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The Cray Compiler Environment

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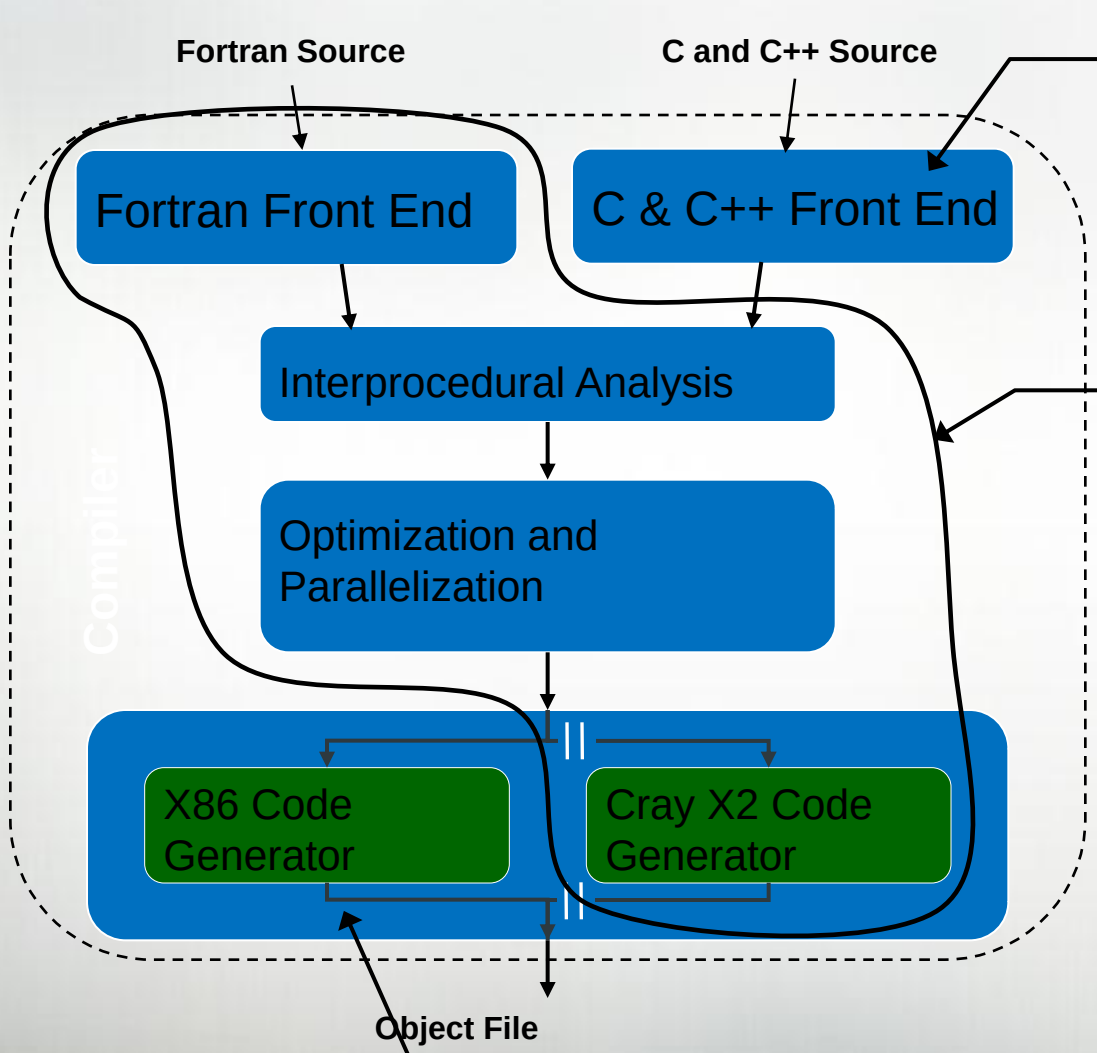
Cray Opteron Compiler: Brief History of Time

- Cray has a long tradition of high performance compilers on Cray platforms (Traditional vector, T3E, X1, X2)
  - Vectorization
  - Parallelization
  - Code transformation
  - More…
- Investigated leveraging an open source compiler called LLVM
- First release December 2008

Technology Sources



C and C++ Front End supplied by Edison Design Group, with Cray-developed code for extensions and interface support

Cray Inc. Compiler Technology

X86 Code Generation from Open Source **LLVM**, with additional Cray-developed optimizations and interface support

Why a Cray X86 Compiler?

