Hewlett Packard Enterprise

Advanced Performance Analysis

LUMI Advanced Workshop

March 5–7, 2025

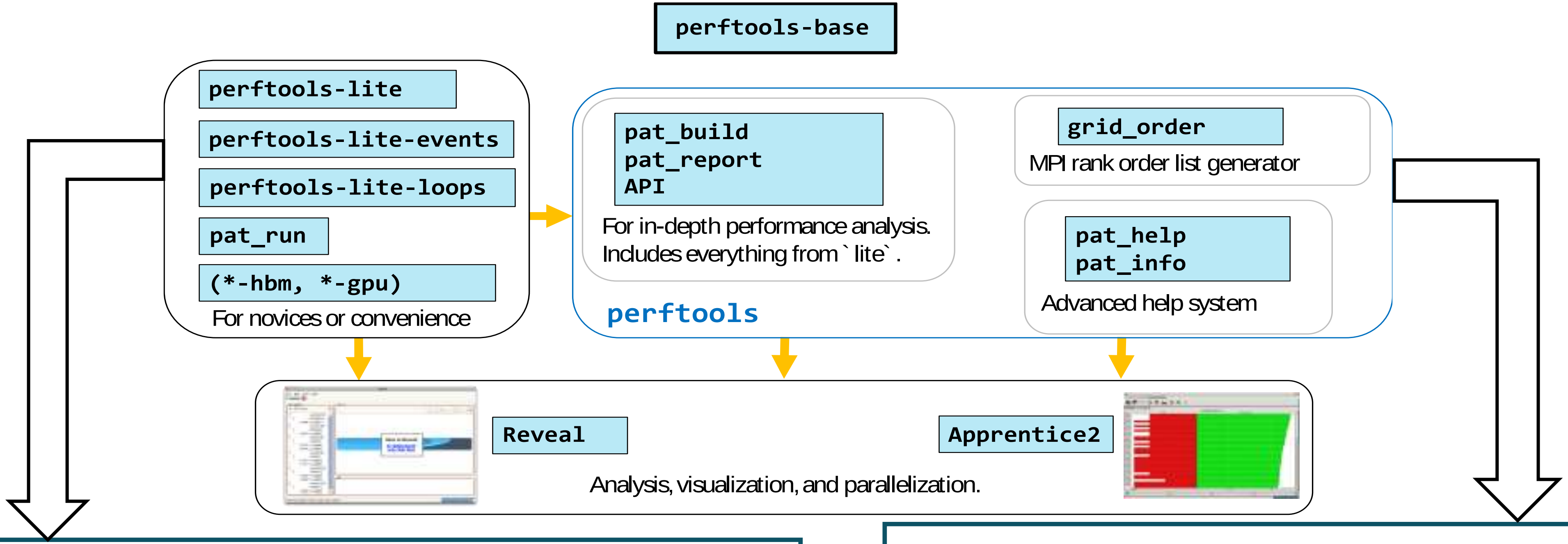
Agenda

- In-depth performance analysis with `perftools`
  - Sampling, tracing, and loop work estimates
  - Automatic Performance Analysis
- Reveal
  - Compiler Feedback and Variable Scoping
- OpenMP profiling
- Perftools API
  - Customized performance analysis
- Hardware performance counters
- Load imbalance analysis
- pat_run
  - Profile existing dynamically linked executables
- Concluding remarks

Perftools

In-depth Perfomance Analysis

Overview



Previous talk:

1. Load the **perftools-lite*** module **wrt desired profiling**
2. Generate the binary
3. Run the binary
4. Look at the **automatically** generated report

This talk:

1. Load the **perftools** module
2. Generate the binary
3. **Manually** generate an **instrumented binary wrt desired profiling**
4. Run the **instrumented binary**
5. **Manually** generate the report
6. Look at the **manually** generated report

Sampling with Perftools

```
> module load perftools-base
> module load perftools
```

```
> make clean; make
> pat_build -S app.exe
```

- This generates a new executable `app.exe+pat` and preserves `app.exe`.
- Object files must be present during this stage.

```
> srun -n 8 ./app.exe+pat
> pat_report -o myrep.trace.rpt app.exe+pat+*/
```

- Running the `app.exe+pat` creates an `app.exe+pat+*/` directory.
- `pat_report` reads that directory and prints a lot of human-readable performance data.
- If worthwhile, a MPI rank reordering file will be produced.

Event Tracing using Perftools

```
> module load perftools-base
> module load perftools
```

```
> make clean; make
> pat_build -u -g mpi app.exe
```

- This generates a new executable `app.exe+pat` and preserves `app.exe`.
- If object files and user libraries have already been compiled with perftools enabled, just relink the application with `rm app.exe; make` instead.
- Traces MPI functions calls and functions defined in the program source files.

```
> srun -n 8 ./app.exe+pat
> pat_report -o myrep.trace.rpt app.exe+pat+*/
```

- Running the `app.exe+pat` creates a `app.exe+pat+*/` directory.
- `pat_report` reads that directory and prints human-readable performance data.

Output: Event Tracing with Perftools

General job information

```
CrayPat/X:  Version 6.4.1 Revision 6a6694f  06/27/16
17:24:11

Number of PEs (MPI ranks):    8
Numbers of PEs per Node:      8
Numbers of Threads per PE:    1
Number of Cores per Socket:  16
Execution start time:  Tue Mar  7 21:28:21 2017
System name and speed:  nid00036  2301 MHz (approx)
Intel haswell CPU  Family:  6  Model: 63  Stepping:  2
```

```
Table 1:  Profile by Function Group and Function

  Time% |     Time |    Imb. |  Imb. |  Calls |Group
        |          |    Time | Time% |        | Function
        |          |         |       |        |  PE=HIDE

 100.0% | 36.703706 |      -- |    -- | 3,036.0 |Total
|-----------------------------------------------------------------
|  97.2% | 35.666406 |      -- |    -- |   457.0 |USER
||----------------------------------------------------------------
||  93.8% | 34.432069 | 0.683771 |  2.2% |    2.0 |jacobi
||   3.4% |  1.232095 | 0.012880 |  1.2% |    1.0 |initmt
||   0.0% |  0.000941 | 0.001077 | 61.0% |    1.0 |main
||   0.0% |  0.000486 | 0.000232 | 36.9% |  150.0 |sendp
||   0.0% |  0.000356 | 0.000445 | 63.5% |  150.0 |sendp3
||   0.0% |  0.000266 | 0.000024 |  9.3% |    1.0 |initcomm
||   0.0% |  0.000172 | 0.000192 | 60.3% |  150.0 |sendp2
||   0.0% |  0.000020 | 0.000008 | 31.8% |    1.0 |exit
||   0.0% |  0.000002 | 0.000001 | 29.9% |    1.0 |initmaxclone_12853_1
||================================================================
```

All user defined routines traced and shown (-T option).

```
||----------------------------------------------------------------
|   2.8% |  1.019139 |      -- |    -- | 2,423.0 |MPI
||----------------------------------------------------------------
||   2.3% | 0.833848 | 0.688832 | 51.7% |   450.0 |MPI_Waitall
||   0.5% | 0.169196 | 0.025124 | 14.8% |   900.0 |MPI_Isend
||   0.0% | 0.012631 | 0.016372 | 64.5% |   900.0 |MPI_Irecv
||   0.0% | 0.001162 | 0.000014 |  1.3% |   152.0 |MPI_Allreduce
||   0.0% | 0.001077 | 0.000043 |  4.4% |     1.0 |MPI_Cart_create
||   0.0% | 0.000703 | 0.000038 |  5.8% |     3.0 |MPI_Type_commit
...
||================================================================|
0.0% |  0.018161 |      -- |    -- |   156.0 |MPI_SYNC
||----------------------------------------------------------------
||   0.0% | 0.014154 | 0.014143 | 99.9% |     2.0 |MPI_Barrier(sync)
||   0.0% | 0.003969 | 0.003266 | 82.3% |   152.0 |MPI_Allreduce(sync)
||   0.0% | 0.000029 | 0.000027 | 92.5% |     1.0 |MPI_Init(sync)
||   0.0% | 0.000009 | 0.000009 | 99.6% |     1.0 |MPI_Finalize(sync)
|=================================================================
```

MPI calls traced

```
Table 2:  Load Balance with MPI Message Stats (limited entries shown)
  Time% |      Time |   MPI | MPI Msg Bytes |  Avg MPI |Group
        |           |   Msg |               | Msg Size | PE=[mmm]
        |           | Count |               |          |

 100.0% | 36.703700 | 602.0 | 197,839,216.0 | 328,636.57 |Total
|-----------------------------------------------------------------
|  97.2% | 35.666406 |   0.0 |           0.0 |       -- |USER
||----------------------------------------------------------------
||  99.1% | 36.361896 |   0.0 |           0.0 |       -- |pe.3
||  96.9% | 35.581600 |   0.0 |           0.0 |       -- |pe.7
||  95.3% | 34.961048 |   0.0 |           0.0 |       -- |pe.5
|=================================================================
|   2.8% |  1.019132 | 602.0 | 197,839,216.0 | 328,636.57 |MPI
||----------------------------------------------------------------
||   4.7% |  1.722054 | 602.0 | 197,839,216.0 | 328,636.57 |pe.5
||   2.4% |  0.881184 | 602.0 | 197,839,216.0 | 328,636.57 |pe.1
||   0.9% |  0.332689 | 602.0 | 197,839,216.0 | 328,636.57 |pe.3
|=================================================================
|   0.0% |  0.018161 |   0.0 |           0.0 |       -- |MPI_SYNC
||----------------------------------------------------------------
||   0.1% |  0.029523 |   0.0 |           0.0 |       -- |pe.6
||   0.1% |  0.019500 |   0.0 |           0.0 |       -- |pe.1
||   0.0% |  0.001622 |   0.0 |           0.0 |       -- |pe.0
|=================================================================
```

Load balance with MPI message statistics

```
Table 3:  MPI Message Stats by Caller (limited entries shown)

    MPI | MPI Msg Bytes |   MPI | MsgSz | 64KiB<= |Function
    Msg |               |   Msg |  <16  |  MsgSz  | Caller
 Bytes% |               | Count | Count |  <1MiB  |  PE=[mmm]
        |               |       |       |  Count  |

 100.0% | 197,839,216.0 | 602.0 | 152.0 |   450.0 |Total
|-----------------------------------------------------------------
| 100.0% | 197,838,600.0 | 450.0 |   0.0 |   450.0 |MPI_Isend
||----------------------------------------------------------------
||  40.0% |  79,104,600.0 | 150.0 |   0.0 |   150.0 |sendp2
3|        |               |       |       |         | sendp
4|        |               |       |       |         |  jacobi
5|        |               |       |       |         |   main
|||||-------------------------------------------------------------
6|||||  40.0% |  79,104,600.0 | 150.0 |   0.0 |   150.0 |pe.0
6|||||  40.0% |  79,104,600.0 | 150.0 |   0.0 |   150.0 |pe.4
6|||||  40.0% |  79,104,600.0 | 150.0 |   0.0 |   150.0 |pe.7
|||||=============================================================
||  40.0% |  79,104,600.0 | 150.0 |   0.0 |   150.0 |sendp1
3|        |               |       |       |         | jacobi
4|        |               |       |       |         |  main
||||--------------------------------------------------------------
5||||  40.0% |  79,104,600.0 | 150.0 |   0.0 |   150.0 |pe.0
5||||  40.0% |  79,104,600.0 | 150.0 |   0.0 |   150.0 |pe.4
5||||  40.0% |  79,104,600.0 | 150.0 |   0.0 |   150.0 |pe.7
||||==============================================================
||  20.0% |  39,629,400.0 | 150.0 |   0.0 |   150.0 |sendp3
```

Load balance with MPI message statistics

Remarks for Tracing

- More information is given in the pat_build man page
- After loading **perftools-base**, tracegroup values are given in **$CRAYPAT_ROOT/share/traces**

```
bracconi@uan04:/project/project_462000031/bracconi> ls $CRAYPAT_ROOT/share/traces
TraceAdios2   TraceCuda    TraceExit@         TraceGMP    TraceJmp@      TraceMPFR    TraceOmp        TracePNetCdf    TraceShmem    TraceSysCall   TraceXpmem
TraceAIO      TraceCurl    TraceFabric        TraceHDF5   TraceLAPACK    TraceMPI     TraceOpenCL     TracePoints     TraceSignal   TraceSysCall@  TraceZMQ
TraceBLACS    TraceDL      TraceFFIO          TraceHeap   TraceLustre    TraceMPI@    TraceOvhdDso@   TracePthread    TraceSpawn    TraceSysFS
TraceBLAS     TraceDL@     TraceFFTW          TraceHIP    TraceMain@     TraceNetCdf  TracePBLAS      TracePthread@   TraceStdIO    TraceSysIO
TraceCaf      TraceDmapp   TraceFFTWcl        TraceHSA    TraceMath      TraceNUMA    TracePetSc      TraceRealTime   TraceString   TraceUmpire
TraceComex    TraceDsmml   TraceGlobalArrays  TraceHuge   TraceMemory    TraceOacc    TracePGAS       TraceScaLAPACK  TraceSync     TraceUpc
bracconi@uan04:/project/project_462000031/bracconi> head -n 5 $CRAYPAT_ROOT/share/traces/TraceBLAS
caxpy_
ccopy_
cdotc_
cdotu_
cgbmv_
```

- **-g tracegroup** instrument the program to trace all function references belonging to trace function group tracegroup.
  - tracegroup : list of coma separated items
  - item : lowercase of ~~Trace~~MPI. **Ex -g mpi,blas,...**
- Only functions actually executed by the program at runtime are traced.

