Cray Performance Measurement and Analysis Tools

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March 2016

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Topics

- **Introduction to Cray performance tools, including:**
  - CrayPat-lite and CrayPat interfaces
  - Collecting performance counter information
  - MPI rank reorder
  - Cray Apprentice2
- **Recent enhancements**
- **Support for GPUs**

Strengths

- Whole program analysis across many nodes
- Novice and advanced user interfaces
- Support for MPI, SHMEM, OpenMP, UPC, CAF, OpenACC, CUDA
- Load Imbalance detection
- HW counter derived metrics

Strengths (2)

- Performance statistics for libraries called by program (BLAS, LAPACK, PETSc, NetCDF, HDF5, etc.)
- Observations of inefficient performance
- Data correlation to user source (line number, function)
- Minimal program perturbation

Two Interfaces to the Performance Tools

- **Support traditional post-mortem performance analysis**
  - Indication of causes of problems
  - Suggestions of modifications for performance improvement
- **CrayPat-lite for first time users**
- **CrayPat for in-depth performance investigation and tuning assistance**

Example CrayPat-lite Output

```
CrayPat/X:  Version 6.1.4.12457 Revision 12457 (xf 12277)  02/26/14 13:58:24
Experiment:                   lite  lite/sample_profile
Number of PEs (MPI ranks):    8164
Numbers of PEs per Node:        16  PEs on each of  510  Nodes
                                 4  PEs on    1  Node
Numbers of Threads per PE:       1
Number of Cores per Socket:      8
Execution start time:  Fri Feb 28 23:06:31 2014
System name and speed:  hera2 2100 MHz

Wall Clock Time:     999.595275 secs
High Memory:             475.52 MBytes
MFLOPS (aggregate):  806112.33 M/sec
I/O Read Rate:            33.57 MBytes/Sec
I/O Write Rate:          215.40 MBytes/Sec
```

Example CrayPat-lite Output (2)

```
Table 1:  Profile by Function Group and Function (top 7 functions shown)
 Time%  |      Time  |    Imb.   |  Imb.   |    Calls  |Group
        |            |    Time   | Time%   |           | Function
        |            |           |         |           |  PE=HIDE

 100.0% | 101.961423 |       -- |     -- | 5315211.9 |Total
|-------------------------------------------------------------------------------------
|  92.5% |  94.267451 |       -- |     -- | 5272245.9 |USER
||------------------------------------------------------------------------------------
||  75.8% |  77.248585 | 2.356249 |   3.0% |    1001.0 |LAMMPS_NS::PairLJCut::compute
||   6.5% |   6.644545 | 0.105246 |   1.6% |      51.0 |LAMMPS_NS::Neighbor::half_bin_newton
||   4.1% |   4.131842 | 0.634032 |  13.5% |       1.0 |LAMMPS_NS::Verlet::run
||   3.8% |   3.841349 | 1.241434 |  24.8% | 5262868.9 |LAMMPS_NS::Pair::ev_tally
||   1.3% |   1.288463 | 0.181268 |  12.5% |    1000.0 |LAMMPS_NS::FixNVE::final_integrate
||====================================================================================
|   7.0% |   7.110931 |       -- |     -- |   42637.0 |MPI
||------------------------------------------------------------------------------------
||   4.8% |   4.851309 | 3.371093 |  41.6% |   12267.0 |MPI_Send
||   1.5% |   1.536106 | 2.592504 |  63.8% |   12267.0 |MPI_Wait
|====================================================================================
```

Example CrayPat-lite Output (3)

```
Table 2:  File Input Stats by Filename

  Read Time |  Read MBytes |  Read Rate |      Reads |  Bytes/ Call |File Name[max10]
            |              | MBytes/sec |            |              | PE=HIDE

 387.432937 | 13006.522781 |  33.571030 | 41596900.0 |       327.87 |Total
|-------------------------------------------------------------------------------------
| 331.691801 |  1395.829828 |   4.208213 | 13153931.0 |       111.27 |/proc/self/maps
|  13.129507 |  4075.682968 | 310.421627 |      868.0 |   4923575.28 |regional.grid.a
|  12.654338 |  2000.329418 | 158.074605 | 26892862.0 |        77.99 |./patch.input
|   3.924810 |   679.265625 | 173.069704 |        3.0 | 237420544.00 |./forcing.radflx.a
. . .
```

More Information from Same Profile

- You don't need to run again for the following:

```
For a complete report with expanded tables and notes, run:
  pat_report /lus/scratch/heidi/lab/craypat-lite/run/sweep3d.mpi.ap2

For help identifying callers of particular functions:
  pat_report -O callers+src /lus/scratch/heidi/lab/craypat-lite/run/
sweep3d.mpi.ap2

To see the entire call tree:
  pat_report -O calltree+src /lus/scratch/heidi/lab/craypat-lite/run/
sweep3d.mpi.ap2
```

The Cray Performance Analysis Framework

- **Supports traditional post-mortem performance analysis**
  - Indication of causes of problems
  - Suggestions of modifications for performance improvement
- **pat_build: provides automatic instrumentation**
- **CrayPat run-time library collects measurements (transparent to the user)**
- **pat_region API**
  - Provides mechanism to control collection of performance data within source code
- **pat_report performs analysis and generates text reports**
- **pat_help: online help utility**
- **Cray Apprentice2: graphical visualization tool**

New perftools-base and Instrumentation Modules

Access perftools Software

- **Load perftools-base module and leave it loaded**
  - Provides access to man pages, Reveal, Cray Apprentice2, and the new instrumentation modules
  - Can keep loaded with no impact to applications
- **Available starting in perftools/6.3.0 in September 2015**
- **Prior to perftools/6.3.0:**
  - Load perftools module

Program Instrumentation Modules

Instrumentation modules available after perftools-base is loaded:

- perftools
- perftools-lite
- perftools-lite-events
- perftools-lite-gpu
- perftools-lite-loops

What Do the Instrumentation Modules Do?

perftools

- Full access to CrayPat functionality
- Use pat_build to instrument, pat_report to process data and collect reports
- Equivalent to loading perftools module in earlier releases

perftools-lite

- Default CrayPat-lite profiling
- Load before building and running program to get a basic performance profile sent to stdout
- Equivalent to loading perftools-lite module in earlier releases

Tips

- Loading perftools without loading perftools-base first will continue to work as in pre-6.3.0 releases until perftools/6.4.0
- Sites can consider loading the default perftools-base for all users. Cray will look at automatically loading this module in a future release.
- Instrumentation modules can be loaded and unloaded for different performance experiments
- Use the 'module list' command to easily see which type of instrumentation is currently active
- Unload the instrumentation module after performance analysis experiments are complete

How to Use CrayPat-lite

Access performance tools software & instrumentation module

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

Build program

```
> make
```

a.out (instrumented program)

Run program (no modification to batch script)

```
aprun a.out
```

Condensed report to stdout
a.out*.rpt (same as stdout)
a.out*.ap2
files

Example Performance Data

Sampling with Line Number information

heidi@limited: /h/heidi — ssh — 81×26

```
Table 2:  Profile by Group, Function, and Line

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

 100.0% | 8376.9 |     -- |      -- |Total
|-----------------------------------------------------------------------------
|  93.2% | 7804.0 |     -- |      -- |USER
||----------------------------------------------------------------------------
||  51.7% | 4328.7 |     -- |      -- |calc3_
3|        |        |        |         | heidi/DARPA/cache_util/calc3.do300-ijswap.F
||||---------------------------------------------------------------------------
4|||  15.7% | 1314.4 |  93.6 |   6.8% |line.78
4|||  13.9% | 1167.7 |  98.3 |   7.9% |line.79
4|||  14.5% | 1211.6 |  97.4 |   7.6% |line.80
4|||   1.2% |  103.1 |  26.9 |  21.2% |line.93
4|||   1.1% |   88.4 |  22.6 |  20.8% |line.94
4|||   1.0% |   84.5 |  17.5 |  17.6% |line.95
4|||   1.0% |   86.8 |  33.2 |  28.2% |line.96
4|||   1.3% |  105.0 |  23.0 |  18.4% |line.97
4|||   1.4% |  116.5 |  24.5 |  17.7% |line.98
||||============================================================================
                                                                144,1         38%
```

MPI Messages By Caller

heidi@limited: /h/heidi — ssh — 81×26

Table 4: MPI Message Stats by Caller

MPI Msg Bytes	MPI Msg Count	MsgSz <16B Count	4KB<= MsgSz <64KB Count	Function Caller PE=[mmm]
140166953.8	8890.6	339.8	8550.8	Total
140166833.8	8875.6	324.8	8550.8	MPI_ISEND
78272400.0	4850.0	75.0	4775.0	calc2_ shalow_
78700800.0	7200.0	2400.0	4800.0	pe.0
78681600.0	4800.0	0.0	4800.0	pe.1
59020800.0	4800.0	1200.0	3600.0	pe.47
59421800.0	3725.0	100.0	3625.0	calc1_ shalow_
78700800.0	7200.0	2400.0	4800.0	pe.0
59011200.0	3600.0	0.0	3600.0	pe.1
59011200.0	3600.0	0.0	3600.0	pe.24

