Creating Hybrid Codes with Cray Reveal

Heidi Poxon
Technical Lead
Programming Environment
Cray Inc.

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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 = zxc(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
   …
   call ppmlr
   do k = 1, kmax
     n = k + 6
     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
   call ppmlr
…
 enddo
enddo
```

```
subroutine ppmlr

call boundary
call flatten
call paraset(nmin-4, nmax+5, para, dx, xa)

call parabola(nmin-4,nmax+4,para,p,dp,p6,pl,flat)
call parabola(nmin-4,nmax+4, para,r,dr,r6,rl,flat)
call parabola(nmin-4,nmax+4,para,u,du,u6,ul,flat)

call states(pl,ul,rl,p6,u6,r6,dp,du,dr,plft,ulft,&
            rlft,prgh,urgh,rrgh)
call riemann(nmin-3,nmax+4,gam,prgh,urgh,rrgh,&
             plft,ulft,rlft pmid umid)
call evolve(umid, pmid)  ← contains more calls

call remap ← contains more calls

call volume(nmin,nmax,ngeom,radius,xa,dx,dvol)

call remap ← contains more calls

return
end
```

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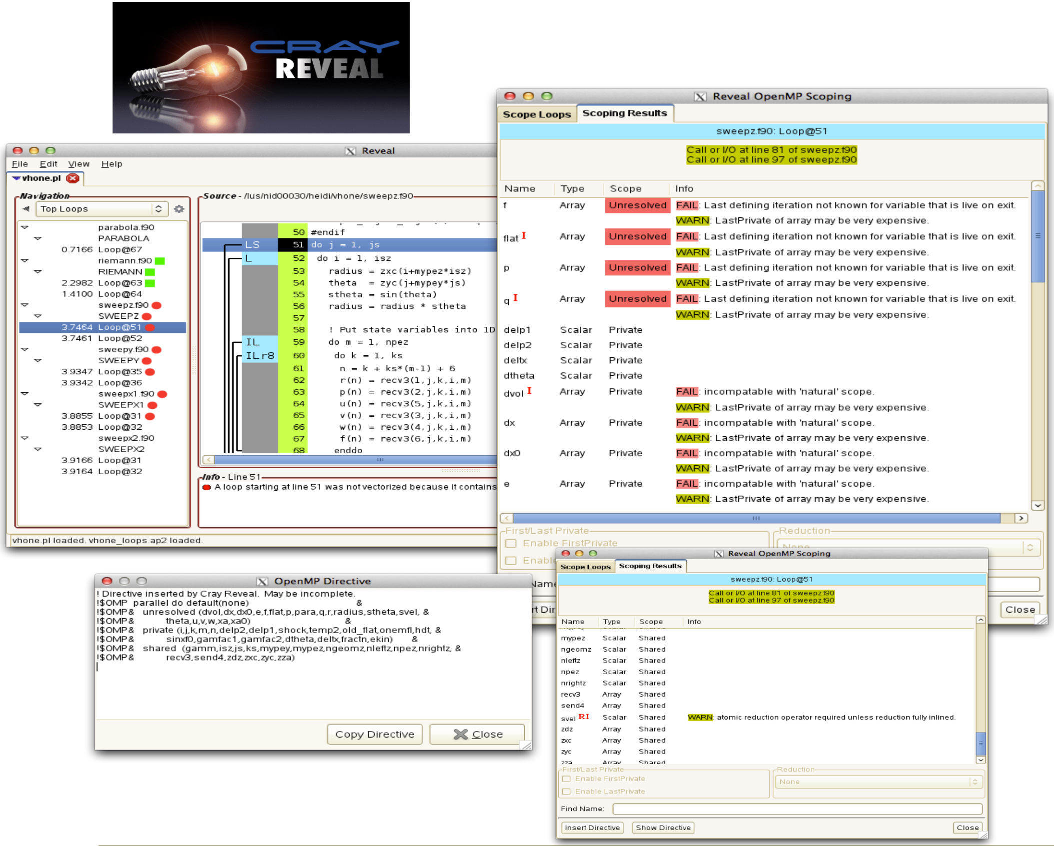