Event Tracing using Perftools for GPU (HIP)

```
> module load PrgEnv-cray
> module load craype-x86-trento craype-accel-amd-gfx90a rocm/6.03
> module load perftools-base
> module load perftools
```

```
> make clean; make
> pat_build -u -g hip app.exe
```

- This generates a new executable app.exe+pat and preserves app.exe.
- If object files and user libraries have already been compiled with perftools enabled, just relink the application with rm app.exe; make instead.
- Traces MPI functions calls, OpenMP offload directives and functions defined in the program source files.

```
> srun -n 8 ./app.exe+pat
> pat_report -T -o myrep.trace.rpt app.exe+pat+*/
```

- Running the app.exe+pat creates a app.exe+pat+*/ directory.
- pat_report reads that directory and prints human-readable performance data.

Output: Event Tracing with Perftools for GPU (HIP)

General job information

```
CrayPat/X:  Version 22.06.0 Revision 4b5ab6256  05/21/22 02:03:49
Number of PEs (MPI ranks):    1
Numbers of PEs per Node:      1
Numbers of Threads per PE:    2
Number of Cores per Socket:  64
Execution start time:  Sun Feb 12 10:34:24 2024
System name and speed:  nid007295  2.010 GHz (nominal)
AMD   Trento             CPU  Family: 25  Model: 48  Stepping:  1
```

```
Table 1:  Profile by Function Group and Function
  Time% |     Time | Imb. |  Imb. |   Calls | Group
        |          | Time | Time% |         |  Function
        |          |      |       |         |   Thread=HIDE
 100.0% | 1.055954 |   -- |    -- | 1,255.0 | Total
|-------------------------------------------------------------------------
|  99.9% | 1.054614 |   -- |    -- |   808.0 | HIP
||------------------------------------------------------------------------
||  88.1% | 0.930584 |   -- |    -- |   110.0 | hipDeviceSynchronize
||  11.7% | 0.123213 |   -- |    -- |   644.0 | hipMalloc
||   0.1% | 0.000684 |   -- |    -- |    18.0 | hipLaunchKernel
||   0.0% | 0.000057 |   -- |    -- |    10.0 | hipMemcpy
||   0.0% | 0.000039 |   -- |    -- |    10.0 | hipMemsetAsync
||   0.0% | 0.000012 |   -- |    -- |     4.0 | hipFree
||   0.0% | 0.000011 |   -- |    -- |     1.0 | hipKernel.count_kernel
||   0.0% | 0.000008 |   -- |    -- |     3.0 | hipGetDeviceProperties
||   0.0% | 0.000004 |   -- |    -- |     4.0 | __hipPushCallConfiguration
||   0.0% | 0.000003 |   -- |    -- |     4.0 | __hipPopCallConfiguration
||=========================================================================
```

Hip routines

```
|   0.1% | 0.001300 |   -- |    -- |   446.0 | ETC
||------------------------------------------------------------------------
||   0.1% | 0.001225 |   -- |    -- |     3.0 | __hip_module_dtor
||   0.0% | 0.000044 |   -- |    -- |    41.0 | hiprtcCreateProgram
||   0.0% | 0.000025 |   -- |    -- |   400.0 | call_init.part.0
||   0.0% | 0.000004 |   -- |    -- |     1.0 | __hip_module_ctor
||   0.0% | 0.000002 |   -- |    -- |     1.0 | __hip_register_globals
||=========================================================================
|   0.0% | 0.000040 |   -- |    -- |     1.0 | USER
||------------------------------------------------------------------------
||   0.0% | 0.000040 |   -- |    -- |     1.0 | main
|==========================================================================
|==========================================================================
```

```
Table 2:  Profile of maximum function times
  Time% |     Time | Imb. |  Imb. | Function
        |          | Time | Time% |  Thread=HIDE
|-----------------------------------------------------------
| 100.0% | 0.930584 |   -- |    -- | hipDeviceSynchronize
|  13.2% | 0.123213 |   -- |    -- | hipMalloc
|   0.1% | 0.001225 |   -- |    -- | __hip_module_dtor
|   0.1% | 0.000684 |   -- |    -- | hipLaunchKernel
|   0.0% | 0.000057 |   -- |    -- | hipMemcpy
|   0.0% | 0.000044 |   -- |    -- | hiprtcCreateProgram
|   0.0% | 0.000040 |   -- |    -- | main
|   0.0% | 0.000039 |   -- |    -- | hipMemsetAsync
|   0.0% | 0.000025 |   -- |    -- | call_init.part.0
|   0.0% | 0.000012 |   -- |    -- | hipFree
|   0.0% | 0.000011 |   -- |    -- | hipKernel.count_kernel
|   0.0% | 0.000008 |   -- |    -- | hipGetDeviceProperties
|   0.0% | 0.000004 |   -- |    -- | __hip_module_ctor
|   0.0% | 0.000004 |   -- |    -- | __hipPushCallConfiguration
|   0.0% | 0.000003 |   -- |    -- | __hipPopCallConfiguration
|   0.0% | 0.000002 |   -- |    -- | __hip_register_globals
|===========================================================
```

Event Tracing using Perftools for GPU (MPI+OpenMP offload)

```
> module load PrgEnv-cray
> module load craype-x86-trento craype-accel-amd-gfx90a rocm
> module load perftools-base
> module load perftools
```

```
> make clean; make
> pat_build -u -g mpi,omp app.exe
```

- This generates a new executable app.exe+pat and preserves app.exe.
- If object files and user libraries have already been compiled with perftools enabled, just relink the application with rm app.exe; make instead.
- Traces MPI functions calls, openMP offload directives and functions defined in the program source files.

```
> srun -n 8 ./app.exe+pat
> pat_report -T -o myrep.trace.rpt app.exe+pat+*/
```

- Running the app.exe+pat creates a app.exe+pat+*/ directory.
- pat_report reads that directory and prints human-readable performance data.

Output: Event Tracing with Perftools for GPU (MPI+OpenMP offload)

```
CrayPat/X:  Version 22.06.0 Revision 4b5ab6256  05/21/22 02:03:49
Number of PEs (MPI ranks):    8
Numbers of PEs per Node:     4  PEs on each of  2  Nodes
Numbers of Threads per PE:    1
Number of Cores per Socket:  64
Execution start time:  Sat Feb 11 10:37:06 2024
System name and speed:  nid007370  2.009 GHz (nominal)
AMD   Trento             CPU  Family: 25  Model: 48  Stepping:  1
```

General job information

```
Table 1:  Profile by Function Group and Function
  Time% |      Time |    Imb. |  Imb. |   Calls | Group
        |           |    Time | Time% |         |  Function
        |           |         |       |         |   PE=HIDE
 100.0% | 24.551284 |      -- |    -- | 3,449.0 | Total
|-----------------------------------------------------------------------------
|  90.3% | 22.160000 |      -- |    -- | 1,733.0 | OACC
||----------------------------------------------------------------------------
||  83.2% | 20.418715 | 0.373699 |  2.1% | 1,094.0 | jacobi.ACC_COPY@li.242
||   4.7% |  1.164765 | 0.021092 |  2.0% |    90.0 | jacobi.ACC_COPY@li.236
||   2.3% |  0.576451 | 0.038592 |  7.2% |   429.0 | jacobi.ACC_COPY@li.268
||   0.0% |  0.000038 | 0.000013 | 28.6% |    60.0 | jacobi.ACC_KERNEL@li.242
||   0.0% |  0.000030 | 0.000020 | 45.6% |    60.0 | jacobi.ACC_KERNEL@li.268
||=============================================================================
```

OpenMP offload regions

```
|   6.2% |  1.515424 |      -- |    -- |   130.0 | USER
||----------------------------------------------------------------------------
||   6.1% |  1.505413 | 0.002802 |  0.2% |     1.0 | initmt
||   0.0% |  0.009833 | 0.000202 |  2.3% |     4.0 | jacobi
||   0.0% |  0.000090 | 0.000026 | 25.7% |     1.0 | main
||   0.0% |  0.000049 | 0.000018 | 30.9% |    60.0 | jacobi.ACC_REGION@li.242
||   0.0% |  0.000032 | 0.000020 | 44.9% |    60.0 | jacobi.ACC_REGION@li.268
||   0.0% |  0.000008 | 0.000001 | 15.6% |     4.0 | jacobi.ACC_DATA_REGION@li.236
||=============================================================================
```

User traced routines

```
|   3.5% |  0.862093 |      -- |    -- |   983.0 | MPI
||----------------------------------------------------------------------------
||   3.4% |  0.825582 | 0.313861 | 31.5% |   180.0 | MPI_Waitall
||   0.1% |  0.028702 | 0.002903 | 10.5% |   360.0 | MPI_Isend
||   0.0% |  0.006636 | 0.016262 | 81.2% |   360.0 | MPI_Irecv
||   0.0% |  0.001061 | 0.000024 |  2.5% |    62.0 | MPI_Allreduce
||   0.0% |  0.000075 | 0.000010 | 12.9% |     1.0 | MPI_Cart_create
||   0.0% |  0.000021 | 0.000004 | 19.6% |     2.0 | MPI_Barrier
||   0.0% |  0.000007 | 0.000002 | 21.2% |     4.0 | MPI_Wtime
||   0.0% |  0.000003 | 0.000003 | 54.7% |     3.0 | MPI_Type_commit
||   0.0% |  0.000002 | 0.000002 | 54.4% |     3.0 | MPI_Type_vector
||   0.0% |  0.000002 | 0.000000 | 24.1% |     1.0 | MPI_Cart_get
||   0.0% |  0.000001 | 0.000000 | 20.9% |     3.0 | MPI_Cart_shift
||   0.0% |  0.000000 | 0.000000 | 21.7% |     1.0 | MPI_Finalize
||   0.0% |  0.000000 | 0.000000 | 20.0% |     1.0 | MPI_Init
||   0.0% |  0.000000 | 0.000000 | 14.0% |     1.0 | MPI_Comm_size
||   0.0% |  0.000000 | 0.000000 | 25.1% |     1.0 | MPI_Comm_rank
||=============================================================================
|   0.0% |  0.005111 |      -- |    -- |    66.0 | MPI_SYNC
||----------------------------------------------------------------------------
||   0.0% |  0.002822 | 0.002792 | 98.9% |     2.0 | MPI_Barrier(sync)
||   0.0% |  0.002211 | 0.000429 | 19.4% |    62.0 | MPI_Allreduce(sync)
||   0.0% |  0.000066 | 0.000062 | 92.8% |     1.0 | MPI_Init(sync)
||   0.0% |  0.000012 | 0.000010 | 80.8% |     1.0 | MPI_Finalize(sync)
||=============================================================================
```

MPI routines

```
|   0.0% |  0.000606 |      -- |    -- |   121.0 | HIP
||----------------------------------------------------------------------------
||   0.0% |  0.000357 | 0.000092 | 23.3% |    60.0 |
hipKernel.__omp_offloading_43b2fce4_1f016d09_jacobi_l242
||   0.0% |  0.000204 | 0.000084 | 33.1% |    60.0 |
hipKernel.__omp_offloading_43b2fce4_1f016d09_jacobi_l268
||   0.0% |  0.000044 | 0.000000 |  0.9% |     1.0 | hipGraphicsUnmapResources
||=============================================================================
==
|   0.0% |  0.000041 | 0.000008 | 17.9% |   400.0 | ETC
||----------------------------------------------------------------------------
||   0.0% |  0.000041 | 0.000008 | 17.9% |   400.0 | __libc_csu_init
|=============================================================================
```

HIP kernels calls during OpenMP offload

Loop Work Estimates using Perftools

```
> module load perftools-base
> module load perftools
```

- Use the compiler flag –h profile_generate for Fortran or -finstrument-loops for C for your build (Cray Compiler only). This flag turns off OpenMP and significant compiler loop restructuring optimizations except for vectorization.

```
> make clean; make
> pat_build -w app.exe
```

- This generates a new executable app.exe+pat and preserves app.exe.
- Loop profiling requires a rebuild of object files and user libraries.
- Automatically traces functions defined in the program source files despite -w

```
> srun -n 8 ./app.exe+pat
> pat_report -T -o myrep.trace.rpt app.exe+pat+*/
```

- Running the app.exe+pat creates a directory app.exe+pat+*/ experiment directory.
- pat_report reads that directory and prints a lot of human-readable performance data.

