Dangerously Clever X1 Application Tricks

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Outline

- Outlandish optimizations that are universally applicable and guaranteed to enhance performance*
- Proof by anecdote
  - With slide after slide of source code
- * Fine print

Optimizations

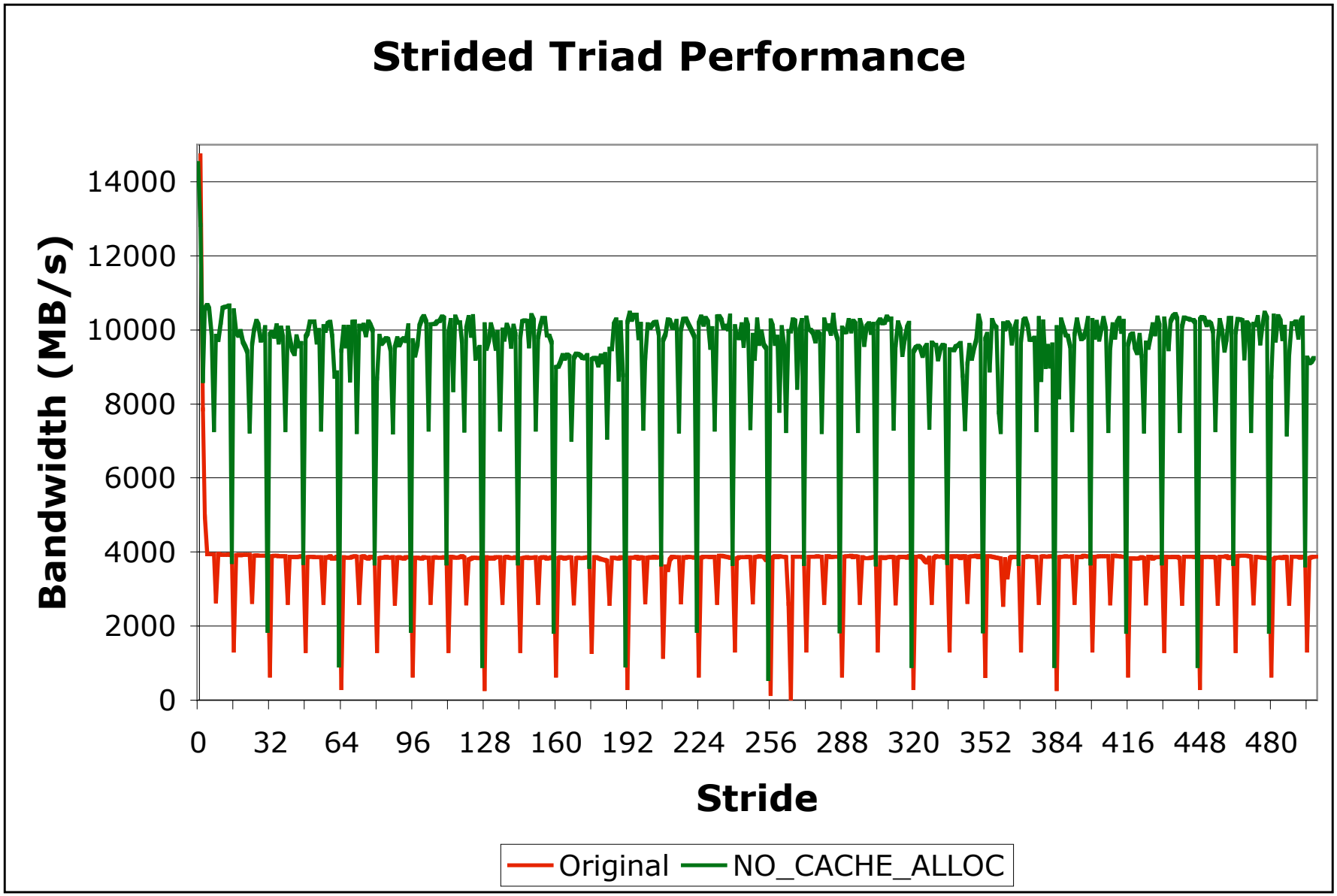
- Avoid using cache
- Replace BLAS calls with do loops
- Minimize vector length
- Move if statements inside loops
- Use more pointers
- Add infinite loops

Avoid using cache

- Why?
  - No spatial locality of memory references
  - Avoiding cache can provide much higher bandwidth
- How?
  - `!dir$ no_cache_alloc` *variable*
- Example
  - Strided triad benchmark