624,3 79%

Automatic Profiling Analysis Custom Template

```
#  You can edit this file, if desired, and use it
#   to reinstrument the program for  tracing like this:
#
#          pat_build -O standard.cray-
    xt.PE-2.1.56HD.pgi-8.0.amd64.pat-5.0.0.2-0apa.512.quad.cores.seal.
    090405.1154.mpi.pat_rt_exp=default:pat_rt_hwpc=none.14999.xf.xf.apa
#
# ----------------------------------------------------------------------
#       HWPC group to collect by default.

  -Drtenv=PAT_RT_HWPC=1  # Summary with TLB metrics.

#
# ----------------------------------------------------------------------
#       Libraries to trace.

  -g mpi

#
# ----------------------------------------------------------------------
#       User-defined functions to trace, sorted by % of samples.
#
#       The way these functions are filtered can be controlled with
#       pat_report options (values used for this file are shown):
#
#       -s apa_max_count=200    No more than 200 functions are listed.
#       -s apa_min_size=800     Commented out if text size < 800 bytes.
#       -s apa_min_pct=1        Commented out if it had < 1% of samples.
#       -s apa_max_cum_pct=90   Commented out after cumulative 90%.
#
#       Local functions are listed for completeness, but cannot be
    traced.

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

```
# 31.29%  38517 bytes
         -T prim_advance_mod_preq_advance_exp_

# 15.07%  14158 bytes
         -T prim_si_mod_prim_diffusion_

. . .


#  Functions below this point account for less than 10% of samples.

#  0.66%  4575 bytes
#         -T bndry_mod_bndry_exchangev_thsave_time_

#  0.10%  46797 bytes
#         -T baroclinic_inst_mod_binst_init_state_

#  0.04%  62214 bytes
#         -T prim_state_mod_prim_printstate_

#  0.00%  118 bytes
#         -T time_mod_timelevel_update_

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

  -o preqx.cray-xt.PE-2.1.56HD.pgi-8.0.amd64.pat-5.0.0.2.x+apa
     # New instrumented program.

  /.AUTO/cray/css.pe_tools/malice/craypat/build/pat/2009Apr03/2.1.56HD/
     amd64/homme/pgi7pat-5.0.0.2/homme/2005Dec08/build.Linux/preqx.cray-
     xt.PE-2.1.56HD.pgi-8.0.amd64.pat-5.0.0.2.x  # Original program.
```

Maximize On-node Communication by Reordering MPI ranks

MPI Rank Reorder – 2 Interfaces Available

- **CrayPat**
  - Run program and let CrayPat determine if communication is dominant, detect communication pattern and suggest MPI rank order if applicable

- **grid_order utility**
  - User knows communication pattern in application and wants to quickly create a new MPI rank placement file
  - Available when perftools module is loaded

When Is Rank Re-ordering Useful?

- Maximize on-node communication between MPI ranks
- Physical system topology agnostic
- Grid detection and rank re-ordering is helpful for programs with significant point-to-point communication
- Relieve on-node shared resource contention by pairing threads or processes that perform different work (for example computation with off-node communication) on the same node

Automatic Communication Grid Detection

- Cray performance tools produce a custom rank order if it's beneficial based on grid size, grid order and cost metric
- Summarized findings in report
- Available with sampling or tracing
- Describe how to re-run with custom rank order

MPI Rank Order Observations

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

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

 100.0% | 463.147240 |        -- |     -- | 21621.0 |Total
|-------------------------------------------------------------------------
|  52.0% | 240.974379 |        -- |     -- | 21523.0 |MPI
||------------------------------------------------------------------------
||  47.7% | 221.142266 | 36.214468 |  14.1% | 10740.0 |mpi_recv
||   4.3% |  19.829001 | 25.849906 |  56.7% | 10740.0 |MPI_SEND
||========================================================================
|  43.3% | 200.474690 |        -- |     -- |    32.0 |USER
||------------------------------------------------------------------------
||  41.0% | 189.897060 | 58.716197 |  23.6% |    12.0 |sweep_
||   1.6% |   7.579876 |  1.899097 |  20.1% |    12.0 |source_
||========================================================================
|   4.7% |  21.698147 |        -- |     -- |    39.0 |MPI_SYNC
||------------------------------------------------------------------------
|   4.3% |  20.091165 | 20.005424 |  99.6% |    32.0 | mpi_allreduce_(sync)
||========================================================================
|   0.0% |   0.000024 |        -- |     -- |    27.0 |SYSCALL
|=========================================================================
```

MPI Rank Order Observations (2)

```
MPI Grid Detection:

    There appears to be point-to-point MPI communication in a 96 X 8
    grid pattern. The 52% of the total execution time spent in MPI
    functions might be reduced with a rank order that maximizes
    communication between ranks on the same node. The effect of several
    rank orders is estimated below.

    A file named MPICH_RANK_ORDER.Grid was generated along with this
    report and contains usage instructions and the Custom rank order
    from the following table.

         Rank     On-Node      On-Node    MPICH_RANK_REORDER_METHOD
        Order    Bytes/PE    Bytes/PE%
                             of Total
                             Bytes/PE

       Custom  2.385e+09       95.55%   3
          SMP  1.880e+09       75.30%   1
         Fold  1.373e+06        0.06%   2
    RoundRobin 0.000e+00        0.00%   0
```

Auto-Generated MPI Rank Order File

```
# The 'USER_Time_hybrid' rank order in this file targets nodes with multi-core
# processors, based on Sent Msg Total Bytes collected for:
#
# Program:      /lus/nid00023/malice/craypat/WORKSHOP/bh2o-demo/Rank/sweep3d/src/sweep3d
# Ap2 File:     sweep3d.gmpi-u.ap2
# Number PEs:   768
# Max PEs/Node: 16
#
# To use this file, make a copy named MPICH_RANK_ORDER, and set the
# environment variable MPICH_RANK_REORDER_METHOD to 3 prior to
# executing the program.
#
0,532,64,564,32,572,96,540,85,596,72,524,40,604,24,588
104,556,16,628,80,636,56,620,48,516,112,580,88,548,120,612
1,403,65,435,33,411,97,443,95,467,25,499,105,507,41,475
73,395,81,427,57,459,17,419,53,399,85,431,21,463,61,391,113,491,49,387,89,451,121,483
6,436,102,468,70,404,38,412,2,530,34,562,66,538,98,522,14,444,46,476,110,508,78,500
86,396,30,428,62,460,54,492,18,514,74,586,58,626,82,546,118,420,22,452,94,388,126,484
129,563,193,531,161,571,225,135,315,167,339,199,347,259,539,241,595,233,523,249,603,307,231,371,239,379,191,331,185,555
153,587,169,627,137,635,201,175,363,159,323,143,355,255,619,177,515,145,579,209,547,291,207,275,183,283,151,267,217,611
7,405,71,469,39,437,103,413,133,406,197,438,165,470,229,47,445,15,509,79,477,31,501
111,397,63,461,55,429,87,421,23,493,119,389,95,453,127,485
134,402,198,434,166,410,230,442,238,466,174,506,158,394,246,474
190,498,254,426,142,458,150,386,182,418,206,490,214,450,222,482
128,533,192,541,160,565,232,525,224,573,240,597,184,557,248,605
168,589,200,517,152,629,136,549,176,637,144,621,208,581,216,613
95,439,37,407,69,447,101,415,13,471,45,503,29,479,77,511
3,440,35,432,67,400,99,408,1,464,43,496,27,472,51,504
19,392,75,424,59,456,83,384,107,416,91,488,115,448,123,480
1132,401,196,441,164,409,228,433,236,465,204,473,244,393,569,561
188,497
252,505,140,425,212,457,156,385,172,417,180,449,148,489,277,365
220,481
131,534,195,542,163,566,227,526,235,574,203,598,243,558,336,344
187,606
251,590,211,630,179,638,139,622,155,550,171,518,219,582,678,362
147,614
761,660,737,652,705,668,745,692,673,700,641,684,713,644,694,654
753,724
729,732,681,756,721,716,764,676,697,748,689,657,740,665,279,374
649,708
760,528,736,536,704,560,744,520,672,568,712,592,752,552,302,334
640,600
728,584,680,624,720,512,696,632,688,616,664,544,608,656,679,703
648,576
762,659,738,651,706,667,746,643,714,691,674,699,754,683,645,759
730,723
722,731,763,658,642,755,739,675,707,650,682,715,698,666,690,747
257,345,265,313,281,305,273,
545,297,633,361,625,321,585,537,601,289,553,353,593,521,513,529
256,373,261,341,264,349,280,304,360,312,376,293,296,368,317,272,381,269,309,285,333,
352,301,320,325,288,357,328,370,766,306,710,378,742,330,
646,298,750,322,718,354,758,290,734,662,686,670,726,702,
262,375,263,343,270,311,271,351,286,319,278,342,287,350,
294,318,358,383,359,310,295,382,326,303,327,367,366,335,
765,661,709,663,741,653,711,669,767,655,743,671,749,695,
677,727,751,693,647,701,717,687,757,685,733,725,719,735,
```

grid_order Utility

- No need to run application if you already know program's data movement pattern
- Originally designed for MPI programs, but also works for SHMEM and PGAS programming models that use Cray PMI
- Utility available if perftools-base modulefile is loaded
- See grid_order(1) man page or run grid_order with no arguments to see usage information

