its execution of the collective subroutine or has finished it. This restriction has the effect of a partial synchronization of invocations of a collective subroutine.

8.4 New intrinsic procedures

8.4.1 ATOMIC_ADD (ATOM, VALUE [, STAT])

Description. Atomic add operation.

Class. Atomic subroutine.

Arguments.

ATOM shall be a scalar coarray or coindexed object of type integer with kind ATOMIC_INT_KIND, where ATOMIC_INT_KIND is a named constant in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT (INOUT) argument. ATOM becomes defined with the value of ATOM + INT(VALUE, ATOMIC_INT_KIND).

VALUE shall be an integer scalar. It is an INTENT (IN) argument.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example.

CALL ATOMIC_ADD(I[3], 42) causes the value of I on image 3 to become defined with the value 46 if the value of I[3] was 4 when the atomic operation executed.

8.4.2 ATOMIC_AND (ATOM, VALUE [, STAT])

Description. Atomic bitwise AND operation.

Class. Atomic subroutine.

Arguments.

ATOM shall be a scalar coarray or coindexed object of type integer with kind ATOMIC_INT_KIND, where ATOMIC_INT_KIND is a named constant in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT (INOUT) argument. ATOM becomes defined with the value IAND (ATOM, INT(VALUE, ATOMIC_INT_KIND)).

VALUE shall be an integer scalar. It is an INTENT(IN) argument.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example. CALL ATOMIC_AND (I[3], 6) causes I on image 3 to become defined with the value 4 if the value of I[3] was 5 when the atomic operation executed.

8.4.3 ATOMIC_CAS (ATOM, OLD, COMPARE, NEW [, STAT])

Description. Atomic compare and swap.

Class. Atomic subroutine.

Arguments.

ATOM shall be a scalar coarray or coindexed object of type integer with kind ATOMIC_INT_KIND or of type logical with kind ATOMIC_LOGICAL_KIND, where ATOMIC_INT_KIND and ATOMIC_LOGICAL_KIND are named constants in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT (INOUT) argument. If the value of ATOM is equal to the value of COMPARE, ATOM becomes defined with the value of INT (NEW, ATOMIC_INT_KIND) if it is of type integer, and with the value of NEW if it is of type logical. If the value of ATOM is not equal to the value of COMPARE, the value of ATOM is not changed.

OLD shall be a scalar of the same type and kind as ATOM. It is an INTENT (OUT) argument. It is defined with the value of ATOM that was used for performing the atomic operation.

COMPARE shall be a scalar of the same type and kind as ATOM. It is an INTENT(IN) argument.

NEW shall be a scalar of the same type as ATOM. It is an INTENT(IN) argument.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example. CALL ATOMIC_CAS(I[3], OLD, Z, 1) causes I on image 3 to become defined with the value 1 if its value is that of Z, and OLD to be defined with the value of I on image 3 that was used for performing the atomic operation.

8.4.4 ATOMIC_FETCH_ADD (ATOM, VALUE, OLD [, STAT])

Description. Atomic fetch and add operation.

Class. Atomic subroutine.

Arguments.

ATOM shall be a scalar coarray or coindexed object of type integer with kind ATOMIC_INT_KIND, where ATOMIC_INT_KIND is a named constant in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT (INOUT) argument. ATOM becomes defined with the value of ATOM + INT(VALUE, ATOMIC_INT_KIND).

VALUE shall be an integer scalar. It is an INTENT (IN) argument.

OLD shall be a scalar of the same type and kind as ATOM. It is an INTENT (OUT) argument. It is defined with the value of ATOM that was used for performing the atomic operation.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example. CALL ATOMIC_FETCH_ADD(I[3], 7, OLD) causes I on image 3 to become defined with the value 12 and the value of OLD on the image executing the statement to be defined with the value 5 if the value of I[3] was 5 when the atomic operation executed.

8.4.5 ATOMIC_FETCH_AND (ATOM, VALUE, OLD [, STAT])

Description. Atomic fetch and bitwise AND operation.

Class. Atomic subroutine.

Arguments.

ATOM shall be a scalar coarray or coindexed object of type integer with kind ATOMIC_INT_KIND, where ATOMIC_INT_KIND is a named constant in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT (INOUT) argument. ATOM becomes defined with the value of IAND(ATOM, INT(VALUE, ATOMIC_INT_KIND)).

VALUE shall be an integer scalar. It is an INTENT (IN) argument.

OLD shall be a scalar of the same type and kind as ATOM. It is an INTENT (OUT) argument. It is defined with the value of ATOM that was used for performing the atomic operation.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example. CALL ATOMIC_FETCH_AND (I[3], 6, IOLD) causes I on image 3 to become defined with the value 4 and the value of IOLD on the image executing the statement to be defined with the value 5 if the value of I[3] was 5 when the atomic operation executed.

8.4.6 ATOMIC_FETCH_OR (ATOM, VALUE, OLD [, STAT])

Description. Atomic fetch and bitwise OR operation.

Class. Atomic subroutine.

Arguments.

ATOM shall be a scalar coarray or coindexed object of type integer with kind ATOMIC_INT_KIND, where ATOMIC_INT_KIND is a named constant in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT (INOUT) argument. ATOM becomes defined with the value of IOR(ATOM, INT(VALUE, ATOMIC_INT_KIND)).

VALUE shall be an integer scalar. It is an INTENT (IN) argument.

OLD shall be a scalar of the same type and kind as ATOM. It is an INTENT (OUT) argument. It is defined with the value of ATOM that was used for performing the atomic operation.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example. CALL ATOMIC_FETCH_OR (I[3], 1, IOLD) causes I on image 3 to become defined with the value 3 and the value of IOLD on the image executing the statement to be defined with the value 2 if the value of I[3] was 2 when the atomic operation executed.

8.4.7 ATOMIC_FETCH_XOR (ATOM, VALUE, OLD [, STAT])

Description. Atomic fetch and bitwise exclusive OR operation.

Class. Atomic subroutine.

Arguments.

ATOM shall be a scalar coarray or coindexed object of type integer with kind ATOMIC_INT_KIND, where ATOMIC_INT_KIND is a named constant in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT (INOUT) argument. ATOM becomes defined with the value of IEOR(ATOM, INT(VALUE, ATOMIC_INT_KIND)).

VALUE shall be an integer scalar. It is an INTENT (IN) argument.

OLD shall be a scalar of the same type and kind as ATOM. It is an INTENT (OUT) argument. It is defined with the value of ATOM that was used for performing the atomic operation.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example. CALL ATOMIC_FETCH_XOR (I[3], 1, IOLD) causes I on image 3 to become defined with the value 2 and the value of IOLD on the image executing the statement to be defined with the value 3 if the value of I[3] was 3 when the atomic operation executed.

8.4.8 ATOMIC_OR (ATOM, VALUE [, STAT])

Description. Atomic bitwise OR operation.

Class. Atomic subroutine.

Arguments.

ATOM shall be a scalar coarray or coindexed object of type integer with kind ATOMIC_INT_KIND, where ATOMIC_INT_KIND is a named constant in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT (INOUT) argument. ATOM becomes defined with the value IOR (ATOM, INT(VALUE, ATOMIC_INT_KIND)).

VALUE shall be an integer scalar. It is an INTENT (IN) argument.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example. CALL ATOMIC_OR (I[3], 1) causes I on image 3 to become defined with the value 3 if the value of I[3] was 2 when the atomic operation executed.

8.4.9 ATOMIC_XOR (ATOM, VALUE [, STAT])

Description. Atomic bitwise exclusive OR operation.

Class. Atomic subroutine.

Arguments.

ATOM shall be a scalar coarray or coindexed object of type integer with kind ATOMIC_INT_KIND, where ATOMIC_INT_KIND is a named constant in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT (INOUT) argument. ATOM becomes defined with the value IEOR (ATOM, INT(VALUE, ATOMIC_INT_KIND)).

VALUE shall be an integer scalar. It is an INTENT (IN) argument.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example. CALL ATOMIC_XOR (I[3], 1) causes I on image 3 to become defined with the value 2 if the value of I[3] was 3 when the atomic operation executed.

8.4.10 CO_BROADCAST (A, SOURCE_IMAGE [, STAT, ERRMSG])

Description. Copy a value to all images of the current team.

Class. Collective subroutine.

Arguments.

A shall have the same dynamic type and type parameter values on all images in the current team. It shall not be a coindexed object. It is an INTENT(INOUT) argument. If it is an array, it shall have the same shape on all images in the current team. A becomes defined, as if by intrinsic assignment, on all images in the current team with the value of A on image SOURCE_IMAGE.

SOURCE_IMAGE shall be an integer scalar. It is an INTENT(IN) argument. It shall be the image index of an image in the current team and have the same value on all images in the current team.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

ERRMSG (optional) shall be a noncoindexed default character scalar. It is an INTENT(INOUT) argument.

The effect of the presence of the optional arguments STAT and ERRMSG is described in 8.3.

Example. If A is the array [1, 5, 3] on image one, after execution of CALL CO_BROADCAST(A,1) the value of A on all images of the current team is [1, 5, 3].

8.4.11 CO_MAX (A [, RESULT_IMAGE, STAT, ERRMSG])

Description. Compute elemental maximum value on the current team of images.

Class. Collective subroutine.

Arguments.

A shall be of type integer, real, or character. It shall have the same type and type parameters on all images in the current team. It shall not be a coindexed object. It is an INTENT(INOUT) argument. If it is a scalar, the computed value is equal to the maximum value of A on all images in the current team. If it is an array it shall have the same shape on all images of the current team and each element of the computed value is equal to the maximum value of all corresponding elements of A on the images in the current team.

RESULT_IMAGE (optional) shall be an integer scalar. It is an INTENT(IN) argument. If it is present, it shall be present on all images in the current team, have the same value on all images in the current team, and that value shall be the image index of an image in the current team.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

ERRMSG (optional) shall be a noncoindexed default character scalar. It is an INTENT(INOUT) argument.

If RESULT_IMAGE is not present, the computed value is assigned to A on all images in the current team. If RESULT_IMAGE is present, the computed value is assigned to A on image RESULT_IMAGE and A on all other images in the current team becomes undefined.

The effect of the presence of the optional arguments STAT and ERRMSG is described in 8.3.

Example. If the number of images in the current team is two and A is the array [1, 5, 3] on one image and [4, 1, 6] on the other image, the value of A after executing the statement CALL CO_MAX(A) is [4, 5, 6] on both images.

8.4.12 CO_MIN (A [, RESULT_IMAGE, STAT, ERRMSG])

Description. Compute elemental minimum value on the current team of images.