- Standard conforming languages and programming models
  - Fortran 2003
  - UPC & CoArray Fortran
    - **Fully optimized** and integrated into the compiler
    - No preprocessor involved
    - Target the network appropriately:
      - GASNet with Portals
      - DMAPP with Gemini & Aries
- Ability and motivation to provide high-quality support for custom Cray network hardware
- Cray technology focused on scientific applications
  - Takes advantage of Cray's extensive knowledge of **automatic vectorization**
  - Takes advantage of Cray's extensive knowledge of **automatic shared memory parallelization**
  - **Supplements**, rather than replaces, the available compiler choices

Cray Opteron Compiler: How to use it

- Make sure it is available
  - module avail PrgEnv-cray
- To access the Cray compiler
  - module load PrgEnv-cray
- To target the various chip
  - module load xtpe-[barcelona,shanghi,istanbul]
- Once you have loaded the module “cc” and “ftn” are the Cray compilers
  - **Recommend just using default options**
  - Use –rm (fortran) and –hlist=m (C) to find out what happened
- man crayftn

Cray Opteron Compiler: Current Capabilities

- Excellent Vectorization
  - Vectorize more loops than other compilers
- OpenMP 3.0
  - Task and Nesting
- PGAS: Functional UPC and CAF available today
- C++ Support
- Automatic Parallelization
  - Modernized version of Cray X1 streaming capability
  - Interacts with OMP directives
- Cache optimizations
  - Automatic Blocking
  - Automatic Management of what stays in cache
- Prefetching, Interchange, Fusion, and much more…

Cray Opteron Compiler: Current Strengths

- Loop Based Optimizations
  - Vectorization
  - OpenMP
    - Autothreading
  - Interchange
  - Pattern Matching
  - Cache blocking/ non-temporal / prefetching
- Fortran 2003 Standard; working on 2008
- PGAS (UPC and Co-Array Fortran)
  - Some performance optimizations available in 7.1
- Optimization Feedback: Loopmark
- Focus

Cray Opteron Compiler: Directives

- Cray compiler supports a full and growing set of directives and pragmas

```
!dir$ concurrent
!dir$ ivdep
!dir$ interchange
!dir$ unroll
!dir$ loop_info [max_trips] [cache_na] ... Many more
!dir$ blockable
```

man directives

man loop_info

Loopmark: Compiler Feedback

- Compiler can generate an filename.lst file.
  - Contains annotated listing of your source code with letter indicating important optimizations

```
%%%   L o o p m a r k   L e g e n d   %%%
   Primary Loop Type        Modifiers
   ------- ---- ----         ---------

                             a - vector atomic memory operation
   A  - Pattern matched      b - blocked
   C  - Collapsed            f - fused
   D  - Deleted              i - interchanged
   E  - Cloned               m - streamed but not partitioned
   I  - Inlined              p - conditional, partial and/or computed
   M  - Multithreaded        r - unrolled
   P  - Parallel/Tasked      s - shortloop
   V  - Vectorized           t - array syntax temp used
   W  - Unwound              w - unwound
```

Example: Cray loopmark messages for Resid

- ftn –rm … or cc –hlist=m …

```
29.  b-------<     do i3=2,n3-1
30.  b b-----<       do i2=2,n2-1
31.  b b Vr--<         do i1=1,n1
32.  b b Vr             u1(i1) = u(i1,i2-1,i3) + u(i1,i2+1,i3)
33.  b b Vr      >            + u(i1,i2,i3-1) + u(i1,i2,i3+1)
34.  b b Vr             u2(i1) = u(i1,i2-1,i3-1) + u(i1,i2+1,i3-1)
35.  b b Vr      >            + u(i1,i2-1,i3+1) + u(i1,i2+1,i3+1)
36.  b b Vr-->         enddo
37.  b b Vr--<         do i1=2,n1-1
38.  b b Vr             r(i1,i2,i3) = v(i1,i2,i3)
39.  b b Vr      >                - a(0) * u(i1,i2,i3)
40.  b b Vr      >                - a(2) * ( u2(i1) + u1(i1-1) + u1(i1+1) )
41.  b b Vr      >                - a(3) * ( u2(i1-1) + u2(i1+1) )
42.  b b Vr-->         enddo
43.  b b----->       enddo
44.  b------->     enddo
```

