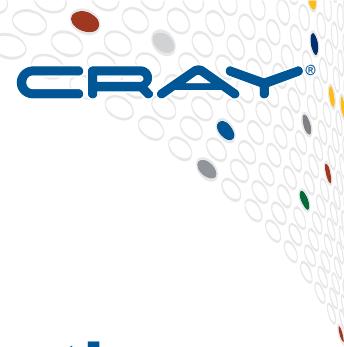




GE Global Research



Porting Computational Physics Applications to the Titan Supercomputer with OpenACC and OpenMP

Aaron Vose - Cray Inc.
GTC - 03/19/2015

Porting - Overview



- Porting methodology:
 - Express underlying algorithmic parallelism.
 - Port to OpenMP first.
 - Port to OpenACC second.
- Case studies / examples:

- TACOMA



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- Delta5D



- NekCEM

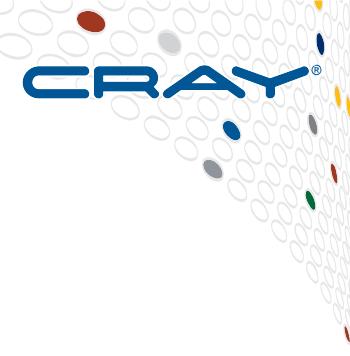


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ANALYZE

Porting - Overview



- For each case study / example code:
(TACOMA, Delta5D, and NekCEM)



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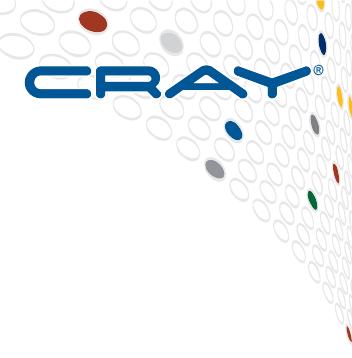
- Introduction to the code and example loop.
- OpenMP / OpenACC porting of the loop.
 - Express underlying algorithmic parallelism.
- OpenACC data motion with simplified call tree.
- Performance results.

Porting - OpenMP



- **Express existing loop-level parallelism with OpenMP directives.**
 - Cray's Reveal tool can do much of this automatically.
- **Port to OpenMP before OpenACC.**
 - OpenACC can reuse most OpenMP scoping.
 - OpenMP porting to CPU is easier than OpenACC porting to GPU.
 - Data motion can be ignored when porting to OpenMP.
- **Modify loops to expose more of underlying algorithms' parallelism.**

Porting - OpenACC



- **Identify candidate loops:**
 - Check loops' trip/iteration count (CrayPAT).
- **Add OpenACC directives / Optimize Kernels:**
 - Check compiler listing for proper vectorization.
 - Ignore data motion (best performed once kernels are done and have known data requirements).
- **Finally, optimize device <-> host data motion.**
 - Perform bottom-up, hierarchical data optimization.

Porting - TACOMA



Case Study I: TACOMA



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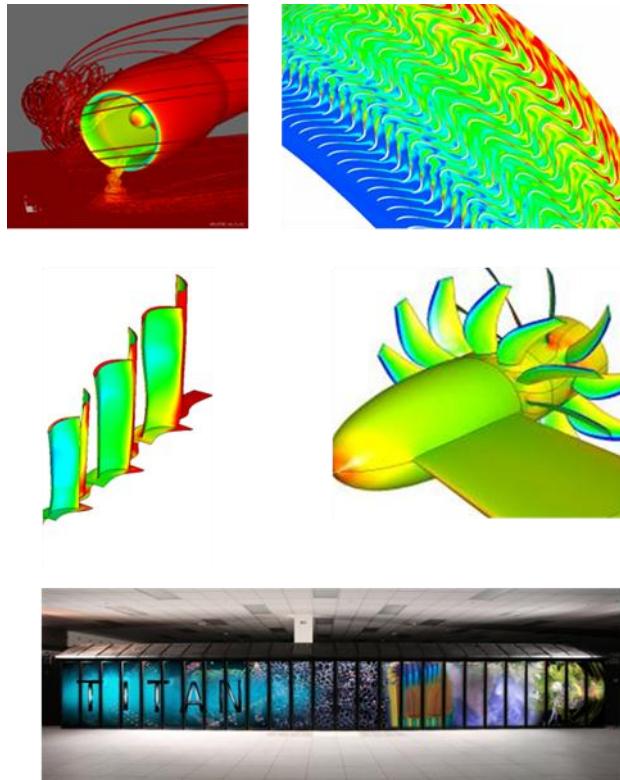
ANALYZE



Porting - TACOMA



- From GE's Brian Mitchell.
- Computational fluid dynamics is essential to design jet engines, gas/steam turbines, and more.
- Finite-volume, block-structured, compressible flow solver, with stability achieved via JST.