Class. Collective subroutine.

Arguments.

A shall be of type integer, real, or character. It shall have the same type and type parameters on all images in the current team. It shall not be a coindexed object. It is an INTENT(INOUT) argument. If it is a scalar, the computed value is equal to the minimum value of A on all images in the current team. If it is an array it shall have the same shape on all images in the current team and each element of the computed value is equal to the minimum value of all corresponding elements of A on the images in the current team.

RESULT_IMAGE (optional) shall be an integer scalar. It is an INTENT(IN) argument. If it is present, it shall be present on all images in the current team, have the same value on all images in the current team, and that value shall be the image index of an image in the current team.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

ERRMSG (optional) shall be a noncoindexed default character scalar. It is an INTENT(INOUT) argument.

If RESULT_IMAGE is not present, the computed value is assigned to A on all images in the current team. If RESULT_IMAGE is present, the computed value is assigned to A on image RESULT_IMAGE and A on all other images in the current team becomes undefined.

The effect of the presence of the optional arguments STAT and ERRMSG is described in 8.3.

Example. If the number of images in the current team is two and A is the array [1, 5, 3] on one image and [4, 1, 6] on the other image, the value of A after executing the statement CALL CO_MIN(A) is [1, 1, 3] on both images.

8.4.13 CO_REDUCE (A, OPERATOR [, RESULT_IMAGE, STAT, ERRMSG])

Description. General reduction of elements on the current team of images.

Class. Collective subroutine.

Arguments.

A shall not be polymorphic. It shall have the same type and type parameters on all images in the current team. It shall not be a coindexed object. It is an INTENT(INOUT) argument. If A is a scalar, the computed value is the result of the reduction operation of applying OPERATOR to the values of A on all images in the current team. If A is an array it shall have the same shape on all images in the current team and each element of the computed value is equal to the result of the reduction operation of applying OPERATOR to all corresponding elements of A on all images in the current team.

OPERATOR shall be a pure function with two scalar, nonallocatable, nonpointer, nonoptional arguments of the same type and type parameters as A. Its result shall have the same type and type parameters as A. The arguments and result shall not be polymorphic. If one argument has the ASYNCHRONOUS, TARGET, or VALUE attribute, both shall have the attribute. OPERATOR shall implement a mathematically commutative and associative operation. OPERATOR shall be the same function on all images in the current team.

RESULT_IMAGE (optional) shall be an integer scalar. It is an INTENT(IN) argument. If it is present, it shall be present on all images in the current team, have the same value on all images in the current team, and that value shall be the image index of an image in the current team.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

ERRMSG (optional) shall be a noncoindexed default character scalar. It is an INTENT(INOUT) argument.

If RESULT_IMAGE is not present, the computed value is assigned to A as if by intrinsic assignment on all images in the current team. If RESULT_IMAGE is present, the computed value is assigned to A as if by intrinsic assignment on image RESULT_IMAGE and A on all other images in the current team becomes undefined.

The computed value of a reduction operation over a set of values is the result of an iterative process. Each iteration involves the evaluation of `OPERATOR`(x,y) for x and y in the set, the removal of x and y from the set, and the addition of the value of `OPERATOR`(x,y) to the set. The process terminates when the set has only one element which is the value of the reduction.

The effect of the presence of the optional arguments STAT and ERRMSG is described in 8.3.

Example. If the number of images in the current team is two and A is the array [1, 5, 3] on one image and [4, 1, 6] on the other image, and MyADD is a function that returns the sum of its two integer arguments, the value of A after executing the statement CALL CO_REDUCE(A, MyADD) is [5, 6, 9] on both images.

8.4.14 CO_SUM (A [, RESULT_IMAGE, STAT, ERRMSG])

Description. Sum elements on the current team of images.

Class. Collective subroutine.

Arguments.

A shall be of numeric type. It shall have the same type and type parameters on all images in the current team. It shall not be a coindexed object. It is an INTENT(INOUT) argument. If it is a scalar, the computed value is equal to a processor-dependent and image-dependent approximation to the sum of the values of A on all images in the current team. If it is an array it shall have the same shape on all images in the current team and each element of the computed value is equal to a processor-dependent and image-dependent approximation to the sum of all corresponding elements of A on the images in the current team.

RESULT_IMAGE (optional) shall be an integer scalar. It is an INTENT(IN) argument. If it is present, it shall be present on all images in the current team, have the same value on all images in the current team, and that value shall be the image index of an image in the current team.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

ERRMSG (optional) shall be a noncoindexed default character scalar. It is an INTENT(INOUT) argument.

If RESULT_IMAGE is not present, the computed value is assigned to A on all images in the current team. If RESULT_IMAGE is present, the computed value is assigned to A on image RESULT_IMAGE and A on all other images in the current team becomes undefined.

The effect of the presence of the optional arguments STAT and ERRMSG is described in 8.3.

Example. If the number of images in the current team is two and A is the array [1, 5, 3] on one image and [4, 1, 6] on the other image, the value of A after executing the statement CALL CO_SUM(A) is [5, 6, 9] on both images.

8.4.15 EVENT_QUERY (EVENT, COUNT [, STAT])

Description. Query the count of an event variable.

Class. Atomic subroutine.

Arguments.

EVENT shall be a scalar of type EVENT_TYPE defined in the intrinsic module ISO_FORTRAN_ENV. It is an INTENT(IN) argument.

COUNT shall be an integer scalar with a decimal range no smaller that that of default integer. It is an INTENT(OUT) argument. If no error conditions occurs, COUNT is assigned the value of the count of EVENT. Otherwise, it is assigned the value 0.

STAT (optional) shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

Example. If EVENT is an event variable for which there have been no successful posts or waits, after the invocation

```
CALL EVENT_QUERY ( EVENT, COUNT )
```

the integer variable COUNT has the value 0. If there have been 10 successful posts to EVENT[2] and 2 successful waits without an UNTIL_COUNT specification, after the invocation

```
CALL EVENT_QUERY ( EVENT[2], COUNT )
```

COUNT has the value 8.

NOTE 8.5

Execution of EVENT_QUERY does not imply any synchronization.

8.4.16 FAILED_IMAGES ([TEAM, KIND])

Description. Indices of failed images.

Class. Transformational function.

Arguments.

TEAM (optional) shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_ENV. Its value shall represent the current or an ancestor team.

KIND (optional) shall be a scalar integer constant expression. Its value shall be the value of a kind type parameter for type INTEGER. The decimal range for integers of this kind shall be at least as large as for default integer.

Result Characteristics. Integer. If KIND is present, the kind type parameter is that specified by the value of KIND; otherwise, the kind type parameter is that of default integer type. The result is an array of rank one whose size is equal to the number of images in the specified team that are known by the invoking image to have failed.

Result Value. If TEAM is present, its value specifies the team; otherwise, the team specified is the current team. The elements of the result are the values of the image indices of the known failed images in the specified team, in numerically increasing order. If the executing image has previously executed an image control statement whose STAT= specifier assigned the value STAT_FAILED_IMAGE from the intrinsic module ISO_FORTRAN_ENV, or invoked a collective subroutine whose STAT argument was set to STAT_FAILED_IMAGE, and has not meanwhile entered or left a CHANGE TEAM construct, at least one image in the set of images participating in that image control statement or collective invocation shall be known to have failed.

Examples. If image 3 is the only image in the current team that is known by the invoking image to have failed, FAILED_IMAGES() has the value [3]. If there are no images in the current team that are known by the invoking image to have failed, FAILED_IMAGES() is a zero-sized array.

8.4.17 GET_TEAM ([LEVEL])

Description. Team value.

Class. Transformational function.

Argument. LEVEL (optional) shall be a scalar integer whose value shall be equal to one of the named constants INITIAL_TEAM, PARENT_TEAM, or CURRENT_TEAM defined in the intrinsic module ISO_FORTRAN_ENV.

Result Characteristics. Scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_ENV.

Result Value. The result is the value of a team variable for the current team if LEVEL is not present, LEVEL is present with the value CURRENT_TEAM, or the current team is the initial team. Otherwise, the result is the value of a team variable for the parent team if LEVEL is present with the value PARENT_TEAM, and for the initial team if LEVEL is present with the value INITIAL_TEAM.

Examples.

```
USE,INTRINSIC :: ISO_FORTRAN_ENV, ONLY: TEAM_TYPE
TYPE(TEAM_TYPE) :: WORLD_TEAM, TEAM2

! Define a team variable representing the initial team
WORLD_TEAM = GET_TEAM()
END

SUBROUTINE TT (A)
USE,INTRINSIC :: ISO_FORTRAN_ENV, ONLY: TEAM_TYPE
REAL A[*]
TYPE(TEAM_TYPE) :: NEW_TEAM, PARENT_TEAM

... ! Form NEW_TEAM

PARENT_TEAM = GET_TEAM()

CHANGE TEAM(NEW_TEAM)

   ! Reference image 1 in parent's team
   A [1,TEAM=PARENT_TEAM] = 4.2

   ! Reference image 1 in current team
   A [1] = 9.0
```

```
  END TEAM
  END SUBROUTINE TT
```

8.4.18 IMAGE_STATUS (IMAGE, [TEAM])

Description. Status of images.

Class. Elemental function.

Arguments.

IMAGE shall be of type integer.

TEAM (optional) shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_ENV. Its value shall represent the current or an ancestor team.

Result Characteristics. Default integer.

Result Value. If TEAM is present, its value specifies the team; otherwise, the team specified is the current team. The result value is STAT_FAILED_IMAGE if the specified image has failed, STAT_STOPPED_IMAGE if that image has initiated normal termination, a positive processor-dependent value different from STAT_FAILED_IMAGE or STAT_STOPPED_IMAGE if some other error has occurred for that image, and zero otherwise.

Example. If image 3 of the current team has failed, IMAGE_STATUS (3) has the value STAT_FAILED_IMAGE.

8.4.19 STOPPED_IMAGES ([TEAM, KIND])

Description. Indices of stopped images.

Class. Transformational function.

Arguments.

TEAM (optional) shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_ENV. Its value shall represent the current or an ancestor team.

KIND (optional) shall be a scalar integer constant expression. Its value shall be the value of a kind type parameter for type INTEGER. The decimal range for integers of this kind shall be at least as large as for default integer.

Result Characteristics. Integer. If KIND is present, the kind type parameter is that specified by the value of KIND; otherwise, the kind type parameter is that of default integer type. The result is an array of rank one whose size is equal to the number of images in the specified team that have initiated normal termination.

