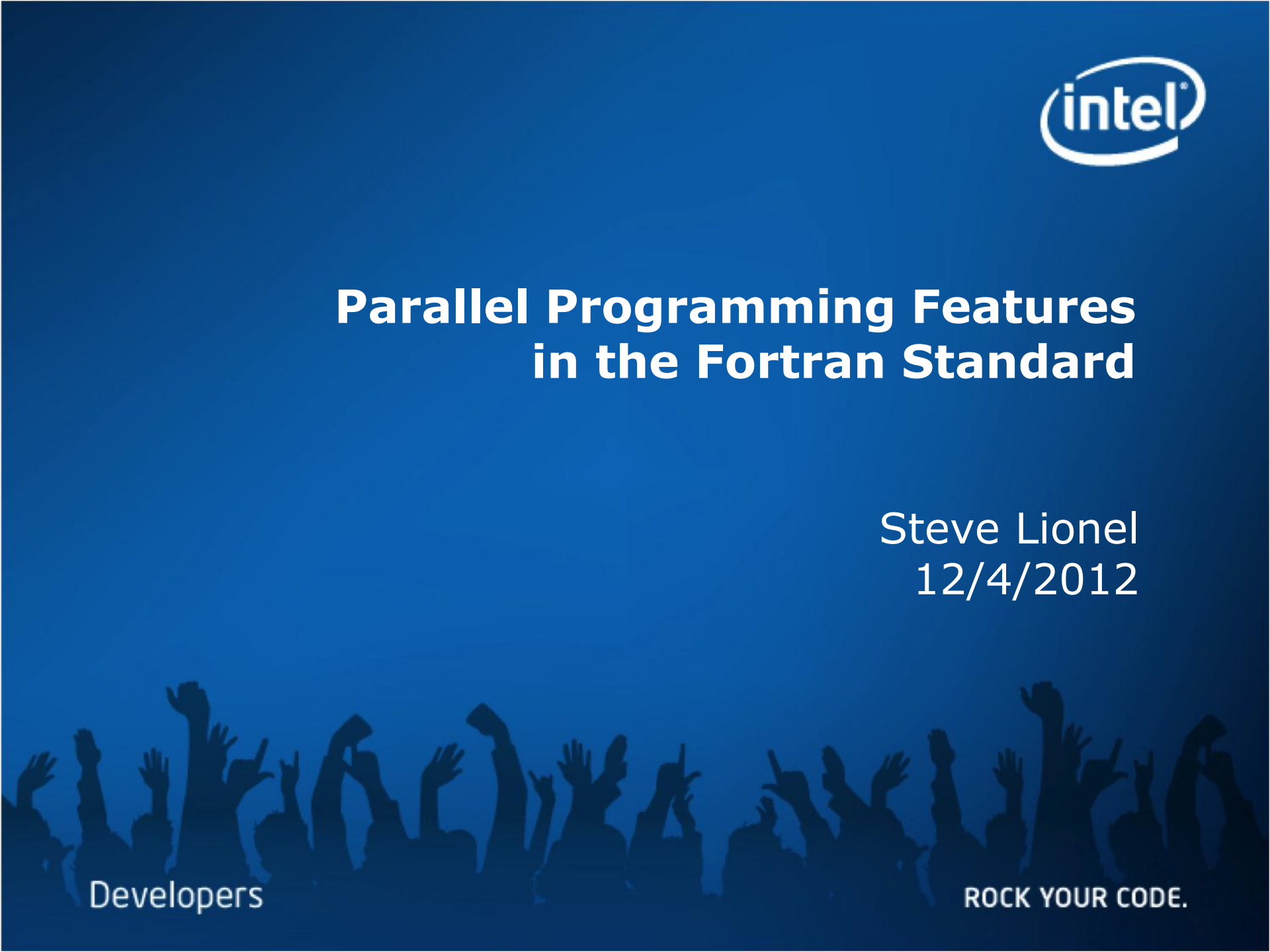
intel
Parallel Programming Features
in the Fortran Standard