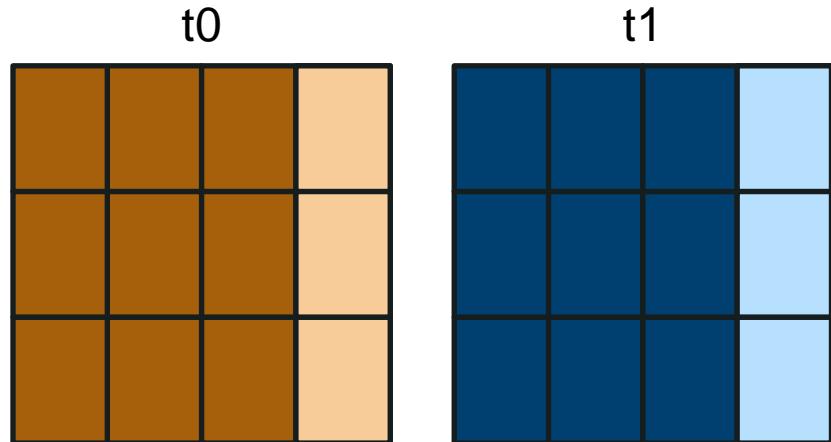
- Example loop nest from TACOMA.
 - Representative of a number of costly routines.
 - Can be made to parallelize on CPUs with OpenMP.
 - GPU vectorization requires more work.



```
do k=1,n3
  do j=1,n2
    do i=1,n1
      df(1:3) = dflux(i,j,k)
      R(i,j,k) += df(1) +
                   df(2) +
                   df(3)
      R(i-1,j,k) -= df(1)
      R(i,j-1,k) -= df(2)
      R(i,j,k-1) -= df(3)
    end do
  end do
end do
```



```
do k=1,n3
  do j=1,n2
    do i=1,n1
      df(1:3) = dflux(i,j,k)
      R(i,j,k)  += df(1) +
                    df(2) +
                    df(3)
      R(i-1,j,k) -= df(1)
      R(i,j-1,k) -= df(2)
      R(i,j,k-1) -= df(3)
    end do
  end do
end do
```



OpenMP



```
do k=1,n3
  do j=1,n2
    do i=1,n1
      df(1:3) = dflux(i,j,k)
      R(i,j,k) += df(1) +
                    df(2) +
                    df(3)
      R(i-1,j,k) -= df(1)
      R(i,j-1,k) -= df(2)
      R(i,j,k-1) -= df(3)
    end do
  end do
end do
```



```
do k=ts3,tn3
  do j=ts2,tn2
    do i=ts1,tn1
      df(1:3) = dflux(i,j,k)
      if mycolor(i,j,k,tid)
        R(i,j,k) += df(1) +
                    df(2) +
                    df(3)
      if mycolor(i-1,j,k,tid)
        R(i-1,j,k) -= df(1)
    end do
  end do
end do
```