Using New Rank Order

- Save grid_order output to file called MPICH_RANK_ORDER
- Export MPICH_RANK_REORDER_METHOD=3
- Run non-instrumented binary with and without new rank order to check overall wallclock time for performance improvements
- Can be used for all subsequent executions of same job size

Using Performance Counters

Performance Counters

- **Cray supports raw counters, derived metrics and thresholds for:**
  - Processor (core and uncore)
  - Network
  - Accelerator
  - Power
- **Predefined groups**
  - Groups together suggested counters for experiments
- **Single interface to access counters**
  - PAT_RT_PERFCTR environment variable
- **See *hwpc, nwpc, accpc, rapl* man pages**

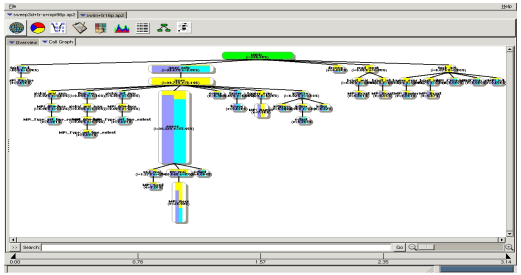
Example: HW counter data and Derived Metrics

```
  PAPI_TLB_DM  Data translation lookaside buffer misses
  PAPI_L1_DCA  Level 1 data cache accesses
  PAPI_FP_OPS  Floating point operations
  DC_MISS      Data Cache Miss
  User_Cycles  Virtual Cycles
========================================================================
USER
------------------------------------------------------------------------
  Time%                                            98.3%
  Time                                         4.434402 secs
  Imb.Time                                           -- secs
  Imb.Time%                                          --
  Calls                      0.001M/sec          4500.0 calls
  PAPI_L1_DCM               14.820M/sec        65712197 misses
  PAPI_TLB_DM                0.902M/sec         3998928 misses
  PAPI_L1_DCA              333.331M/sec      1477996162 refs
  PAPI_FP_OPS              445.571M/sec      1975672594 ops
  User time (approx)         4.434 secs     11971868993 cycles  100.0%Time
  Average Time per Call                        0.000985 sec
  CrayPat Overhead : Time       0.1%
  HW FP Ops / User time    445.571M/sec      1975672594 ops    4.1%peak(DP)
  HW FP Ops / WCT          445.533M/sec
  Computational intensity     0.17 ops/cycle     1.34 ops/ref
  MFLOPS (aggregate)       1782.28M/sec
  TLB utilization           369.60 refs/miss    0.722 avg uses
  D1 cache hit,miss ratios   95.6% hits         4.4% misses
  D1 cache utilization (misses)  22.49 refs/miss   2.811 avg hits
========================================================================
```

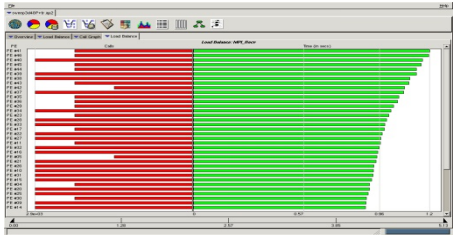
PAT_RT_PERFCTR=1
Flat profile data
Raw counts
Derived metrics