Result Value. If TEAM is present, its value specifies the team; otherwise, the team specified is the current team. The elements of the result are the values of the indices of the images that have initiated normal termination in the specified team, in numerically increasing order. If the executing image has previously executed an image control statement whose STAT= specifier assigned the value STAT_STOPPED_IMAGE from the intrinsic module ISO_FORTRAN_ENV or invoked a collective subroutine whose STAT argument was set to STAT_STOPPED_IMAGE, and has not meanwhile entered or left a CHANGE TEAM construct, at least one of the images participating in that image control statement or collective invocation shall have initiated normal termination.

Examples. If image 3 is the only image in the current team that has initiated normal termination, STOPPED_IMAGES() has the value [3]. If there are no images in the current team that have initiated normal termination, STOPPED_IMAGES() is a zero-sized array.

8.4.20 TEAM_ID ([TEAM])

Description. Team identifier.

Class. Transformational function.

Argument. TEAM (optional) shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_ENV. Its value shall represent the current or an ancestor team.

Result Characteristics. Default integer scalar.

Result Value. If TEAM is present its value specifies the team; otherwise, the team specified is the current team. If the specified team is the initial team, the result is -1; otherwise, the result value is the team identifier of the invoking image in the specified team.

Example. The following code illustrates the use of TEAM_ID to control which code is executed.

```
TYPE(TEAM_TYPE) :: ODD_EVEN
    :
ME = THIS_IMAGE()
FORM TEAM ( 2-MOD(ME,2), ODD_EVEN )
CHANGE TEAM (ODD_EVEN)
  SELECT CASE (TEAM_ID())
  CASE (1)
    :  ! Code for images with odd image indices in parent team
  CASE (2)
    :  ! Code for images with even image indices in parent team
  END SELECT
END TEAM
```

8.5 Modified intrinsic procedures

8.5.1 ATOMIC_DEFINE and ATOMIC_REF

The intrinsic subroutines ATOMIC_DEFINE and ATOMIC_REF in ISO/IEC 1539-1:2010 are modified to take account of the possibility that an ATOM argument is located on a failed image and to add the optional argument STAT.

The STAT argument shall be a noncoindexed scalar of type integer. It is an INTENT(OUT) argument.

8.5.2 IMAGE_INDEX

The intrinsic function IMAGE_INDEX in ISO/IEC 1539-1:2010 is modified by adding two additional versions that specify the team with the argument TEAM or the argument TEAM_ID, and a modified result if either of these versions is invoked.

The TEAM argument shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_ENV. Its value shall represent the current or an ancestor team.

The TEAM_ID argument shall be a positive integer scalar. If the current team is the initial team, its value is ignored. Otherwise, its value shall be that of a team identifier for a team that was formed by execution of a FORM TEAM statement for the current team.

8.5.3 MOVE_ALLOC

The intrinsic subroutine MOVE_ALLOC in ISO/IEC 1539-1:2010, as modified by ISO/IEC 1539-1:2010/Cor 2:2013, is modified to take account of the possibility of failed images and to add two optional arguments, STAT and ERRMSG, and a modified result if either is present.

The STAT argument shall be a noncoindexed integer scalar with a decimal exponent range of at least four. It is an INTENT(OUT) argument.

The ERRMSG argument shall be a noncoindexed default character scalar. It is an INTENT(INOUT) argument.

If the execution is successful

(1) The allocation status of TO becomes unallocated if FROM is unallocated on entry to MOVE_-ALLOC. Otherwise, TO becomes allocated with dynamic type, type parameters, array bounds, array cobounds, and value identical to those that FROM had on entry to MOVE_ALLOC.

(2) If TO has the TARGET attribute, any pointer associated with FROM on entry to MOVE_ALLOC becomes correspondingly associated with TO. If TO does not have the TARGET attribute, the pointer association status of any pointer associated with FROM on entry becomes undefined.

(3) The allocation status of FROM becomes unallocated.

When a reference to MOVE_ALLOC is executed for which the FROM argument is a coarray, there is an implicit synchronization of all active images of the current team. On each active image, execution of the segment (8.5.2 of ISO/IEC 1539-1:2010) following the CALL statement is delayed until all other active images of the current team have executed the same statement the same number of times since execution last began in this team.

If the STAT argument appears and execution is successful on all images, the argument is assigned the value zero; if a failed image is detected and execution is otherwise successful, the STAT= specifier is assigned the value STAT_FAILED_IMAGE in the intrinsic module ISO_FORTRAN_ENV.

If the STAT argument appears and an error condition occurs, the argument is assigned the value STAT_-STOPPED_IMAGE in the intrinsic module ISO_FORTRAN_ENV if the reason is that a successful execution would have involved an interaction with an image that has initiated termination; otherwise, the value is a processor-dependent positive value that is different from the value of STAT_STOPPED_IMAGE or STAT_FAILED_IMAGE.

If the STAT argument does not appear and an error condition occurs or an image involved in execution of the statement has failed, error termination is initiated.

If the ERRMSG argument is present and an error condition occurs, the processor shall assign an explanatory message to the argument. If no error condition occurs, the processor shall not change the value of the argument.

8.5.4 NUM_IMAGES

The intrinsic function NUM_IMAGES in ISO/IEC 1539-1:2010 is modified by adding two versions that specify the team with the argument TEAM or the argument TEAM_ID, and a modified result if either of these versions is invoked.

The TEAM argument shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_-ENV. Its value shall represent the current or an ancestor team.

The TEAM_ID argument shall be a positive integer scalar. If the current team is the initial team, its value is ignored. Otherwise, its value shall be that of a team identifier for a team that was formed by execution of a FORM TEAM statement for the current team.

8.5.5 THIS_IMAGE

The intrinsic function THIS_IMAGE in ISO/IEC 1539-1:2010, as modified by ISO/IEC 1539-1:2010/Cor 1:2012, is modified by adding an optional argument TEAM and a modified result if TEAM is present.

The TEAM argument shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_-ENV. Its value shall represent the current or an ancestor team. If TEAM is present, the result is the image index that the invoking image has in the team specified by the value of TEAM; otherwise, the result value is the image index of the invoking image in the current team.

9 Required editorial changes to ISO/IEC 1539-1:2010(E)

9.1 General

The following editorial changes, if implemented, would provide the facilities described in foregoing clauses of this Technical Specification. Descriptions of how and where to place the new material are enclosed in braces {}. Edits to different places within the same clause are separated by horizontal lines.

In the edits, except as specified otherwise by the editorial instructions, underwave (underwave) and strike-out (~~strike-out~~) are used to indicate insertion and deletion of text.

9.2 Edits to Introduction

{In paragraph 1 of the Introduction}

After "informally known as Fortran 2008, plus the facilities defined in ISO/IEC TS 29113:2012" add "and ISO/IEC TS 18508:2015".

{In the Introduction and after the paragraph added by ISO/IEC TS 29113:2012, insert new paragraph}

- Features previously described in ISO/IEC TS 18508:2015:

Optional STAT= and ERRMSG= specifiers are added to the CRITICAL statement. Optional arguments are added to the intrinsic procedures ATOMIC_DEFINE, ATOMIC_REF, IMAGE_INDEX, MOVE_ALLOC, NUM_IMAGES, and THIS_IMAGE. Extensions of image selector syntax permit designation of coarrays across team boundaries and optional STAT= specifiers. The STOPPED_IMAGES intrinsic procedure provides the indices of stopped images. The teams facility uses the CHANGE TEAM construct, TEAM_TYPE derived type, FORM TEAM and SYNC TEAM statements, and the GET_TEAM and TEAM_ID intrinsic procedures, to provide a capability for a subset of the images of the program to act as if it consists of all images for the purposes of image index values, coarray allocations, and synchronization. The collective subroutines CO_BROADCAST, CO_MAX, CO_MIN, CO_REDUCE, and CO_SUM perform computations based on values on all active images of the current team, offering the possibility of efficient execution of reduction operations. The additional atomic subroutines ATOMIC_ADD, ATOMIC_AND, ATOMIC_CAS, ATOMIC_FETCH_ADD, ATOMIC_FETCH_AND, ATOMIC_FETCH_OR, ATOMIC_FETCH_XOR, ATOMIC_OR, and ATOMIC_XOR perform integer addition, compare and swap, and bitwise computations. The event facility uses the EVENT POST and EVENT WAIT statements, the EVENT_TYPE derived type, and the EVENT_QUERY intrinsic procedure to allow one-sided ordering of execution segments. The FAIL TEAM statement, the FAILED_IMAGES and IMAGE_STATUS intrinsic procedures, and the defined constant STAT_FAILED_IMAGE provide support for continued execution after one or more images have failed.

9.3 Edits to clause 1

{In 1.3 Terms and definitions, insert new terms as follows}

1.3.8a
asynchronous progress
ability of images to define or reference coarrays without requiring the images on which the data reside to execute any particular statements

1.3.30a
collective subroutine

intrinsic subroutine that is invoked on the active images of the current team to perform a calculation on those images and assign the computed value on one or all of them (13.1)

1.3.68a
established coarray
coarray that is accessible within a CHANGE TEAM construct from outside the construct (8.1.4a)

1.3.83a
active image
an image that has not failed or initiated termination (2.3.6)

1.3.83b
failed image
an image for which references or definitions of a variable on the image fail when that variable should be accessible; or an image that is not a stopped image and fails to respond during the execution of an image control statement or a reference to a collective subroutine (2.3.6)

1.3.83d
stopped image
an image that has initiated normal termination (2.3.6)

1.3.145a
team
set of images that can readily execute independently of other images (2.3.4)

1.3.145a.1
current team
the team specified in the CHANGE TEAM statement of the innermost executing CHANGE TEAM construct, or the initial team if no CHANGE TEAM construct is active (2.3.4)

1.3.145a.2
initial team
the current team when the program began execution (2.3.4)

1.3.145a.3
parent team
team from which the current team was formed by executing a FORM TEAM statement (2.3.4)

1.3.145a.4
team identifier
integer value identifying a team (2.3.4)

1.3.154.1-
event variable
scalar variable of type EVENT_TYPE (13.8.2.8a) from the intrinsic module ISO_FORTRAN_ENV

1.3.154.3
team variable
scalar variable of type TEAM_TYPE (13.8.2.26) from the intrinsic module ISO_FORTRAN_ENV

9.4 Edits to clause 2

{In 2.1 High level syntax, Add new construct and statements into the syntax list as follows: In R213 *executable-construct* insert alphabetically "*change-team-construct*"; in R214 *action-stmt* insert alphabetically "*event-post-stmt*", "*event-wait-stmt*", "*fail-image-stmt*", "*form-team-stmt*", and "*sync-team-stmt*".