OpenMP

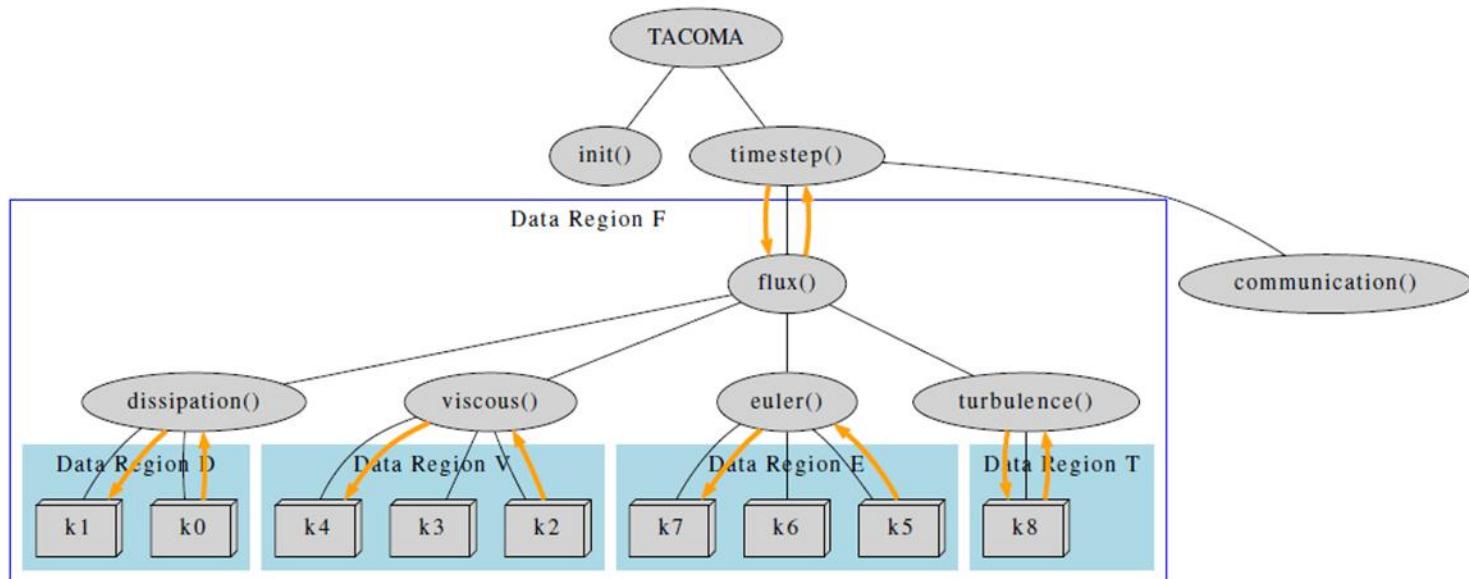


```
do k=1,n3
  do j=1,n2
    do i=1,n1
      df(1:3) = dflux(i,j,k)
      R(i,j,k) += df(1) +
                    df(2) +
                    df(3)
      R(i-1,j,k) -= df(1)
      R(i,j-1,k) -= df(2)
      R(i,j,k-1) -= df(3)
    end do
  end do
end do
```

```
do
  df(i,j,k,1:3) = dflux(i,j,k)
end do

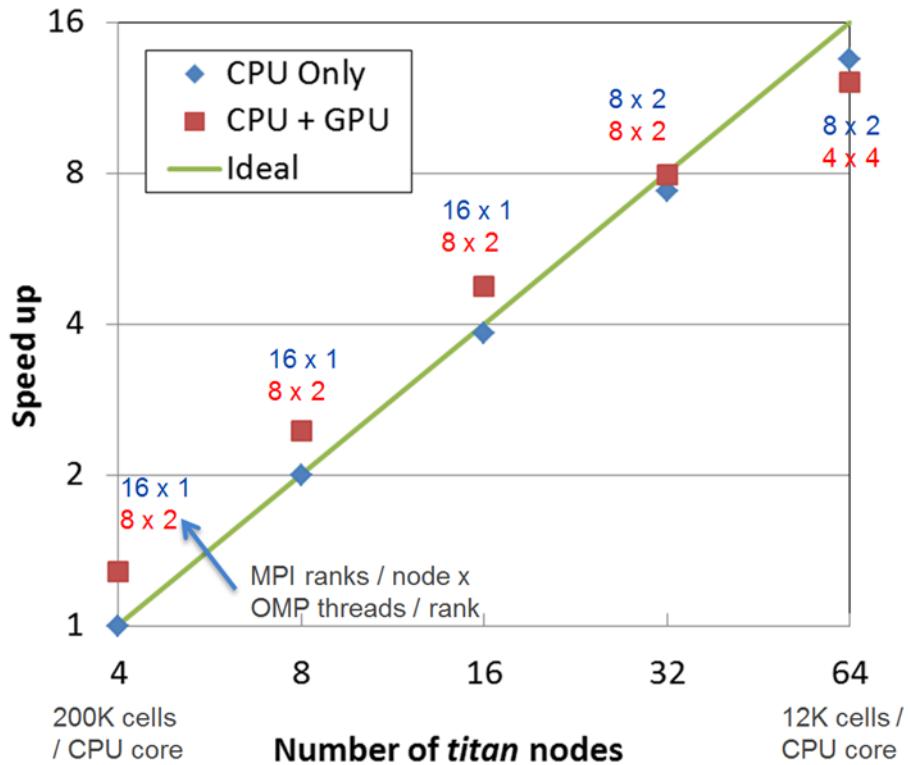
do
  R(i,j,k) += df(i,j,k,1) +
               df(i,j,k,2) +
               df(i,j,k,3)
  R(i,j,k) -= df(i+1,j,k,1) +
               df(i,j+1,k,2) +
               df(i,j,k+1,3)
end do
```

OpenACC



- **Create OpenACC data regions:**
 - Keep data on the GPU device as long as possible.
 - Create data regions in bottom-up, hierarchical fashion.