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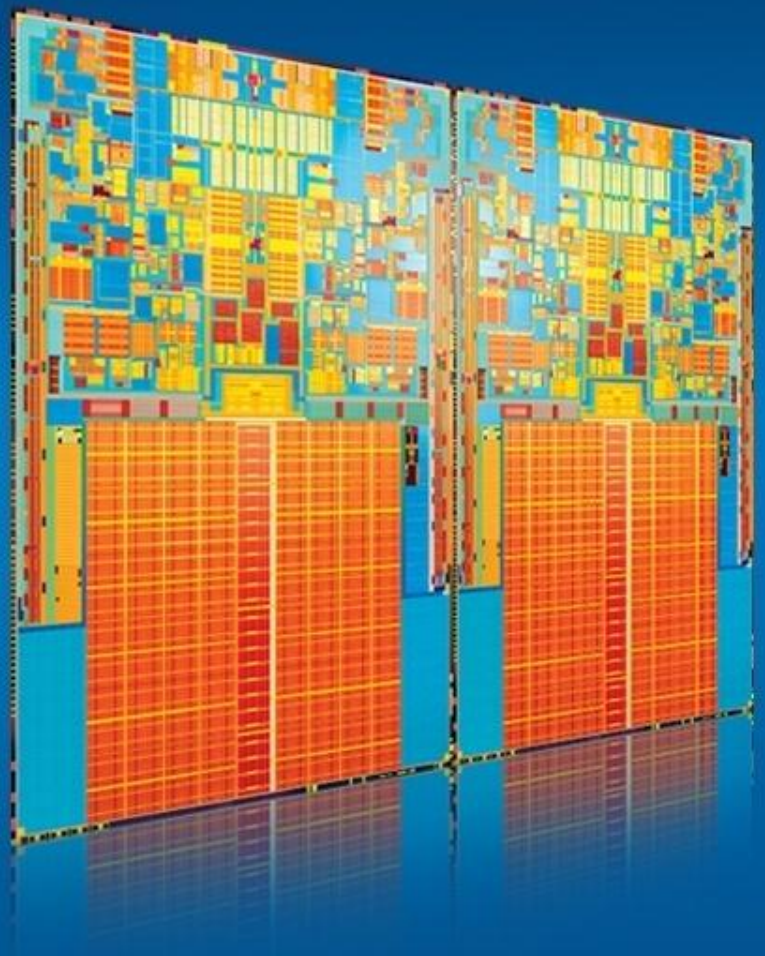
12/4/2012
Developers
ROCK YOUR CODE.

