Parallel Programming Features in the Fortran Standard

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Agenda

• Overview of popular parallelism methodologies
• FORALL – a look back
• DO CONCURRENT
• Coarrays
• Fortran 2015
• Q+A
Fortran on the Side
Popular Parallelism Methodologies

• Defined by multi-vendor consortiums
  – OpenMP*
    – Threading on shared-memory systems
    – Directive-based
    – Single program execution, fork-join parallelism
    – Requires compiler support
    – OpenMP Architecture Review Board – OpenMP.org
  – Message Passing Interface (MPI)
    – Shared or distributed memory
    – API (procedure call) based
    – Multiple copies of program run in parallel
    – No explicit compiler support required, but...
    – MPI Forum – mpi-forum.org
Popular Parallelism Methodologies

• Implementation-specific
  – OS threads (Windows threads, pthreads, etc.)
    – Defined by OS vendor
    – API based
    – Single copy of program, typically “worker threads”
    – No explicit compiler support required
  – Auto-Parallel
    – Feature of Intel (and some other) compilers
    – Directives needed for best performance
    – Loops and array operations only
    – Compiler support required
The Fortran Way
FORALL (1/2)

- Provides array assignments controlled by a “triplet-spec” and, optionally, a mask
- Originally part of High-Performance Fortran, a dialect extending Fortran 90
- Adopted in Fortran 95
- Example:

```fortran
FORALL (I=1:10, J=1:10, B(I,J)/=0)
    A(I,J) = REAL(I+J+2)
    B(I,J) = A(I,J) + B(I,J) * REAL(I*J)
END FORALL
```
FORALL (2/2)

• Not a loop construct!
• Each array assignment evaluated completely in turn
• Inefficient to parallelize
DO CONCURRENT (1/3)

• New in Fortran 2008
• Uses FORALL header, but no mask
• Iterations can execute in any order and to any degree of parallelism
  – Programmer is responsible for making sure there are no loop-carried dependencies
• Intel Fortran will attempt to parallelize with auto-parallel enabled
• Helps vectorization
• Fork-join model
DO CONCURRENT (2/3)

• Example:
  DO CONCURRENT (I=1:N)
    A(I) = T + (B(I) * C(I))
  END DO

• Limitations
  – Must use BLOCK to create iteration-private variables
    – Intel Fortran doesn’t yet support BLOCK 😞
  – Not suitable for reductions
  – I/O allowed, but no dependence on order
DO CONCURRENT (3/3)

• Example using BLOCK:
  DO CONCURRENT (I=1:N)
    BLOCK
      REAL :: T
      T = A(I) + B(I)
      C(I) = T + SQRT(I)
    END BLOCK
  END DO

• Scatter/Gather example:
  DO CONCURRENT (I=1:M)
    A(IND(I)) = I
  END DO
Coarrays

• New in Fortran 2008
• Derived from “F--” specification in early 2000s
• Cray implementation on T3E and X1 supercomputers
• Partitioned Global Address Space (PGAS) model
  – PGAS also used by UPC, X10, Chapel
• Multiple copies of program run in parallel
  – Each copy called an “image”
Coarrays

• What is a coarray?
  – Variable declared to have CODIMENSIONs with []
    – REAL, DIMENSION(1000), CODIMENSION [*] :: X
  – Last codimension must be * - computed at runtime from number of images
  – Can be array or scalar
  – Each image has its own piece of the coarray
  – Images can reference other image’s pieces by using “coindices” enclosed in []
    – X[3]
  – Images can reference their own piece by omitting the []
Coarrays

REAL :: X(2,2) [*] ! Assume four images

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X(2,1) on image 2

X(1,2)[3] on image 4
Coarrays

• Mapping of objects with codimensions: 2D real, codimension[2,*] :: x

• Mapping of X if program run with 6 images:

  Image 1  X[1,1]  Image 3  X[1,2]  Image 5  X[1,3]
  Image 2  X[2,1]  Image 4  X[2,2]  Image 6  X[2,3]

  Mapping of X if program run with 9 images:

  Image 1  X[1,1]  Image 3  X[1,2]  Image 5  X[1,3]  Image 7  X[1,4]  Image 9  X[1,5]
Coarrays

• Coarrays can be...
  – ALLOCATABLE
  – Polymorphic
  – Used in assignments and expressions
  – Used in READ and WRITE statements
  – Passed as arguments to procedures
  – Used as dummy arguments in procedures (explicit interface required)

• Coarrays can’t be...
  – Allocated differently in different images
  – Interoperable with C
Coarrays and Synchronization

• Implicit synchronization points
  – At image start
  – When a coarray is allocated
  – At image end

• Explicit synchronization
  – SYNC ALL
  – SYNC IMAGES (image-list)
  – SYNC MEMORY (image-list)
  – Critical sections (CRITICAL...END CRITICAL)
  – LOCK and UNLOCK statements
  – ATOMIC_DEFINE and ATOMIC_REF intrinsics
  – ERROR STOP
Intrinsics for coarrays

- `NUM IMAGES()`
- `IMAGE_INDEX(varname)`
- `LCOBOUND(varname)`
- `UCOBOUND(varname)`
- `THIS_IMAGE()`
Input and Output with coarrays

- “Standard output” (unit 6) preconnected in all images
  - Intel Fortran will “merge the streams” and display in image 1
  - Order of output not guaranteed
- “Standard input” (unit 5) preconnected for image 1 only
- For all other units, each image has their own independent set
Example coarray code

my_subgrid( 0, 1:my_M) = my_subgrid( my_N, 1:my_M)[my_north_P,me_Q]
my_subgrid( my_N+1, 1:my_M) = my_subgrid( 1, 1:my_M)[my_south_P,me_Q]
my_subgrid( 1:my_N, my_M+1) = my_subgrid( 1:my_N, 1 )[me_P, my_east_Q]
my_subgrid( 1:my_N, 0 ) = my_subgrid( 1:my_N, my_M )[me_P, my_west_Q]

max_global = MAXVAL( ABS( my_subgrid_new_values(1:my_N,1:my_M) - &
                      my_subgrid(1:my_N,1:my_M) ) )
SYNC ALL ! protects both max_global and my_subgrid
IF (me == 1) THEN
   DO I= 2,NUM_IMAGES()
      max_local = max_global[I]
      max_global = MAX( max_global, max_local )
   END DO
END IF
Coarrays in Intel Fortran (1/2)

- Supported on Linux and Windows only
- Underlying transport is Intel MPI
  - Run-time libraries provided
- Shared memory model included with Composer XE
- Distributed memory model (cluster) requires Intel Cluster Studio XE license
- Windows cluster support added in Composer XE 2011 Update 6
Coarrays in Intel Fortran (2/2)

• Compile with -coarray (/Qcoarray) to get coarray syntax and features enabled
• For shared memory, just run executable
• For distributed memory, use -coarray=distributed (/Qcoarray:distributed) and define MPI ring
• Whole programs only – can’t create coarray-using library for use by non-coarray programs
Fortran 2015
Fortran 2015

• Name for next revision of Fortran Standard
• Technical work to be completed in 2014
• Enhancements to C Interoperability (TS29113)
• Enhancements to coarray features
  – Draft under development
    – Teams
    – Events
    – Collective procedures
    – Additional atomic procedures

• Corrections and Clarifications
Q+A
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