TACOMA - Performance



Porting - Delta5D



Case Study II: Delta5D



COMPUTE

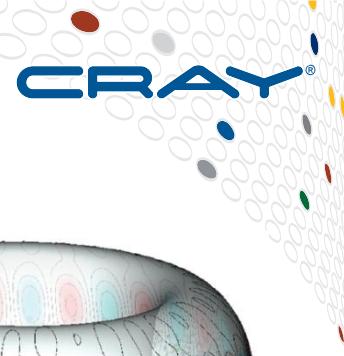
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ANALYZE

Porting - Delta5D



- From ORNL's Donald Spong.
- Monte-Carlo fusion code.
- Boozer space particle orbits.
- Hamiltonian guiding center equations solved with 4th order Runge Kutta.

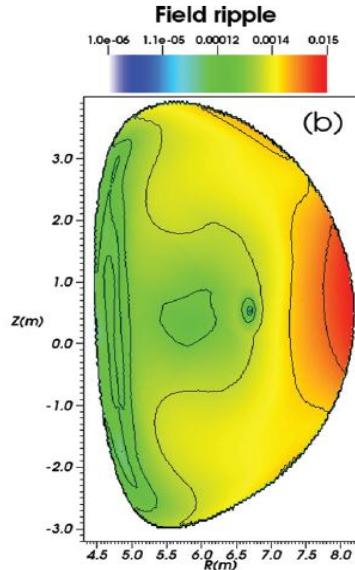
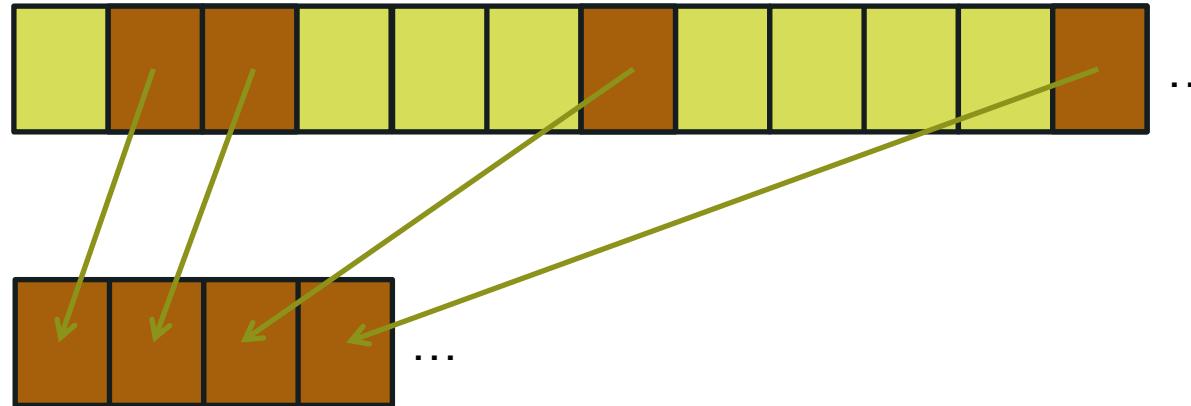


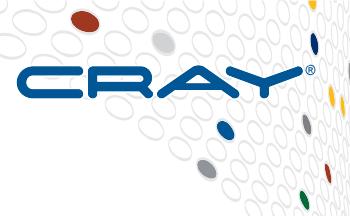
Figure 2 – TAE eigenmode structure projected onto an outer flux surface.

- Example loop from Delta5D.
 - Fast enough to run in serial on CPU; slow on GPU.
 - Data motion rules out running on CPU.
 - Needs to run in parallel on GPU.