Strided triad benchmark

```
real(8), allocatable :: a(:), b(:), c(:)
!dir$ no_cache_alloc a,b,c
…
do stride = 1, 500
  …
  do iter = 1, iters
    …
    !dir$ unroll(8)
    a(::stride) = b(::stride) + s*c(::stride)
    …
```


Strided Triad Performance
Bandwidth (MB/s)
14000
12000
10000
8000
6000
4000
2000
0
0
32
64
96
128
160
192
224
256
288
320
352
384
416
448
480
Stride
Original
NO_CACHE_ALLOC

BLAS calls → do loops

- Why?
  - Compiler can optimize special cases
  - BLAS calls aren't yet inlined
  - BLAS calls aren't highly optimized
    - True for fewer and fewer calls
- CUG 2003 example: CGEMM
  - BLAS improved, no longer an advantage
- Example: Benchmark loop over DGER

Benchmark loop over DGER

```
do iter = 1, niters
   call dger(n,n,alpha,x,1,y,1,a,n)
   do j = 1, n
      do i = 1, n
         a(i,j) = a(i,j) + alpha*x(i)*y(j)
      end do
   end do
end do
```

Benchmark loop over DGER

- N = 4480, niters = 100, one MSP
- DGER performance
  - 2.4 GF
  - 20% efficiency
- Do-loop performance
  - 138 GF
  - 1078% efficiency

Loopmarks?

```
Di---------<    do iter = 1, niters
Di Mr------<       do j = 1, n
Di Mr Vm--<          do i = 1, n
Di Mr Vm                a(i,j) = …
Di Mr Vm-->          end do
Di Mr------>       end do
Di---------->   end do
```

Loopmarks!

```
Di--------<    do iter = 1, niters
Di Mr-----<       do j = 1, n
Di Mr Vm--<          do i = 1, n
Di Mr Vm                a(i,j) = …
Di Mr Vm-->          end do
Di Mr----->       end do
Di-------->    end do
```

Loop over DGER?

```
do iter = 1, niters
   do j = 1, n
      do i = 1, n
         a(i,j) = a(i,j) + alpha*x(i)*y(j)
      end do
   end do
end do
```

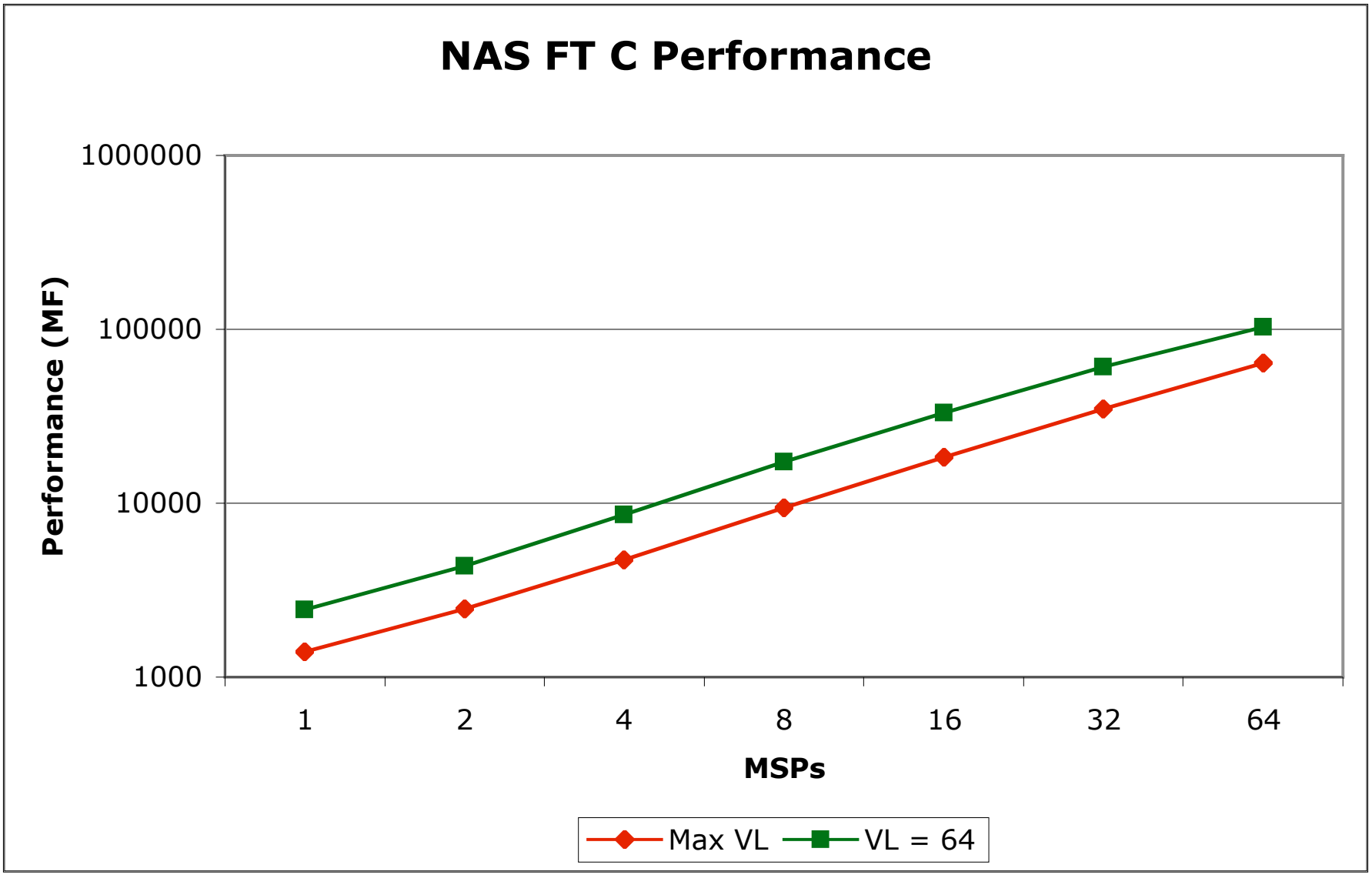
No loop over DGER!

```
nalpha = niters*alpha
do j = 1, n
   do i = 1, n
      a(i,j) = a(i,j) + nalpha*x(i)*y(j)
   end do
end do
```