Example: Cray loopmark messages for Resid (cont)

ftn-6289 ftn: VECTOR File = resid.f, Line = 29

*A loop starting at **line 29 was not vectorized** because a recurrence was found on "U1" between lines 32 and 38.*

ftn-6049 ftn: SCALAR File = resid.f, Line = 29

*A loop starting **at line 29 was blocked with block size 4.***

ftn-6289 ftn: VECTOR File = resid.f, Line = 30

A loop starting at line 30 was not vectorized because a recurrence was found on "U1" between lines 32 and 38.

ftn-6049 ftn: SCALAR File = resid.f, Line = 30

A loop starting at line 30 was blocked with block size 4.

ftn-6005 ftn: SCALAR File = resid.f, Line = 31

*A loop starting at **line 31 was unrolled 4 times.***

ftn-6204 ftn: VECTOR File = resid.f, Line = 31

*A loop starting at **line 31 was vectorized.***

ftn-6005 ftn: SCALAR File = resid.f, Line = 37

A loop starting at line 37 was unrolled 4 times.

ftn-6204 ftn: VECTOR File = resid.f, Line = 37

*A loop starting at **line 37 was vectorized.***

Cray Opteron Compiler: Current Weaknesses

- Tuned Performance
  - Vectorization (We vectorize too much)
  - Non-temporal caching
  - Cache blocking
  - Many end-cases
- Spilling
- Scheduling
- Still a young compiler

Byte Swapping

- -hbyteswapio
  - Link time option
  - Applies to all unformatted fortran IO
- Assign command
  - With the PrgEnv-cray module loaded do this:

```
setenv FILENV assign.txt
assign -N swap_endian g:su
assign -N swap_endian g:du
```

- Can use assign to be more precise

OpenMP

- OpenMP is **ON** by default
  - Optimizations controlled by –Othread#
  - To shut off use –Othread0 or –xomp or –hnoomp
- Autothreading is NOT on by default;
  - -hautothread to turn on
  - Modernized version of Cray X1 streaming capability
  - Interacts with OMP directives

If you do not want to use OpenMP and have OMP directives in the code, make sure to make a run with OpenMP shut off at compile time

New feature: OMP TASK

- An OpenMP task is an explicit region of code whose execution can be deferred and/or executed in parallel with the surrounding code
  - Completion is guaranteed by synchronization or end of parallel region
  - Must be contained inside a OMP parallel region
  - A task is “put on a queue” to be executed “later”
  - Any thread of the same parallel region that is sitting on a sync point can grab a task off the queue and execute it
- Sort of like “futures” but with limitations
  - Don’t have ID’s, must wait for all or none
  - But maybe are good enough?