Agenda

- Overview of popular parallelism methodologies
- FORALL – a look back
- DO CONCURRENT
- Coarrays
- Fortran 2015
- Q+A



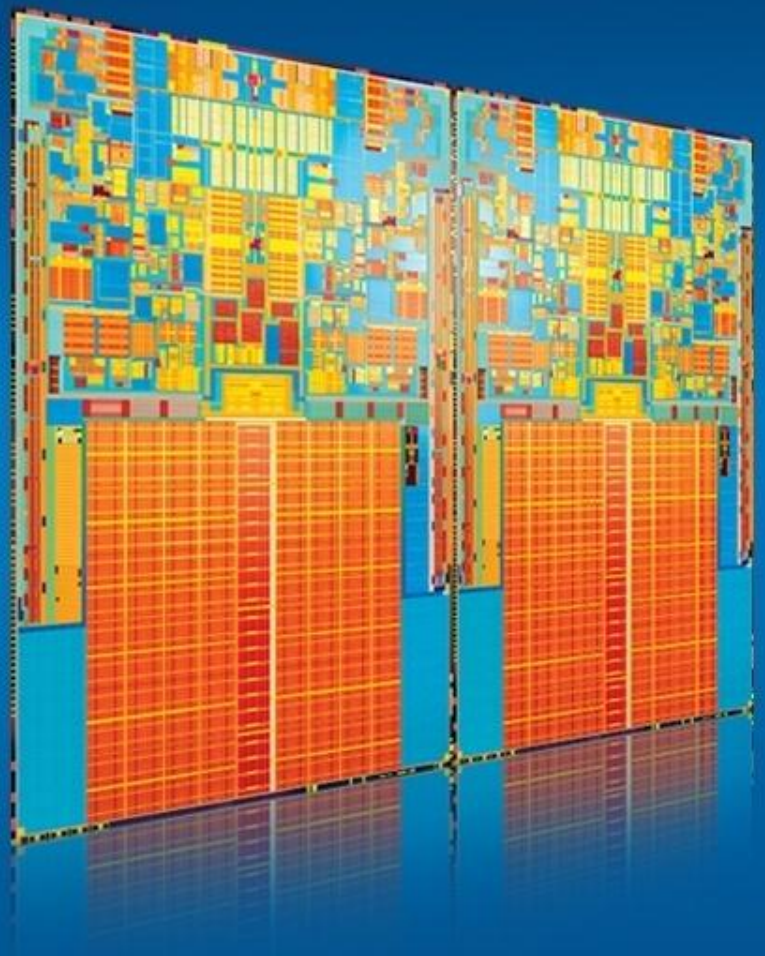
Fortran on the Side

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

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

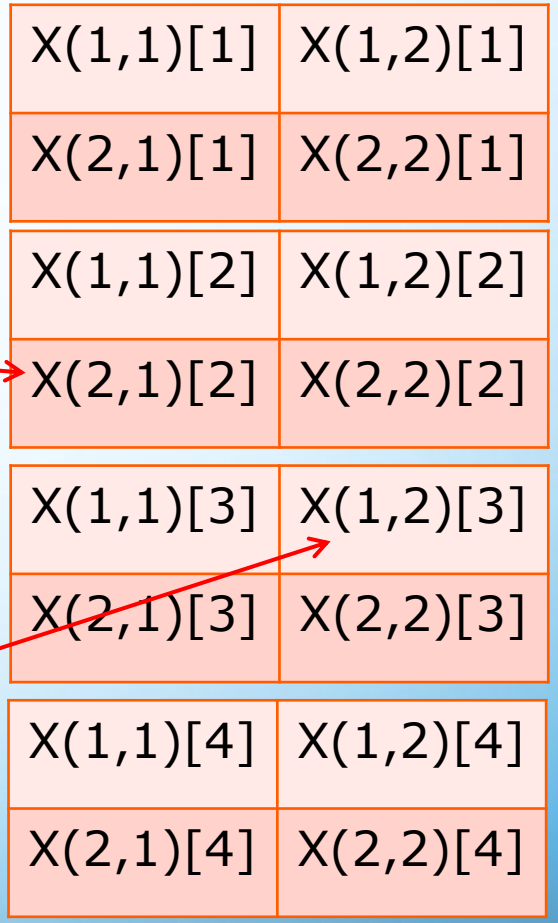
- What is a coarray?
  - Variable declared to have CODIMENSIONs with []
    - REAL, DIMENSION(1000), CODIMENSION [*] :: X
  - Last codimension must be * - computed at runtime from number of images
  - Can be array or scalar
  - Each image has its own piece of the coarray
  - Images can reference other 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

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]
Image 2 X[2,1]	Image 4 X[2,2]	Image 6 X[2,3]	Image 8 X[2,4]	