{In 2.3.4 Program execution, after the first paragraph, insert 5.1, paragraphs 1 and 2, of this Technical Specification with the following changes: In the first paragraph delete "in ISO/IEC 1539-1:2010" following "R624" and insert "(8.5.2c)" following "FORM TEAM statement". In the second paragraph insert "(8.1.4a)" following "CHANGE TEAM construct". }

{After 2.3.5 Execution sequence, insert a new subclause "2.3.6 Image execution states" consisting of five paragraphs, with the third, fourth, and fifth paragraphs consisting of the first three paragraphs of 6.1 Introduction and Note 6.1 of this Technical Specification after changing "(6.4)" in the second paragraph to "13.8.2.21b", and the first and second paragraphs as follows.}

A stopped image is an image that has initiated termination of execution.

An active image is an image that is not a failed image or a stopped image.

{In 2.4.7 Coarray, after the first paragraph, insert 5.1 paragraph 3 of this Technical Specification.}

{In 2.4.7 Coarray, edit the second paragraph as follows.}

For each coarray on an image in a team, there is a corresponding coarray with the same type, type parameters, and bounds on every other image in that team.

{In 2.4.7 Coarray, edit the first sentence of the third paragraph as follows.}

The set of corresponding coarrays on all images in a team is arranged in a rectangular pattern.

9.5 Edits to clause 4

{In 4.5.2.1 Syntax, edit constraint C433 as follows}

C433 (R425) If EXTENDS appears and the type being defined has ~~an ultimate~~ a component of type EVENT_TYPE or LOCK_TYPE from the intrinsic module ISO_FORTRAN_ENV, at any level of nonpointer component selection, its parent type shall have ~~an ultimate~~ a component at some level of nonpointer component selection of type EVENT_TYPE or LOCK_TYPE, respectively.

{In 4.5.6.2 The finalization process, add to the end of NOTE 4.48}

in the current team

9.6 Edits to clause 6

{In 6.6 Image selectors, replace R624 with}

R624	*image-selector*	**is**	*lbracket cosubscript-list* ■ ■ [, *team-identifier*] [, STAT = *stat-variable*] *rbracket*
R624a	*team-identifier*	**is**	TEAM_ID = *scalar-int-expr*
		or	TEAM = *team-variable*

C627a (R624) *stat-variable* shall not be a coindexed object.

{In 6.6 Image selectors, edit the last sentence of the second paragraph as follows.}

An image selector shall specify an image index value that is not greater than the number of images in the team specified by a *team-identifier* if it appears, or in the current team otherwise.

{In 6.6 Image selectors, after paragraph 2 insert the two paragraphs following C509 in 5.4 of this Technical Specification with the following change: following "FORM TEAM statement" insert "(8.5.2c)" }

{In 6.7.1.2, Execution of an ALLOCATE statement, edit paragraphs 3 and 4 as follows}

If an *allocation* specifies a coarray, its dynamic type and the values of corresponding type parameters shall be the same on every active image in the current team. The values of corresponding bounds and corresponding cobounds shall be the same on ~~every image~~ these images. If the coarray is a dummy argument, its ultimate argument (12.5.2.3) shall be the same coarray on ~~every image~~ these images.

When an ALLOCATE statement is executed for which an *allocate-object* is a coarray, there is an implicit synchronization of all active images in the current team. On ~~each image~~ these images, execution of the segment (8.5.2) following the statement is delayed until all other active images in the current team have executed the same statement the same number of times since execution last began in this team.

{In 6.7.3.2, Deallocation of allocatable variables, edit paragraphs 11 and 12 as follows}

When a DEALLOCATE statement is executed for which an *allocate-object* is a coarray, there is an implicit synchronization of all active images in the current team. On ~~each image~~ these images, execution of the segment (8.5.2) following the statement is delayed until all other active images in the current team have executed the same statement the same number of times since execution last began in this team. If the coarray is a dummy argument, its ultimate argument (12.5.2.3) shall be the same coarray on ~~every image~~ these images.

There is also an implicit synchronization of all active images in the current team in association with the deallocation of a coarray or coarray subcomponent caused by the execution of a RETURN or END statement or the termination of a BLOCK construct.

{In 6.7.4 STAT=specifier, edit paragraph 2 as follows}

If the STAT= specifier appears, successful execution of the ALLOCATE or DEALLOCATE statement on all images in the current team causes the *stat-variable* to become defined with the value zero; otherwise, if a failed image is detected and execution is otherwise successful, the STAT= specifier is assigned the value of the named constant STAT_FAILED_IMAGE in the intrinsic module ISO_FORTRAN_ENV (13.8.2).

{In 6.7.4 STAT= specifier, para 3, replace the text to the bullet list with}

If the STAT= specifier appears in an ALLOCATE or DEALLOCATE statement with a coarray *allocate-object* and an error condition occurs, the specified variable is assigned a positive value. The value shall be that of the named constant STAT_STOPPED_IMAGE in the intrinsic module ISO_FORTRAN_ENV if the reason is that a successful execution would have involved an interaction with an image that has initiated termination; otherwise, the value is a processor-dependent positive value that is different from the values of the named constants STAT_STOPPED_IMAGE or STAT_FAILED_IMAGE in the intrinsic module ISO_FORTRAN_ENV. In all of these cases, each *allocate-object* has a processor-dependent allocation status:

{At the end of 6.7.4 STAT= specifier, append the following new paragraph}

If the STAT argument does not appear and an error condition occurs or an image involved in execution of the statement has failed, error termination is initiated.

9.7 Edits to clause 8

{In 8.1.1 General, paragraph 1, following the BLOCK construct entry in the list of constructs insert}

- CHANGE TEAM construct;

{Following 8.1.4 BLOCK construct insert 5.3 CHANGE TEAM construct from this Technical Specification as 8.1.4a, with rule, constraint, and Note numbers modified, the reference "(5.2)" in C506 changed to "(13.8.2.26)", and in the third paragraph following C508, delete "of ISO/IEC 1539-1:2010". }

{In 8.1.5 CRITICAL construct: In para 1, line 1, after "one image" add "in the current team". In para 1, at the end of R811, add "[*sync-stat-list*]". In para 2, line 1, at the end of the sentence, add "or the executing image fails". After para 2 add the paragraph following R811 in 6.3 CRITICAL construct of this Technical Specification. In para 3, line 1, after "other image" add "in the current team".}

{Following 8.4 STOP and ERROR STOP statements, insert 6.2 FAIL IMAGE statement from this Technical Specification as 8.4a, with rule and Note numbers modified.}

{In 8.5.1 Image control statements, paragraph 2, insert extra bullet points following the CRITICAL and END CRITICAL line}

- CHANGE TEAM and END TEAM;
- EVENT POST and EVENT WAIT;
- FORM TEAM;
- SYNC TEAM;

{In 8.5.1 Image control statements, edit paragraph 3 as follows}

All image control statements except CRITICAL, END CRITICAL, EVENT POST, EVENT WAIT, FORM TEAM, LOCK, and UNLOCK include the effect of executing a SYNC MEMORY statement (8.5.5).

{In 8.5.2 Segments, after the first sentence of paragraph 3, insert the following }

A coarray that is of type EVENT_TYPE (13.8.2.8a) may be referenced or defined during the execution of a segment that is unordered relative to the execution of another segment in which that coarray of type EVENT_TYPE is defined.

{In 8.5.2 Segments, edit the first sentence of NOTE 8.34 as follows}

The model upon which the interpretation of a program is based is that there is a permanent memory location for each coarray and that all images on which it is established can access it.

{Following 8.5.2 Segments insert 7.3 EVENT POST statement from this Technical Specification as 8.5.2a, with rule and constraint numbers modified, and change the "(7.2)" in C704 to "(13.8.2.8a)". }

{Following 8.5.2 Segments insert 7.4 EVENT WAIT statement from this Technical Specification as 8.5.2b, with rule and constraint numbers modified.}

{Following 8.5.2 Segments insert 5.5 FORM TEAM statement from this Technical Specification as 8.5.2c, with rule and Note numbers modified.}

{In 8.5.3 SYNC ALL statement, edit paragraph 2 as follows}

Execution of a SYNC ALL statement performs a synchronization of all active images in the current team. Execution on an image, M, of the segment following the SYNC ALL statement is delayed until each other active image in the current team has executed a SYNC ALL statement as many times as has image M since execution last began in this team. The segments that executed before the SYNC ALL statement on an image precede the segments that execute after the SYNC ALL statement on another image.

{In 8.5.4 SYNC IMAGES, edit paragraphs 1 through 4 as follows}

If *image-set* is an array expression, the value of each element shall be positive and not greater than the number of images in the current team, and there shall be no repeated values.

If *image-set* is a scalar expression, its value shall be positive and not greater than the number of images in the current team.

An *image-set* that is an asterisk specifies all images in the current team.

Execution of a SYNC IMAGES statement performs a synchronization of the image with each of the other active images in the *image-set*. Executions of SYNC IMAGES statements on images M and T correspond if the number of times image M has executed a SYNC IMAGES statement in the current team with T in its image set since execution last began in this team is the same as the number of times image T has executed a SYNC IMAGES statement in the current team with M in its image set since execution last began in this team. The segments that executed before the SYNC IMAGES statement on either image precede the segments that execute after the corresponding SYNC IMAGES statement on the other image.

{Following 8.5.5 SYNC MEMORY statement, insert 5.6 SYNC TEAM statement from this Technical Specification as 8.5.5a, with the rule number modified.}

{In 8.5.6 LOCK and UNLOCK statements: in para 1, change "image and" to "image, that image has not failed, and the lock variable"; in para 4, add new second sentence "If an image fails after locking and before unlocking a lock variable, the variable becomes unlocked."}

{In 8.5.7 STAT= and ERRMSG= specifiers in image control statements replace paragraphs 1 and 2 by}

If the STAT= specifier appears in a CHANGE TEAM, END TEAM, EVENT POST, EVENT WAIT, FORM TEAM, LOCK, SYNC ALL, SYNC IMAGES, SYNC MEMORY, SYNC TEAM, or UNLOCK statement and its execution is successful on the involved images, the specified variable is assigned the value zero; otherwise, if a failed image is detected and execution is otherwise successful, the STAT= specifier is assigned the value of the named constant STAT_FAILED_IMAGE in the intrinsic module ISO_FORTRAN_ENV (13.8.2).