Multi-level OpenMP

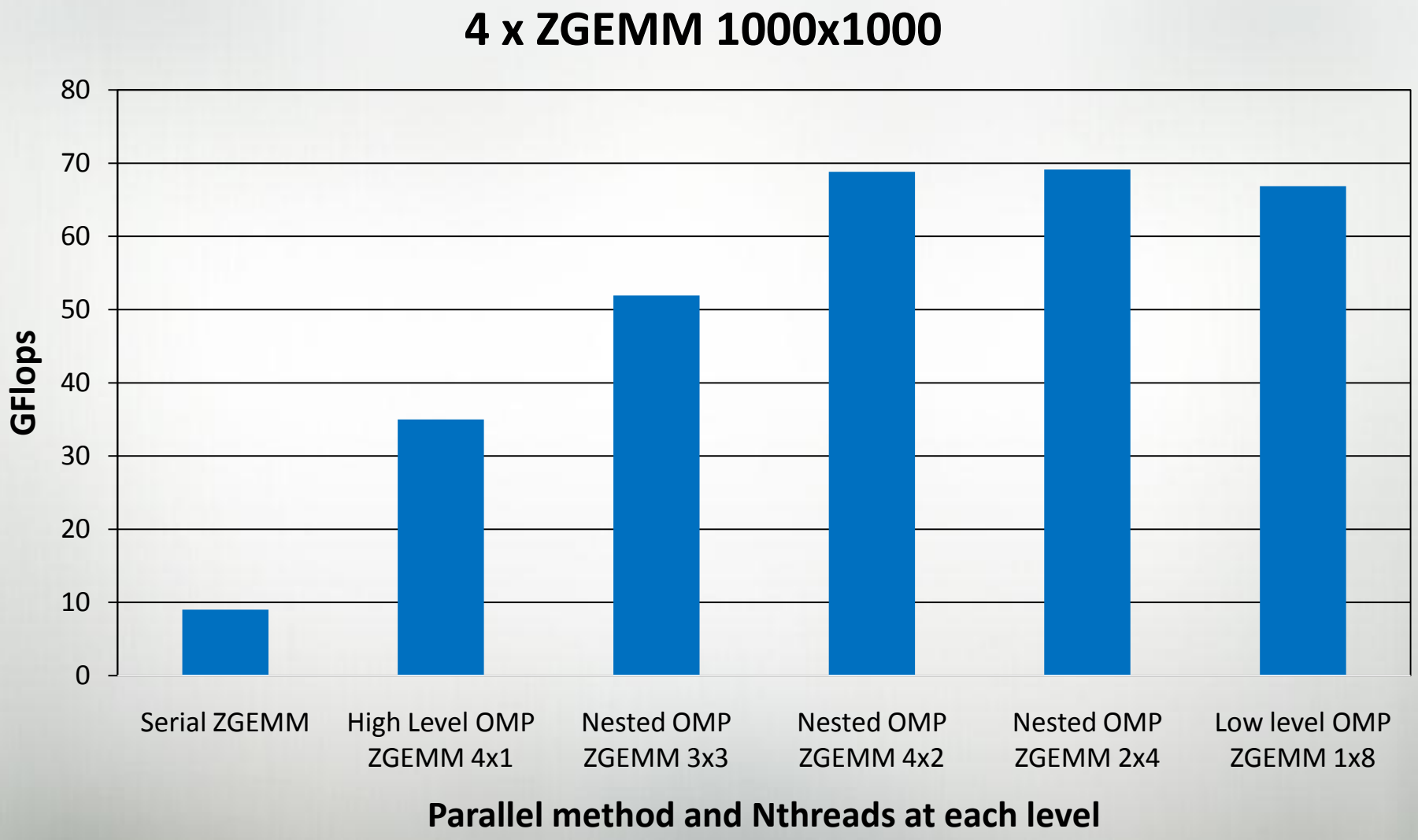
- Nested OpenMP
  - OMP parallel region inside of an OMP parallel region
  - “New threads” are used at each level
    - Need to use new ENV VARS to control nesting
    - Need to use ENV VARS not in OMP standard for better control
- OMP Tasks inside of parallel regions
  - Can be nested
  - Can be both more and less natural way of programming

Multi-level OpenMP

```
!$omp parallel do …
do i=1,4
   call complex_matmul(…)
enddo

Subroutine complex_matmul(…)
!$omp      parallel do private(j,jend,jsize)! num_threads(p2)
   do j=1,n,nb
     jend = min(n, j+nb-1)
     jsize = jend - j + 1
     call zgemm( transA,transB, m,jsize,k,                    &
          alpha,A,ldA,B(j,1),ldb, beta,C(1,j),ldC)
   enddo
```