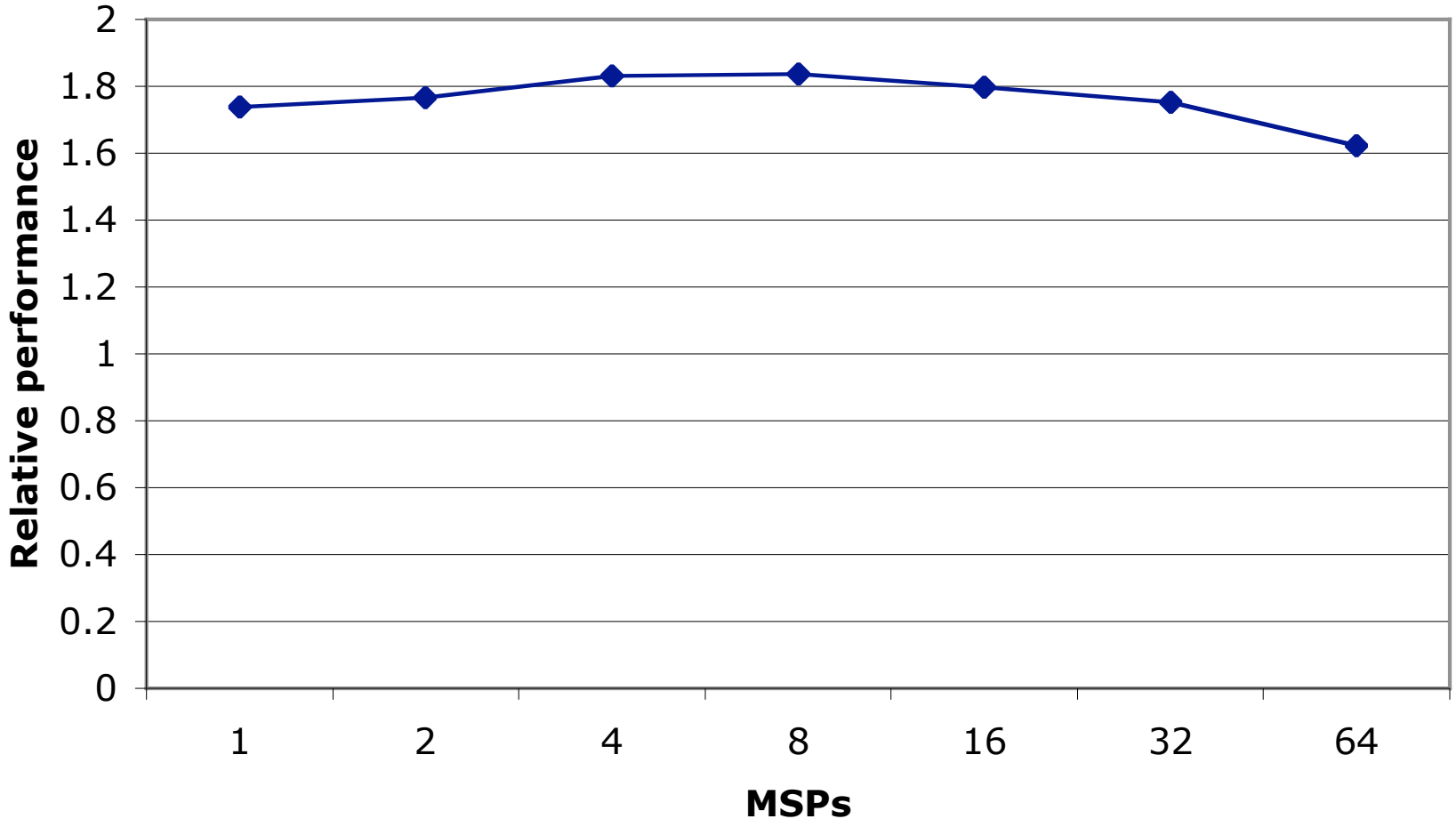
Minimize vector length*

* within reason

- Why?
  - `shortloop` - Loops disappear in favor of pure vector instructions
  - Cache and vector-register locality
- How?
  - Tile vector loops in blocks of 64
    - Multistream an outer loop
  - Look for "`Vs`" in loopmarks
  - Add "`!dir$ shortloop`" if compiler can't tell
- Example: NAS FT C (5 directives)


NAS FT C Performance
Performance (MF)
1000000
100000
10000
1000
1
2
4
8
16
32
64
MSPs
Max VL
VL = 64

Performance Improvement of VL=64



Move if statements inside loops

- Do what?
  - Move if statements inside loops even though they are loop-independent
- Why?
  - Fuse loops together
  - Demote temporary arrays to scalars
  - Compiler promotes scalars to vector registers
  - Register blocking - reduce memory load/store
- Check loopmarks afterward for "`V`"
- Example: POP "`state`" subroutine

POP "state", before

```
…
 if (present(RHOOUT)) then
    RHOOUT = merge(((unt0 + RHO0)*BULK_MOD*DENOMK)*p001,
$                       c0, KMT >= k)
 endif
 if (present(RHOFULL)) then
    RHOFULL = merge(((unt0 + RHO0)*BULK_MOD*DENOMK)*p001,
$                       c0, KMT >= k)
 endif
…
```

POP "state", after

```
 do j = 1, jmt ; do i = 1, imt
    …
    if (present(RHOOUT)) then
       RHOOUT(i,j)  = merge(
$                  ((unt0 + rho0)*bulk_mod*denomk)*p001,
$                  c0, kmt_mask)
    endif
    if (present(RHOFULL)) then
       RHOFULL(i,j) = merge(
$                  ((unt0 + rho0)*bulk_mod*denomk)*p001,
$                  c0, kmt_mask)
    endif
    …
 end do; end do
```