- If a particle's trajectory takes it outside the confined plasma volume, append it to a list of escaped particles:



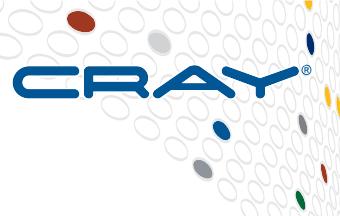
Delta5D - Algo. Parallelism



```
do i=1,maxorb
  ! -- Record this particle if it has "escaped".
  if(psinor(i) .gt. 1.) then
    iloss = iloss + 1
    phi_loss(iloss) = y(6*i-3)
    psi_loss(iloss) = y(6*i-4)/psimax
    thet_loss(iloss) = y(6*i-5)
    elost = elost + hkin(i)/ejoule
  end if
end do
```

v1

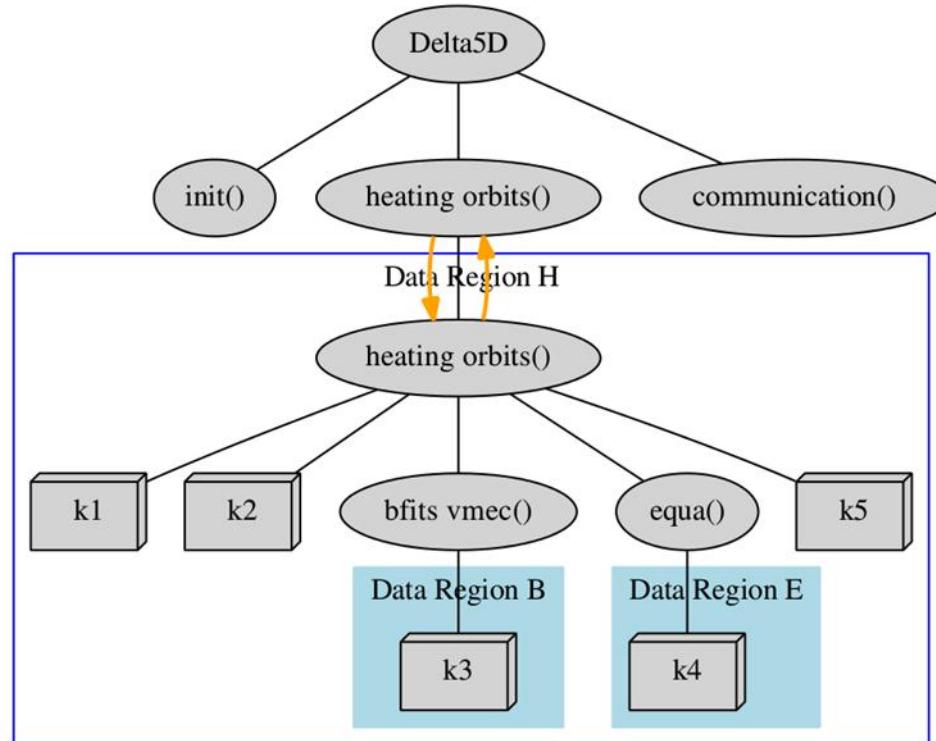
Delta5D - Algo. Parallelism



```
do i=1,maxorb
    ! -- Record this particle if it has "escaped".
    if(psinor(i) .gt. 1.) then
!$acc atomic capture
        iloss      = iloss + 1                      ! update-statement
        my_iloss   = iloss                          ! capture-statement
!$acc end atomic
        phi_loss(my_iloss)   = y(6*i-3)
        psi_loss(my_iloss)   = y(6*i-4)/psimax
        thet_loss(my_iloss)  = y(6*i-5)
        elost = elost + hkin(i)/ejoule
    end if
end do
```

v2

Delta5D - OpenACC Data



Delta5D - OpenACC Performance



OpenACC Sequential	OpenACC Atomics
19.446s	0.425s

- 45x kernel speedup.
- Up to ~5-10% improvement in total runtime.

Porting - NekCEM



Case Study III: NekCEM



COMPUTE

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ANALYZE

- From ANL's Mi Sun Min.
- Nekton for Computational
Electro Magnetics.
- High-fidelity electro-magnetics solver based on spectral element methods.
- Written in Fortran and C.

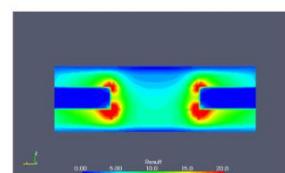
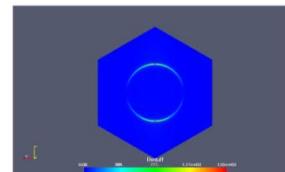
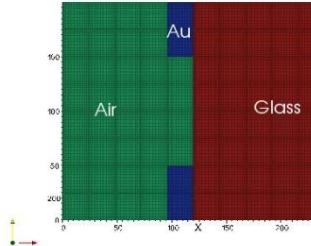


Figure 5. 3D nanohole with radius of 50 nm.