Simplifying the Task with Reveal



- 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)

Loop Incl Time Total	Loop Hit	Loop Trips Avg	Loop Trips Min	Loop Trips Max	Function=/.LOOP[.] PE=HIDE
8.995914	100	25	0	25	sweepy_.LOOP.1.li.33
8.995604	2500	25	0	25	sweepy_.LOOP.2.li.34
8.894750	50	25	0	25	sweepz_.LOOP.05.li.49
8.894637	1250	25	0	25	sweepz_.LOOP.06.li.50
4.420629	50	25	0	25	sweepx2_.LOOP.1.li.29
4.420536	1250	25	0	25	sweepx2_.LOOP.2.li.30
4.387534	50	25	0	25	sweepx1_.LOOP.1.li.29
4.387457	1250	25	0	25	sweepx1_.LOOP.2.li.30
2.523214	187500	107	0	107	riemann_.LOOP.2.li.63
1.541299	20062500	12	0	12	riemann_.LOOP.3.li.64
0.863656	1687500	104	0	108	parabola_.LOOP.6.li.67

The CCE Program Library (PL)

- An **application wide repository** for compiler and tools information
  - User to specifies 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.

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

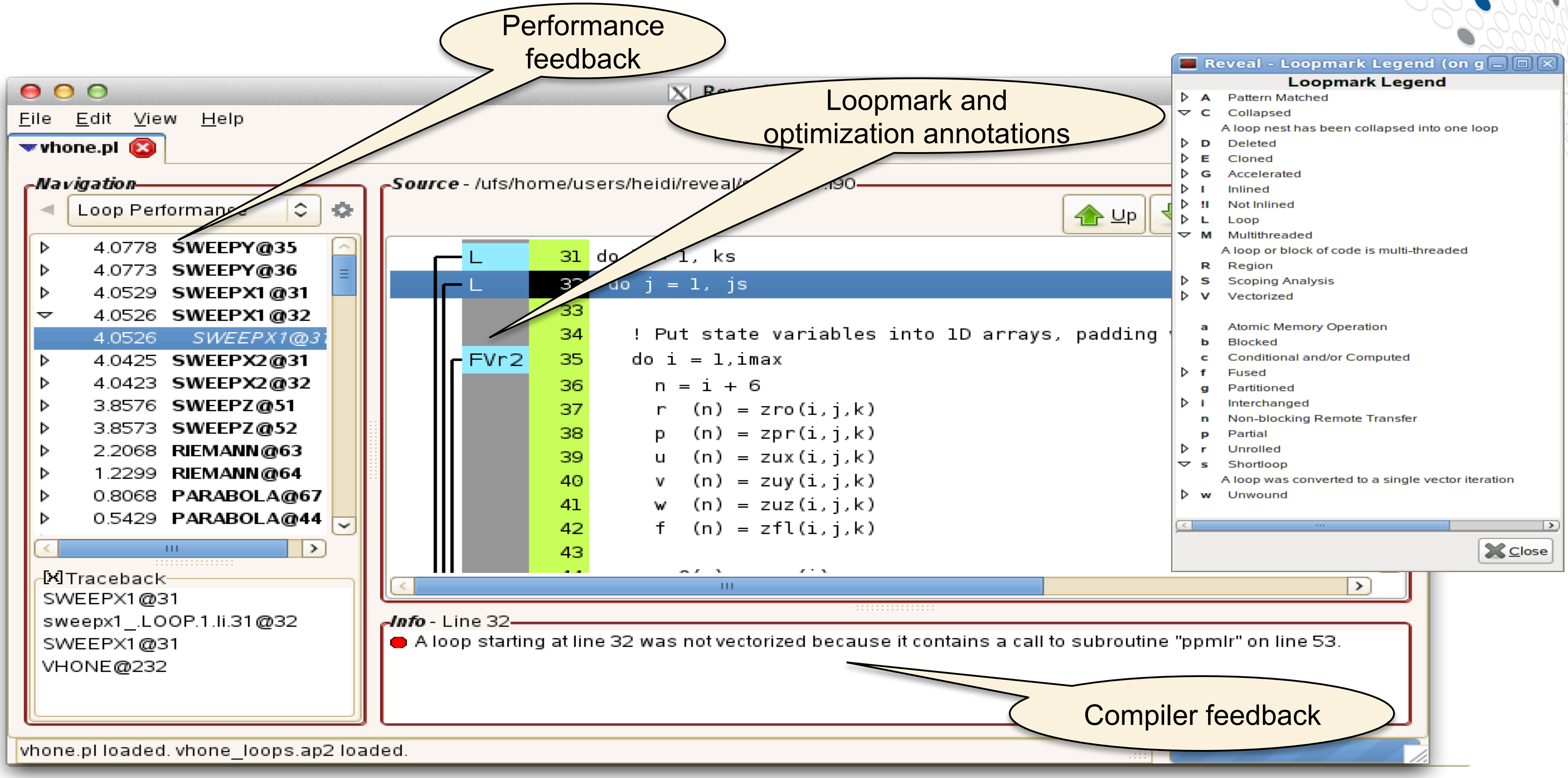
- Use with compiler information only (no need to run program):