Case Study: PARQUET



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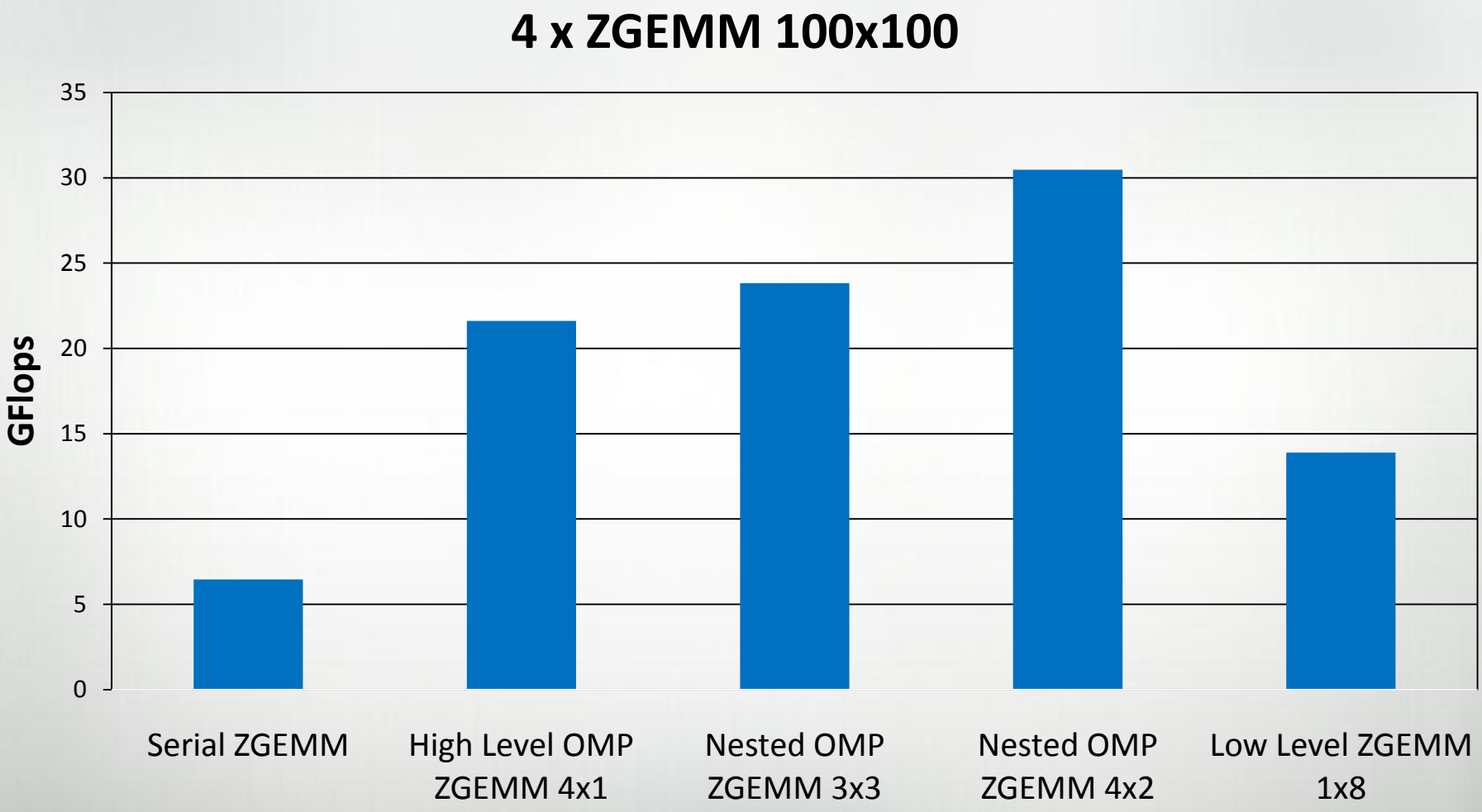

Lessons from nested parallel regions

- Nested omp can GREATLY expand the amount of parallelism one can attack using OpenMP
- Most people set the environment variable via omp_num_threads
  - This, as currently defined, is not adequate for nested parallel regions
  - Using the “num_threads” clause may be both tricky and impractical
  - Cray has invented its own cray_omp_num_threads variable
- Nested parallel regions is a relatively static distribution
- OMP tasking may be a way of getting around some or all of these issues

Cray Compiler: Future Capabilities

- 7.2 release planned for Q1 10
  - Mostly about performance
  - Magny Cours support

And beyond….

- Fortran 2008
- More tasking capabilities
- Optimized PGAS
- Support for AVX (256 bit vectors)
- Support for Intel

Cray Compiler: Final Thoughts

- Cray Compiler is an interesting alternative for some codes
- Unique and different capabilities can result is significantly different performance.
- Gemini and PGAS will make the Cray compiler even more relevant.


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