Visualizing Performance of Your Application Through Cray Apprentice2

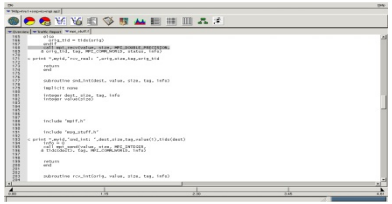
Cray Apprentice²

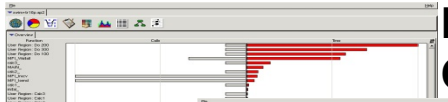


Load balance views

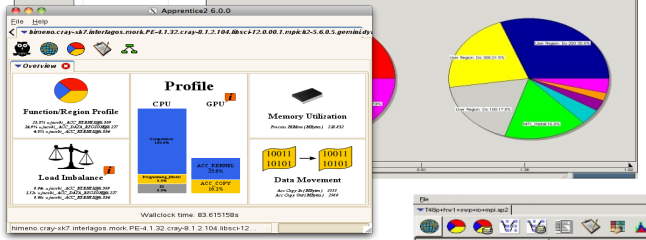


Source code mapping

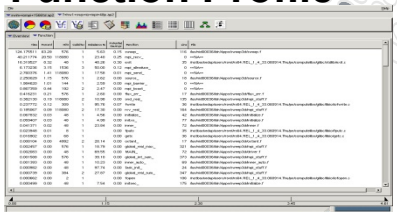


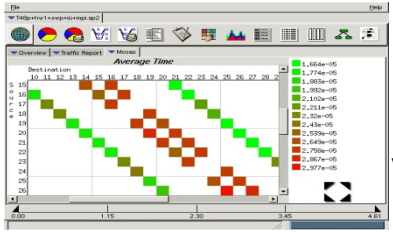


Program Overview

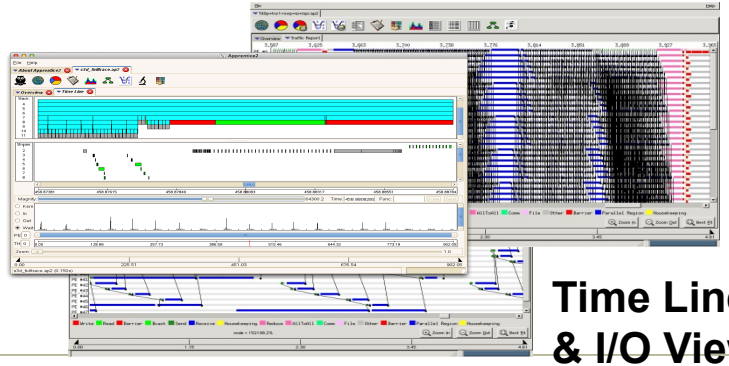


Function Profile

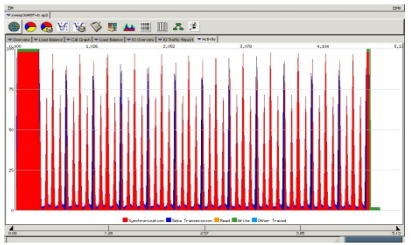




Pair-wise Communication View



Time Line & I/O Views



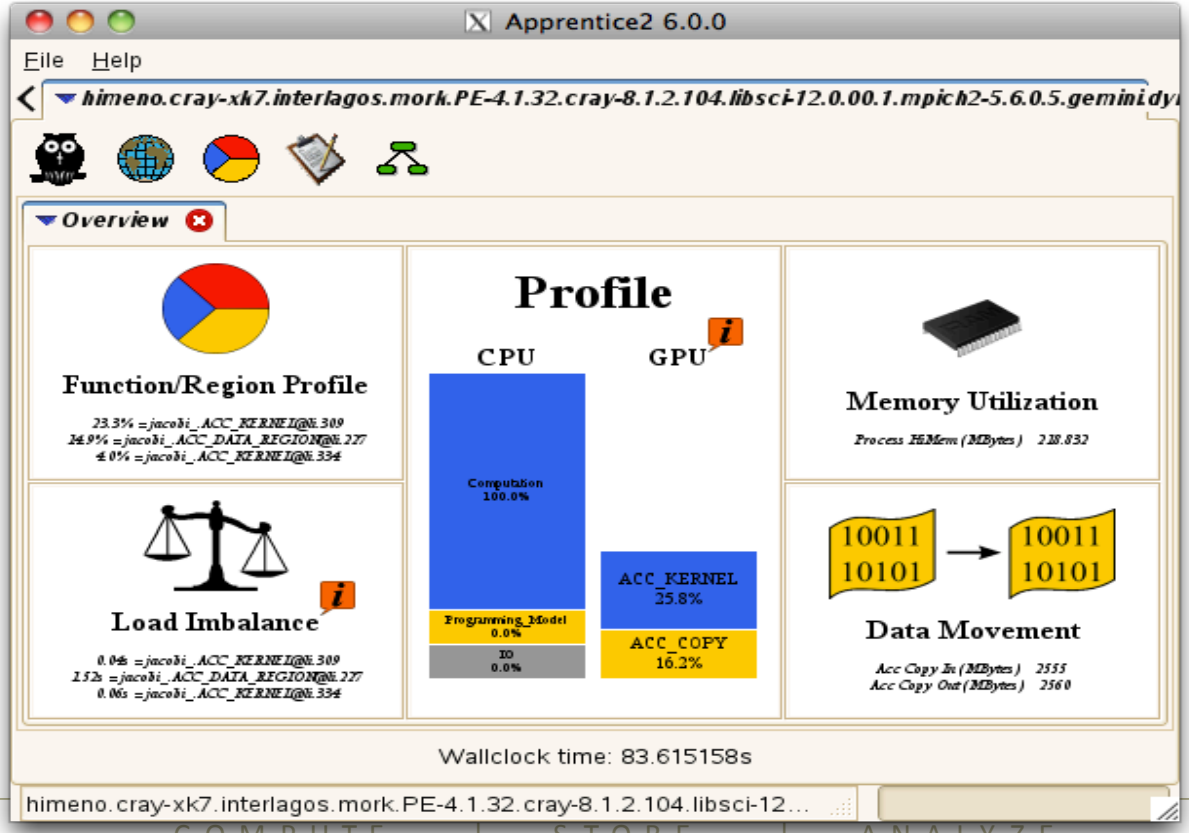
Communication & I/O Activity View

Installing Apprentice2 on Laptop

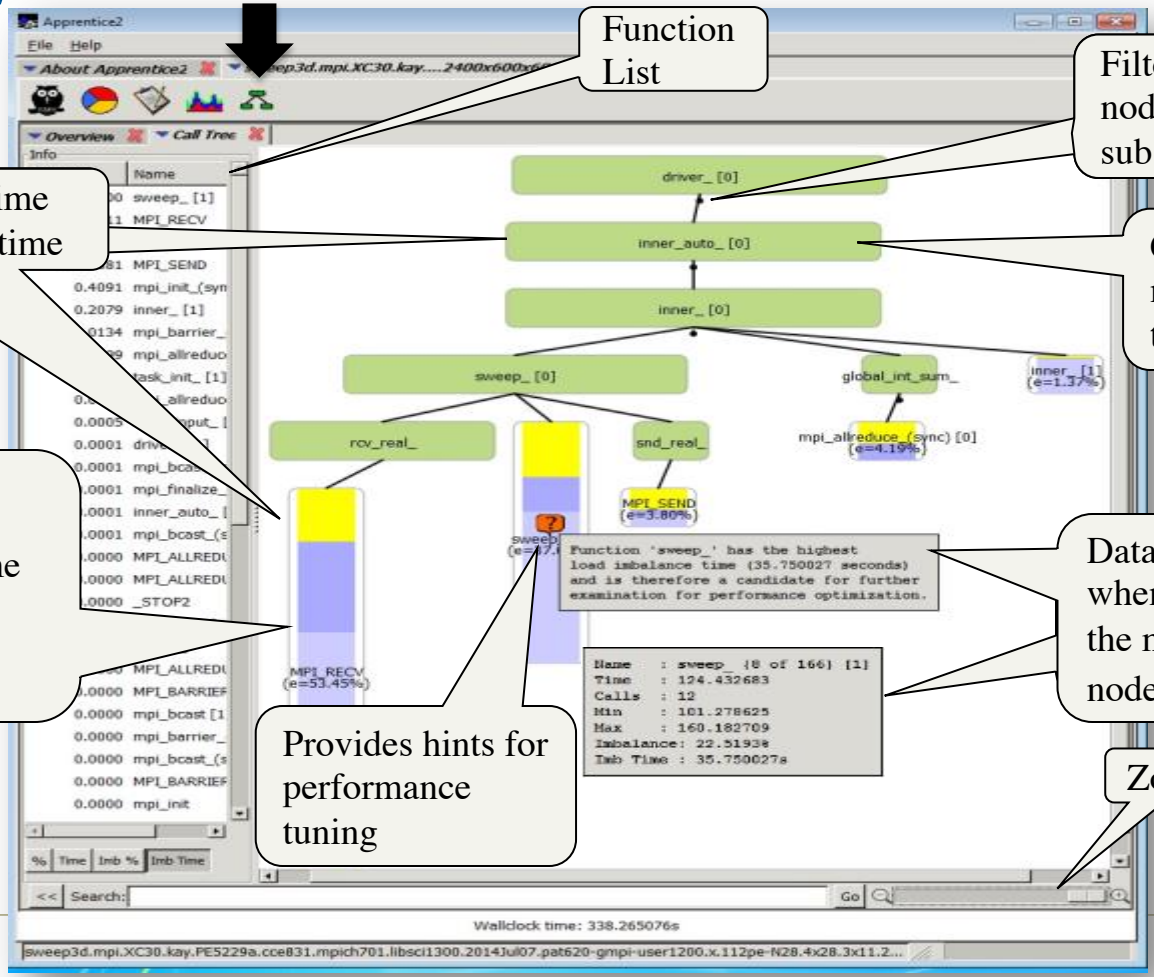
From a Cray login node

- `> module load perftools`
- **Go to:**
  - $CRAYPAT_ROOT/share/desktop_installers/
- **Download .dmg or .exe installer to laptop**
- **Double click on installer and follow directions to install**