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

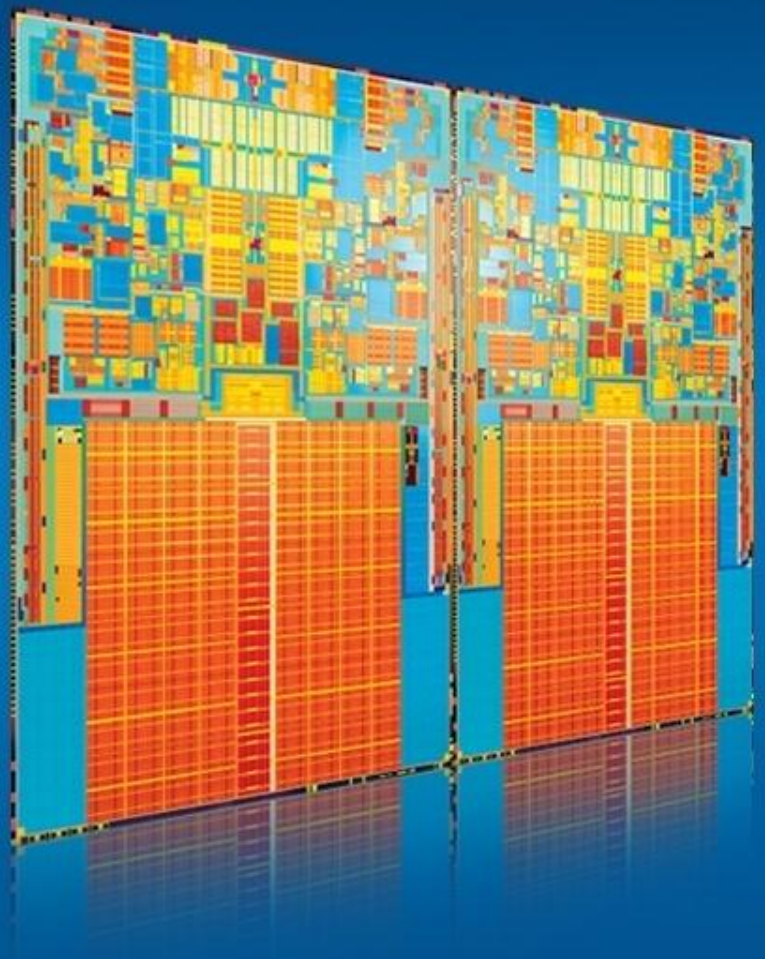
```
my_subgrid(      0, 1:my_M) = my_subgrid(   my_N, 1:my_M)[my_north_P,me_Q]
my_subgrid( my_N+1, 1:my_M) = my_subgrid(      1, 1:my_M)[my_south_P,me_Q]
my_subgrid( 1:my_N, my_M+1) = my_subgrid( 1:my_N, 1     )[me_P, my_east_Q]
my_subgrid( 1:my_N, 0     ) = my_subgrid( 1:my_N, my_M  )[me_P, my_west_Q]