```
> reveal vhone.pl
```

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

```
> reveal vhone.pl vhone_loops.ap2
```

Visualize Compiler and Performance Information



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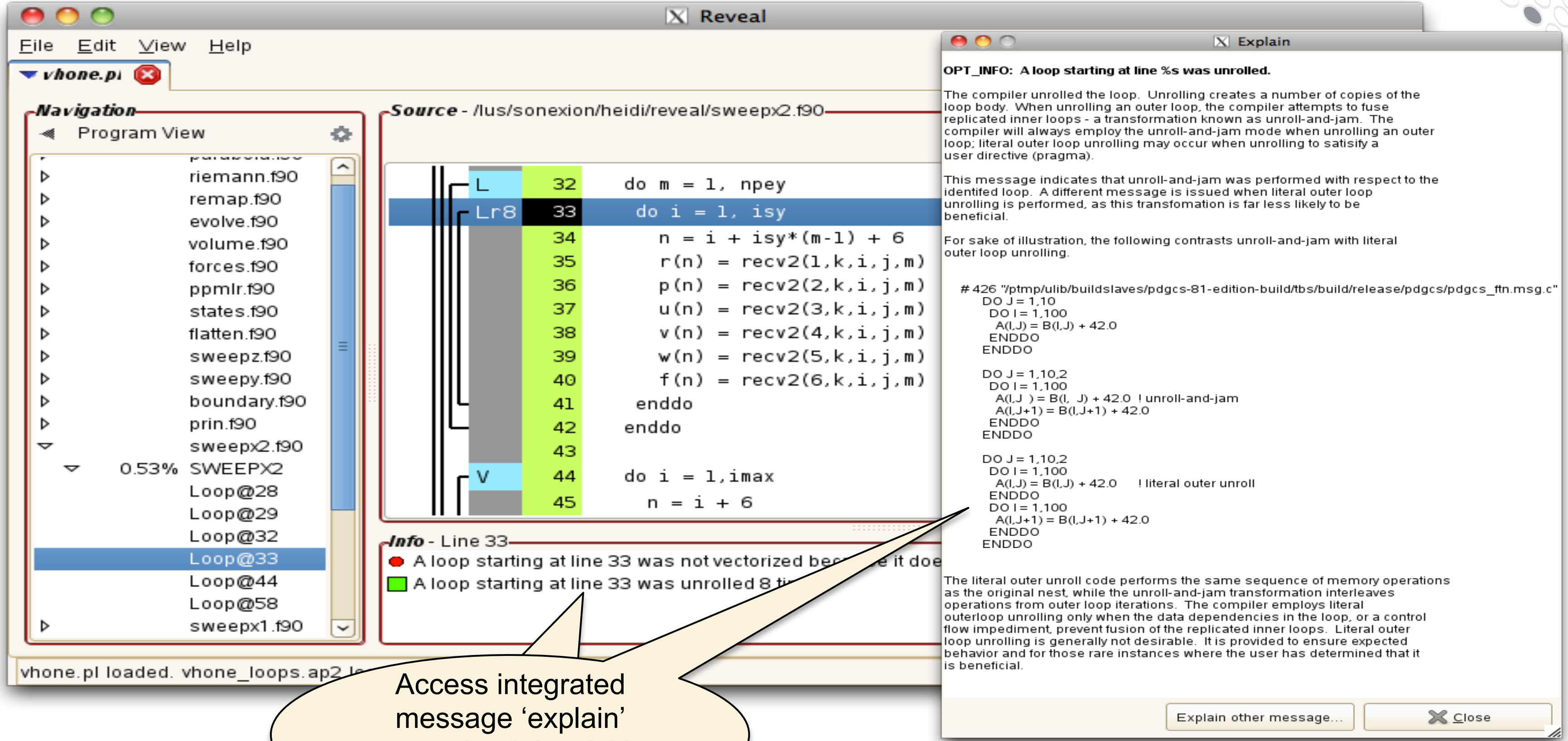
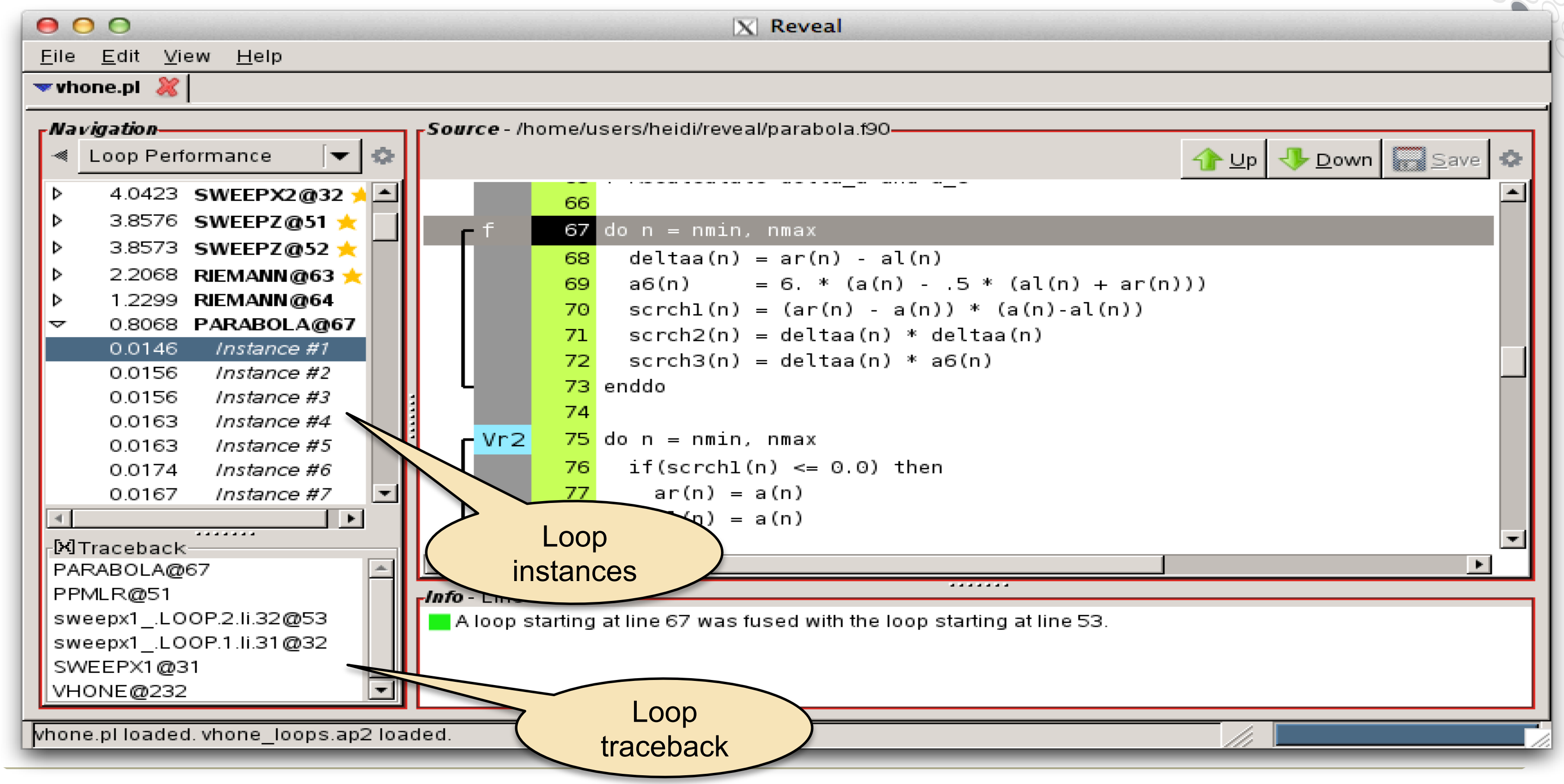
Access Cray Compiler Message Information

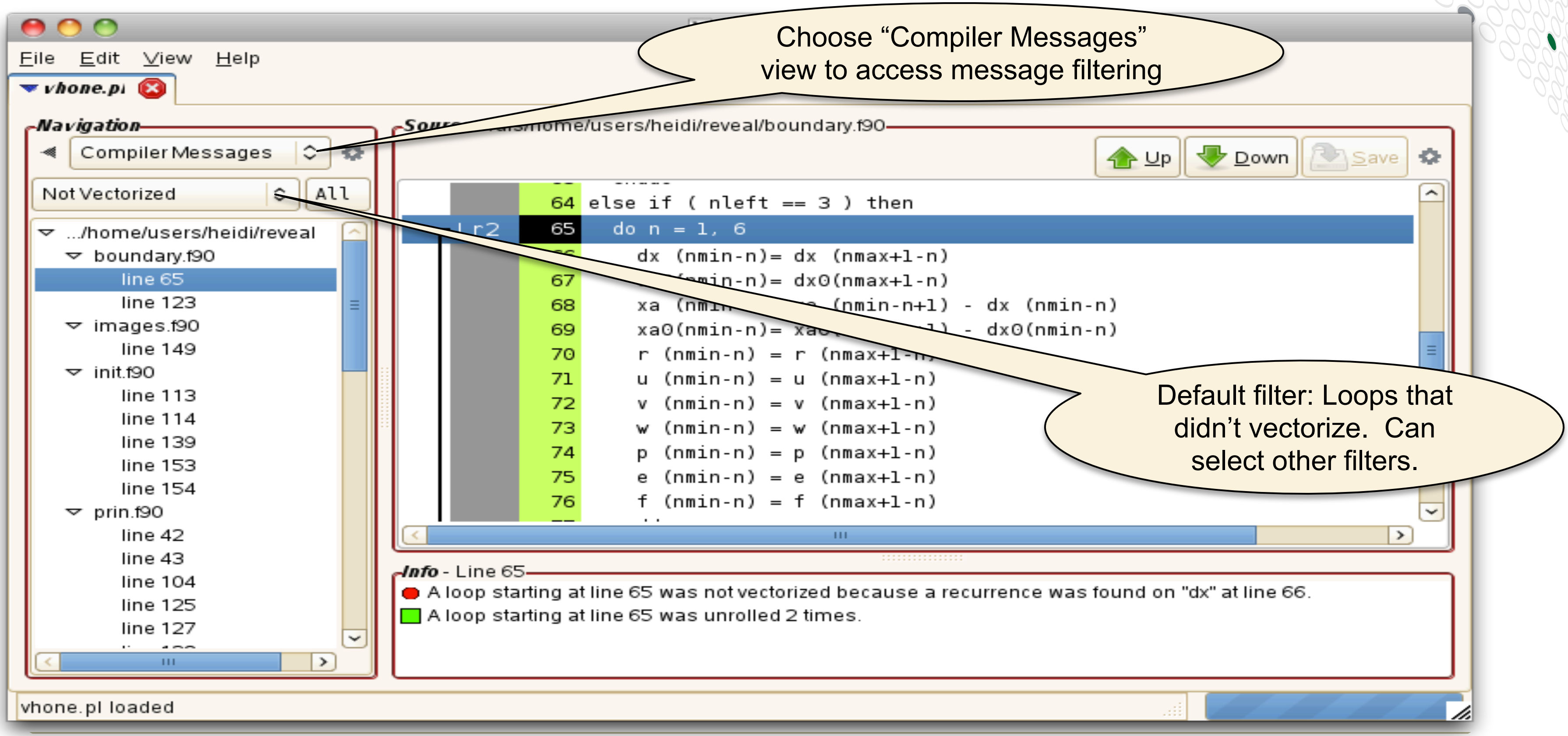


