Creating Hybrid Codes with Cray Reveal

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When to Move to a Hybrid Programming Model

● **When code is network bound**
  ● Increased MPI collective and point-to-point wait times

● **When MPI starts leveling off**
  ● Too much memory used, even if on-node shared communication is available
  ● As the number of MPI ranks increases, more off-node communication can result, creating a network injection issue

● **When contention of shared resources increases**
Approach to Adding Parallelism

1. Identify key high-level loops
   ● Determine where to add additional levels of parallelism

2. Perform parallel analysis and scoping
   ● Split loop work among threads

3. Add OpenMP layer of parallelism
   ● Insert OpenMP directives

4. Analyze performance for further optimization, specifically vectorization of innermost loops
   ● We want a performance-portable application at the end
WARNING!!!

- Nothing comes for free, nothing is automatic
  - Hybridization of an application is difficult
  - Efficient code requires interaction with the compiler to generate
    - High level OpenMP structures
    - Low level vectorization of major computational areas

- Performance is also dependent upon the location of the data
  - CPU: NUMA, first-touch
  - Accelerator: resident or data-sloshing

- Software such as Cray's Hybrid Programming Environment provides tools to help, but cannot replace the developer's inside knowledge
The Problem – How Do I Parallelize This Loop?

- How do I know this is a good loop to parallelize?
- What prevents me from parallelizing this loop?
- Can I get help building a directive?

subroutine sweepz
  do j = 1, js
  do i = 1, isz
    radius = zx(i+mypez*isz)
    theta = zyc(j+mypey*js)
    do m = 1, npez
      do k = 1, ks
        n = k + ks*(m-1) + 6
        r(n) = recv3(1,j,k,i,m)
        p(n) = recv3(2,j,k,i,m)
        u(n) = recv3(5,j,k,i,m)
        v(n) = recv3(3,j,k,i,m)
        w(n) = recv3(4,j,k,i,m)
        f(n) = recv3(6,j,k,i,m)
      enddo
    enddo
  enddo
enddo

subroutine ppmlr
  do k = 1, kmax
    xa(n) = zza(k)
    dx(n) = zdz(k)
    xa0(n) = zza(k)
    dx0(n) = zdz(k)
    e(n) = p(n)/(r(n)*gamm)+0.5*(u(n)**2+v(n)**2+w(n)**2)
  enddo
enddo

! contains more calls

...
Simplifying the Task with Reveal

- Navigate to relevant loops to parallelize
- Identify parallelization and scoping issues
- Get feedback on issues down the call chain (shared reductions, etc.)
- Automatically insert parallel directives into source
- Validate scoping correctness on existing directives
Hybridization Step 1: Loop Work Estimates

- Identify high-level serial loops to parallelize

- Gather loop statistics using CCE and the Cray performance tools to determine which loops have the most work
  - Based on runtime analysis
  - Approximates how much work exists within a loop
Collecting Loop Work Estimates

- > module swap PrgEnv-intel PrgEnv-cray
- > module load `perftools-lite-loops` (assumes `perftools-base` is loaded)

Build and run application, producing CrayPat-lite output to stdout and a .ap2 file for use with Reveal later

- > module unload `perftools-lite-loops`
  - Loop analysis performed with reduced compiler optimization
  - Advanced loop optimizations excluded such as unroll, interchange, etc.
# Example Loop Work Estimates

## Table 2: Loop Stats by Function (from -hprofile_generate)

<table>
<thead>
<tr>
<th>Loop Incl</th>
<th>Loop Hit</th>
<th>Loop Trips Avg</th>
<th>Loop Trips Min</th>
<th>Loop Trips Max</th>
<th>Function=/.LOOP[.]</th>
<th>PE=HIDE</th>
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<tr>
<td></td>
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<td>0</td>
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<td>sweepz_.LOOP.06.li.50</td>
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<tr>
<td></td>
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<td>0</td>
<td>25</td>
<td>sweepx2_.LOOP.1.li.29</td>
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<td>1250</td>
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<td>0</td>
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<td>sweepx1_.LOOP.1.li.29</td>
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<td>4.387457</td>
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<td>12</td>
<td>riemann_.LOOP.3.li.64</td>
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<td></td>
<td>0.863656</td>
<td>1687500</td>
<td>104</td>
<td>0</td>
<td>108</td>
<td>parabola_.LOOP.6.li.67</td>
</tr>
</tbody>
</table>
The CCE Program Library (PL)

- An **application wide repository** for compiler and tools information
  - User to specify a repository of compiler information for an application build

- Provides the framework for application analysis
  - Whole application IPA information for optimization
  - Automatic whole application inlining and cloning
  - Various inter-procedural optimizations
  - Whole application static error detection

- Provides **ability for tools to annotate loops with runtime feedback** and **other performance hints** without source change
  - Support for the Cray refactoring tool, Reveal.

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Generate a Program Library

- `> cc -h pl=himeno.pl  -hwp* himeno.c`
- `> ftn -h pl=vhone.pl  file1.f90`

* Optionally add whole program analysis for additional inlining. Not required for Reveal.
Launch Reveal

● Use with compiler information only (no need to run program):

  > reveal vhone.pl

● Use with compiler + loop work estimates (include performance data):

  > reveal vhone.pl vhone_loops.ap2
Visualize Compiler and Performance Information

Performance feedback

Loopmark and optimization annotations

Compiler feedback
Access Cray Compiler Message Information

- Access integrated message 'explain' support by right clicking on message.
Navigate Loops through Call Chain
Navigate Code via Compiler Messages

Choose “Compiler Messages” view to access message filtering.