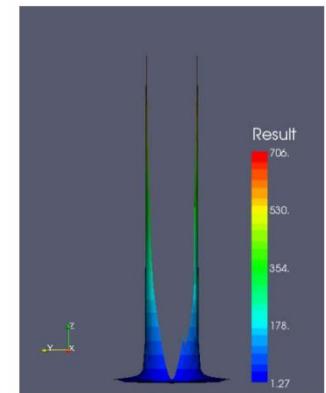
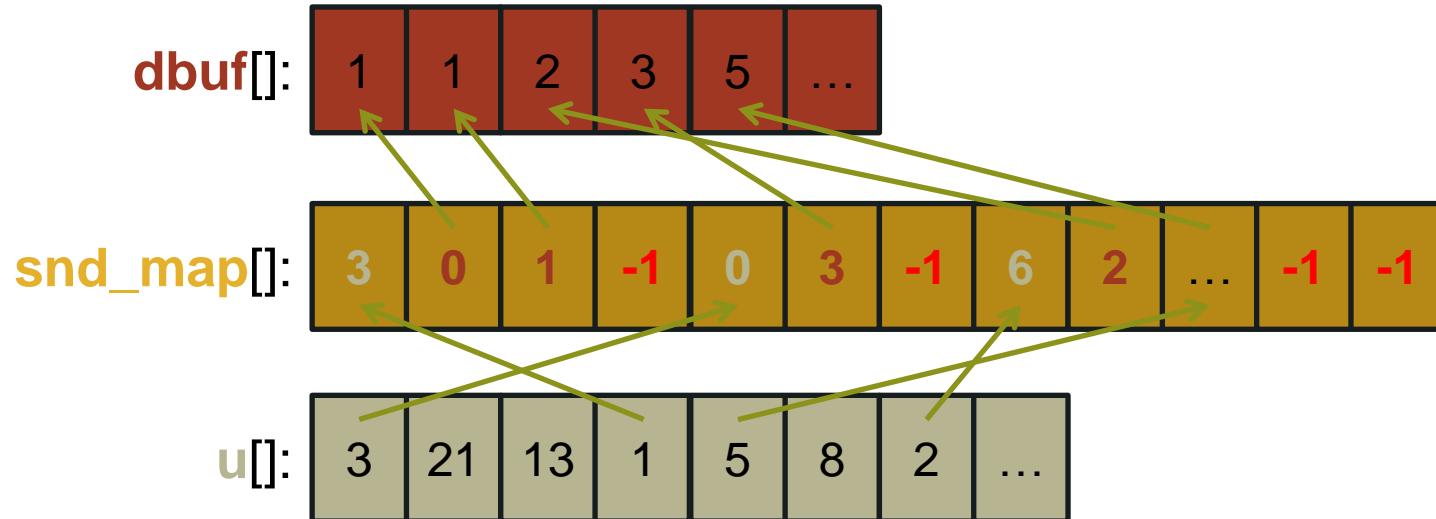


Figure 6. 3D nanohole with radius of 50 nm.

- Example loop from NekCEM.

- Initial loop structure does not vectorize on GPU.
- Gather/scatter benefits from high GPU bandwidth.
- Data motion needed around MPI communication.

- Scatter from **u** to **dbuf** with indirect addressing using description vector **snd_map** internally terminated by **-1**.



```
for(k=0; k<vn; k++) {  
    l_map = snd_map;  
    while( (i=*l_map++) != -1 ) {  
        t = u[i+k*dstride];  
        j = *l_map++;  
        do {  
           dbuf[j*vn] = t;  
        } while( (j=*l_map++) != -1 );  
    }  
    dbuf++;  
}
```