Access integrated message 'explain' support by right clicking on message

Navigate Loops through Call Chain



Navigate Code via Compiler Messages



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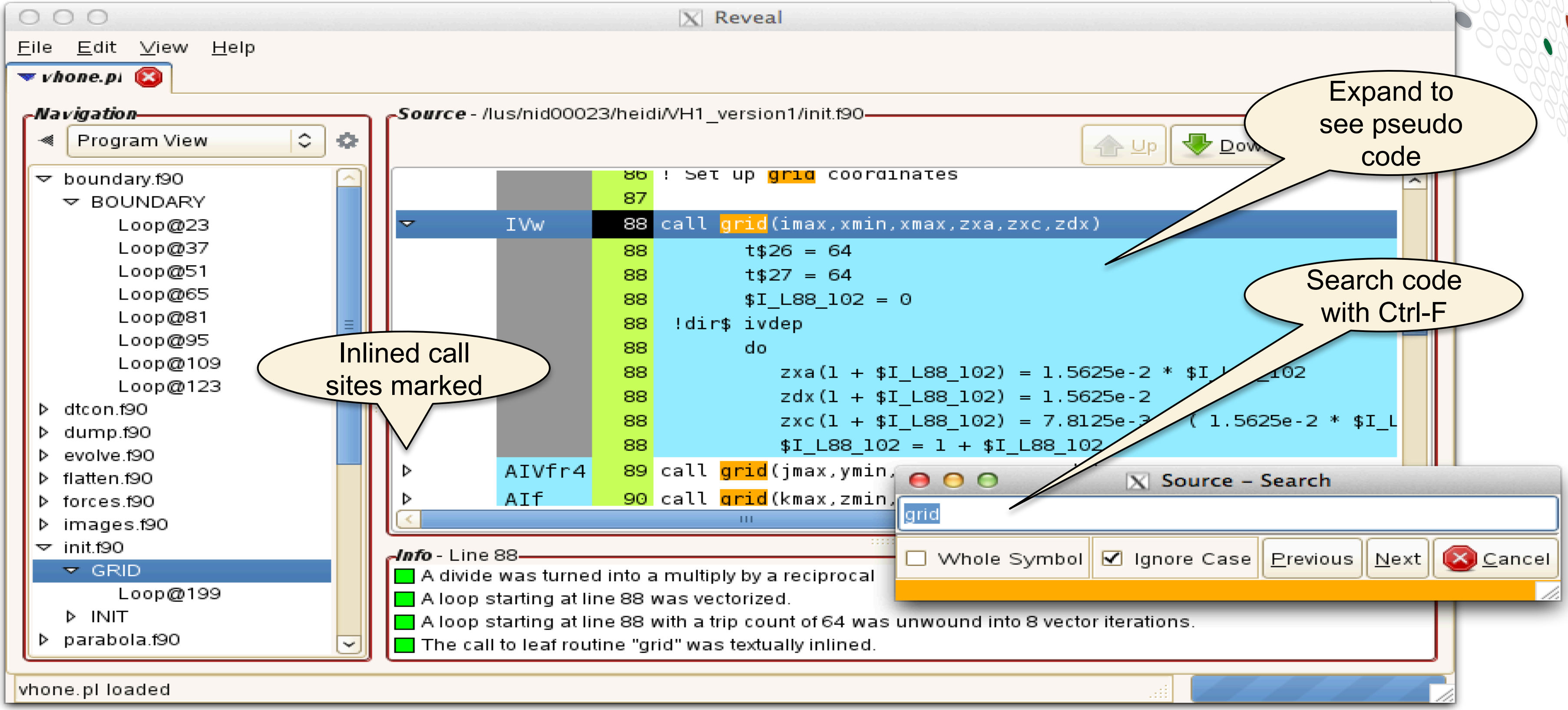
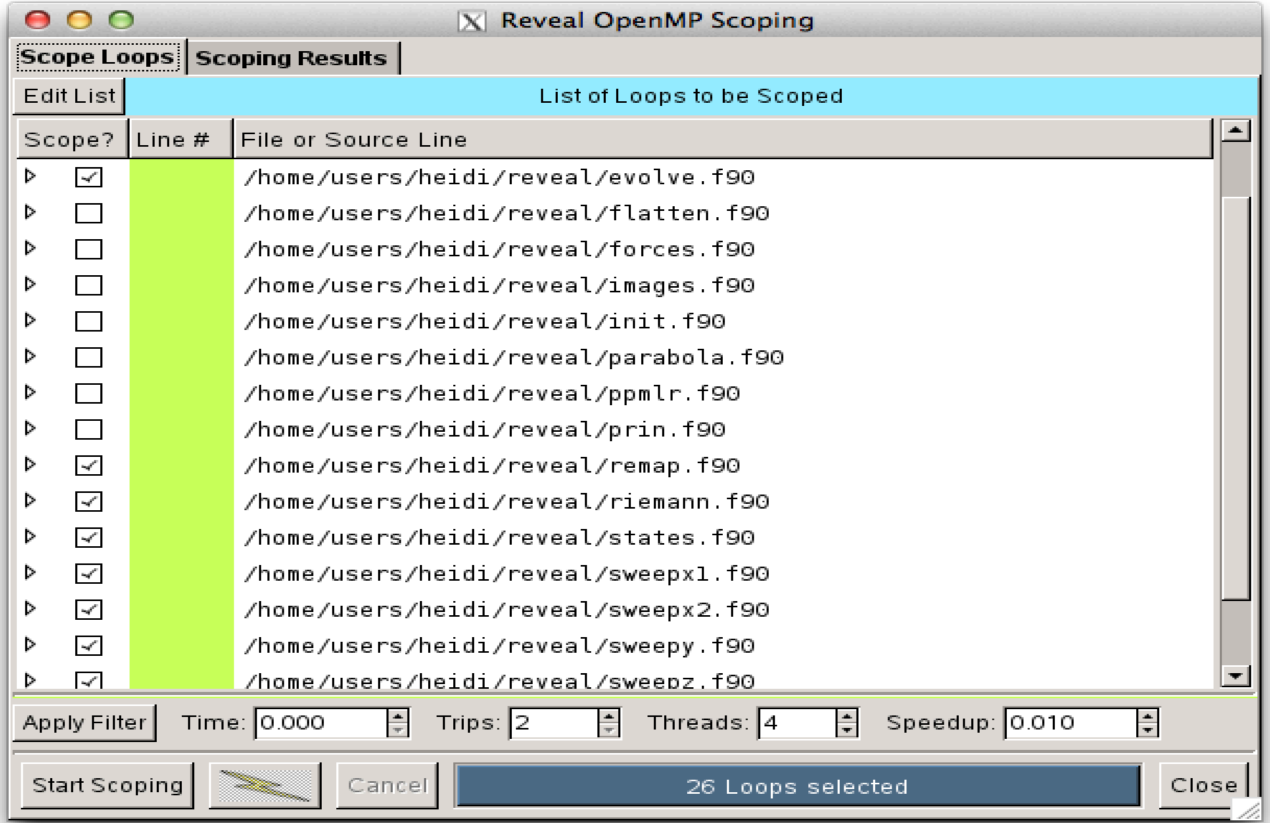
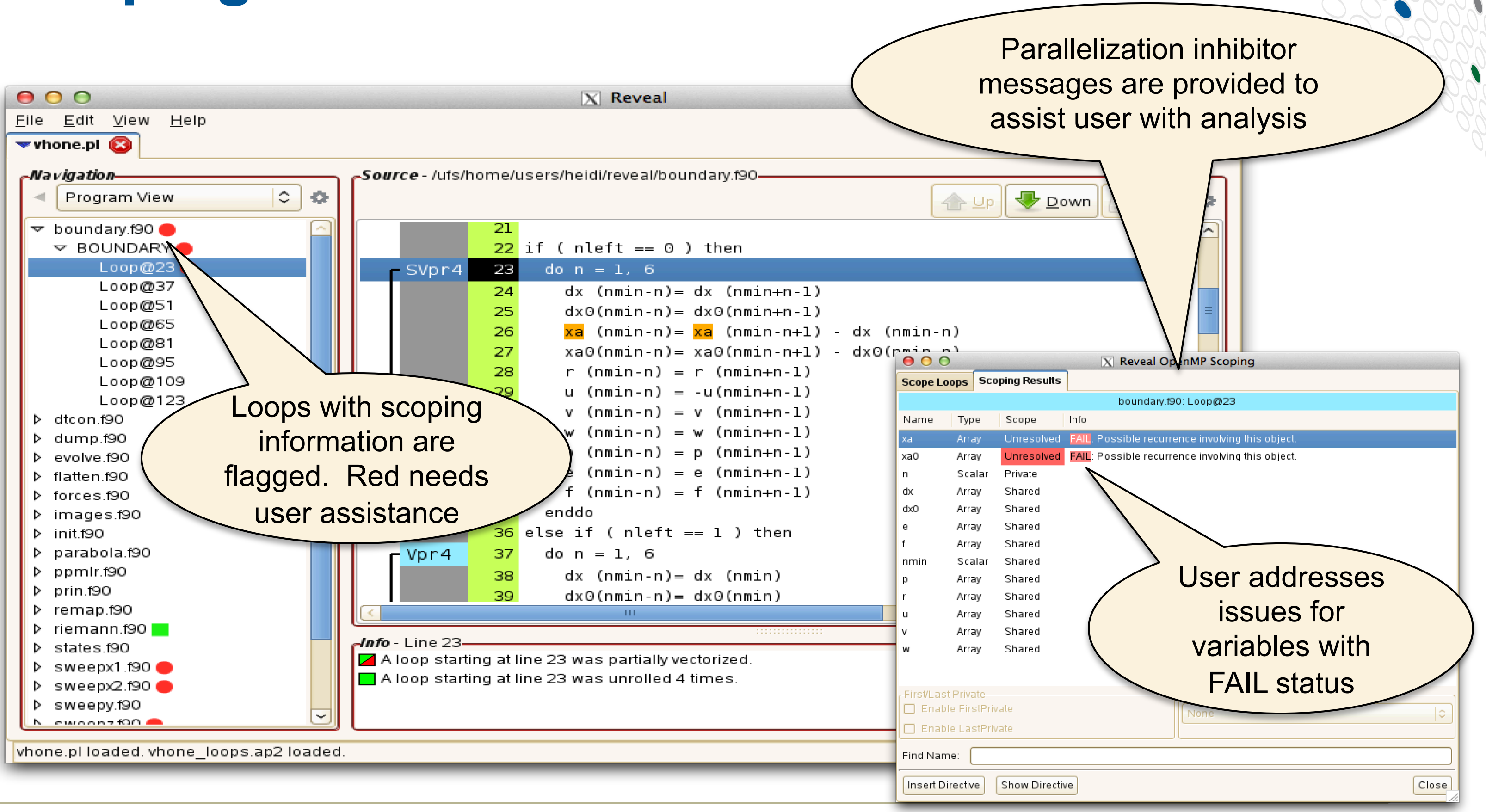
View Pseudo Code for Inlined Functions