Automatic Profiling Analysis (1/2)

```
> module load perftools-base
> module load perftools
```

```
> make clean; make
> pat_build app.exe
```

- The APA (-O apa) is the default experiment. No option needed.
- The pat_build generates a binary instrumented for sampling (different from the pure sampling shown before with –S option)

```
> srun -n 8 app.exe+pat
> pat_report -o myrep.txt app+pat+*/
```

- Running the "+pat" binary creates an experiment directory.
- Applying pat_report to the app+pat+*/ directory generates an *.apa file therein.

Automatic Profiling Analysis (2/2)

```
> vi app.exe+pat+*/*.apa
```

- The *.apa file contains instructions for the next step, i.e. tracing. Modify it according to your needs.

```
> pat_build -O app.exe+pat+*/*.apa
```

- Generates an instrumented binary app.exe+apa for tracing according to the instructions in the app.exe+pat+*/*.apa file.

```
> srun -n 8 ./app.exe+apa
> pat_report -o myrep.txt app.exe+apa+*/
```

- Running the app.exe+apa binary creates a new data file or directory.
- Applying pat_report to the app+apa+*/ directory generates a new report.

Output: APA with perftools

Sampling profiling

```
CrayPat/X:  Version 6.4.1 Revision 6a6694f  06/27/16 17:24:11

Number of PEs (MPI ranks):   8
Numbers of PEs per Node:     8
Numbers of Threads per PE:   1
Number of Cores per Socket:  16

Execution start time:  Wed Mar  8 14:24:42 2017
System name and speed:  nid00036  2301 MHz (approx)
Intel haswell CPU  Family:  6  Model: 63  Stepping:  2
...

 Samp% |   Samp | Imb. |  Imb. |Group
       |        | Samp | Samp% | Function
       |        |      |       |  PE=HIDE

 100.0% | 3,685.0 |   -- |    -- |Total
|-----------------------------------------------
|  84.2% | 3,104.5 |   -- |    -- |USER
||----------------------------------------------
||  81.9% | 3,018.1 | 57.9 |  2.2% |jacobi
||   2.3% |    86.1 |  2.9 |  3.7% |initmt
||==============================================
|  13.3% |   489.9 |   -- |    -- |ETC
||----------------------------------------------
||  12.2% |   451.2 |  6.8 |  1.7% |_cray_scopy_HSW
||   1.0% |    38.6 |  2.4 |  6.6% |_cray_sset_HSW
||==============================================
|   2.5% |    90.6 |   -- |    -- |MPI
||----------------------------------------------
||   1.9% |    69.6 | 46.4 | 45.7% |MPI_Waitall
|===============================================
...
Total
------------------------------------------------------------------------------
  CPU_CLK_THREAD_UNHALTED:THREAD_P              109,408,212,031
  CPU_CLK_THREAD_UNHALTED:REF_XCLK                3,588,344,079
  DTLB_LOAD_MISSES:MISS_CAUSES_A_WALK                53,188,056
  PM_ENERGY:NODE               30.382 /sec            1,112 J
  CPU_CLK                      3.05GHz
  TLB utilization              268.83 refs/miss       0.53 avg uses
  D1 cache hit,miss ratios     70.8% hits             29.2% misses
  D1 cache utilization (misses)  3.43 refs/miss       0.43 avg hits
  D2 cache hit,miss ratio      67.8% hits             32.2% misses
  D1+D2 cache hit,miss ratio   90.6% hits             9.4% misses
  D1+D2 cache utilization      10.65 refs/miss        1.33 avg hits
  D2 to D1 bandwidth           6,149.405MiB/sec  236,055,684,984 bytes
```

APA file

```
# ----------------------------------------------------------------------
# Collect the default PERFCTR group.

  -Drtenv=PAT_RT_PERFCTR=default

…

# Libraries to trace.

  -g mpi

# ----------------------------------------------------------------------

# User-defined functions to trace, sorted by % of samples.
…

  -w  # Enable tracing of user-defined functions.
      # Note: -u should NOT be specified as an additional option.

# 81.90% 3735 bytes
        -T jacobi

# 2.34% 2450 bytes
        -T initmt

# ----------------------------------------------------------------------

-o himeno.exe+apa # New instrumented program.
…
```

Suggestion to collect Performance counters

Augment list if needed, i.e. –g mpi,io

Create the binary for tracing

Add or remove functions as needed.

Event Tracing tuned profiling

```
CrayPat/X:  Version 6.4.1 Revision 6a6694f  06/27/16 17:24:11

Number of PEs (MPI ranks):   8
Numbers of PEs per Node:     8
Numbers of Threads per PE:   1
Number of Cores per Socket:  16
...
Table 1:  Profile by Function Group and Function

  Time% |      Time |     Imb. |  Imb. |   Calls |Group
        |           |     Time | Time% |         | Function
        |           |          |       |         |  PE=HIDE

 100.0% | 37.748701 |       -- |    -- | 2,584.0 |Total
|------------------------------------------------------------
|  95.9% | 36.184768 |       -- |    -- |     5.0 |USER
||-----------------------------------------------------------
||  92.5% | 34.935081 | 1.178364 |  3.7% |     2.0 |jacobi
||   3.3% |  1.248950 | 0.016487 |  1.5% |     1.0 |initmt
||===========================================================
|   4.1% |  1.537996 |       -- |    -- | 2,423.0 |MPI
||-----------------------------------------------------------
||   3.6% |  1.344349 | 1.096798 | 51.3% |   450.0 |MPI_Waitall
...
==============================================================
USER / jacobi
--------------------------------------------------------------
  Time%                                  92.5%
  Time                          34.935081 secs
  Imb. Time                      1.178364 secs
  Imb. Time%                              3.7%
  Calls                   0.057 /sec   2.0 calls
  CPU_CLK_THREAD_UNHALTED:THREAD_P       104,712,083,433
  CPU_CLK_THREAD_UNHALTED:REF_XCLK         3,465,232,627
  DTLB_LOAD_MISSES:MISS_CAUSES_A_WALK         44,033,261
  DTLB_STORE_MISSES:MISS_CAUSES_A_WALK        26,116,487
  L1D:REPLACEMENT                          6,955,645,277
  L2_RQSTS:ALL_DEMAND_DATA_RD              3,675,034,522
  L2_RQSTS:DEMAND_DATA_RD_HIT              1,408,925,969
  MEM_UOPS_RETIRED:ALL_LOADS              22,406,881,264
  CPU_CLK                         3.02GHz
  TLB utilization          319.41 refs/miss    0.62 avg uses
  D1 cache hit,miss ratios   69.0% hits       31.0% misses
  D1 cache utilization (misses)  3.22 refs/miss   0.40 avg hits
```

Using `pat_report`

- Always need to run `pat_report` at least once to perform data conversion
  - Experiment directory contains *.xf files in the xf-files/ subdirectory
  - Perftools combines information from `xf` output and executable to produce `ap2` stored in the ap2-files/ subdirectory: instrumented binary must still exist when data is converted!
  - Resulting `ap2` files are the input for subsequent `pat_report` calls and Reveal or Apprentice[2]
  - Always use the entire experiment directory as input and not single ap2 files
  - `xf` files and instrumented binary files could be removed once `ap2` file is generated.

- Generates a text report of performance results
  - Data laid out in tables
  - Many options for sorting, slicing or dicing data in the tables.

```
> pat_report –O <table option> app.exe+pat+*/
> pat_report –O help (list of available profiles)
```

  - Volume and type of information depends upon sampling vs tracing

Using `pat_report`

- The performance numbers reported are in general an average over all tasks (also explains non-integer values)

```
 Time% |       Time |     Imb. |  Imb. |  Calls |Group
       |            |     Time | Time% |        | Function
       |            |          |       |        |  PE=HIDE

 100.0% | 20.643909 |       -- |    -- | 1149.0 |Total
|-----------------------------------------------------------
|  98.8% | 20.395989 |       -- |    -- |  219.0 |USER
||----------------------------------------------------------
||  91.1% | 18.797060 | 0.115535 |  0.7% |    2.0 |jacobi
||   7.7% |  1.597866 | 0.006647 |  0.5% |    1.0 |initmt
||   0.0% |  0.000402 | 0.000167 | 33.5% |   53.0 |sendp3
```

- Not always meaningful
  - controller/worker schemes
  - MPMD
- To solve this you can filter the *.ap2 file

```
> pat_report -sfilter_input='condition' …
```

  - The 'condition' should be an expression involving 'pe' such as 'pe<1024' or 'pe%2==0'.
  - This option is also useful when the size of the full data file makes a report incorporating data from all PEs take too long or exceed the available memory
- More help:
  - `pat_report -h` => usage
  - `pat_report -O -h` => available report tables
  - `pat_report -s -h` => options for content and format
  - `pat_report -d -h` => options for data columns

General Remarks

- Always check that the instrumenting binary has not affected the run time significantly compared to the original executable
- Collecting event traces on large numbers of frequently called functions, or setting the sampling interval very low can introduce a lot of overhead (check `trace-text-size` option to `pat_build`)
- Highly recommended to run on Lustre!
- The runtime analysis can be modified using environment variables of the form `PAT_RT_*`
  - Check the `PAT_LD_OBJECT_TMPDIR` variable if you cannot preserve the original build tree
- `pat_build` may recognize for instance MPI in your application and trace `MPI_Init` and `MPI_Finalize` when adding –g mpi trace all MPI calls
- Processing the `app+*/` directory from `perftools-lite` yields all the options of `pat_build` to reproduce the experiment with regular `perftools`.

OpenMP profiling

OpenMP Data Collection and Reporting

- For OpenMP programs
  - Measure the overhead incurred by entering and leaving parallel regions and work-sharing constructs within parallel regions
  - Show per-thread timings in addition to other data.
  - Calculate the load balance across threads for such constructs.
- For programs that use both MPI and OpenMP
  - Profiles by default show the load balance over PEs of the average time in the threads for each PE
  - But you can also see load balances for each programming model separately.
- Options for `pat_report`
  - `profile_pe.th`
    - Imbalance based on the set of all threads in the program
  - `profile_pe_th` (default view)
    - Highlights imbalance across MPI ranks
    - Uses max for thread aggregation to avoid showing under-performers
    - Aggregated thread data merged into MPI rank data
  - `profile_th_pe`
    - For each thread, show imbalance over MPI ranks
    - Example: Load imbalance shown where thread 4 in each MPI rank didn't get much work

OpenMP Data Collection and Reporting

- OpenMP support needs to be enabled during compilation
- OpenMP tracing calls inserted by default when perftools is loaded

Table 1: Profile by Function Group and Function

Time%	Time	Imb. Time	Imb. Time%	Calls	Group / Function / PE=HIDE / Thread=HIDE
100.0%	2.452453	--	--	1426.8	Total
96.9%	2.377154	--	--	309.8	USER
82.1%	2.013394	0.027282	1.8%	100.0	work.LOOP@li.533
10.6%	0.259470	0.000282	0.1%	1.0	exit
2.4%	0.057711	0.000562	1.3%	1.0	initializeMatrix
1.0%	0.024130	0.000313	1.7%	1.0	setPEsParams.SINGLE@li.355
1.6%	0.039963	--	--	909.0	MPI
1.6%	0.039247	0.079519	89.3%	301.5	MPI_Wait
1.2%	0.029108	--	--	101.0	OMP
1.2%	0.029058	0.012000	39.0%	100.0	work.REGION@li.492(ovhd)

Work sharing construct

Region

Overhead

Table 2: Load Imbalance by Thread

Max. Time	Imb. Time	Imb. Time%	Thread / PE=HIDE
2.452470	0.316486	17.2%	Total
2.453287	0.000817	0.0%	thread.0
2.078727	0.036293	2.3%	thread.2
2.074969	0.048712	3.1%	thread.1
2.066243	0.043468	2.8%	thread.3

Perftools API

Customized performance analysis.