If the STAT= specifier appears in a CHANGE TEAM, END TEAM, EVENT POST, EVENT WAIT, FORM TEAM, LOCK, SYNC ALL, SYNC IMAGES, SYNC MEMORY, SYNC TEAM, or UNLOCK statement and an error condition occurs, the specified variable is assigned a positive value. The value shall be the named constant STAT_STOPPED_IMAGE in the intrinsic module ISO_FORTRAN_ENV if the reason is that a successful execution would have involved an interaction with an image that has initiated termination; otherwise, the value is a processor-dependent positive value that is different from the values of the named constants STAT_STOPPED_IMAGE or STAT_FAILED_IMAGE in the intrinsic module ISO_FORTRAN_ENV.

The set of images involved in execution of an END TEAM, FORM TEAM, or SYNC ALL statement is that of the current team. The set of images involved in execution of a CHANGE TEAM or SYNC TEAM statement is that of the team specified by the value of the specified *team-variable*. The set of images involved in execution of a SYNC IMAGES statement is the union of its *image-set* and the executing image. The images involved in execution of a LOCK or UNLOCK statement are the ones on which the referenced lock variable is located and the executing image. The images involved in execution of an EVENT POST statement are the ones on which the referenced event variable is located and the executing image.

After execution of an image control statement with a STAT= specifier, all failed images involved in the statement shall be known by the executing image to have failed.

If the STAT= specifier appears in a CHANGE TEAM, END TEAM, SYNC ALL, SYNC IMAGES, or SYNC TEAM statement and an error condition occurs, the effect is the same as that of executing the SYNC MEMORY statement, except for defining the STAT= variable.

{In 8.5.7 STAT= and ERRMSG= specifiers in image control statements replace paragraphs 4 and 5 by}

If the STAT= specifier does not appear in a CHANGE TEAM, END TEAM, EVENT POST, EVENT WAIT, FORM TEAM, LOCK, SYNC ALL, SYNC IMAGES, SYNC MEMORY, SYNC TEAM, or UNLOCK statement and its execution is not successful or an image involved in execution of the statement has failed, error termination is initiated.

If an ERRMSG= specifier appears in a CHANGE TEAM, END TEAM, EVENT POST, EVENT WAIT, FORM

TEAM, LOCK, SYNC ALL, SYNC IMAGES, SYNC MEMORY, SYNC TEAM, or UNLOCK statement and its execution is not successful, the processor shall assign an explanatory message to the specified variable. If the execution is successful, the processor shall not change the value of the variable.

9.8 Edits to clause 9

{In 9.5.1, Referring to a file, edit the first sentence of paragraph 4 as follows}

In a READ statement, an *io-unit* that is an asterisk identifies an external unit that is preconnected for sequential formatted input on image 1 in the initial team only (9.6.4.3).

9.9 Edits to clause 13

{In 13.1 Classes of intrinsic procedures, edit paragraph 1 as follows}

Intrinsic procedures are divided into ~~seven~~ eight classes: inquiry functions, elemental functions, transformational functions, elemental subroutines, pure subroutines, atomic subroutines, collective subroutines, and (impure) subroutines.

{In 13.1 Classes of intrinsic procedures, replace paragraph 3 by paragraphs 1 through 4 and NOTES 8.1 and 8.2 of 8.2 Atomic subroutines of this Technical Specification, with these changes: Delete "of ISO/IEC 1539-1:2010" and renumber the NOTES.}

{In 13.1 Classes of intrinsic procedures, insert the contents of 8.3 Collective subroutines of this Technical Specification after paragraph 3 and Note 13.1, with these changes: In paragraph 2 of 8.3, delete "of ISO/IEC 1539-1:2010"; In paragraph 5 of 8.3, add "(13.8.2)" after the first "ISO_FORTRAN_ENV".}

{In 13.5 Standard generic intrinsic procedures, paragraph 2 after the line "A indicates ... atomic subroutine" insert a new line}

C indicates that the procedure is a collective subroutine

{In 13.5 Standard generic intrinsic procedures, Table 13.1, insert new entries into the table, alphabetically}

ATOMIC_ADD	(ATOM, VALUE [, STAT])	A	Atomic add operation.
ATOMIC_AND	(ATOM, VALUE [, STAT])	A	Atomic bitwise AND operation.
ATOMIC_CAS	(ATOM, OLD, COMPARE, NEW [, STAT])	A	Atomic compare and swap.
ATOMIC_FETCH_ADD	(ATOM, VALUE, OLD [,STAT])	A	Atomic fetch and add operation.
ATOMIC_FETCH_AND	(ATOM, VALUE, OLD [,STAT])	A	Atomic fetch and bitwise AND operation.
ATOMIC_FETCH_OR	(ATOM, VALUE, OLD [,STAT])	A	Atomic fetch and bitwise OR operation.
ATOMIC_FETCH_XOR	(ATOM, VALUE, OLD [,STAT])	A	Atomic fetch and bitwise exclusive OR operation.
ATOMIC_OR	(ATOM, VALUE [, STAT])	A	Atomic bitwise OR operation.
ATOMIC_XOR	(ATOM, VALUE [, STAT])	A	Atomic bitwise exclusive OR operation.
CO_BROADCAST	(A, SOURCE_IMAGE [, STAT, ERRMSG])	C	Copy a value to all images of the current team.
CO_MAX	(A [, RESULT_IMAGE, STAT, ERRMSG])	C	Compute maximum of elements across images.
CO_MIN	(A [, RESULT_IMAGE, STAT, ERRMSG])	C	Compute minimum of elements across images.
CO_REDUCE	(A, OPERATOR	C	General reduction of elements across images.

	[, RESULT_IMAGE, STAT, ERRMSG])		
CO_SUM	(A [, RESULT_IMAGE, STAT, ERRMSG])	C	Sum elements across images.
EVENT_QUERY	(EVENT, COUNT [, STAT])	A	Count of an event variable.
FAILED_IMAGES	([TEAM, KIND])	T	Indices of failed images.
GET_TEAM	([LEVEL])	T	Team value.
IMAGE_STATUS	(IMAGE [, TEAM])	E	Status of images.
STOPPED_IMAGES	([TEAM, KIND])	T	Indices of stopped images.
TEAM_ID	([TEAM])	T	Team identifier.

{In 13.5 Standard generic intrinsic procedures, Table 13.1, edit the entries for ATOMIC_DEFINE, ATOMIC_REF, IMAGE_INDEX, MOVE_ALLOC, NUM_IMAGES, and THIS_IMAGE, as modified by ISO/IEC 1539-1:2010/Cor 1:2012, as follows}

ATOMIC_DEFINE	(ATOM, VALUE [, STAT])	A	Define a variable atomically.
ATOMIC_REF	(VALUE, ATOM [, STAT])	A	Reference a variable atomically.
IMAGE_INDEX	(COARRAY, SUB) or (COARRAY, SUB, TEAM) or (COARRAY, SUB, TEAM_ID)	I	Image index from cosubscripts.
MOVE_ALLOC	(FROM, TO [, STAT, ERRMSG])	PS	Move an allocation.
NUM_IMAGES	( ) or (TEAM) or (TEAM_ID)	T	Number of images.
THIS_IMAGE	([TEAM])	T	Index of the invoking image.
THIS_IMAGE	(COARRAY [, TEAM]) or (COARRAY, DIM [, TEAM])	T	Cosubscript(s) for this image.

{In 13.5, Standard generic intrinsic procedures, paragraph 3, insert "in the initial team" after "image 1"}

{In 13.7 Specifications of the standard intrinsic procedures, insert subclauses 8.4.1 through 8.4.20 of this Technical Specification in order alphabetically, with subclause numbers adjusted accordingly.}

{In 13.7.20 ATOMIC_DEFINE, edit the subclause title as follows}

13.7.20 ATOMIC_DEFINE (ATOM, VALUE [,STAT])

{In 13.7.20 ATOMIC_DEFINE, add the argument description as follows}

STAT (optional) shall be a noncoindexed integer scalar with a decimal range of at least four. It is an INTENT(OUT) argument.

{In 13.7.21 ATOMIC_REF, edit the subclause title as follows}

13.7.21 ATOMIC_REF (VALUE, ATOM [,STAT])

{In 13.7.21 ATOMIC_REF, add the argument description and a paragraph as follows}

STAT (optional) shall be a noncoindexed integer scalar with a decimal range of at least four. It is an INTENT(OUT) argument.

If an error condition occurs, the VALUE argument becomes undefined.

{In 13.7.79 IMAGE_INDEX, edit the subclause title as follows}

13.7.79 IMAGE_INDEX (COARRAY, SUB) or IMAGE_INDEX (COARRAY, SUB, TEAM) or IMAGE_INDEX (COARRAY, SUB, TEAM_ID)

{In 13.7.79 IMAGE_INDEX, edit the COARRAY argument description as follows}

COARRAY shall be a coarray of any type. If the function is invoked with a TEAM_ID argument, it shall be established in an ancestor of the specified team. Otherwise, it shall be established in the specified team.

{In 13.7.79 IMAGE_INDEX, add the arguments descriptions as follows}

TEAM shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_ENV. Its value shall represent the current or an ancestor team.

TEAM_ID shall be a positive integer scalar. If the current team is the initial team, its value is ignored. Otherwise, its value shall be that of a team identifier for a team that was formed by execution of a FORM TEAM statement for the current team.

If TEAM appears, it specifies the team. Otherwise, the team specified is the current team.

{In 13.7.79 IMAGE_INDEX, replace paragraph 5 with}

Result Value. If the value of SUB is a valid sequence of cosubscripts for COARRAY in the specified team, the result is the index of the corresponding image in that team. Otherwise, the result is zero.

{In 13.7.118 MOVE_ALLOC, edit the subclause title as follows}

13.7.118 MOVE_ALLOC (FROM, TO [, STAT, ERRMSG])

{In 13.7.118 MOVE_ALLOC, add the arguments descriptions as follows}

STAT (optional) shall be a noncoindexed default integer scalar. It is an INTENT(OUT) argument.

ERRMSG (optional) shall be a noncoindexed default character scalar. It is an INTENT(INOUT) argument.

{In 13.7.118 MOVE_ALLOC, replace paragraphs 4 through 6 and the paragraph that was added by ISO/IEC 1539-1:2010/Cor 2:2013 by paragraphs 4 through 8 of 8.5.3 of this Technical Specification, deleting "of ISO/IEC 1539-1:2010" in paragraph 5.}

{In 13.7.126 NUM_IMAGES, edit the subclause title as follows}

13.7.126 NUM_IMAGES ( ) or NUM_IMAGES (TEAM) or NUM_IMAGES (TEAM_ID)

{In 13.7.126 NUM_IMAGES, replace paragraph 3 with}

Arguments.