Default filter: Loops that didn’t vectorize. Can select other filters.
View Pseudo Code for Inlined Functions

Inlined call sites marked

Expand to see pseudo code

Search code with Ctrl-F
Hybridization Step 2: Scope Selected Loop(s)
Loops with scoping information are flagged. Red needs user assistance.

Parallelization inhibitor messages are provided to assist user with analysis.

User addresses issues for variables with FAIL status.
Review Scoping Results (2)

Variable from inlining – hover over ‘I’ to see what symbol means

See where variable came from (@function_name)
**Review Scoping Results (3)**

Reveal identifies shared reductions down the call chain.

Reveal identifies calls that prevent parallelization.

---

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Scope</th>
<th>Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ks</td>
<td>Scalar</td>
<td>Shared</td>
<td></td>
</tr>
<tr>
<td>mypey</td>
<td>Scalar</td>
<td>Shared</td>
<td></td>
</tr>
<tr>
<td>ndim</td>
<td>Scalar</td>
<td>Shared</td>
<td></td>
</tr>
<tr>
<td>npey</td>
<td>Scalar</td>
<td>Shared</td>
<td></td>
</tr>
<tr>
<td>recv1</td>
<td>Array</td>
<td>Shared</td>
<td></td>
</tr>
<tr>
<td>send2</td>
<td>Array</td>
<td>Shared</td>
<td></td>
</tr>
<tr>
<td>sver</td>
<td>Scalar</td>
<td>Shared</td>
<td>Atomic reduction operator required unless reduction fully</td>
</tr>
<tr>
<td>zdy</td>
<td>Array</td>
<td>Shared</td>
<td></td>
</tr>
<tr>
<td>zxc</td>
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<td>Shared</td>
<td></td>
</tr>
<tr>
<td>zya</td>
<td>Array</td>
<td>Shared</td>
<td></td>
</tr>
</tbody>
</table>

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*March 2016*
Hybridization Step 3: Generate OpenMP Directives

```
! Directive inserted by Cray Reveal. May be incomplete.
!
!$OMP  parallel do default(none) &
!$OMP&   unresolved (dvol,dx,dx0,e,f,flat,p,para,q,r,radius,svel,u,v,w, &
!$OMP&            xa,xa0) &
!$OMP&   private (i,j,k,m,n,$$_n,delp2,delp1,shock,temp2,old_flat, &
!$OMP&            onemfl,hdt,sinxf0,gamfac1,gamfac2,dtheta,deltx,fractn, &
!$OMP&            ekin) &
!$OMP&   shared  (gamm,isy,js,ks,mypey,ndim,ngeomy,nlefty,npey,nrighty, &
!$OMP&            recv1,send2,zdy,zxc,zya)

do k = 1, ks
  do i = 1, isy
    radius = zxc(i+mypey*isy)
  ! Put state variables into 1D arrays, padding with 6 ghost zones
  do m = 1, npey
    do j = 1, js
      n = j + js*(m-1) + 6
      r(n) = recv1(1,k,j,i,m)
      p(n) = recv1(2,k,j,i,m)
      u(n) = recv1(4,k,j,i,m)
      v(n) = recv1(5,k,j,i,m)
      w(n) = recv1(3,k,j,i,m)
      f(n) = recv1(6,k,j,i,m)
    enddo
  enddo
  do j = 1, jmax
    n = j + 6
```

Reveal generates OpenMP directive with illegal clause marking variables that need addressing
Or Validate User Inserted Directives

User inserted directive with mis-scoped variable ‘n’
Hybridization Step 4: Performance Analysis

Choose “Compiler Messages” view to access message filtering

See loops that didn’t vectorize. Can select other filters.

See all compiler messages for a loop nest
Observations and suggestions

D1 cache utilization:
61.7% of total execution time was spent in 1 functions with D1 cache hit ratios below the desirable minimum of 90.0%. Cache utilization might be improved by modifying the alignment or stride of references to data arrays in these functions.

<table>
<thead>
<tr>
<th>D1 cache</th>
<th>Time%</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>hit ratio</td>
<td>74.3%</td>
<td>61.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>calc3</td>
</tr>
</tbody>
</table>

D1 + D2 cache utilization:
61.7% of total execution time was spent in 1 functions with combined D1 and D2 cache hit ratios below the desirable minimum of 97.0%. Cache utilization might be improved by modifying the alignment or stride of references to data arrays in these functions.

<table>
<thead>
<tr>
<th>D1+D2 cache</th>
<th>Time%</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>hit ratio</td>
<td>96.6%</td>
<td>61.7%</td>
</tr>
<tr>
<td></td>
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<td>calc3</td>
</tr>
</tbody>
</table>
Summary

- Reveal can be used to simplify the task of adding OpenMP to MPI programs.

- The result is performance portable code: OpenMP directives (programs can be built with any compiler that supports OpenMP)

- Reveal can be used as a stepping stone for codes targeted for nodes with higher core counts and as the first step in adding directives to applications to target GPUs

- Reveal auto-parallelization provides possible automatic performance improvements on KNL with minimal developer investment