API for Adding User Instrumentation

The Perftools API calls enable you to insert functions into your source code that write special tracing records into the experiment data file at runtime. Useful for large routines

- API calls are supported in both Fortran and C
- API works for sampling, tracing, and loop profiling as well as with the `perftools-lite*` modules
- When `perftools` module is loaded
  - -I`$CRAYPAT_ROOT/include` is added to compiling flag (C header `pat_api.h`, Fortran header `pat_apif.h` and Fortran 77 header files, `pat_apif.h` and `pat_apif77.h` are available)
  - Macro `CRAYPAT`and –DCRAYPAT is added to compiling flag

- `int PAT_region_begin (int id, char *label)`
  - `id` is a unique identifier for the region
  - label is the description that will appear in profiling output
- `int PAT_region_end (int id)`
  - `id` must match begin call

- Fortran subroutines with extra final integer argument for return value similar to MPI.
- Data collection through API can be controlled with `PAT_RT_TRACE_API`
- For more information, see `pat_build` man page in the section APPLICATION PROGRAM INTERFACE

PAT Regions Example in C and Fortran

C:

```
#ifdef CRAYPAT
#include "pat_api.h“
#endif
...
#ifdef CRAYPAT
PAT_region_begin( 1, ”jacobi_part1");
#endif
// the execution of this code segment will
// appear in CrayPAT output as “jacobi_part1”
 ...
#ifdef CRAYPAT
PAT_region_end( 1);
#endif
 ...
#ifdef CRAYPAT
PAT_region_begin( 2, ”jacobi_part2”);
#endif
// the execution of this code segment will
// appear in CrayPAT output as “jacobi_part2”
 ...
#ifdef CRAYPAT
PAT_region_end( 2);
#endif
 ...
```

Fortran:

```
#ifdef CRAYPAT
#include "pat_apif.h“
#endif
...
#ifdef CRAYPAT
Call PAT_region_begin( 1, ”jacobi_part1“, istat)
#endif
// the execution of this code segment will
// appear in CrayPAT output as “jacobi_part1”
 ...
#ifdef CRAYPAT
Call PAT_region_end( 1, istat)
#endif
 ...
#ifdef CRAYPAT
Call PAT_region_begin( 2, ”jacobi_part2”, istat)
#endif
// the execution of this code segment will
// appear in CrayPAT output as “jacobi_part2”
 ...
#ifdef CRAYPAT
Call PAT_region_end( 2, istat)
#endif
```

Event Tracing w/ and w/o Perftools API (C)

Regions

With API

Time%	Time	Imb. Time	Imb. Time%	Calls	Group / Function / PE=HIDE
100.0%	45.429778	--	--	3,336.0	Total
82.6%	37.513233	--	--	757.0	USER
69.9%	31.777804	7.855317	22.7%	150.0	#1.jacobi_part1
9.9%	4.480465	0.484320	11.1%	150.0	#2.jacobi_part2
2.8%	1.252451	0.066733	5.8%	1.0	initmt
0.0%	0.001015	0.002053	76.5%	1.0	main
0.0%	0.000479	0.000493	58.0%	150.0	sendp
0.0%	0.000298	0.000075	22.9%	2.0	jacobi
0.0%	0.000297	0.000026	9.2%	1.0	initcomm
0.0%	0.000271	0.000211	50.0%	150.0	sendp3
0.0%	0.000132	0.000255	75.2%	150.0	sendp2
0.0%	0.000019	0.000000	2.8%	1.0	exit
17.3%	7.843884	--	--	2,423.0	MPI
16.8%	7.652373	2.858017	31.1%	450.0	MPI_Waitall
0.4%	0.170341	0.033417	18.7%	900.0	MPI_Isend
0.0%	0.016676	0.018946	60.8%	900.0	MPI_Irecv
0.0%	0.001239	0.000039	3.4%	1.0	MPI_Cart_create
0.0%	0.001214	0.000015	1.4%	152.0	MPI_Allreduce
0.0%	0.000933	0.000022	2.6%	3.0	MPI_Type_commit
0.0%	0.000644	0.000031	5.2%	3.0	MPI_Cart_shift
0.0%	0.000459	0.000027	6.5%	3.0	MPI_Type_vector
0.0%	0.000004	0.000002	34.5%	2.0	MPI_Barrier

Without API

Time%	Time	Imb. Time	Imb. Time%	Calls	Group / Function / PE=HIDE
100.0%	45.649773	--	--	3,036.0	Total
83.4%	38.065287	--	--	457.0	USER
80.6%	36.771025	7.132552	18.6%	2.0	jacobi
2.8%	1.291914	0.077825	6.5%	1.0	initmt
0.0%	0.001031	0.000933	54.3%	1.0	main
0.0%	0.000520	0.000342	45.3%	150.0	sendp
0.0%	0.000337	0.000028	8.7%	1.0	initcomm
0.0%	0.000320	0.000264	51.6%	150.0	sendp3
0.0%	0.000121	0.000322	83.1%	150.0	sendp2
0.0%	0.000017	0.000001	3.9%	1.0	exit
16.4%	7.500291	--	--	2,423.0	MPI
16.0%	7.298155	4.192142	41.7%	450.0	MPI_Waitall
0.4%	0.183874	0.048775	24.0%	900.0	MPI_Isend
0.0%	0.014285	0.020122	66.8%	900.0	MPI_Irecv
0.0%	0.001146	0.000013	1.3%	1.0	MPI_Cart_create
0.0%	0.001003	0.000012	1.4%	152.0	MPI_Allreduce
0.0%	0.000756	0.000012	1.7%	3.0	MPI_Type_commit
0.0%	0.000566	0.000009	1.8%	3.0	MPI_Type_vector
0.0%	0.000501	0.000015	3.3%	3.0	MPI_Cart_shift
0.0%	0.000005	0.000002	34.1%	2.0	MPI_Barrier
0.0%	0.000000	0.000000	15.4%	4.0	MPI_Wtime
0.0%	0.000000	0.000000	18.7%	1.0	MPI_Cart_get

Load Imbalance Analysis

Load Imbalance

Common cause for performance bottlenecks when running applications at scale

- Look for high imbalance time and percentage
  - User functions
    Imbalance time = Maximum time – Average time
  - Synchronization (Collective communication and barriers)
    Imbalance time = Average time – Minimum time
  - Imbalance percentage of time that the rest of the team is not engaged in useful work on the given function
- Also look for MPI (SYNC) time.
  - Measure for time spent waiting in collectives
  - Only available with event tracing experiments
- Guidance on rank reordering for better load balance might appear in report
  (MPI Utilization: …)

```
Table 1:  Profile by Function Group and Function

  Time% |      Time |     Imb. |   Imb. |     Calls |Group
        |           |     Time |  Time% |           | Function
        |           |          |        |           |  PE=HIDE

 100.0% | 1.957703 |       -- |     -- | 42,970.8 |Total
|-----------------------------------------------------------------
|  60.0% | 1.174021 |       -- |     -- |  3,602.0 |USER
||----------------------------------------------------------------
||  30.8% | 0.603850 | 0.176924 |  23.0% |  1,198.0 |function3_
||  19.2% | 0.375117 | 0.128748 |  26.0% |  1,200.0 |function2_
||   9.1% | 0.178111 | 0.081880 |  32.0% |  1,200.0 |function1_
||================================================================
|  36.0% | 0.704928 |       -- |     -- |  9,613.0 |MPI_SYNC
||----------------------------------------------------------------
||  25.8% | 0.505174 | 0.385130 |  76.2% |  9,596.0 |mpi_barrier_(sync)
||  10.2% | 0.199537 | 0.199518 | 100.0% |      1.0 |mpi_init_(sync)
||================================================================
|   4.0% | 0.078736 |       -- |     -- | 29,754.8 |MPI
||----------------------------------------------------------------
||   2.3% | 0.045351 | 0.003531 |   7.3% |  9,596.0 |MPI_BARRIER
||   1.1% | 0.021520 | 0.051295 |  71.6% |  8,756.9 |MPI_ISEND
|=================================================================
```

Communication Bottlenecks

- Sort messages by caller
  - Available in default report for tracing (lite-events) experiments
- Analyze message sizes
  - Useful when tuning MPI env vars (eager, rendez-vous, …)
  - Found in default report
- Put barrier in front of collectives to filter sync times
- Use rank reordering for max. on-node communication
  - Look for guidance and instructions in report
  - `grid_order` utility
- Visualizing data
  - Apprentice2 (`app2 app.exe+*/`) imbalance or activity report
  - `pat_report -s pe=ALL` shows data by MPI rank

```
   MPI |      MPI Msg |  MPI Msg |   MsgSz |  4KiB<= |Function
   Msg |        Bytes |    Count |     <16 |   MsgSz | Caller
 Bytes% |             |          |   Count |  <64KiB |  PE=[mmm]
       |              |          |         |   Count |
 100.0% | 34,940,767.4 |  8,771.9 |   258.6 | 8,513.3 |Total
|-----------------------------------------------------------------
| 100.0% | 34,940,647.4 |  8,756.9 |   243.6 | 8,513.3 |MPI_ISEND
||----------------------------------------------------------------
||  56.2% | 19,622,700.0 |  4,837.5 |    56.2 | 4,781.2 |calc2_
3|        |              |          |         |         | shalow_
||||--------------------------------------------------------------
4|||  56.4% | 19,718,400.0 |  7,200.0 | 2,400.0 | 4,800.0 |pe.0
4|||  56.4% | 19,699,200.0 |  4,800.0 |     0.0 | 4,800.0 |pe.32
4|||  42.3% | 14,784,000.0 |  4,800.0 | 1,200.0 | 3,600.0 |pe.63
|||[==============================================================
```

```
Total
------------------------------------------------------------
MPI Msg Bytes%                              100.0%
MPI Msg Bytes                      4,465,684,125.8
MPI Msg Count                             13,057.0 msgs
MsgSz <16 Count                              719.0 msgs
16<= MsgSz <256 Count                         28.0 msgs
256<= MsgSz <4KiB Count                        0.7 msgs
4KiB<= MsgSz <64KiB Count                    279.8 msgs
64KiB<= MsgSz <1MiB Count                 12,029.6 msgs
============================================================
MPI_Send
------------------------------------------------------------
MPI Msg Bytes%                              100.0%
MPI Msg Bytes                      4,465,680,353.8
MPI Msg Count                             12,318.0 msgs
MsgSz <16 Count                                8.0 msgs
16<= MsgSz <256 Count                          0.0 msgs
256<= MsgSz <4KiB Count                        0.7 msgs
4KiB<= MsgSz <64KiB Count                    279.8 msgs
64KiB<= MsgSz <1MiB Count                 12,029.6 msgs
```

```
MPI_Send / LAMMPS_NS::Comm::reverse_comm
------------------------------------------------------------
MPI Msg Bytes%                               48.6%
MPI Msg Bytes                      2,171,466,150.3
MPI Msg Count                              6,006.0 msgs
MsgSz <16 Count                                0.0 msgs
16<= MsgSz <256 Count                          0.0 msgs
256<= MsgSz <4KiB Count                        0.0 msgs
4KiB<= MsgSz <64KiB Count                      0.0 msgs
64KiB<= MsgSz <1MiB Count                  6,006.0 msgs
============================================================
MPI_Send / LAMMPS_NS::Comm::reverse_comm /
LAMMPS_NS::Verlet::run
------------------------------------------------------------
MPI Msg Bytes%                               48.6%
MPI Msg Bytes                      2,169,218,110.3
MPI Msg Count                              6,000.0 msgs
MsgSz <16 Count                                0.0 msgs
16<= MsgSz <256 Count                          0.0 msgs
256<= MsgSz <4KiB Count                        0.0 msgs
4KiB<= MsgSz <64KiB Count                      0.0 msgs
64KiB<= MsgSz <1MiB Count                  6,000.0 msgs
```

Hardware Performance Counters (HWPC)

Hardware Performance Counters

- Perftools supports the use of hardware counters to collect hardware events
  - All counters accessed through the PAPI interface.
  - Predefined sets of hardware counters are specified that can be instrumented for performance analysis experiment.
  - Number of simultaneous counters limited by hardware.
- Perftools provides information at the function call level on hardware features like caches, vectorization and memory bandwidth.
  - Very useful feature for deep understanding of application performance bottlenecks.
  - Impact of compiler options and code optimization.
- HWPC collection can slow down the execution notably.
  - Should be used within a tracing experiment only for a small set of functions or ideally through an automatic performance analysis.
- Check the list of available hardware counters:
  - Use `papi_avail` on a compute node to get a list