TEAM shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_ENV. Its value shall represent the current or an ancestor team.

TEAM_ID shall be a positive integer scalar. If the current team is the initial team, its value is ignored. Otherwise, its value shall be that of a team identifier for a team that was formed by execution of a FORM TEAM statement for the current team.

If TEAM appears, it specifies the team. Otherwise, the team specified is the current team.

{In 13.7.126 NUM_IMAGES, replace paragraph 5 with}

Result Value. The number of images in the team specified.

{In 13.7.165, as modified by ISO/IEC 1539-1:2010/Cor 1:2012, THIS_IMAGE ( ) or THIS_IMAGE (COARRAY) or THIS_IMAGE (COARRAY, DIM) edit the subclause title as follows }

13.7.165 THIS_IMAGE ([TEAM]) or THIS_IMAGE (COARRAY [, TEAM]) or THIS_IMAGE (COARRAY, DIM [, TEAM])

{In 13.7.165, as modified by ISO/IEC 1539-1:2010/Cor 1:2012, THIS_IMAGE ( ) or THIS_IMAGE (COARRAY) or THIS_IMAGE (COARRAY, DIM) insert a new argument at the end of paragraph 3 }

TEAM (optional) shall be a scalar of type TEAM_TYPE defined in the intrinsic module ISO_FORTRAN_-ENV. Its value shall represent the current or an ancestor team. If COARRAY appears, it shall be established for TEAM.

{In 13.7.165, as modified by ISO/IEC 1539-1:2010/Cor 1:2012, THIS_IMAGE ( ) or THIS_IMAGE (COARRAY) or THIS_IMAGE (COARRAY, DIM) at the end of paragraph 5 add }

Case (iv): The result of THIS_IMAGE (TEAM) is a scalar with a value equal to the index of the invoking image in the team specified by the value of TEAM.

Case (v): The result of THIS_IMAGE (COARRAY, TEAM) is the sequence of cosubscript values for COARRAY that would specify the invoking image in the team specified by the value of TEAM.

Case (vi): The result of THIS_IMAGE (COARRAY, DIM, TEAM) is the value of cosubscript DIM in the sequence of cosubscript values for COARRAY that would specify the invoking image in the team specified by the value of TEAM.

{In 13.7.172 UCOBOUND, edit the Result Value as follows.}

The final upper cobound is the final cosubscript in the cosubscript list for the coarray that selects the image with index ~~NUM_IMAGES( )~~ equal to the number of images in the current team when the coarray was established.

{In 13.8.2 The ISO_FORTRAN_ENV intrinsic module, insert a new subclause}

13.8.2.7a CURRENT_TEAM

The value of the default integer scalar constant CURRENT_TEAM identifies the current team in an invocation of the function GET_TEAM.

{In 13.8.2 The ISO_FORTRAN_ENV intrinsic module, insert a new subclause 13.8.2.8a consisting of subclause 7.2 EVENT_TYPE of this Technical Specification, but omitting the final sentence of the first paragraph and the fourth sentence of the second paragraph.}

{In 13.8.2 The ISO_FORTRAN_ENV intrinsic module, insert a new subclause}

13.8.2.9a INITIAL_TEAM

The value of the default integer scalar constant INITIAL_TEAM identifies the initial team in an invocation of the function GET_TEAM.

{In 13.8.2 The ISO_FORTRAN_ENV intrinsic module, insert a new subclause}

13.8.2.19a PARENT_TEAM

The value of the default integer scalar constant PARENT_TEAM identifies the parent team in an invocation of the function GET_TEAM.

{In 13.8.2 The ISO_FORTRAN_ENV intrinsic module, insert a new subclause 13.8.2.21b consisting of subclause 6.4 STAT_FAILED_IMAGE of this Technical Specification.}

{In 13.8.2.24 STAT_STOPPED_IMAGE, edit the paragraph as follows.}

The value of the default integer scalar constant STAT_STOPPED_IMAGE is assigned to the variable specified in a STAT= specifier (6.7.4, 8.5.7) or a STAT argument in a call to a collective subroutine if execution of the statement with that specifier or argument requires synchronization with an image that has initiated termination of execution. This value shall be positive ~~and different from the value of IOSTAT_INQUIRE_INTERNAL_UNIT~~.

{In 13.8.2.24 STAT_STOPPED_IMAGE, insert a new Note after paragraph 1}

In addition to detecting that an image has initiated normal termination by having the variable in a STAT=specifier or a STAT argument of a call to a collective subroutine assigned the value STAT_STOPPED_IMAGE, an image can get the indices of the images that have initiated normal termination in a specified team by invoking the intrinsic function STOPPED_IMAGES.

{In 13.8.2 The ISO_FORTRAN_ENV intrinsic module, append a new subclause 13.8.2.26 consisting of subclause 5.2 TEAM_TYPE of this Technical Specification, but omitting the final sentence of the first paragraph.}

{In 13.8.2 The ISO_FORTRAN_ENV intrinsic module, append a new subclause}

13.8.2.26a Uniqueness of values of named constants

The values of the named constants IOSTAT_INQUIRE_INTERNAL_UNIT, STAT_FAILED_IMAGE, STAT_LOCKED, STAT_LOCKED_OTHER_IMAGE STAT_STOPPED_IMAGE, and STAT_UNLOCKED shall be distinct.

9.10 Edits to clause 16

{In 16.4 Statement and construct entities, in paragraph 1, after "DO CONCURRENT" replace "or" with a comma; after "ASSOCIATE construct" insert ", or as a coarray specified by a *codimension-decl* in a CHANGE TEAM construct,"}

{In 16.4 Statement and construct entities, add the following new paragraph after paragraph 8}

The associate names of a CHANGE TEAM construct have the scope of the block. They have the declared type, dynamic type, type parameters, rank, bounds, and cobounds as specified in 8.1.4a.

{In 16.5.1.6 Construct association, append the following sentence to the paragraph 1}

Execution of a CHANGE TEAM statement establishes an association between each coselector and the corresponding associate name of the construct.

{In 16.6.5 Events that cause variables to become defined, add the following list item}

(33) Failure of the image that locked a lock variable before it has unlocked the variable causes the variable to become unlocked.

{In 16.6.6 Events that cause variables to become undefined, add the following list item}

(27) When an image fails during the execution of a segment, a data object on a non-failed image becomes undefined if it might be defined or undefined by execution of a statement of the segment other than an invocation of an atomic subroutine.

{In 16.6.7, Variable definition context, after item (13) insert a new list item}

(13a) a coarray in a *codimension-decl* in a CHANGE TEAM construct if the coarray named by the corresponding *coselector-name* of that construct appears in a variable definition context within that construct;

{In 16.6.7, at the end of the list of variable definition contexts in para 1, replace the "." at the end of entry (15) with ";" and add two new entries as follows}

(16) a *team-variable* in a FORM TEAM statement;

(17) an *event-variable* in an EVENT POST or EVENT WAIT statement.

9.11 Edits to annex A

{In A.2 Processor dependencies, in the list item beginning "the effect of calling COMMAND_ARGUMENT_COUNT", insert "in the initial team" after "image 1".}

{In A.2 Processor dependencies, in the list item beginning "the value assigned to a CMDSTAT", replace "CMDSTAT or STATUS" with "CMDSTAT, STAT, or STATUS".}

{At the end of A.2 Processor dependencies, replace the final full stop with a semicolon and add new items as follows}

- the conditions that cause an image to fail (13.8.2.21b);
- the computed value of the CO_SUM intrinsic subroutine (13.7.42e);
- the computed value of the CO_REDUCE intrinsic subroutine (13.7.42d);
- how sequences of event posts in unordered segments interleave with each other (8.5.2a);
- the image index value assigned by a FORM TEAM statement without a NEW_INDEX= specifier (8.5.2c);
- the value of an expression that includes a reference to a coindexed object on a failed image (2.3.6).

9.12 Edits to annex C

{In C.5 Clause 8 notes, at the end of the subclause insert subclauses A.1.1, A.1.2, A.1.3, A.2.1, A.3.1, A.3.2, and A.3.3 from this Technical Specification as subclauses C.5.5 to C.5.11.}

{In C.10 Clause 13 notes, at the end of the subclause insert subclauses A.4.1 and A.4.2 from this Technical Specification as subclauses C.10.2 and C.10.3., deleting "in ISO/IEC 1539-1:2010" in A.4.2.1}

Annex A

(Informative)

Extended notes

A.1 Clause 5 notes

A.1.1 Example using three teams

Compute fluxes over land, sea and ice in different teams based on surface properties. Assumption: Each image deals with areas containing exactly one of the three surface types.

```
SUBROUTINE COMPUTE_FLUXES(FLUX_MOM, FLUX_SENS, FLUX_LAT)
USE,INTRINSIC :: ISO_FORTRAN_ENV, ONLY: TEAM_TYPE
REAL, INTENT(OUT) :: FLUX_MOM(:,:), FLUX_SENS(:,:), FLUX_LAT(:,:)
INTEGER, PARAMETER :: LAND=1, SEA=2, ICE=3
CHARACTER(LEN=10)  :: SURFACE_TYPE
INTEGER            :: MY_SURFACE_TYPE, N_IMAGE
TYPE(TEAM_TYPE)    :: TEAM_SURFACE_TYPE

   CALL GET_SURFACE_TYPE(THIS_IMAGE(), SURFACE_TYPE) ! Surface type
   SELECT CASE (SURFACE_TYPE)                   ! of the executing image
   CASE ("LAND")
      MY_SURFACE_TYPE = LAND
   CASE ("SEA")
      MY_SURFACE_TYPE = SEA
   CASE ("ICE")
      MY_SURFACE_TYPE = ICE
   CASE DEFAULT
      ERROR STOP
   END SELECT
   FORM TEAM(MY_SURFACE_TYPE, TEAM_SURFACE_TYPE)

   CHANGE TEAM(TEAM_SURFACE_TYPE)
      SELECT CASE (TEAM_ID( ))
      CASE (LAND    )   ! Compute fluxes over land surface
         CALL COMPUTE_FLUXES_LAND(FLUX_MOM, FLUX_SENS, FLUX_LAT)
      CASE (SEA)    ! Compute fluxes over sea surface
         CALL COMPUTE_FLUXES_SEA(FLUX_MOM, FLUX_SENS, FLUX_LAT)
      CASE (ICE)    ! Compute fluxes over ice surface
         CALL COMPUTE_FLUXES_ICE(FLUX_MOM, FLUX_SENS, FLUX_LAT)
      CASE DEFAULT
         ERROR STOP
      END SELECT
   END TEAM
END SUBROUTINE COMPUTE_FLUXES
```

