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:

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
• 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

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:

<table>
<thead>
<tr>
<th>Image 1</th>
<th>Image 3</th>
<th>Image 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>X[1,1]</td>
<td>X[1,2]</td>
<td>X[1,3]</td>
</tr>
<tr>
<td>Image 2</td>
<td>Image 4</td>
<td>Image 6</td>
</tr>
<tr>
<td>X[2,1]</td>
<td>X[2,2]</td>
<td>X[2,3]</td>
</tr>
</tbody>
</table>

Mapping of X if program run with 9 images:

<table>
<thead>
<tr>
<th>Image 1</th>
<th>Image 3</th>
<th>Image 5</th>
<th>Image 7</th>
<th>Image 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>X[1,1]</td>
<td>X[1,2]</td>
<td>X[1,3]</td>
<td>X[1,4]</td>
<td>X[1,5]</td>
</tr>
<tr>
<td>Image 2</td>
<td>Image 4</td>
<td>Image 6</td>
<td>Image 8</td>
<td></td>
</tr>
</tbody>
</table>
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

\[
\begin{align*}
\text{my\_subgrid}(0, 1:\text{my\_M}) &= \text{my\_subgrid}(\text{my\_N}, 1:\text{my\_M})[\text{my\_north\_P}, \text{me\_Q}] \\
\text{my\_subgrid}(\text{my\_N}+1, 1:\text{my\_M}) &= \text{my\_subgrid}(1, 1:\text{my\_M})[\text{my\_south\_P}, \text{me\_Q}] \\
\text{my\_subgrid}(1:\text{my\_N}, \text{my\_M}+1) &= \text{my\_subgrid}(1:\text{my\_N}, 1)[\text{me\_P}, \text{my\_east\_Q}] \\
\text{my\_subgrid}(1:\text{my\_N}, 0) &= \text{my\_subgrid}(1:\text{my\_N}, \text{my\_M})[\text{me\_P}, \text{my\_west\_Q}] \\

\text{max\_global} &= \text{MAXVAL}(\text{ABS}(\text{my\_subgrid\_new\_values}(1:\text{my\_N},1:\text{my\_M}) - & & \\
& & \text{my\_subgrid}(1:\text{my\_N},1:\text{my\_M}) ) ) \\
\text{SYNC ALL} & ! \text{protects both max\_global and my\_subgrid} \\
\text{IF} (\text{me} == 1) & \text{THEN} \\
\text{DO I= 2,NUM\_IMAGES()} & \\
& \text{max\_local} = \text{max\_global}[\text{I}] \\
& \text{max\_global} = \text{MAX}(\text{max\_global}, \text{max\_local} ) \\
\text{END DO} \\
\text{END IF}
\end{align*}
\]
Coarrays in Intel Fortran (1/2)

• New in Intel [Visual] Fortran Composer XE 2011
• 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

• 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
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