When To Collect Hardware Performance Counters

- Use to understand the “why” of a bottleneck.
- Default set of CPU counters are already collected for whole program
  - Used to present memory and vector summary metrics
- To collect performance counters
  - Set `PAT_RT_PERFCTR` environment variable to list of events or group prior to execution. (Or use `-Drtenv=PAT_RT_PERFCTR=<event list> | <group>` for `pat_build`. Environment variable has priority.)
- Run the following utility on a compute node to get list of events for a processor:
  - `papi_native_avail`
  - `papi_avail`
- Use pat_help to see counter groups and derived metrics
  - `$> pat_help counters processor_type deriv`
  - Example: `$> pat_help counters rome deriv`

```
==================================================================
  Total
------------------------------------------------------------------
  Time%                                               100.0%
  Time                                             70.507153 secs
  Imb. Time                                               -- secs
  Imb. Time%                                              --
  Calls                     5.744 /sec                405.0 calls
  PAPI_BR_TKN             0.064G/sec    4,506,524,243.125 branch
  PAPI_TOT_INS           12.154G/sec  856,922,640,377.375 instr
  PAPI_BR_INS             0.124G/sec    8,718,726,704.750 branch
  PAPI_TOT_CYC                        244,793,361,310.500 cycles
  Instr per cycle                                    3.50 inst/cycle
  MIPS                97,229.58M/sec
  Average Time per Call                          0.174092 secs
  CrayPat Overhead : Time  0.0%
==================================================================
```

pat_run

Launch a dynamically-linked program instrumented for performance analysis

Profile Existing Dynamically Linked Binaries

```
$> srun -n 16 pat_run ./app.exe
$> pat_report app.exe+*/ > my_report
```

- Insert `pat_run` before executable. No instrumentation needed
- Useful if source code is not accessible but program is dynamically linked

```
$> export PAT_RT_PERFCTR=1
$> srun -n 8 pat_run ./app.exe
```

- Use existing perftools capability
- Optionally collect a different group of performance counters

```
$> pat_report -P -O callers+src app.exe+*/ > my_callers_report
```

- Create additional views of the data with `pat_report` options
- If at least object files and libraries are available
  - load the `perftools-preload` module before relinking
  - more information like line number hot spots are given

Final notes and Recap on Perftools

Perftools-lite modules vs Perftools module

- Perftools-lite modules : "novice" approach
  - Little/no knowledge of the application and do not want to dive deeper into the source code or profiling tools

  - Load the –lite module, make, run, analysis of automatically generated report
    – Sampling perftools-lite , tracing perftools-lite-events , loop work estimate perftools-lite-loops, GPU perftools-lite-gpu

  - Everything is automatic
    – Compilation and run commands are the same : instrumented binary has the same name as the original one
    – Report automatically generated

- Perftools module : "advanced" approach
  - Good knowledge of the application and the used libraries (MPI, openMP, gpu, io and more)

  - module load perftools, make, pat_build opt, run, pat_report, analysis of generated report
    – Sampling opt= ,-S; tracing opt=-u, loop work estimate opt=-w, GPU opt=-g omp/cuda/hip
    – AND MUCH MORE opt=-g mpi,io,blas,lapack,netcdf…

  - Everything is generated by the user
    – The original binary must be instrumented with pat_build and the options corresponding to the analysis to be performed
    – Run command must use the name of the new instrumented binary generated by the pat_build command
    – Report must be generated with pat_report

Summary

<table>
<tr><th></th><th>Sampling</th><th>Event Tracing</th><th>Loop Work Estimates</th><th>APA</th><th>Step</th></tr>
<tr><td rowspan="2"><code>perftools-lite</code></td><td>Is the default experiment.</td><td>Available through <code>perftools-lite-events</code></td><td>Available through <code>perftools-lite-loops</code></td><td>N/A</td><td>1</td></tr>
<tr><td colspan="4">Rebuild for all except <code>pat_run</code>. Rerun for all.</td><td>2</td></tr>
<tr><td rowspan="7"><code>perftools</code></td><td></td><td></td><td>Rebuild with <code>-h profile_generate</code> for Fortran or <code>-finstrument-loops</code> for C. Only for Cray Compiler</td><td>Is the default experiment</td><td>0</td></tr>
<tr><td><code>pat_build …</code></td><td><code>pat_build [-w|-u] [-g]</code></td><td><code>pat_build -w …</code></td><td><code>pat_build …</code></td><td>1</td></tr>
<tr><td colspan="4">For all: Run <code>app.exe+pat</code></td><td>2</td></tr>
<tr><td colspan="4">For all: <code>pat_report app+pat+*/</code></td><td>3</td></tr>
<tr><td colspan="3" rowspan="3"></td><td><code>pat_build -O *.apa</code></td><td>4</td></tr>
<tr><td>Run <code>app.exe+apa</code></td><td>5</td></tr>
<tr><td><code>pat_report <apa>.xf</code></td><td>6</td></tr>
</table>

Summary

	Sampling	Event Tracing	Loop Work Estimates	APA
Reveal	N/A	N/A	Need a program library obtained with the **-hpl=<app>.pl** compiler option for Fortran or **-fcray-program-library-path=<app.pl>** for C and optionally an **<app>+*/** directory from a loop profiling experiment (Cray compiler only)	N/A
Hardware performance counters	Can be enabled via -Drtenv=PAT_RT_PERFCTR=<event list> | <group> option for **pat_build** or the environment variable PAT_RT_PERFCTR. For **perftools-lite*** only the environment variable is applicable. Note that for **perftools-lite** some counters are already collected.			Is typically specified in the **<app>+*/*.apa** file. Note that during the sampling phase, some counters are already collected.
Apprentice2	Can be applied to all **<app>+*/** directories			
pat_run	When you can't compile (only dynamically linked binary or objects and libraries are available).			
pat_info	Can be applied to all **<app>+*/** directories			

What does perftools support?

Cray Performance Tools Components

Reveal
- compiler optimization presentation
- OpenMP
- memory activity tracking

Apprentice2 (app2)

CrayPat runtime

perftools / perftools-lite experiments
- pre-defined vs custom instrumentation
- sampling
- tracing with runtime summarization
- predefined trace groups
- full trace

pat_build

pat_report

pat_run

pat_region API

grid_order

pat_view

pat_help

Performance counters
- PAPI
- CPU, GPU, network, energy
- default, predefined groups, individual events

Programming Models

MPI
OpenMP
CUDA
OpenACC / OpenMP 4.5
PGAS (upc, Forttran coarrays)
SHMEM
OpenCL
HIP

Distros

CLE
Mac
Windows
RH/Centos
SLES

Languages

Fortran
C
C++
Chapel

Platforms

Cray XC, CS, Shasta
HPE Apollo 2000 Gen10Plus, Apollo 80*
Mac (app2, reveal), Windows (app2)

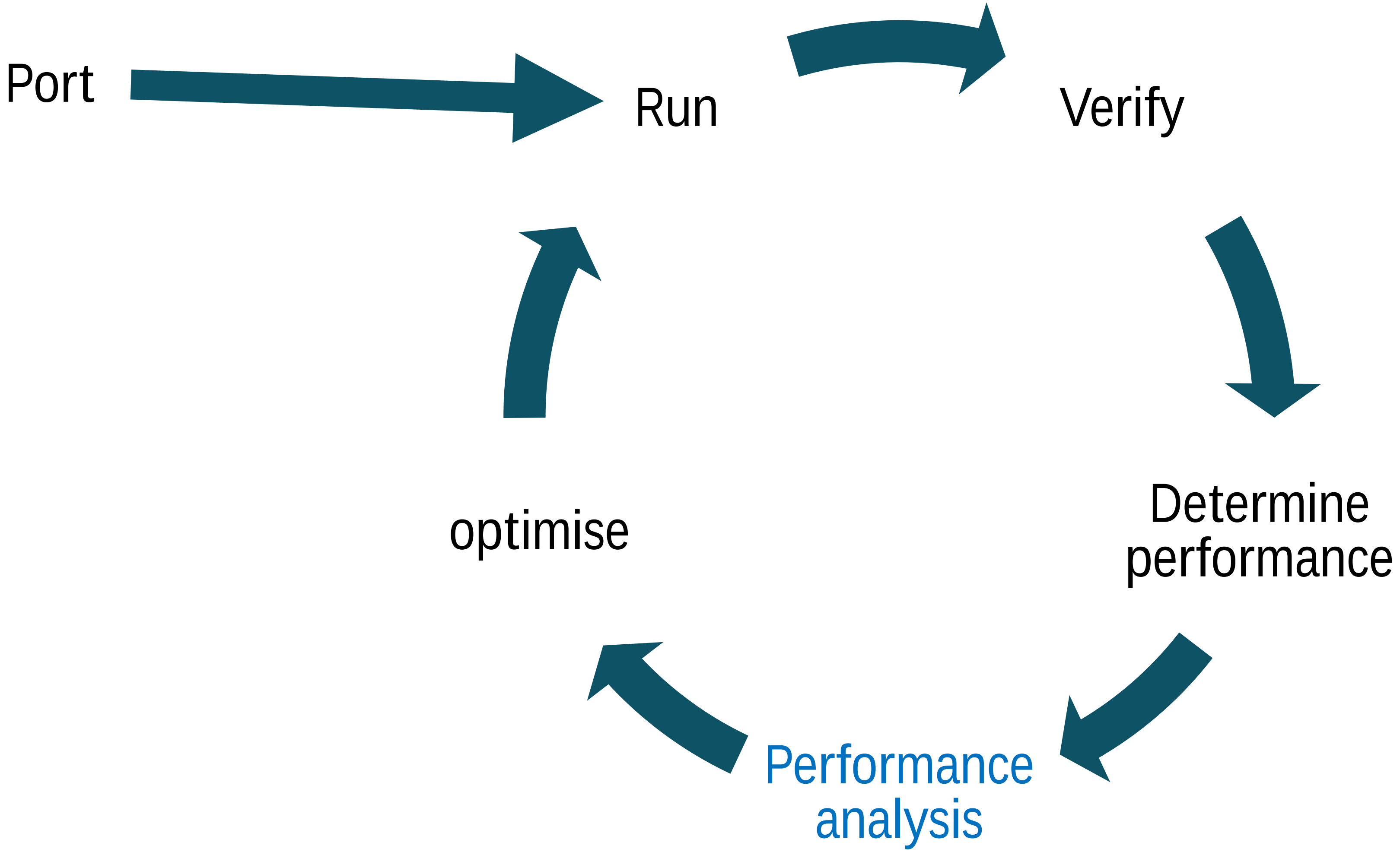
Compilers

CCE
GCC
Intel
PGI
AMD (aocc, hipclang)

Processors

Intel (SNB, IVB, HSW, KNL, BDW, SKL)
ARM (Cavium TX2)
AMD (Rome, Milan, MI60/MI100,MI200)
NVIDIA (Pascal, Volta)

Optimisation Cycle



Reveal

Performance analysis and code restructuring assistant

Motivation: Compiler Listings (CCE)

- Much information produced by compiler.
  - Can be listed together with source code for better clarity.
  - Use `-fsave-loopmark` for C and `–hlist=m` (or `a`) for Fortran.
  - It generates an `*.lst` file for every source code file.
  - A + sign indicates that more information can be found after the routine definition.
  - Can also be inspected in Reveal with a corresponding program library.