Hybridization Step 2: Scope Selected Loop(s)



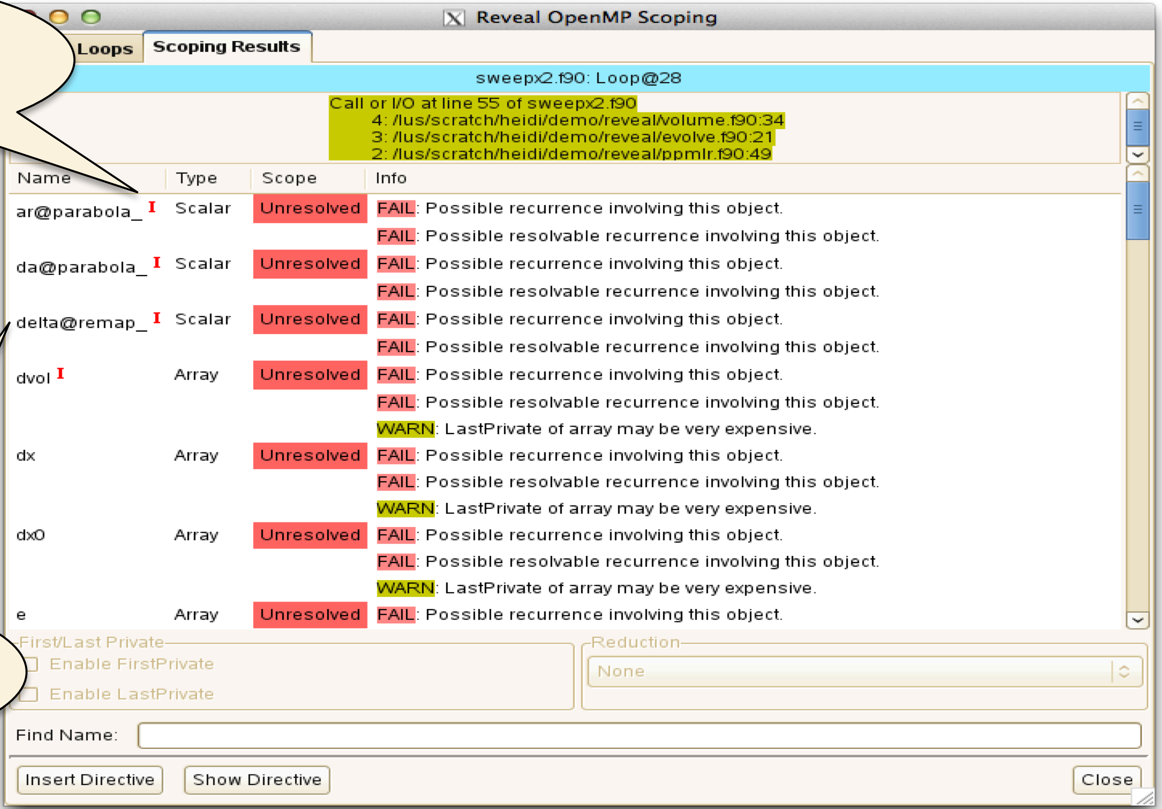
Review Scoping Results



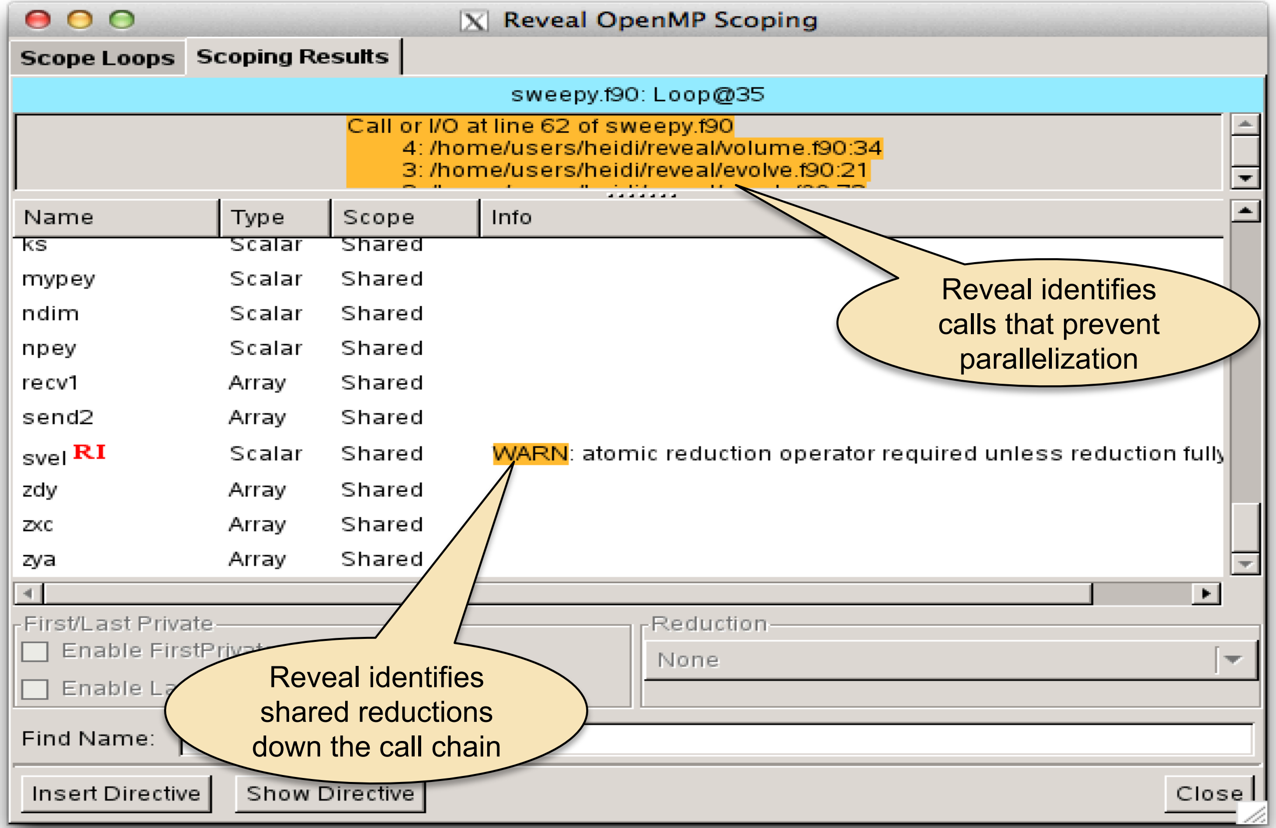
Review Scoping Results (2)

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

See where variable came from (@function_name)



Review Scoping Results (3)

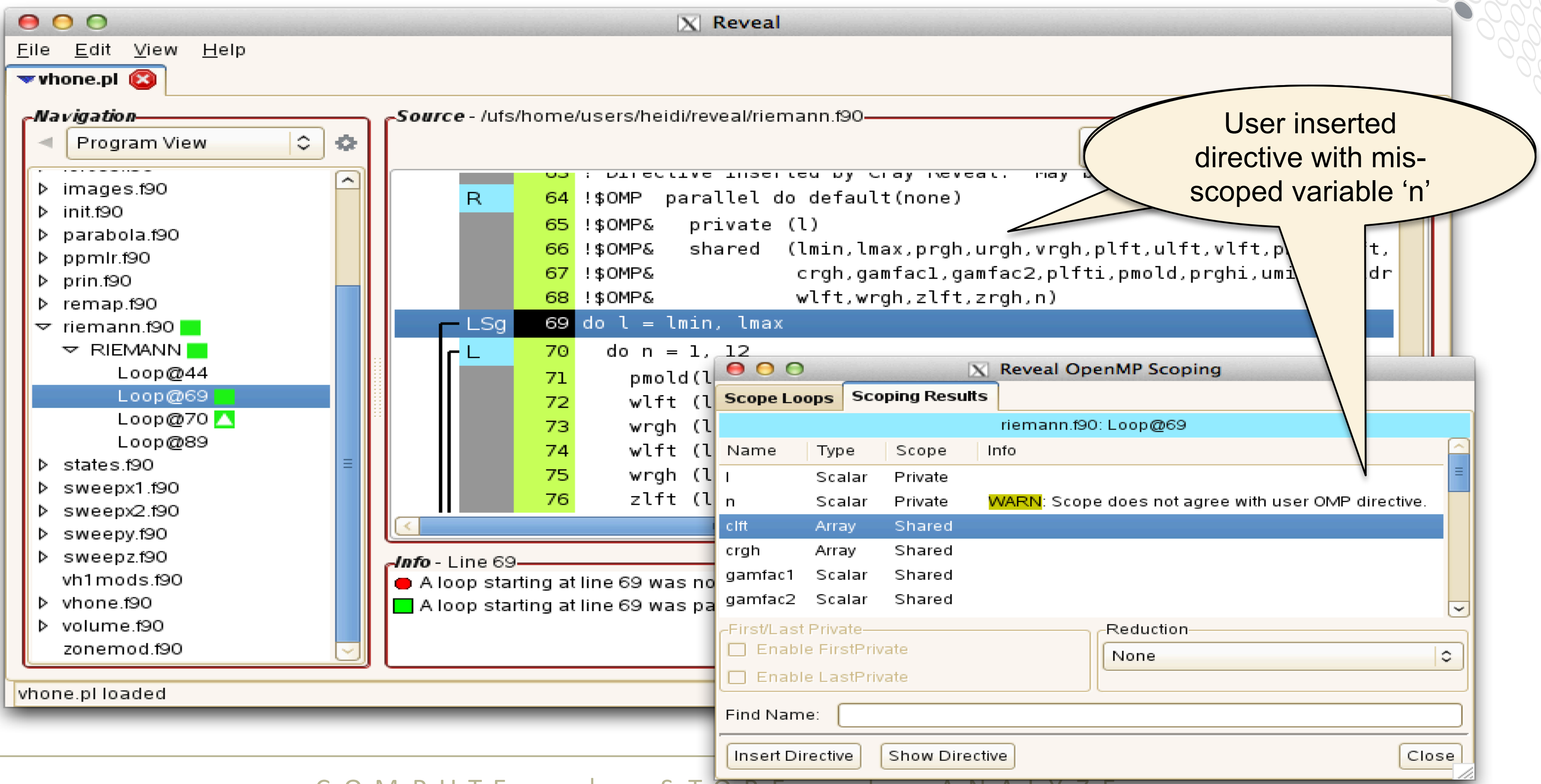