A.1.2 Accessing coarrays in sibling teams

The following program shows the subdivision of a 4 x 4 grid into 2 x 2 teams and addressing of sibling teams.

```
PROGRAM DEMO
```

```
! Initial team : 16 images. Algorithm design is a 4 x 4 grid.
! Desire 4 teams, for the upper left (UL), upper right (UR),
!                          Lower left (LL), lower right (LR)
  USE,INTRINSIC :: ISO_FORTRAN_ENV, ONLY: team_type
  TYPE (team_type) :: t
  INTEGER,PARAMETER :: UL=11, UR=22, LL=33, LR=44
  REAL    :: A(10,10)[4,*]
  INTEGER :: mype, teamid, newpe
  INTEGER :: UL_image_list(4) = [1, 2, 5, 6], &
             LL_image_list(4) = UL_image_list + 2,  &
             UR_image_list(4) = UL_image_list + 8,  &
             LR_image_list(4) = UL_image_list + 10

  mype = THIS_IMAGE()
  IF (any(mype == UL_image_list)) teamid = UL
  IF (any(mype == LL_image_list)) teamid = LL
  IF (any(mype == UR_image_list)) teamid = UR
  IF (any(mype == LR_image_list)) teamid = LR
  FORM TEAM (teamid, t)

  a = 3.14

  CHANGE TEAM (t, b[2,*] => a)
    ! Inside change team, image pattern for B is a 2 x 2 grid
    b(5,5) = b(1,1)[2,1]

    ! Outside the team addressing:

    newpe = THIS_IMAGE()
    SELECT CASE (team_id())
    CASE (UL)
       IF (newpe == 3) THEN
           b(:,10) = b(:,1)[1, 1, TEAM_ID=UR]  ! Right column of UL gets
                                               ! left column of UR
       ELSE IF (newpe == 4) THEN
           b(:,10) = b(:,1)[2, 1, TEAM_ID=UR]
       END IF
    CASE (LL)
       ! Similar to complete column exchange across middle of the
       ! original grid
    END SELECT
   END TEAM
END PROGRAM DEMO
```

A.1.3 Reducing the codimension of a coarray

This example illustrates how to use a subroutine to coordinate cross-image access to a coarray for row and column processing.

```
PROGRAM row_column
  USE, INTRINSIC :: iso_fortran_env, ONLY : team_type
  IMPLICIT NONE

  TYPE(team_type), target :: row_team, col_team
  TYPE(team_type), pointer :: used_team
```

```
  REAL, ALLOCATABLE :: a(:,:)[:,:]
  INTEGER :: ip, na, p, me(2)

  p = ... ; q = ... ! such that p*q == num_images()
  na = ...          ! local problem size

  ! allocate and initialize data
  ALLOCATE(a(na,na)[p,*])
  a = ...

  me = this_image(a)

  FORM TEAM(me(1), row_team, NEW_INDEX=me(2))
  FORM TEAM(me(2), col_team, NEW_INDEX=me(1))

  ! make a decision on whether to process by row or column
  IF (...) THEN
     used_team => row_team
  ELSE
     used_team => col_team
  END IF

  ... ! do local computations on a

  CHANGE TEAM (used_team)

    CALL further_processing(a, ...)

  END TEAM
CONTAINS
  SUBROUTINE further_processing(a, ...)
    REAL :: a(:,:)[*]
    INTEGER :: ip

    ! update ip-th row or column submatrix
    a(:,:)[ip] = ...

    SYNC ALL
    ... ! do further local computations on a

  END SUBROUTINE
END PROGRAM row_column
```

A.2 Clause 6 notes

A.2.1 Example involving failed images

Parallel algorithms often use work sharing schemes based on a specific mapping between image indices and global data addressing. To allow such programs to continue when one or more images fail, spare images can be used to re-establish execution of the algorithm with the failed images replaced by spare images, while retaining the image mapping.

The following example illustrates how this might be done. In this setup, failure cannot be tolerated for image 1 in the initial team.

```
PROGRAM possibly_recoverable_simulation
  USE, INTRINSIC :: iso_fortran_env, ONLY: team_type, STAT_FAILED_IMAGE
  IMPLICIT NONE
  INTEGER, ALLOCATABLE :: failed_img(:)
  INTEGER :: images_used, i, images_spare, status
  INTEGER :: id[*], me[*]
  TYPE(team_type) :: simulation_team
  LOGICAL :: read_checkpoint, done[*]

  images_used = ...  ! A value slightly less num_images()
  images_spare = num_images() - images_used
  read_checkpoint = this_image() > images_used

  setup : DO
    me = this_image()
    id = 1
    IF (me > images_used) id = 2
!
! Set up spare images as replacement for failed ones
  IF (image_status(1) == STAT_FAILED_IMAGE) &
      ERROR STOP "cannot recover"
  IF (this_image() == 1) THEN
     failed_img = failed_images()
     k = images_used
     DO i = 1, size(failed_img)
        DO k = k+1, num_images()
           IF (image_status(k) == 0) EXIT
        END DO
        IF (k > num_images()) ERROR STOP "cannot recover"
        me[k] = failed_img(i)
        id[k] = 1
     END DO
     images_used = k
  END IF
!
! Set up a simulation team of constant size.
! id == 2 does not participate in team execution
  FORM TEAM (id, simulation_team, NEW_INDEX=me, STAT=status)
  simulation : CHANGE TEAM (simulation_team, STAT=status)
  IF (status==STAT_FAILED_IMAGE) EXIT simulation
      IF (TEAM_ID() == 1) THEN
        iter : DO
          CALL simulation_procedure(read_checkpoint, status, done)
!         simulation_procedure:
!           sets up required objects (maybe coarrays)
!           reads checkpoint if requested
!           returns status on its internal synchronizations
!           returns .TRUE. in done once complete
             read_checkpoint = .FALSE.
          IF (status == STAT_FAILED_IMAGE) THEN
             read_checkpoint = .TRUE.
             EXIT simulation
          ELSE IF (done)
             EXIT iter
          END IF
```

```
         END DO iter
       END IF
     END TEAM simulation (STAT=status)
     SYNC ALL (STAT=status)
     IF (this_image() > images_used) done = done[1]
     IF (done) EXIT setup
   END DO setup
END PROGRAM possibly_recoverable_simulation
```

Supporting fail-safe execution imposes obligations on library writers who use the parallel language facilities. Every synchronization statement, allocation or deallocation of coarrays, or invocation of a collective procedure must specify a synchronization status variable, and implicit deallocation of coarrays must be avoided. In particular, coarray module variables that are allocated inside the team execution context are not persistent.

A.3 Clause 7 notes

A.3.1 EVENT_QUERY example

The following example illustrates the use of events via a program in which image 1 acts as master and distributes work items to the other images. Only one work item at a time can be active on a worker image, and each deals with the result (e.g. via I/O) without directly feeding data back to the master image.

Because the work items are not expected to be balanced, the master keeps cycling through all images to find one that is waiting for work.

An event is posted by each worker to indicate that it has completed its work item. Since the corresponding variables are needed only on the master, we place them in an allocatable array component of a coarray. An event on each worker is needed for the master to post the fact that it has made a work item available for it.

```
PROGRAM work_share
   USE, INTRINSIC :: iso_fortran_env, ONLY: event_type
   USE :: mod_work, ONLY:   & ! Module that creates work items
          work,             & ! Type for holding a work item
          create_work_item, & ! Function that creates work item
          process_item,     & ! Function that processes an item
          work_done           ! Logical function that returns true
                              !  if all work done

   TYPE :: worker_type
       TYPE(event_type), ALLOCATABLE :: free(:)
   END TYPE
   TYPE(event_type)  :: submit[*]    ! Post when work ready for a worker
   TYPE(worker_type) :: worker[*]    ! Post when worker is free
   TYPE(work)        :: work_item[*] ! Holds the data for a work item
   INTEGER :: count, i, nbusy[*]

    IF (this_image() == 1) THEN
      ! Get started
      ALLOCATE(worker%free(2:num_images()))
      nbusy = 0 ! This holds the number of workers working
      DO i = 2, num_images() ! Start the workers working
         IF (work_done()) EXIT
         nbusy = nbusy + 1
         work_item[i] = create_work_item()
         EVENT POST (submit[i])
```

```
      END DO
      ! Main work distribution loop
      master : DO
         image : DO i = 2, num_images()
            CALL EVENT_QUERY(worker%free(i), count)
            IF (count == 0) CYCLE image! Worker is not free
            EVENT WAIT (worker%free(i))
            nbusy = nbusy - 1
            IF (work_done()) CYCLE
            nbusy = nbusy + 1
            work_item[i] = create_work_item()
            EVENT POST (submit[i])
         END DO image
         IF ( nbusy==0 ) THEN ! All done. Exit on all images.
            DO i = 2, num_images()
               EVENT POST (submit[i])
            END DO
            EXIT master
         END IF
      END DO master
   ELSE
      ! Work processing loop
      worker : DO
         EVENT WAIT (submit)
         IF (nbusy[1] == 0) EXIT
         CALL process_item(work_item)
         EVENT POST (worker[1]%free(this_image()))
      END DO worker
   END IF
END PROGRAM work_share
```