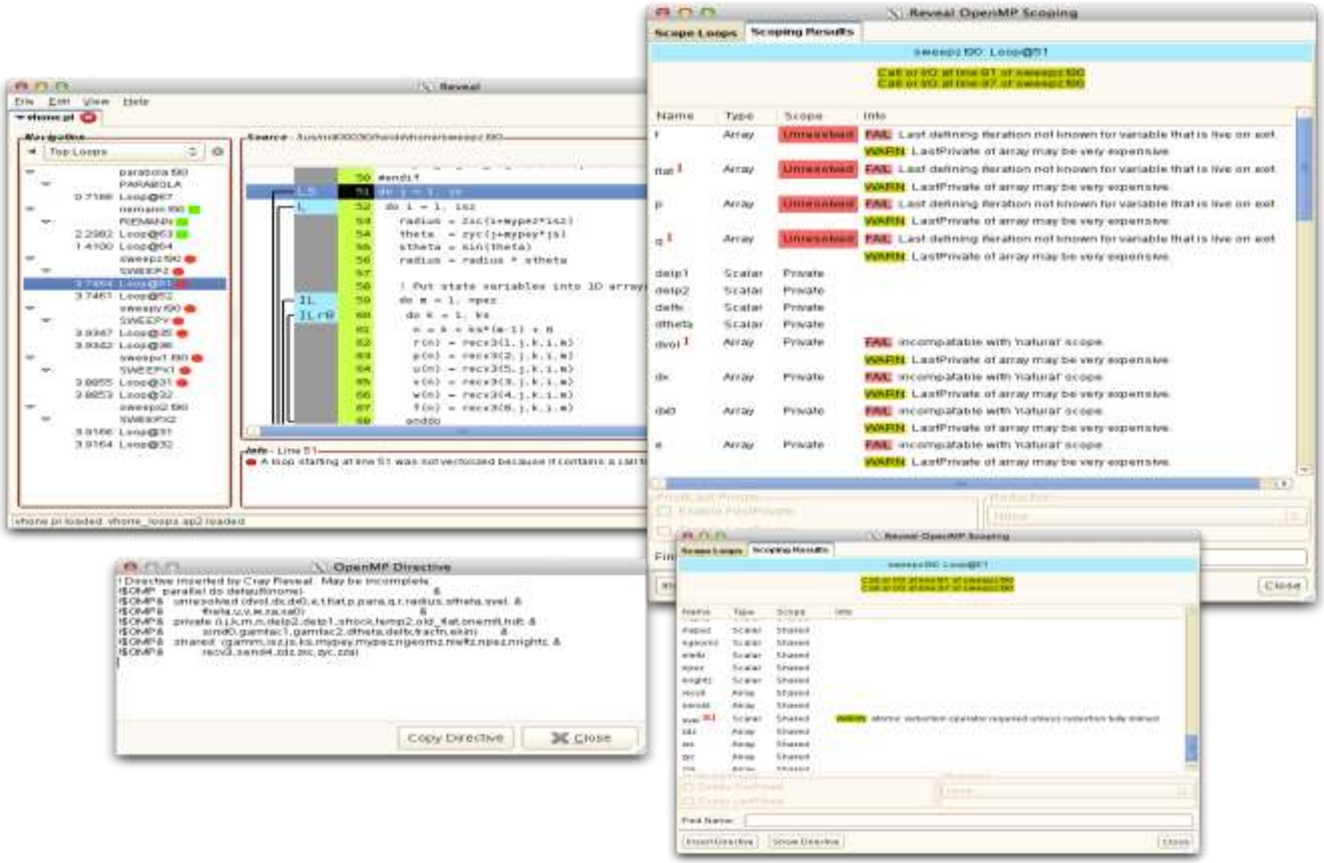
```
%%%    L o o p m a r k   L e g e n d    %%%

Primary Loop Type          Modifiers
------- ---- ----          ---------
A - Pattern matched        a - atomic memory operation
                           b - blocked
C - Collapsed              c - conditional and/or computed
D - Deleted
E - Cloned
F - Flat - No calls        f - fused
G - Accelerated            g - partitioned
I - Inlined                i - interchanged
M - Multithreaded          m - partitioned
                           n - non-blocking remote transfer
                           p - partial
R - Rerolling              r - unrolled
                           s - shortloop
V - Vectorized             w - unwound

+ - More messages listed at end of listing
------------------------------------------
```

```
210.  + 1---------------<   for(i=0 ; i<imax ; ++i)
211.  + 1 2-------------<     for(j=0 ; j<jmax ; ++j)
212.    1 2 Vr2---------<       for(k=0 ; k<kmax ; ++k){
213.    1 2 Vr2                   a[0][i][j][k]=1.0;
214.    1 2 Vr2                   a[1][i][j][k]=1.0;
215.    1 2 Vr2                   a[2][i][j][k]=1.0;
216.    1 2 Vr2                   a[3][i][j][k]=1.0/6.0;
217.    1 2 Vr2                   b[0][i][j][k]=0.0;
218.    1 2 Vr2                   b[1][i][j][k]=0.0;
219.    1 2 Vr2                   b[2][i][j][k]=0.0;
220.    1 2 Vr2                   c[0][i][j][k]=1.0;
221.    1 2 Vr2                   c[1][i][j][k]=1.0;
222.    1 2 Vr2                   c[2][i][j][k]=1.0;
223.    1 2 Vr2 A-------<>        p[i][j][k]=(float)((i+it)*(i+it))/(float)((mx-1)*(mx-1));
224.    1 2 Vr2 A-------<>        wrk1[i][j][k]=0.0;
225.    1 2 Vr2 A-------<>        wrk2[i][j][k]=0.0;
226.    1 2 Vr2 A-------<>        bnd[i][j][k]=1.0;
227.    1 2 Vr2-------->>>      }
228.                        }
```

```
CC-6294 CC: VECTOR initmt, File = himeno.c, Line = 210
  A loop was not vectorized because a better candidate was found at line 212.

CC-6294 CC: VECTOR initmt, File = himeno.c, Line = 211
  A loop was not vectorized because a better candidate was found at line 212.

CC-6005 CC: SCALAR initmt, File = himeno.c, Line = 212
  A loop was unrolled 2 times.

CC-6204 CC: VECTOR initmt, File = himeno.c, Line = 212
  A loop was vectorized.
```

Using Reveal

- Easily navigate through source code to highlighted dependences or bottlenecks
- It can also:
  - Reduce effort associated with adding OpenMP to MPI programs
  - Identify work-intensive loops to parallelize, perform dependence analysis, scope variables and generate OpenMP directives
  - Great first step when moving large, complex loops to GPUs



- Desktop client installer: /opt/cray/pe/perftools/<version>/share/desktop_installers/
  - Only available for macOS
- Alternatively, run directly on LUMI (with the GUI export)

Input to Reveal: Program Library

- Mandatory

```
> ftn -O3 -hpl=my_program.pl -c my_program_file1.f90
> cc -O3 -fcray-program-library-path=my_program.pl -c my_program_file2.c
> reveal my_program.pl &
```

  - Recompile only sources to generate program library `my_program.pl`
  - The PL is a persistent repository of compiler information and is built up with each compiler invocation

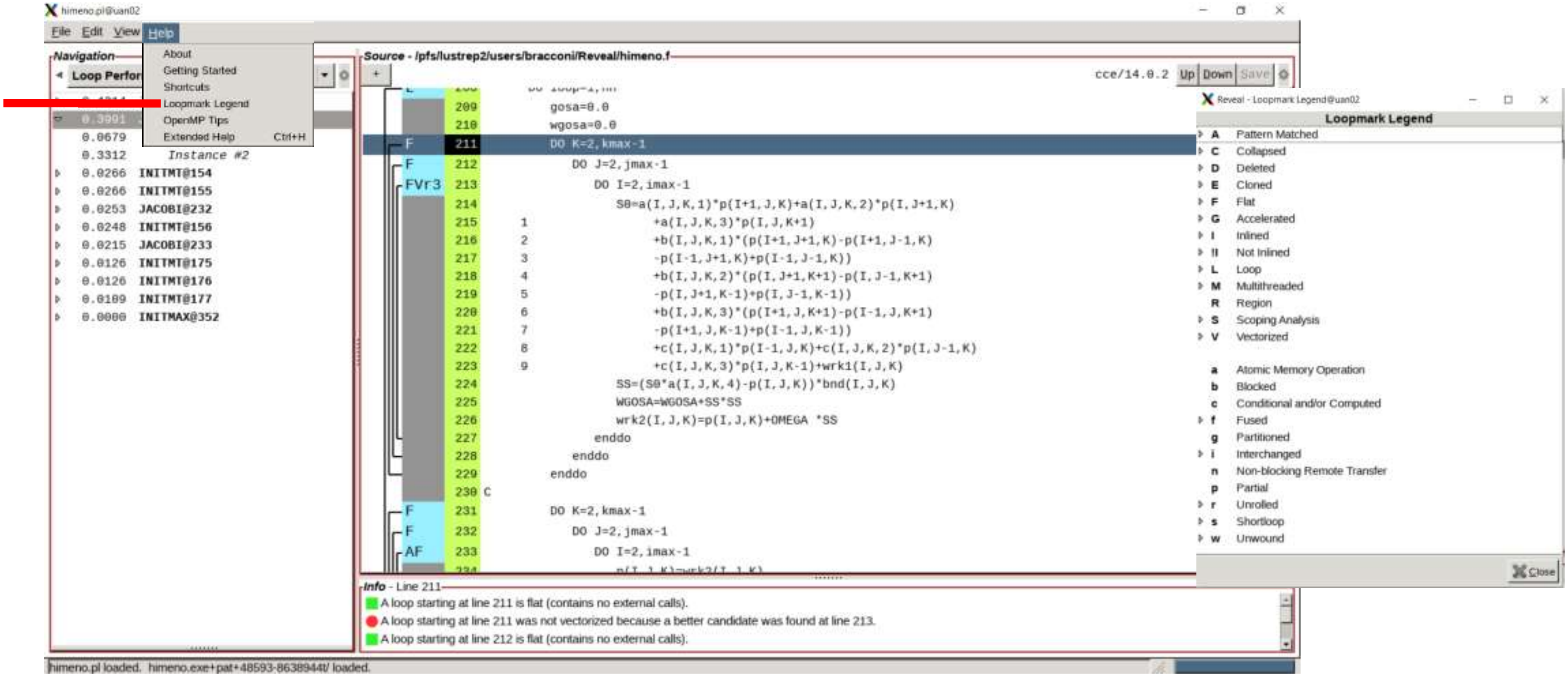
- Optional but highly recommended

```
> ftn -O3 -hpl=my_program.pl -c my_program_file1.f90
> cc -O3 -fcray-program-library-path=my_program.pl -c my_program_file2.c
> reveal my_program.pl [CrayPAT experiment_data_directory] &
```

  - **Collect loop work estimates in a separate experiment directory** and load it too with `my_program.pl`
  - Note that `-hprofile_generate` option disables OpenMP and significant compiler loop restructuring optimizations except for vectorization