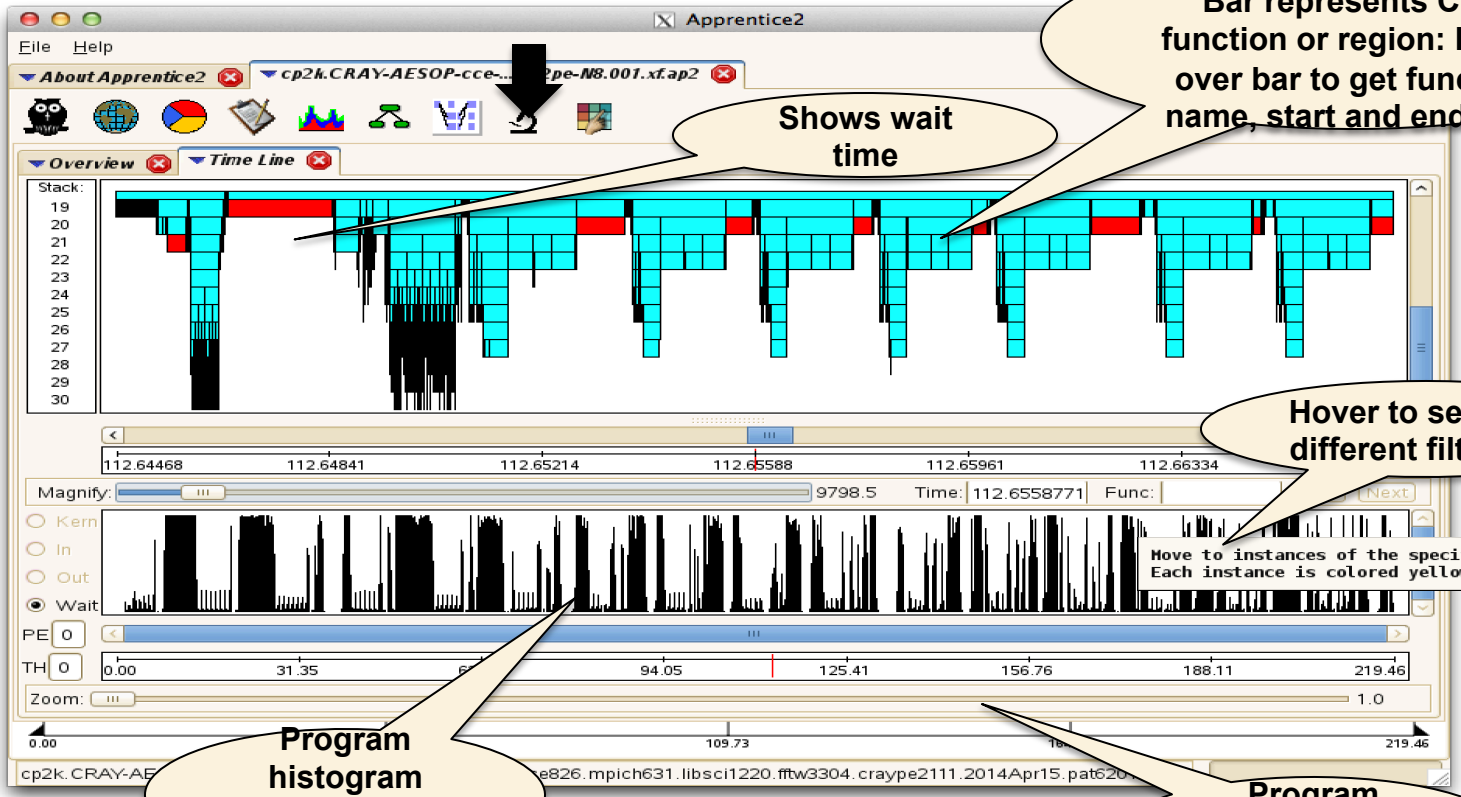
Apprentice2 Overview with GPU Data



Call Tree View



CPU Program Timeline: 36GB CP2K Full Trace

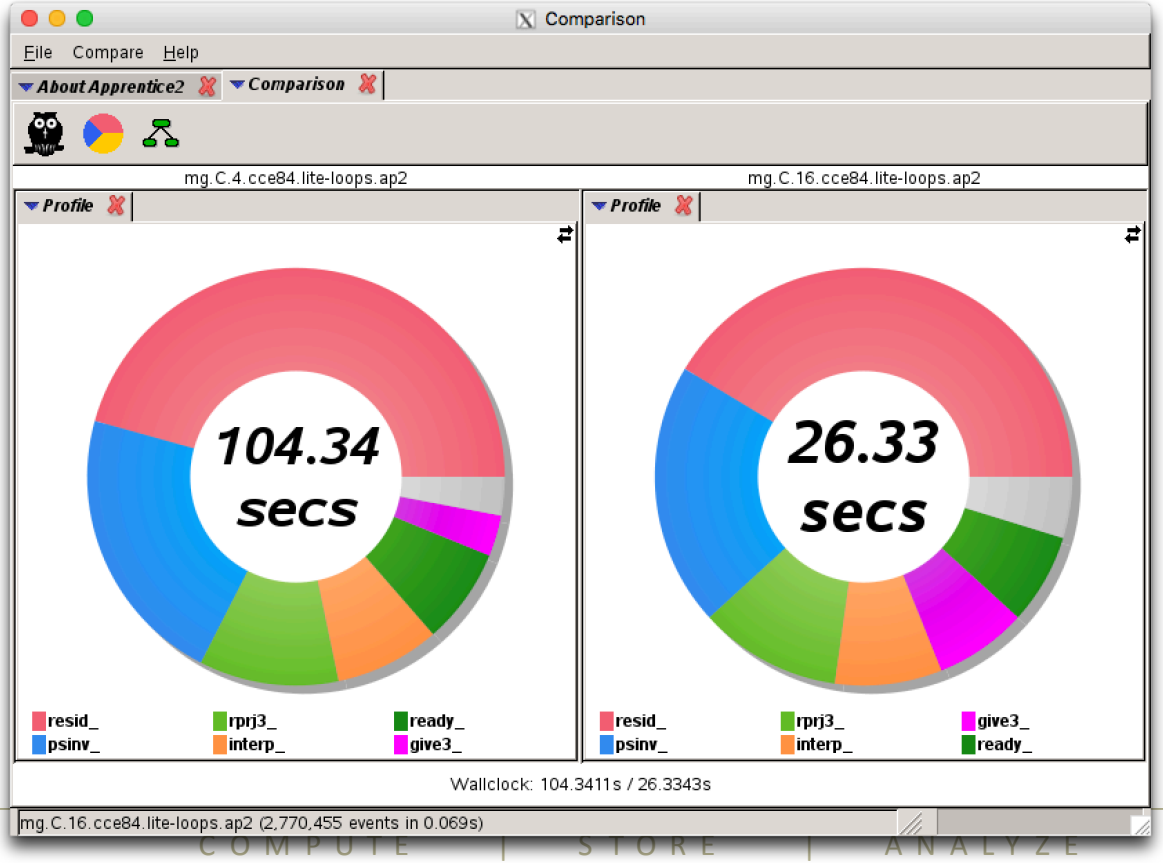


What's New?

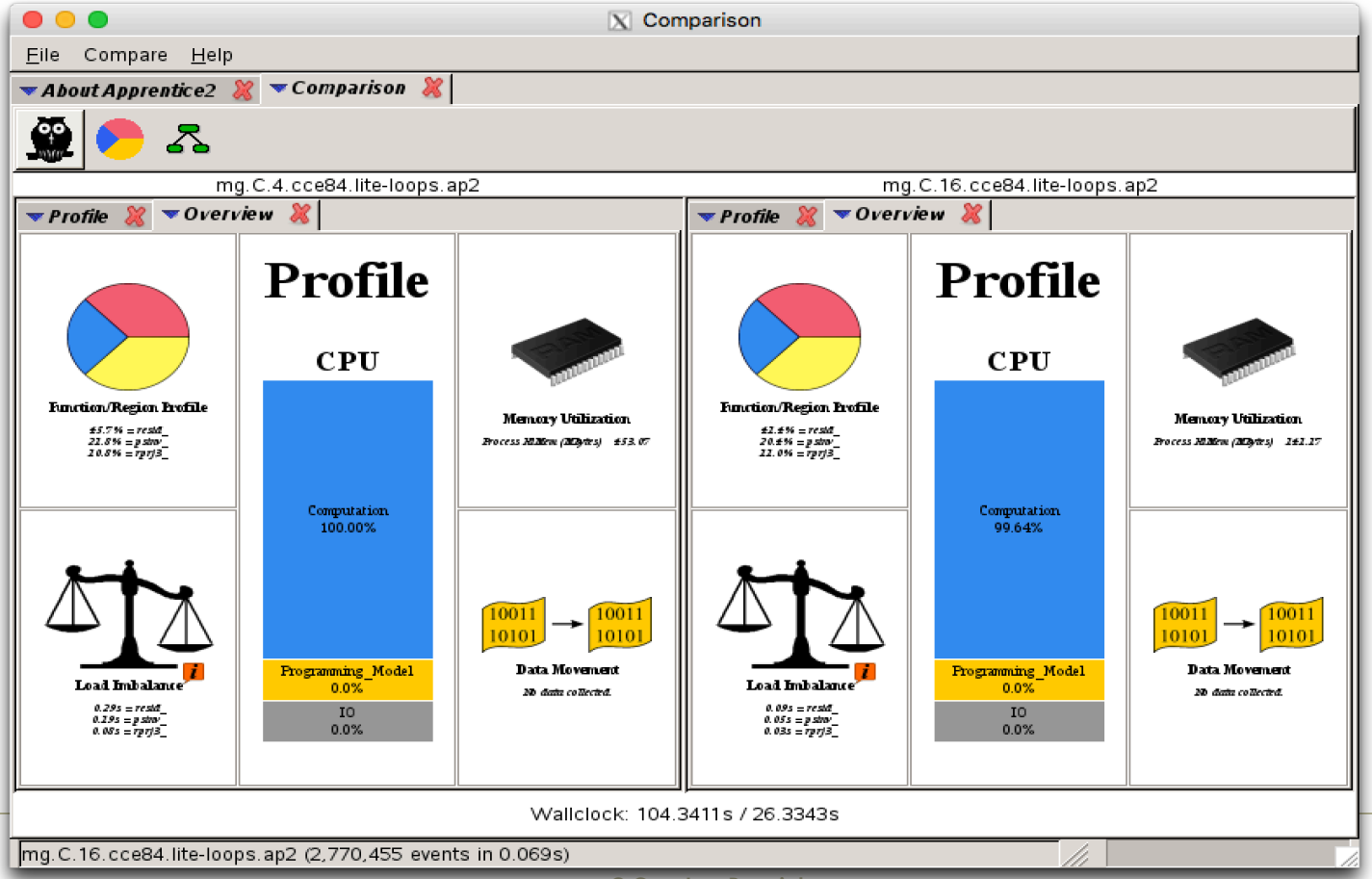
Recent Enhancements

- **Improved ease of use:**
  - perftools-base module, pat_info utility
- **Profile comparison in Cray Apprentice2**
  - Useful for comparing MPI vs MPI+OpenMP, scaling bottlenecks, etc.
- **2D communication heat map (Cray Apprentice2 Mosaic) in summarized mode**
- **Visualize sampling data over time with associated call stack**

Apprentice2 Comparison



Apprentice2 Comparison (2)



Pat_info Utility

- Can be used to generate a quick summary statement regarding the contents of a CrayPat .ap2 file or set of files without running pat_report or Apprentice2
- Useful if you have multiple .ap2 files in a directory or if you want to review what experiments you have already performed
- Works on a single .ap2 file or a directory of .ap2 files
- When invoked with no arguments, the command looks in the current directory for .ap2 files
- When invoked with a directory argument, information about all .ap2 files in that directory are displayed