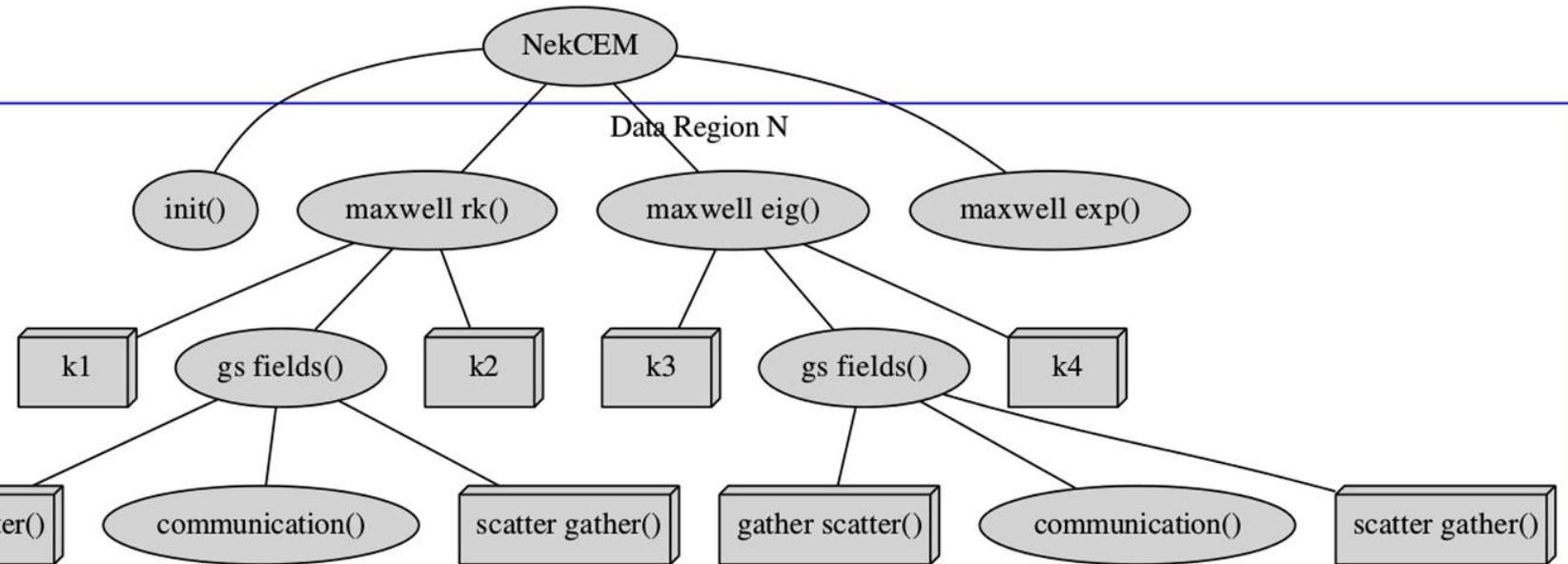
v1

```
for(k=0; k<vn; k++) {  
    for(i=0; snd_map[i]!=-1; i=j+1){  
        for(j=i+1; snd_map[j]!=-1; j++){  
            dbuf[ k+snd_map[j]*vn ] = u[snd_map[i]+k*dstride];  
        }  
    }  
}
```

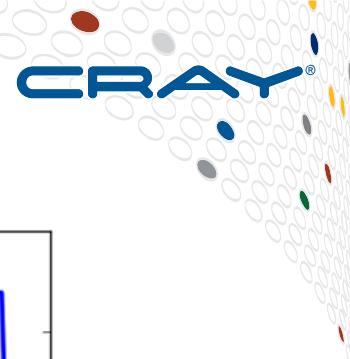
v2

```
for(k=0; k<vn; k++) {  
    for(i=0; i<snd_m_nt; i++) {  
        for(j=0; j<snd_mapf[i*2+1]; j++) {  
            dbuf[k+snd_map[snd_mapf[i*2]+j+1]*vn] =  
                u[snd_map[snd_mapf[i*2]]+k*dstride];  
        }  
    }  
}
```