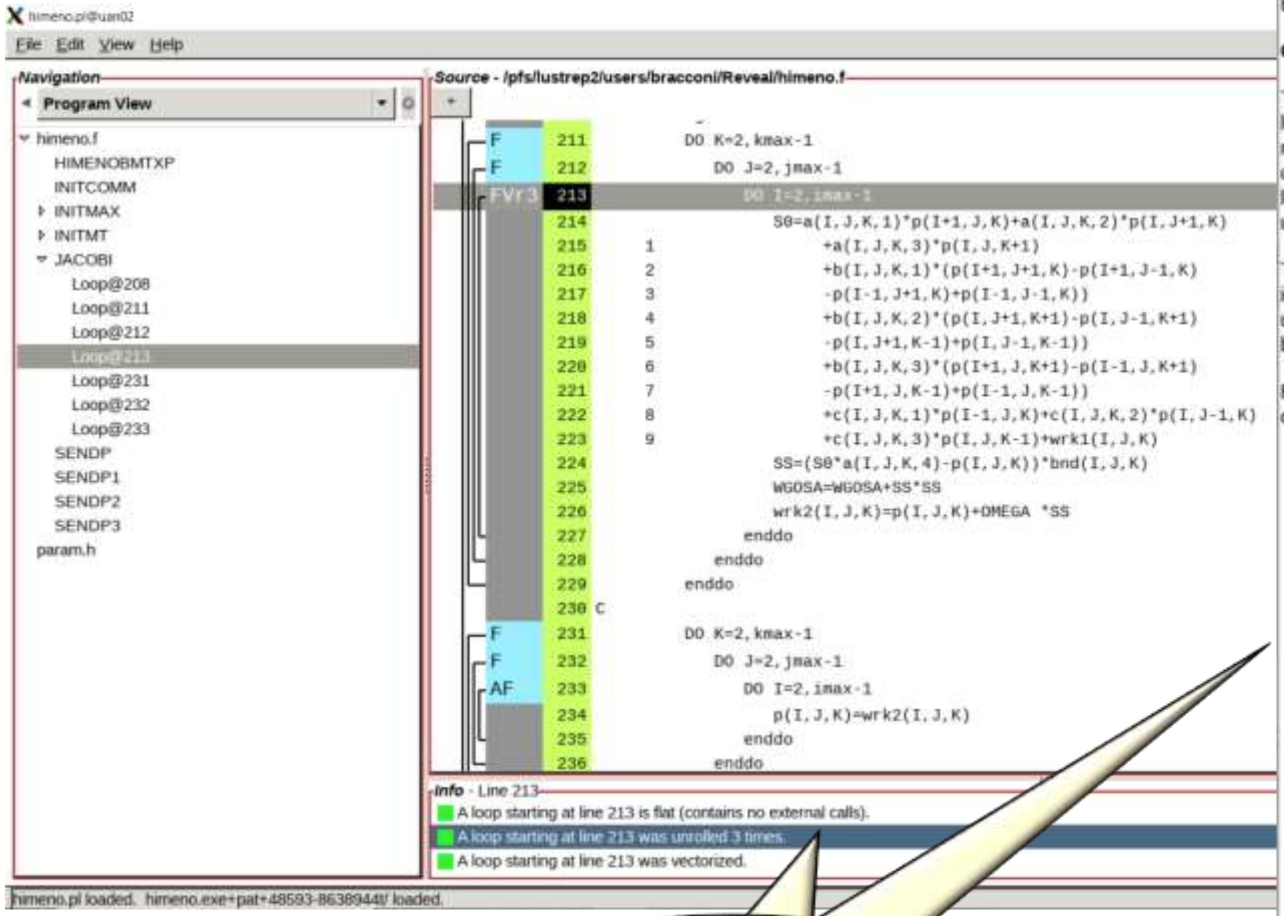
Reveal

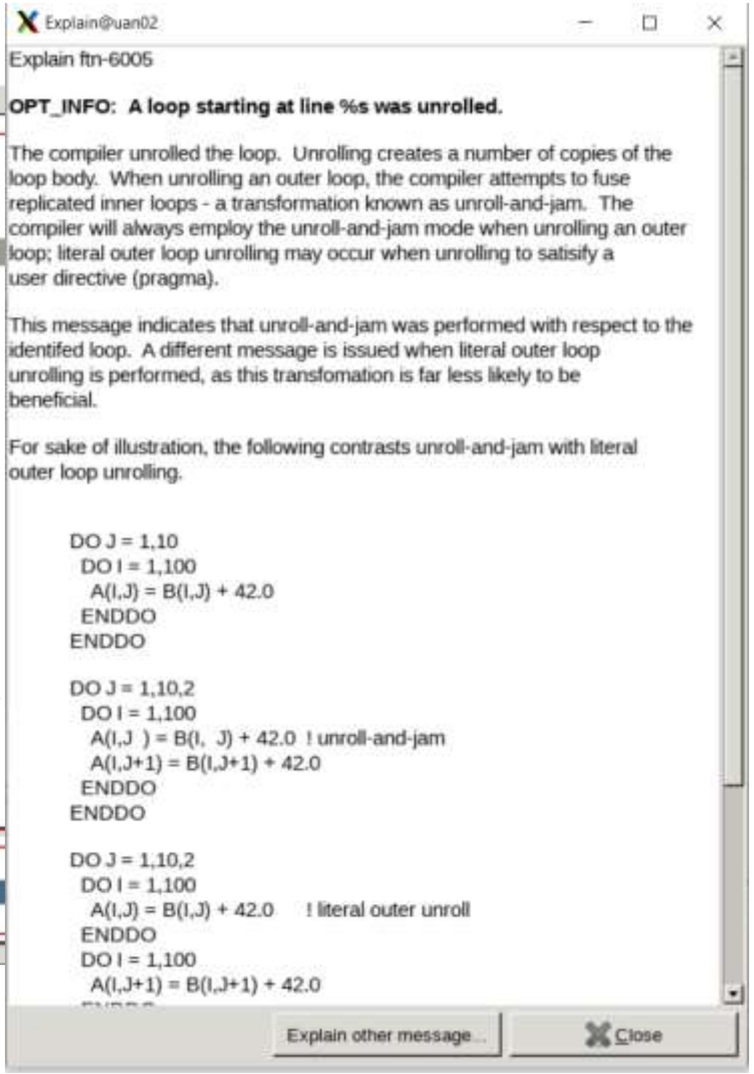
- View source, performance, and optimization information at the same time.



Reveal

- Access Cray compiler message information

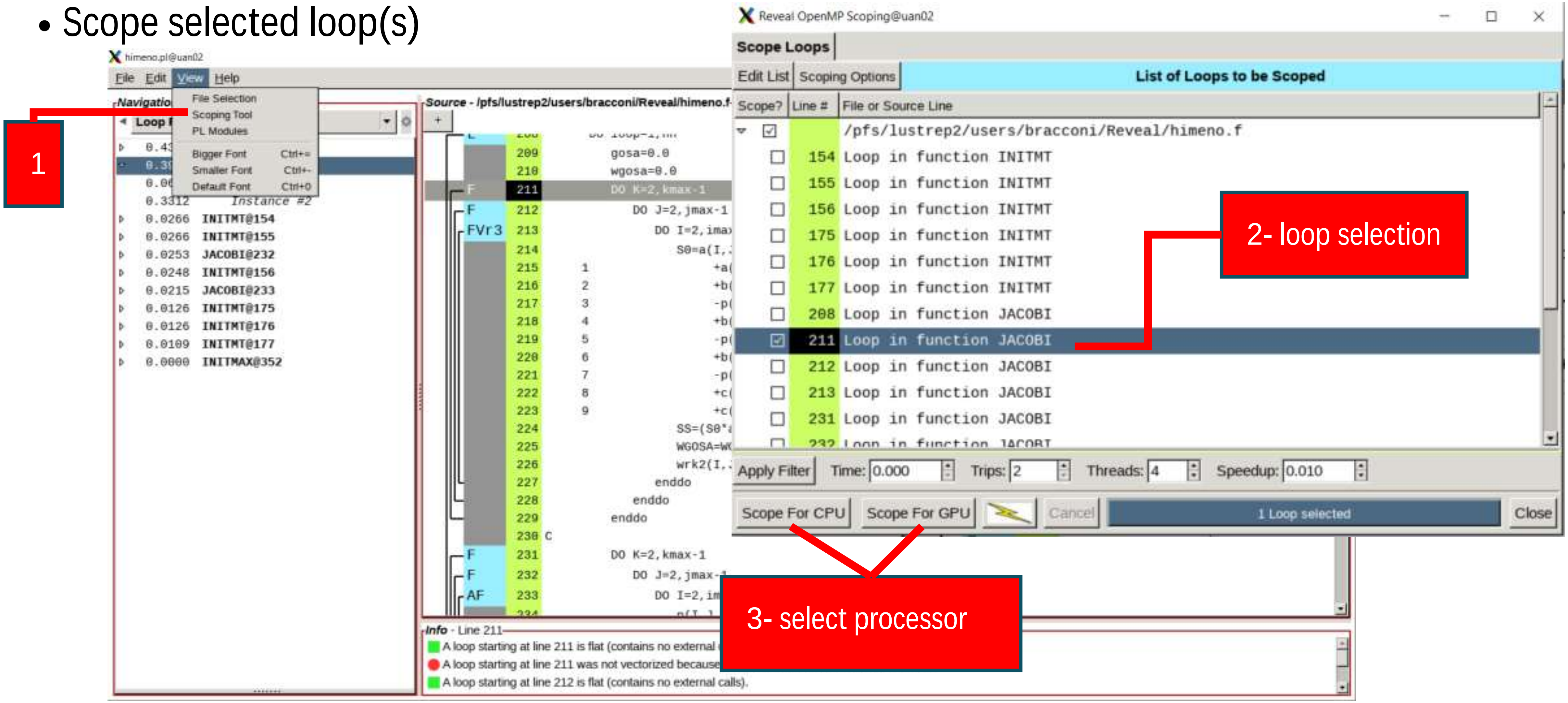




Double click on optimization message for more detailed information

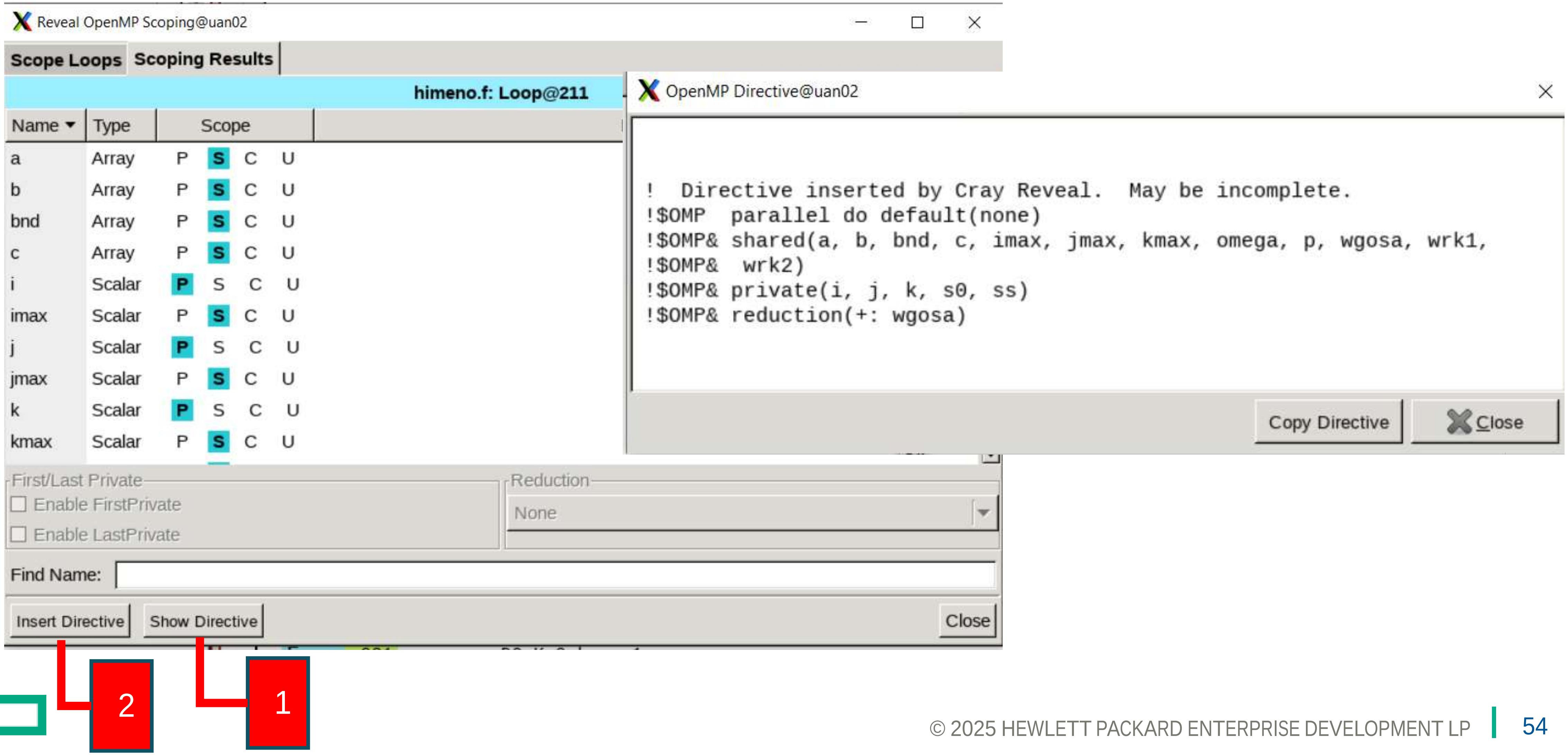
Reveal

- Scope selected loop(s)