Example pat_info Utility Output

```
# When given a single .ap2 file argument, it defaults to the long form
# (counter lists are added with the -c option):

kay-esl$ pat_info -c
sweep3d.mpi+17552-12s.ap2
ap2:                                sweep3d.mpi+17552-12s.ap2
ap2_size:           289792
RTS:                                yes
Experiment:         samp_cs_time
PE:                                 CRAY
NumPEs:                             96
NumThreads:         0
NumLeafNodes:       928
OpenMP:                             yes
Original prog:      /lus/scratch/clark/sweep3d/sweep3d.mpi+orig
prog_size:          (not available)
NumHWPC:            16
  CYCLES_RTC
  L1D:REPLACEMENT
  L2_RQSTS:ALL_DEMAND_DATA_RD
  FP_COMP_OPS_EXE:SSE_SCALAR_DOUBLE
  FP_COMP_OPS_EXE:SSE_FP_SCALAR_SINGLE
  FP_COMP_OPS_EXE:X87
  FP_COMP_OPS_EXE:SSE_PACKED_SINGLE
  SIMD_FP_256:PACKED_SINGLE
  FP_COMP_OPS_EXE:SSE_FP_PACKED_DOUBLE
  SIMD_FP_256:PACKED_DOUBLE
  L2_RQSTS:DEMAND_DATA_RD_HIT
  CPU_CLK_UNHALTED:THREAD_P
  CPU_CLK_UNHALTED:REF_P
  MEM_UOPS_RETIRED:ALL_LOADS
  DTLB_LOAD_MISSES:MISS_CAUSES_A_WALK
  DTLB_STORE_MISSES:MISS_CAUSES_A_WALK
NumCPMC:            2
  PM_ENERGY:NODE
  PM_ENERGY:ACC
```

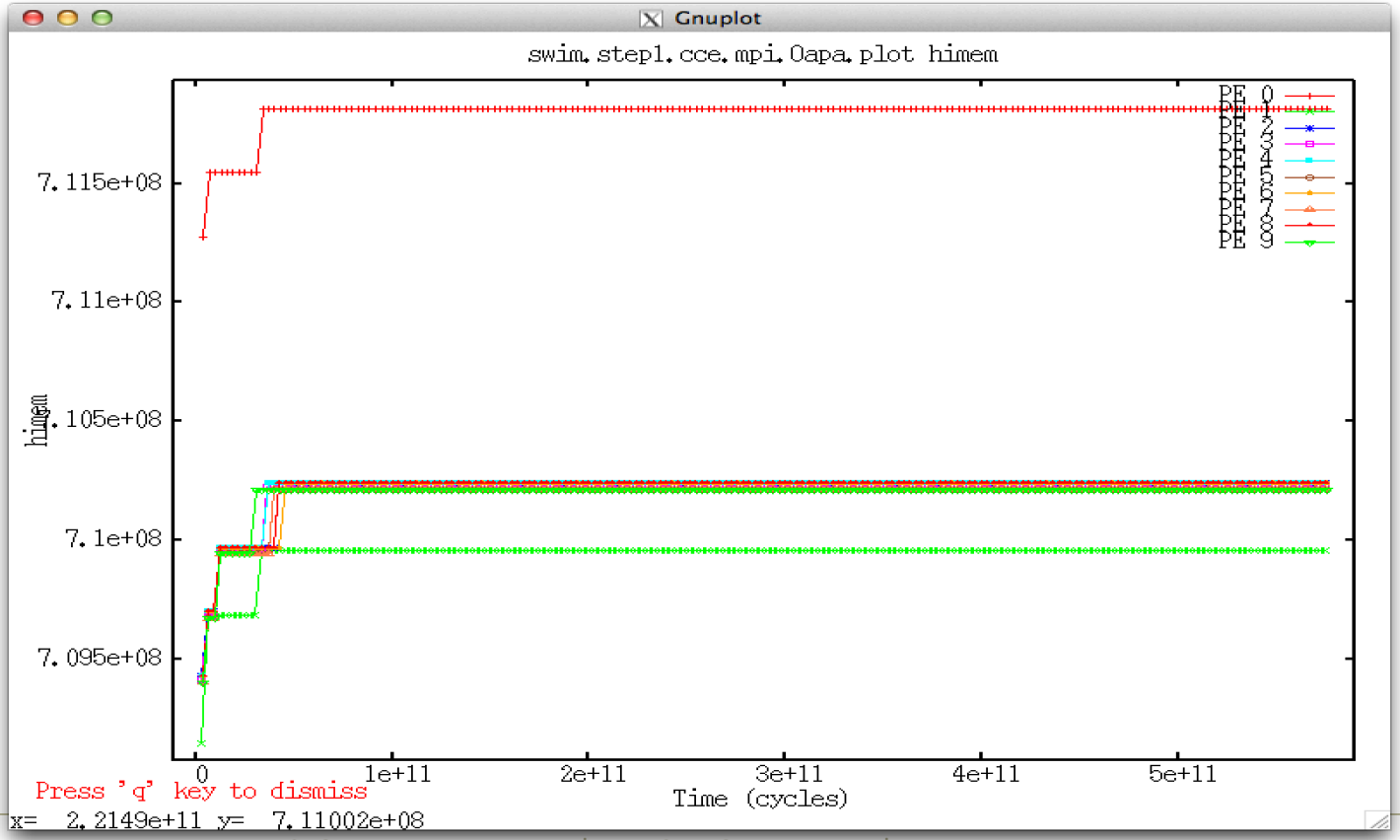
Sampling Over Time

- Available in perftools/6.2.3 (available in April 2015)
- Intended for collecting higher overhead performance data
- Sampling experiment in non-summary mode
  - `PAT_RT_SUMMARY=0`
  - `PAT_RT_SAMPLING_DATA=cray_pm`
- Records data every 100 Program Counter addresses by default (user can adjust)
- Examples:
  - Heap, shared heap
  - Perfctr (selected performance counters)
  - Rusage (resource usage (getrusage)
  - Cray PM, RAPL

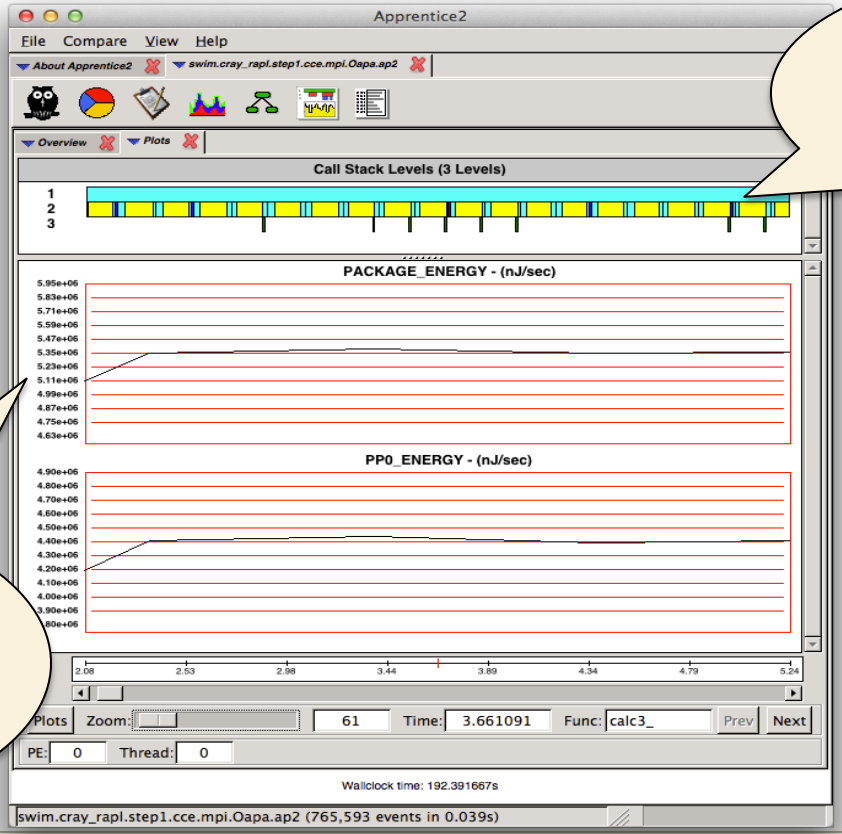
Visualize Samples Over Time

- **Plots show activity over time**
- **pat_report generates gnuplot files**
  - > pat_report [-r] -f plot $some.xf
  - > pat_report [-r] -f plot $some.ap2
- **Visualize (pat_report launches gnuplot)**
  - > pat_report $some.plot
  - > pat_report $some.plot/himem.gp
  - > pat_report -s pe=N
    - plot data only for pe N
  - > pat_report -s filter_input='pe<10'
    - specify a subset of pe values for which to plot data
- **Run "pat_help plots" or see craypat(1) man page for more info**