A.3.2 EVENT_QUERY example that tolerates image failure

This example is an adaptation of the example of A.2.1 to make it able to execute in the presence of the failure of one or more of the worker images. The function create_work_item now accepts an integer argument to indicate which work item is required. It is assumed that the work items are indexed 1, 2, ... It is also assumed that if an image fails while processing a work item, that work item can subsequently be processed by another image.

```
PROGRAM work_share
   USE, INTRINSIC :: iso_fortran_env, ONLY: event_type
   USE :: mod_work, ONLY:   & ! Module that creates work items
          work,             & ! Type for holding a work item
          create_work_item, & ! Function that creates work item
          process_item,     & ! Function that processes an item
          work_done           ! Logical function that returns true
                              !  if all work done

   TYPE :: worker_type
      TYPE(event_type), ALLOCATABLE :: free(:)
   END TYPE
   TYPE(event_type)  :: submit[*]     ! Whether work ready for a worker
   TYPE(worker_type) :: worker[*]     ! Whether worker is free
   TYPE(work)        :: work_item[*]  ! Holds the data for a work item
   INTEGER :: count, i, k, kk, nbusy[*], np, status
   INTEGER, ALLOCATABLE :: working(:) ! Items being worked on
```

```
      INTEGER, ALLOCATABLE :: pending(:) ! Items pending after image failure

       IF (this_image() == 1) THEN
         ! Get started
         ALLOCATE(worker%free(2:num_images()))
         ALLOCATE(working(2:num_images()), pending(num_images()-1))
         nbusy = 0              ! This holds the number of workers working
         k = 1                  ! Index of next work item
         np = 0                 ! Number of work items in array pending
         DO i = 2, num_images() ! Start the workers working
            IF (work_done()) EXIT
            working(i) = 0
            CALL EVENT_QUERY(submit[i],count,STAT=status) ! Test image i
            IF (status==STAT_FAILED_IMAGE) CYCLE
            work_item[i] = create_work_item(k)
            working(i) = k
            k = k + 1
            nbusy = nbusy + 1
            EVENT POST (submit[i], STAT=status)
         END DO
         ! Main work distribution loop
         master : DO
            image : DO i = 2, num_images()
               CALL EVENT_QUERY(submit[i],count,STAT=status) ! Test image i
               IF (status==STAT_FAILED_IMAGE) THEN      ! Image i has failed
                  IF (working(i)>0) THEN           ! It failed while working
                     np = np + 1
                     pending(np) = working(i)
                     working(i) = 0
                  END IF
                  CYCLE image
               END IF
               CALL EVENT_QUERY(worker%free(i), count)
               IF (count == 0) CYCLE image        ! Worker is not free
               EVENT WAIT (worker%free(i))
               nbusy = nbusy - 1
               IF (np>0) THEN
                  kk = pending(np)
                  np = np - 1
               ELSE
                  IF (work_done()) CYCLE image
                  kk = k
                  k = k + 1
               END IF
               nbusy = nbusy + 1
               working(i) = kk
               CALL EVENT_QUERY(submit[i],count,STAT=status) ! Test image i
               IF (status/=STAT_FAILED_IMAGE) &
                         work_item[i] = create_work_item(kk)
               EVENT POST (submit[i],STAT=status)
               ! If image i has failed, this will not hang and the failure
               ! will be handled on the next iteration of the loop
            END DO image
            IF ( nbusy==0 ) THEN ! All done. Exit on all images.
               DO i = 2, num_images()
```

```
                EVENT POST (submit[i],STAT=status)
                IF (status==STAT_FAILED_IMAGE) CYCLE
             END DO
             EXIT master
          END IF
       END DO master
    ELSE
       ! Work processing loop
       worker : DO
          EVENT WAIT (submit)
          IF (nbusy[1] == 0) EXIT worker
          CALL process_item(work_item)
          EVENT POST (worker[1]%free(this_image()))
       END DO worker
    END IF
END PROGRAM work_share
```

A.3.3 EVENTS example

A tree is a graph in which every node except one has a single “parent” node to which it is connected by an edge. The node without a parent is the “root”. The nodes that have a given node as parent are the “children” of that node. The root is at level 1, its children are at level 2, etc.

A multifrontal code to solve a sparse set of linear equations involves a tree. Work at a node starts after work at all its children is complete and their data has been passed to it.

Here we assume that all nodes have been assigned to images. Each image has a list of its nodes and these are ordered in decreasing tree level (all those at level L preceding those at level $L-1$). For each node, array elements hold the number of children, details about the parent and an event variable. This allows the processing to proceed asynchronously subject to the rule that a parent must wait for all its children as follows:

```
PROGRAM TREE
  USE, INTRINSIC :: ISO_FORTRAN_ENV
  INTEGER,ALLOCATABLE :: NODE(:) ! Tree nodes that this image handles
  INTEGER,ALLOCATABLE :: NC(:)   ! NODE(I) has NC(I) children
  INTEGER,ALLOCATABLE :: PARENT(:), SUB(:)
                ! The parent of NODE(I) is NODE(SUB(I))[PARENT(I)]
  TYPE(EVENT_TYPE),ALLOCATABLE :: DONE(:)[*]
  INTEGER :: I, J, STATUS
! Set up the tree, including allocation of all arrays.
  DO I = 1, SIZE(NODE)
    ! Wait for children to complete
    EVENT WAIT(DONE(I),UNTIL_COUNT=NC(I),STAT=STATUS)
    IF (STATUS/=0) EXIT

    ! Process node, using data from children
    IF (PARENT(I)>0) THEN
       ! Node is not the root.
       ! Place result on image PARENT(I) for node NODE(SUB)[PARENT(I)]
       ! Tell PARENT(I) that this has been done.
       EVENT POST(DONE(SUB(I))[PARENT(I)],STAT=STATUS)
       IF (STATUS/=0) EXIT
    END IF
  END DO
END PROGRAM TREE
```

A.4 Clause 8 notes

A.4.1 Collective subroutine examples

The following example computes a dot product of two scalar coarrays using the co_sum intrinsic to store the result in a noncoarray scalar variable:

```
  subroutine codot(x,y,x_dot_y)
     real :: x[*],y[*],x_dot_y
     x_dot_y = x*y
     call co_sum(x_dot_y)
  end subroutine codot
```

The function below demonstrates passing a noncoarray dummy argument to the co_max intrinsic. The function uses co_max to find the maximum value of the dummy argument across all images. Then the function flags all images that hold values matching the maximum. The function then returns the maximum image index for an image that holds the maximum value:

```
  function find_max(j) result(j_max_location)
    integer, intent(in) :: j
    integer j_max,j_max_location
    j_max = j
    call co_max(j_max)
! Flag images that hold the maximum j
    if (j==j_max) then
       j_max_location = this_image()
    else
       j_max_location = 0
    end if
! Return highest image index associated with a maximal j
    call co_max(j_max_location)
  end function find_max
```

A.4.2 Atomic memory consistency

A.4.2.1 Relaxed memory model

Parallel programs sometimes have apparently impossible behavior because data transfers and other messages can be delayed, reordered and even repeated, by hardware, communication software, and caching and other forms of optimization. Requiring processors to deliver globally consistent behavior is incompatible with performance on many systems. Fortran specifies that all ordered actions will be consistent (2.3.5 and 8.5 in ISO/IEC 1539-1:2010), but all consistency between unordered segments is deliberately left processor dependent or undefined. Depending on the hardware, this can be observed even when only two images and one mechanism are involved.

A.4.2.2 Examples with atomic operations

When variables are being referenced (atomically) from segments that are unordered with respect to the segment that is is atomically defining or redefining the variables, the results are processor dependent. This supports use of so-called "relaxed memory model" architectures, which can enable more efficient execution on some hardware implementations.

The following examples assume the following declarations:

```
   MODULE example
     USE,INTRINSIC :: ISO_FORTRAN_ENV
     INTEGER(ATOMIC_INT_KIND) :: x[*] = 0, y[*] = 0
```

Example 1:

With x[j] and y[j] still in their initial state (both zero), image j executes the following sequence of statements:

```
  CALL ATOMIC_DEFINE(x,1)
  CALL ATOMIC_DEFINE(y,1)
```

and image k executes the following sequence of statements:

```
  DO
    CALL ATOMIC_REF(tmp,y[j])
    IF (tmp==1) EXIT
  END DO
  CALL ATOMIC_REF(tmp,x[j])
  PRINT *,tmp
```

The final value of tmp on image k can be either 0 or 1. That is, even though image j thinks it wrote x[j] before writing y[j], this ordering is not guaranteed on image k.

There are many aspects of hardware and software implementation that can cause this effect, but conceptually this example can be thought of as the change in the value of y propagating faster across the inter-image connections than the change in the value of x.

Changing the execution on image j by inserting

```
  SYNC MEMORY
```

in between the definitions of x and y is not sufficient to prevent unexpected results; even though x and y are being updated in ordered segments, the references from image k are both from a segment that is unordered with respect to image j.

To guarantee the expected value for tmp of 1 at the end of the code sequence on image k, it is necessary to ensure that the atomic reference on image k is in a segment that is ordered relative to the segment on image j that defined x[j]; SYNC MEMORY is certainly necessary, but not sufficient unless it is somehow synchronized.

Example 2:

With the initial state of x and y on image j (i.e. x[j] and y[j]) still being zero, execution of

```
    CALL ATOMIC_REF(tmp,x[j])
    CALL ATOMIC_DEFINE(y[j],1)
    PRINT *,tmp
```

on image k1, and execution of

```
    CALL ATOMIC_REF(tmp,y[j])
    CALL ATOMIC_DEFINE(x[j],1)
    PRINT *,tmp
```

on image k2, in unordered segments, might print the value 1 both times.

This can happen by such mechanisms as “load buffering”; one might imagine that what is happening is that the writes (ATOMIC_DEFINE) are overtaking the reads (ATOMIC_REF).

It is likely that insertion of SYNC MEMORY between the calls to ATOMIC_REF and ATOMIC_DEFINE will be sufficient to prevent this anomalous behavior, but that is only guaranteed by the standard if the SYNC MEMORY executions cause an ordering between the relevant segments on images k1 and k2.

Example 3:

Because there are no segment boundaries implied by collective subroutines, with the initial state as before, execution of

```
    IF (THIS_IMAGE()==1) THEN
      CALL ATOMIC_DEFINE(x[3],23)
      y = 42
    ENDIF
    CALL CO_BROADCAST(y,1)
    IF (THIS_IMAGE()==2) THEN
      CALL ATOMIC_REF(tmp,x[3])
      PRINT *,y,tmp
    END IF
```

could print the values 42 and 0.

Example 4:

Assuming the declarations

```
INTEGER(ATOMIC_INT_KIND) :: x[*]= 0, z = 0
```

the statements

```
CALL ATOMIC_ADD(x[1], 1)         ! (A)
IF (THIS_IMAGE() == 2) THEN
  wait : DO
     CALL ATOMIC_REF(z, x[1])    ! (B)
     IF (z == NUM_IMAGES()) EXIT wait
  END DO wait                    ! (C)
END IF
```

will execute the “wait” loop on image 2 until all images have completed statement (A). The updates of x[1] are performed by each image in the same manner, but arbitrary order. Because the result from the complete set of updates will eventually become visible by execution of statement (B) for some loop iteration on image 2, the termination condition is guaranteed to be eventually fulfilled, provided that no image failure occurs, every image executes the above code, and no other code is executed in an unordered segment that performs updates to x[1]. Furthermore, if two SYNC MEMORY statements are inserted in the above code before statement (A) and after statement (C), respectively, the segment started by the second SYNC MEMORY on image 2 is ordered after the segments on all images that end with the first SYNC MEMORY.