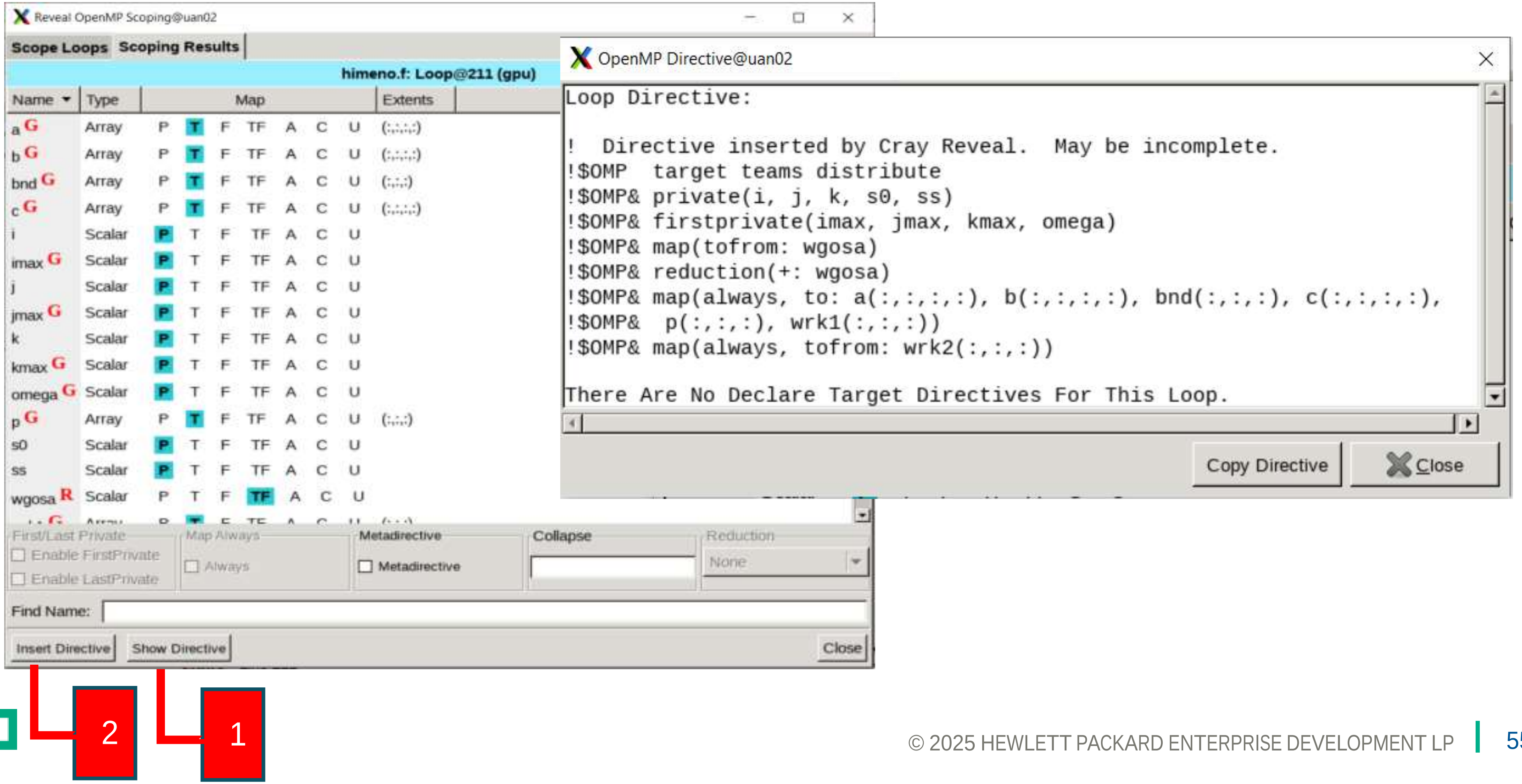
Reveal

- Scope selected loop(s) for CPU



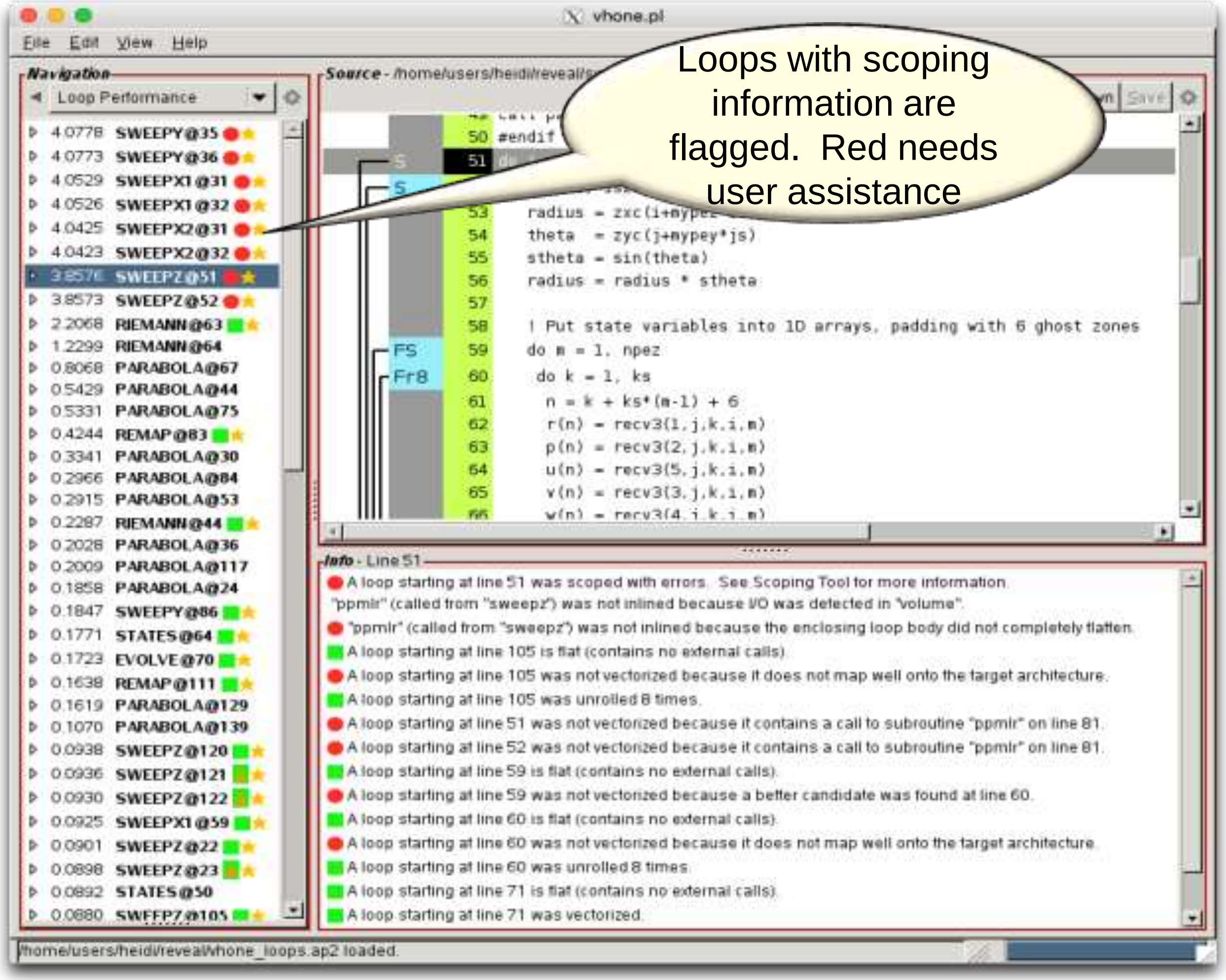
Reveal

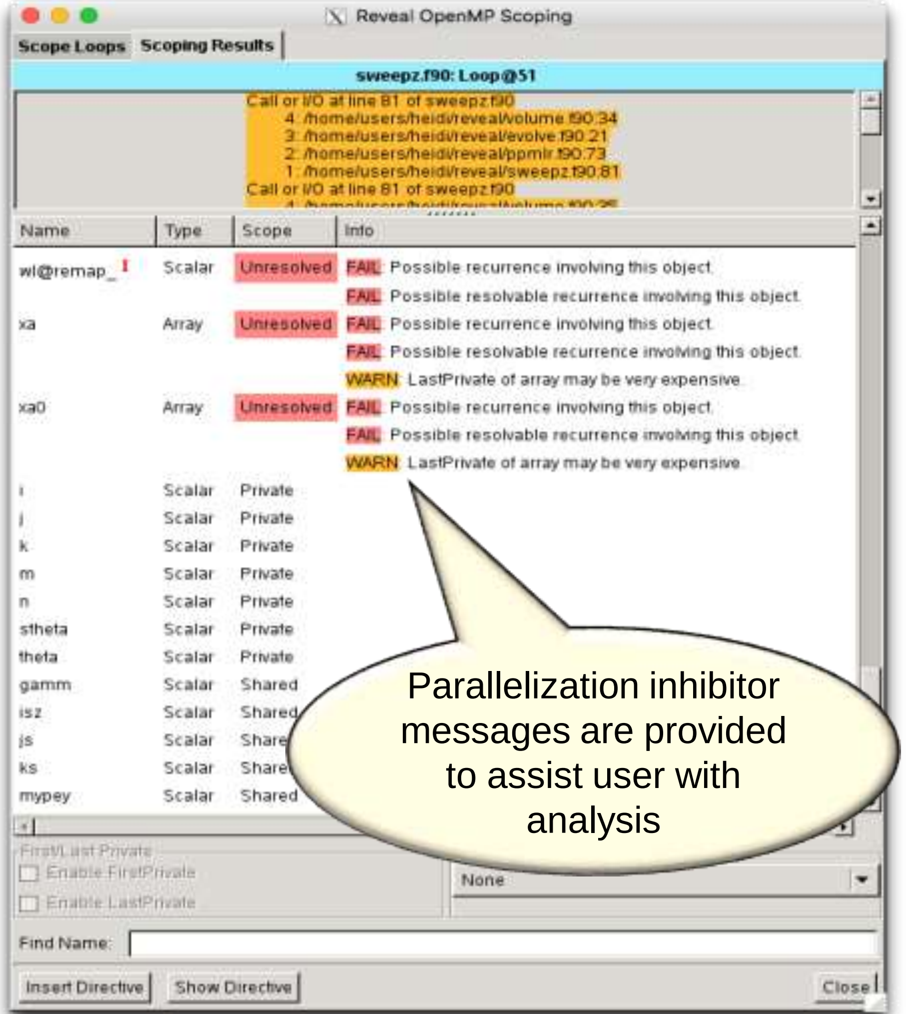
- Scope selected loop(s) for GPU



Reveal

- Review scoping results.





Reveal

- Generate OpenMP directives.

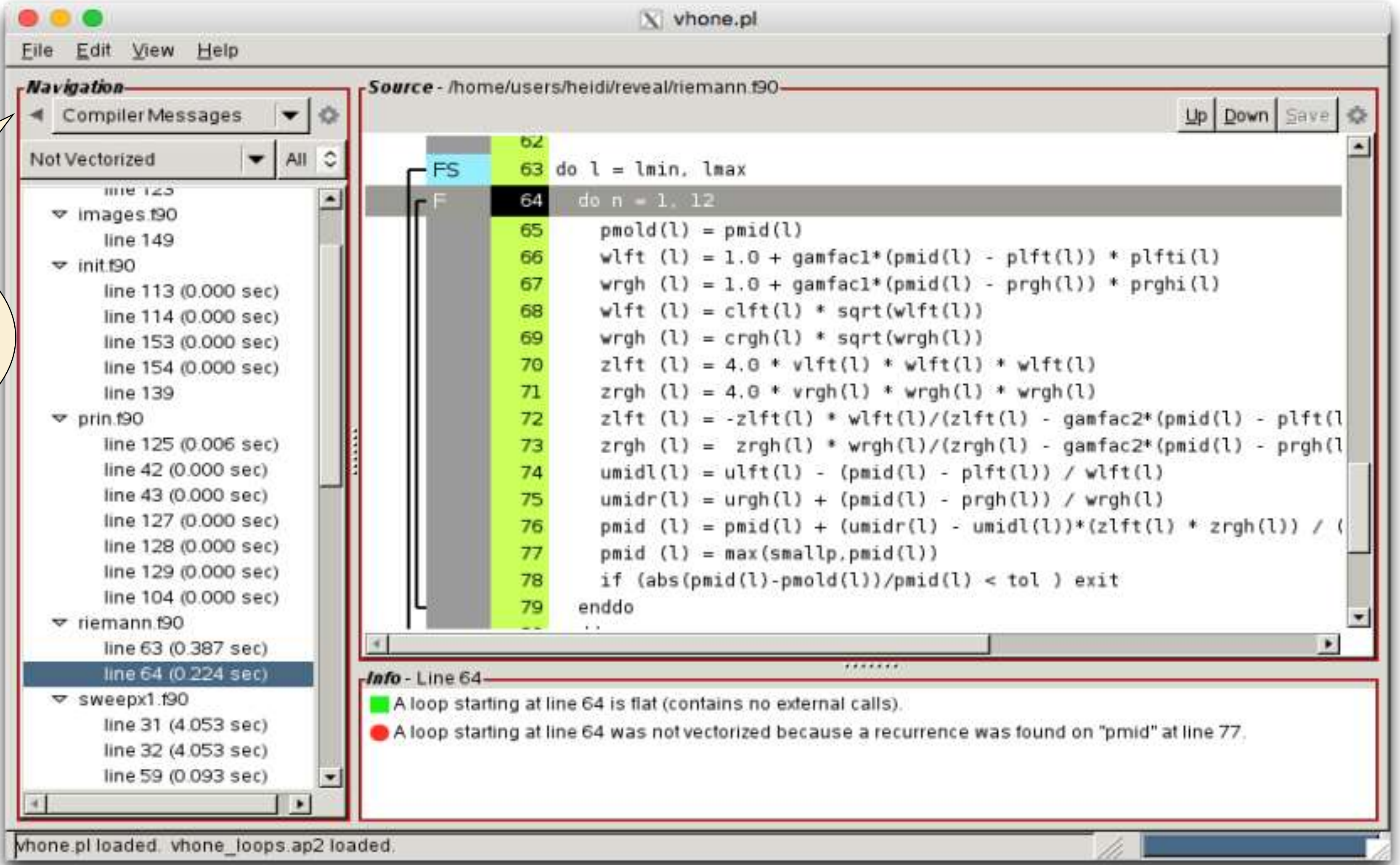
```
! Directive inserted by Cray Reveal.  May be incomplete.
!$OMP  parallel do default(none)                                       &
!$OMP&   unresolved (dvol,dx,dx0,e,f,flat,p,para,q,r,radius,svel,u,v,w,   &
!$OMP&            xa,xa0)                                               &
!$OMP&   private (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

Reveal

- Look for vectorization opportunities.

Choose “Compiler Messages” view to access message filtering, then select desired type of message



Questions?