"state" performance

- POP benchmark run on one MSP
  - 320x384x40 grid points worldwide
- Results from "samp_cs_time"
- Before

```
|   16.3% |       33.7% |   19545 |state@state_mod_
```

- After

```
|   13.5% |       31.7% |   15663 |state@state_mod_
```

- 25% performance improvement in "state"

Use more pointers: Why?

- Communication optimization
- Replace MPI with direct load/store
- Co-Array Fortran requires non-local changes (arguments must be Co-Arrays)
- Use pointers to cheat

Use more pointers: How?

- Declare a co-array of `INTEGER(8)`
- Declare Cray pointer on receiver
- Sender stores array addresses in receiver co-array location (address from `LOC`)
- Receiver associates pointer with local value of integer co-array (assigned by sender)
- Receiver uses pointer to access sender data
- Example: Scatter from POP/CICE

POP/CICE scatter (sender)

```
integer(8) :: remote_address(NPROC_X*NPROC_Y)[*]
real(dbl_kind) :: workg(imt_global,jmt_global)

integer(8) :: address

if (my_image == master_image) then
   address = loc(workg)
   do i = 1, num_images()
      remote_address(master_image)[i] = address
   end do
end if

… ! Synchronize
```

POP/CICE scatter (receivers)

```
      integer(8) :: remote_address(NPROC_X*NPROC_Y)[*]
      real(dbl_kind) :: work(ilo:ihi,jlo:jhi)

      real(dbl_kind) ::
$         workg_remote(imt_global,jmt_global)
      pointer(workg_address, workg_remote)

      … ! Synchronize

      workg_address = remote_address(master_image)
      work(ilo:ihi,jlo:jhi) =
$         workg_remote(ilog:ihig,jlog:jhig)
```

While you're at it, add some infinite loops!