Memory High Water Mark



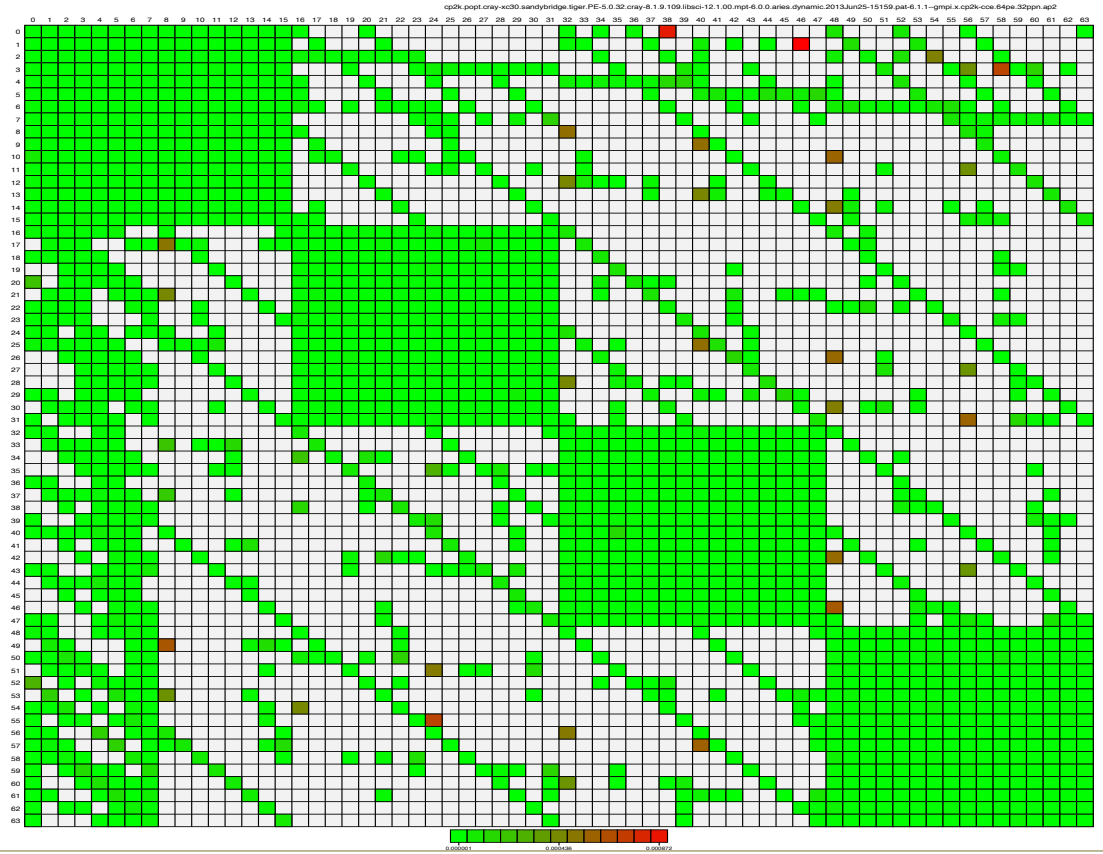
Energy Consumption Over Time (XC Systems)



Call stack:
Bar represents function or region: Hover over bar to get function name, start and end time

Plots of energy consumed by the socket and by the cores within a socket over time. Can also show memory high water mark, etc.

What is My Program's Communication Pattern?



GPU Support

What to Determine About Your Application

- Where are the dominant bottlenecks (excessive communication, excessive data movement, etc.)
- What parts of my code ran on the GPU?
- Was the GPU used efficiently?
- Was the host stalled, waiting for completion of accelerated regions?

Performance Feedback Available

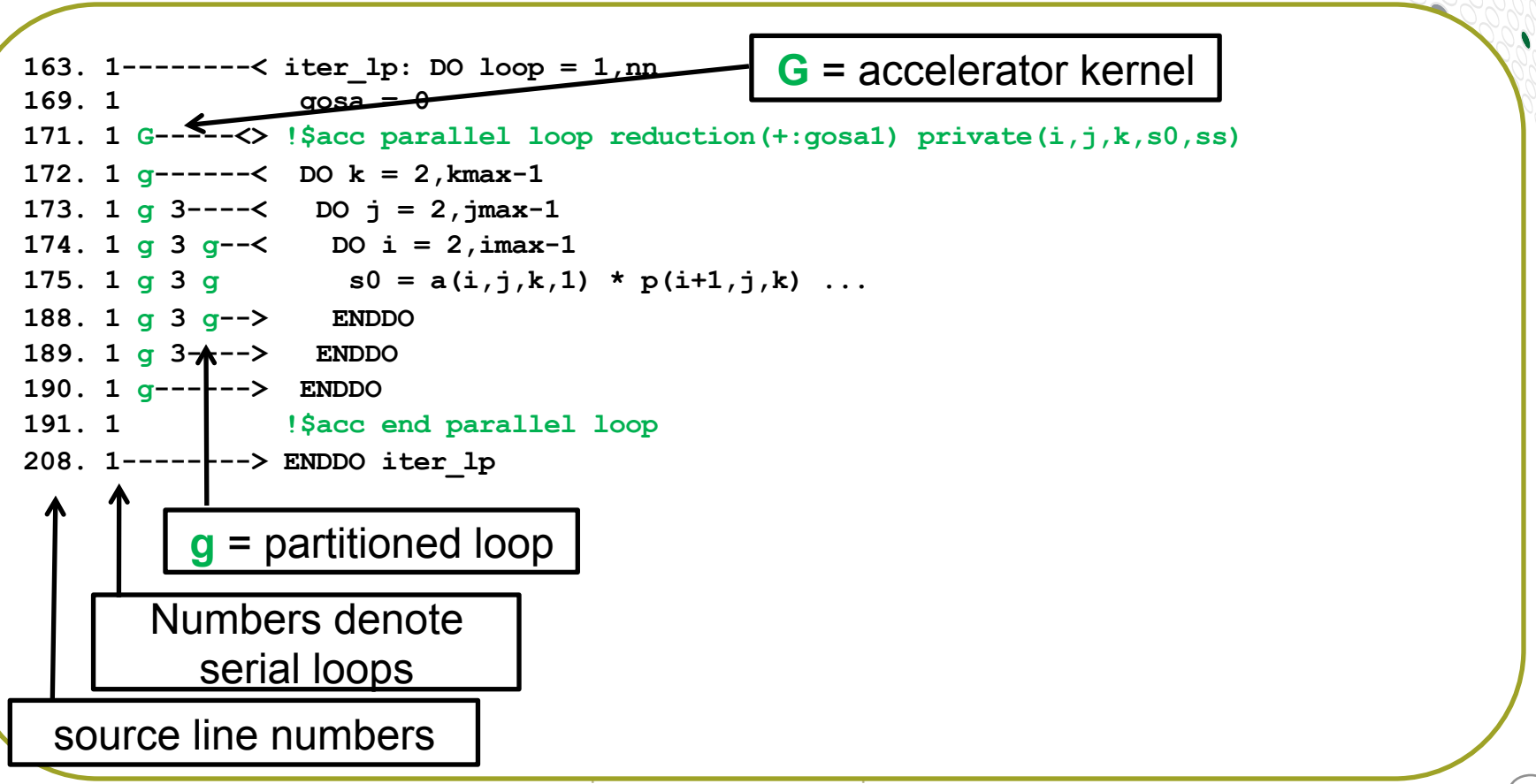
OpenACC and OpenMP 4.0 accelerator directives:

- **Compiler feedback through listings (static analysis)**
  - CCE: -hlist=a
- **Runtime commentary of accelerator activity**
  - CCE: setenv CRAY_ACC_DEBUG <1,2,3>
- **Application profiling**
  - Cray Performance Tools

Compiler feedback – Extremely Useful

- **Did the compiler recognize the accelerator directives?**
  - A good sanity check
- **How will the compiler move data?**
  - First major code optimization: removing unnecessary data movements
- **How will the compiler schedule loop iterations across GPU threads?**
  - Did it parallelize the loopnests?
  - Did it schedule the loops sensibly?
  - Another main optimization: correcting poor loop scheduling

Acceleration Feedback



Data Movement Feedback

```
163. 1--------< DO loop = 1,nn
169. 1           gosa1 = 0
171. 1 G-----<> !$acc parallel loop reduction(+:gosa1) private(i,j,k,s0,ss)
172. 1 g------<  DO k = 2,kmax-1
173. 1 g 3----<   DO j = 2,jmax-1
174. 1 g 3 g--<    DO i = 2,imax-1
175. 1 g 3 g         s0 = a(i,j,k,1) * p(i+1,j,k) ...
188. 1 g 3 g-->    ENDDO
189. 1 g 3---->   ENDDO
190. 1 g------>  ENDDO
191. 1          !$acc end parallel loop
208. 1--------> ENDDO
```

Over-cautious: compiler worried about halos; could specify copyout(wrk2)

```
ftn-6418 ftn: ACCEL File = himeno_F_v02.F90, Line = 171
  If not already present: allocate memory and copy whole array "p" to accelerator, free
   at line 191 (acc_copyin).

ftn-6416 ftn: ACCEL File = himeno_F_v02.F90, Line = 171
  If not already present: allocate memory and copy whole array "wrk2" to accelerator,
   copy back at line 191 (acc_copy).
```