Hybridization Step 3: Generate OpenMP Directives

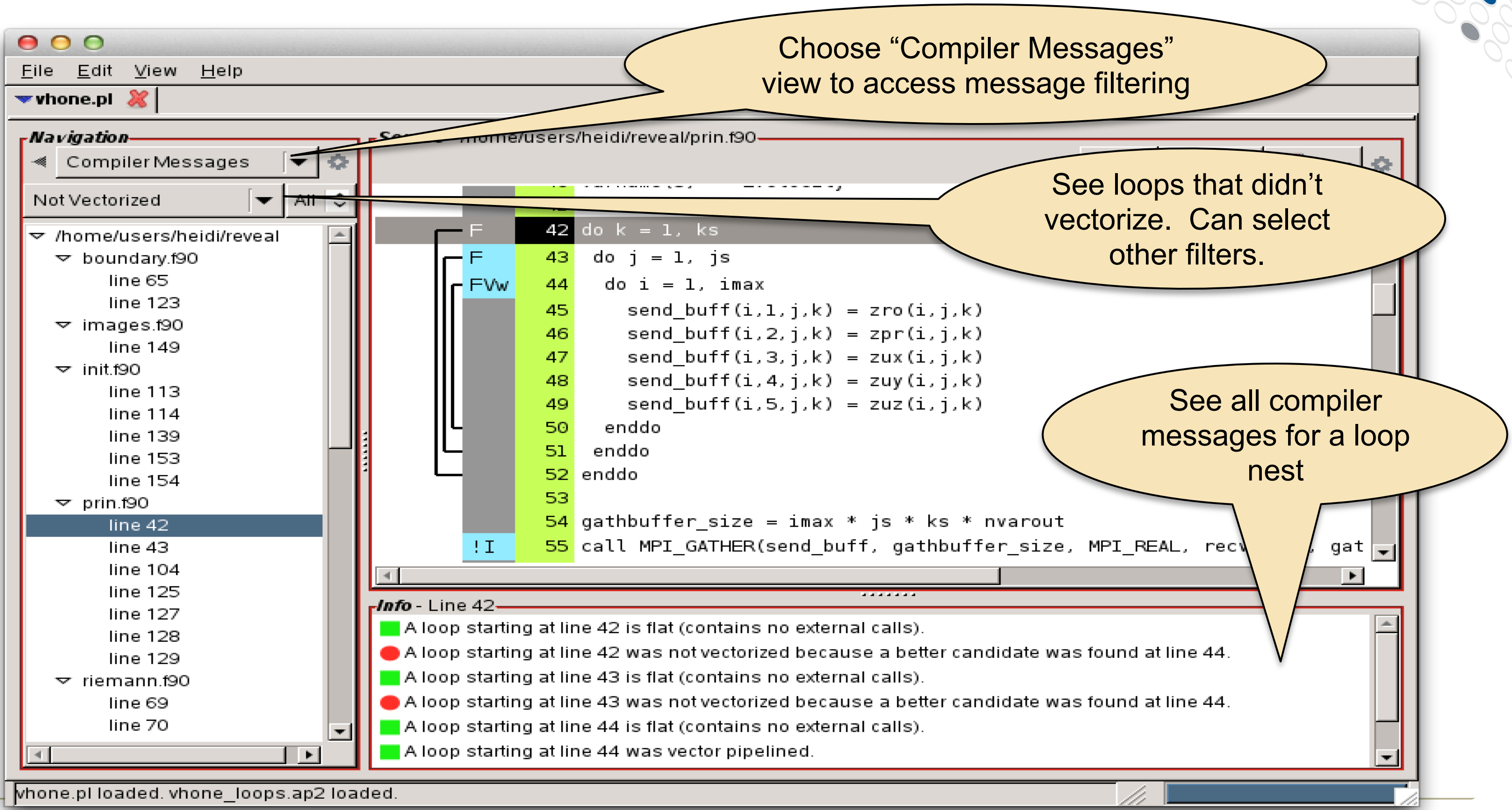
```
! Directive inserted by Cray Reveal.  May be incomplete.
!$OMP  parallel do default(none)                                    &
!$OMP&   unresolved (dvol,dx,dx0,e,f,flat,p,para,q,r,radius,svel,u,v,w,  &
!$OMP&          xa,xa0)                                             &
!$OMP&   private (i,j,k,m,n,$$_n,delp2,delp1,shock,temp2,old_flat,   &
!$OMP&          onemfl,hdt,sinxf0,gamfac1,gamfac2,dtheta,deltx,fractn,  &
!$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



Hybridization Step 4: Performance Analysis



Hybridization Step 4: Performance Analysis (2)

```
================  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.

        D1     Time%    Function
     cache
       hit
     ratio

       74.3%    61.7%   calc3_

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.

     D1+D2     Time%    Function
     cache
       hit
     ratio

       96.6%    61.7%   calc3_
…
```

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

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Thank You