- Why?! … Synchronization!
- How?
  - Initialize integer co-array to zero
  - Sender puts address (guaranteed nonzero)
  - Receivers spin-wait for nonzero value
- Declare the co-array `VOLATILE`!
  - Otherwise you might spin-wait on a register
  - Wait for comic ray to change register value?

Scatter synchronization

```
integer(8), volatile :: remote_address(NPROC_X*NPROC_Y)[*]
logical, volatile :: remote_flag(NPROC_X*NPROC_Y)[*]
…
do while (remote_address(master_image) == 0)
end do
… ! Copy data
remote_address(master_image) = 0
remote_flag(my_image)[master_image] = .true.

if (my_image == master_image) then
   do i = 1, num_images()
      do while (.not. remote_flag(i))
      end do
      remote_flag(i) = .false.
   end do
end if
```

Scatter performance

- 8-MSP POP/CICE production-like run
  - Ten simulation days
- "`global_scatter`" MPI
  - `mpi_isend`, `mpi_irecv`, `mpi_wait`
  - 31,635 samples from "`samp_cs_time`"
- "`global_scatter`" CAF
  - 1,767 samples
  - 18x faster for this subroutine
  - 4.2% → 0.3% of runtime

Scatter call-tree profiling

- `pat_report -b functions,callers`
- MPI version

```
||   3.4% |     3.4% |  26048 |global_scatter@ice_mpi_internal_
|||  0.5% |    14.0% |   3502 |global_scatter@ice_mpi_internal_
|||  0.0% |    14.9% |      1 |global_scatter@ice_mpi_internal_
|||  0.3% |    47.9% |   2015 |global_scatter@ice_mpi_internal_
|||  0.0% |    48.1% |      1 |global_scatter@ice_mpi_internal_
|||  0.0% |    87.7% |      3 |global_scatter@ice_mpi_internal_
|||  0.0% |    93.7% |     15 |global_scatter@ice_mpi_internal_
|||||      |        |        | global_scatter@ice_mpi_internal_
|||||      |        |        | global_scatter@ice_mpi_internal_
|||  0.0% |    94.1% |      6 |global_scatter@ice_mpi_internal_
|||||      |        |        | global_scatter@ice_mpi_internal_
|||||      |        |        | global_scatter@ice_mpi_internal_
|||  0.0% |    97.2% |      2 |global_scatter@ice_mpi_internal_
||   0.0% |    97.6% |      3 |global_scatter@ice_mpi_internal_
||||     |        |        | global_scatter@ice_mpi_internal_
||||     |        |        | global_scatter@ice_mpi_internal_
|||      |        |        | global_scatter@ice_mpi_internal_
|||      |        |        | global_scatter@ice_mpi_internal_
|||  0.0% |    98.7% |      1 |global_scatter@ice_mpi_internal_
|||  0.0% |    99.5% |      1 |global_scatter@ice_mpi_internal_
|   0.0% |    99.9% |     37 |global_scatter@ice_mpi_internal_
```

- Co-array version

```
|    0.3% |      93.2% |    1767 |global_scatter@ice_mpi_internal_
```

Scatter line profiling

- `pat_report -b functions,lines`
- MPI version - not useful, it's all in calls
- Co-array version (first sync loop)

```
|   0.3% |     93.2% |   1767 |global_scatter@ice_mpi_internal_
||-------------------------------------
||   0.2% |      93.2% |   1552 |line.253
||   0.0% |      93.2% |    100 |line.256
||   0.0% |      93.2% |     67 |line.255
||   0.0% |      93.2% |     34 |line.264
||   0.0% |      93.2% |     10 |line.243
||   0.0% |      93.2% |      3 |line.216
||   0.0% |      93.2% |      1 |line.295
||=====================================
```

Is any of this useful?

- Avoid using cache
  - Rarely, more of a tweak
  - In real apps, not often obvious when to apply
- Replace BLAS calls with do loops
  - Only if outer loops over BLAS are independent
  - Ask Cray when BLAS will automatically inline
- Minimize vector length
  - Yes, register re-use is good
  - May be more important with X1E

Is any of this useful?

- Move if statements inside loops
  - Maybe, again more of a tweak
  - More important for X1E?
- Use more pointers
  Add infinite loops
  - Yes! Minimize latency! Eliminate copies!
  - Needed less often when optimized MPI collectives are available
  - Deadlock prone, not portable

Questions?