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)

- 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

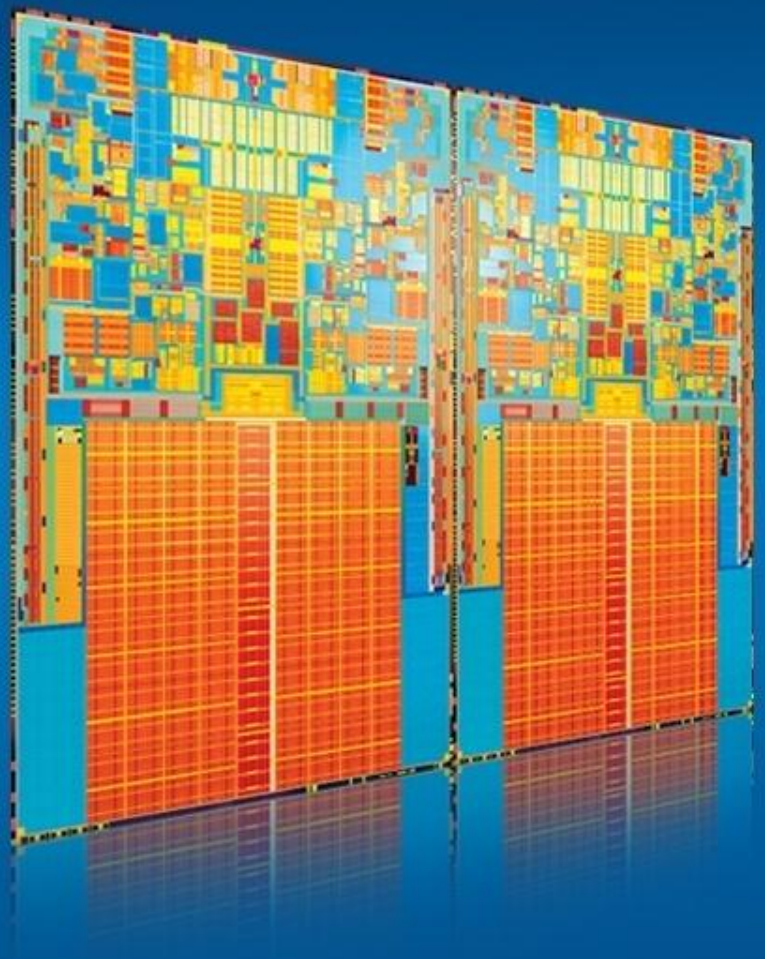


Fortran 2015

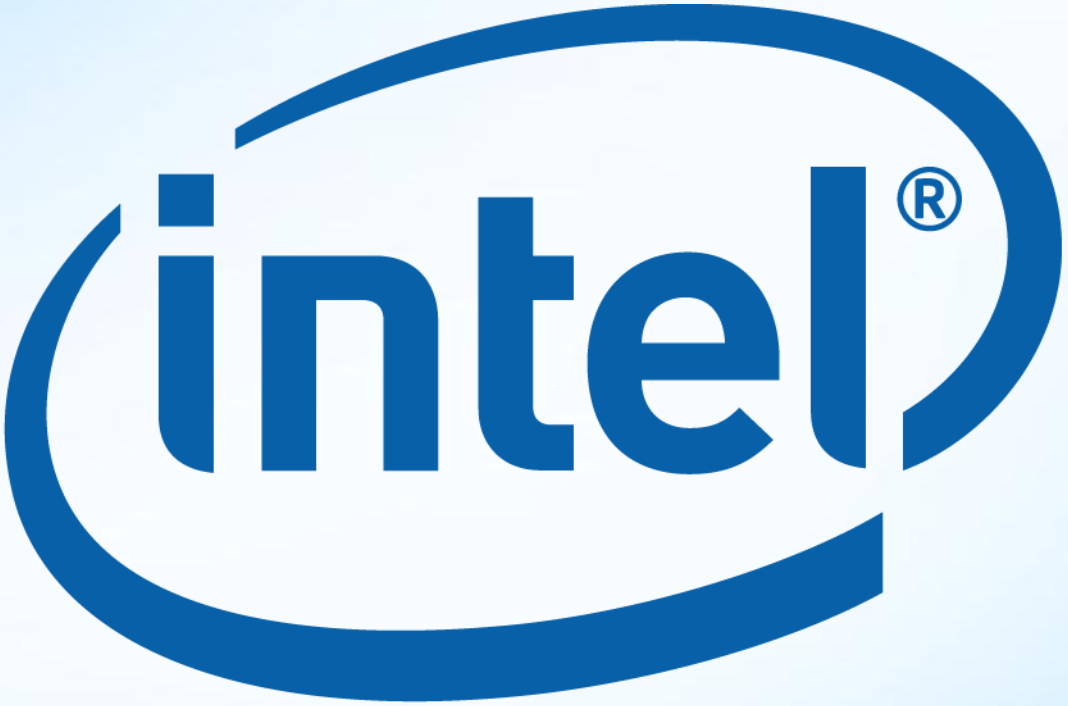
intel Software

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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