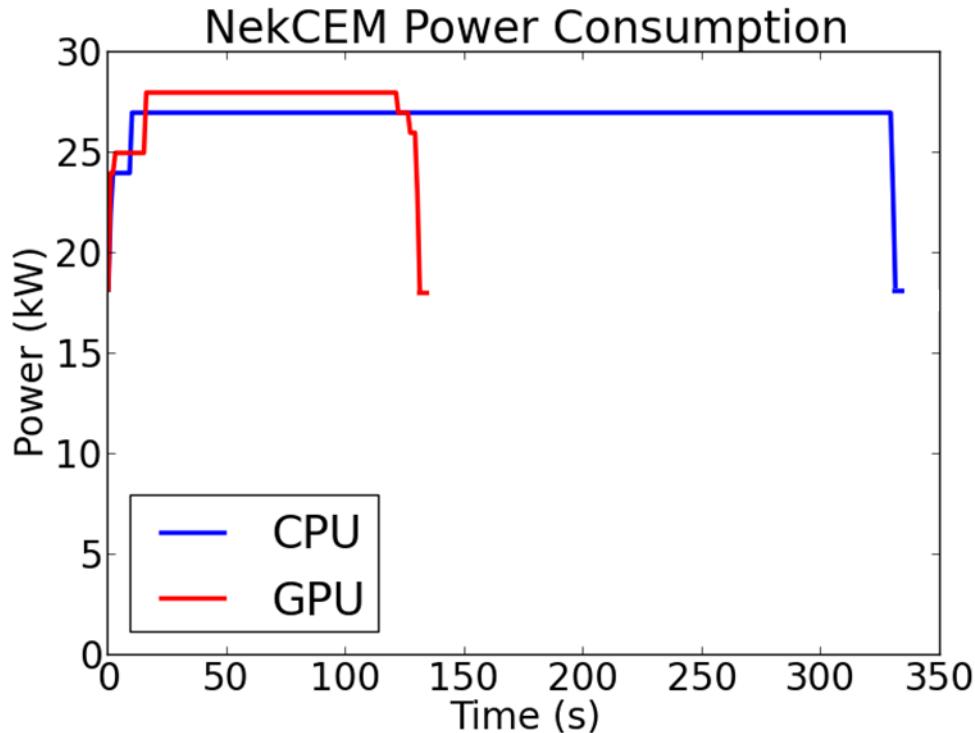
v3



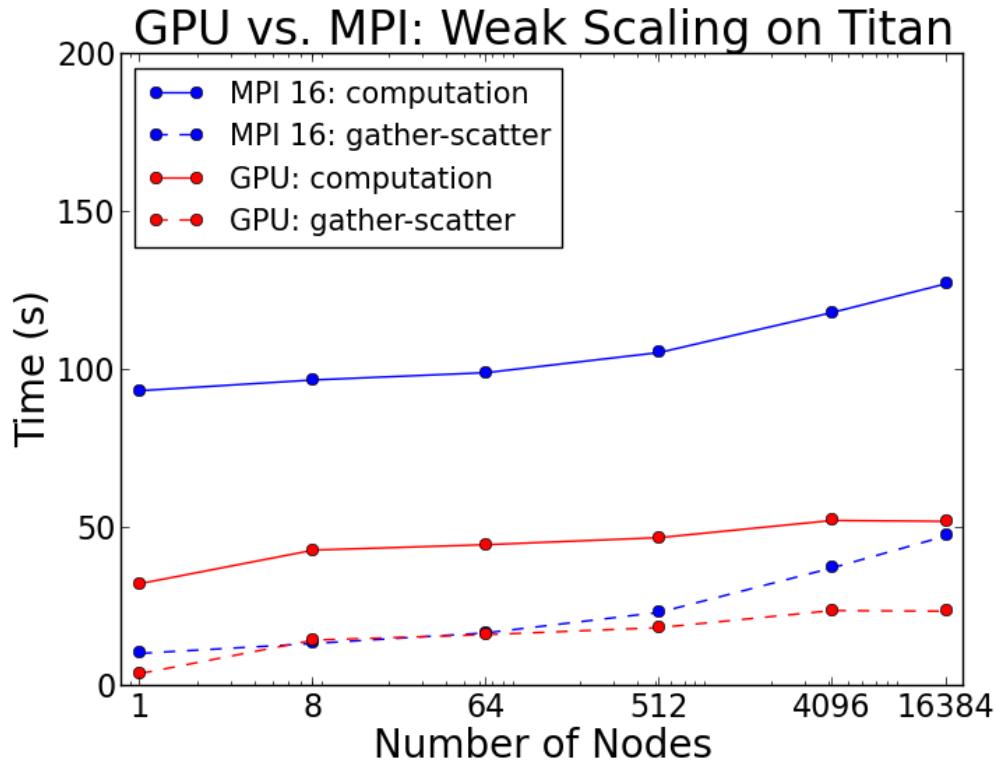
NekCEM - Performance



GPU run uses
39% the total
energy of the
CPU run!



NekCEM - Performance



Porting - Conclusion



● Lessons learned:

- Port to OpenMP before OpenACC.
 - Reuse scoping work.
- Optimize OpenACC data motion last.
 - Perform bottom-up, hierarchical data optimization.
- Express underlying algorithm's parallelism.
 - Don't limit parallelism by existing implementation.

Porting - Legal



- **Contact Information:** Aaron Vose -- email: avose@cray.com -- phone: (865) 574-8140.
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