Loop Scheduling

```
163. 1--------< DO loop = 1,nn
169. 1           gosa1 = 0
171. 1 G-----<> !$acc parallel loop reduction(+:gosa1) private(i,j,k,s0,ss)
172. 1 g------<  DO k = 2,kmax-1
173. 1 g 3----<   DO j = 2,jmax-1
174. 1 g 3 g--<    DO i = 2,imax-1
175. 1 g 3 g        s0 = a(i,j,k,1) * p(i+1,j,k) ...
188. 1 g 3 g-->    ENDDO
189. 1 g 3---->   ENDDO
190. 1 g------>  ENDDO
191. 1          !$acc end parallel loop
208. 1--------> ENDDO

ftn-6430 ftn: ACCEL File = himeno_F_v02.F90, Line = 172
  A loop starting at line 172 was partitioned across the thread blocks.

ftn-6509 ftn: ACCEL File = himeno_F_v02.F90, Line = 173
  A loop starting at line 173 was not partitioned because a better candidate was found at line 174.

ftn-6412 ftn: ACCEL File = himeno_F_v02.F90, Line = 173
  A loop starting at line 173 will be redundantly executed.

ftn-6430 ftn: ACCEL File = himeno_F_v02.F90, Line = 174
  A loop starting at line 174 was partitioned across the 128 threads within a threadblock.
```

CCE Runtime Activity Commentary

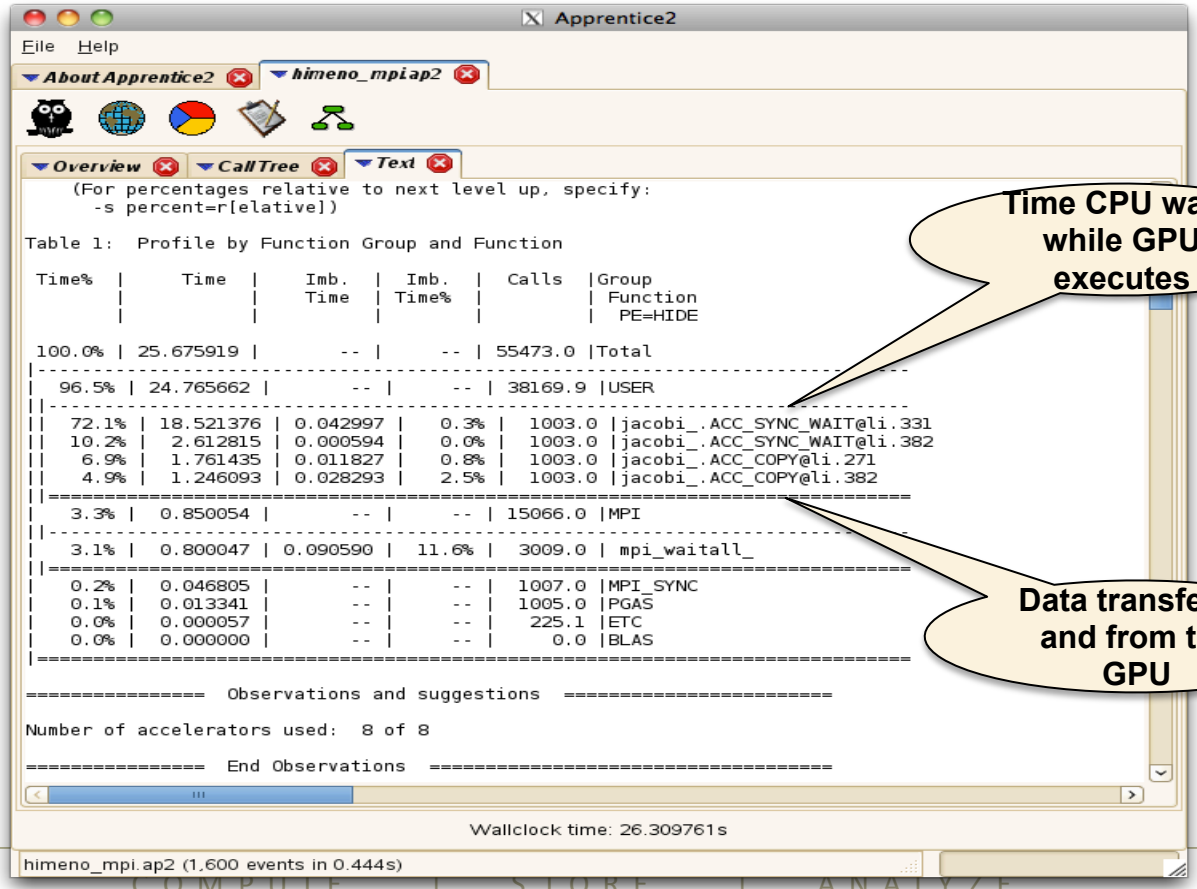
- Setenv CRAY_ACC_DEBUG <1,2,3>

```
ACC: Initialize CUDA
ACC: Get Device 0
ACC: Create Context
ACC: Set Thread Context
ACC: Start transfer 2 items from saxpy.c:17
ACC:       allocate, copy to acc 'x' (4194304 bytes)
ACC:       allocate, copy to acc 'y' (4194304 bytes)
ACC: End transfer (to acc 8388608 bytes, to host 0 bytes)
ACC: Execute kernel saxpy$ck_L17_1 blocks:8192 threads:128 async(auto) from saxpy.c:17
ACC: Wait async(auto) from saxpy.c:18
ACC: Start transfer 2 items from saxpy.c:18
ACC:       free 'x' (4194304 bytes)
ACC:       copy to host, free 'y' (4194304 bytes)
ACC: End transfer (to acc 0 bytes, to host 4194304 bytes)
```

Collecting GPU Statistics for OpenACC / OpenMP

- **Make sure the following modules are loaded:**
  - craype-accel-nvidia35 accelerator module
  - PrgEnv-cray module
  - perftools module (perftools-base is already loaded)
- **Instrument binary for tracing and collecting GPU statistics**
  - pat_build –u –g mpi,blas my_program
- **Run application**
- **Create report with GPU statistics**
  - pat_report my_program.xf > GPU_stats_report

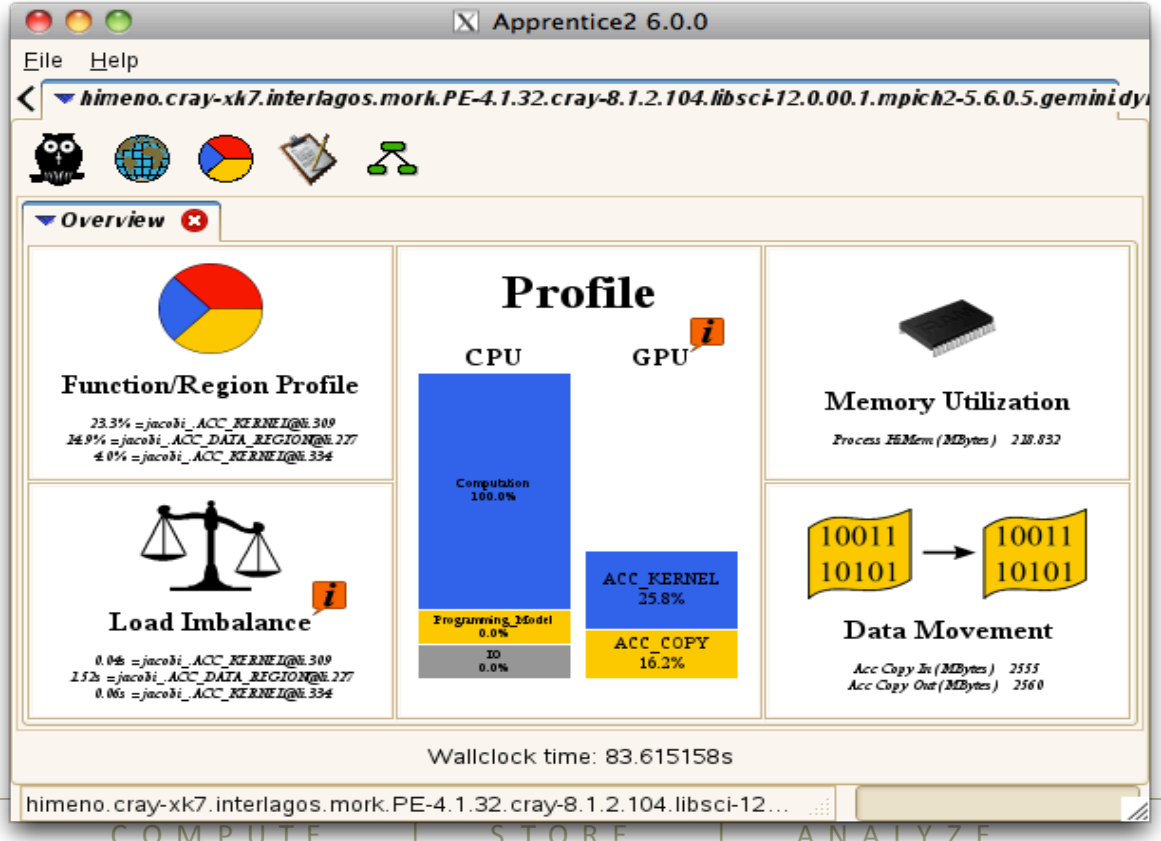
Profile with GPU Information



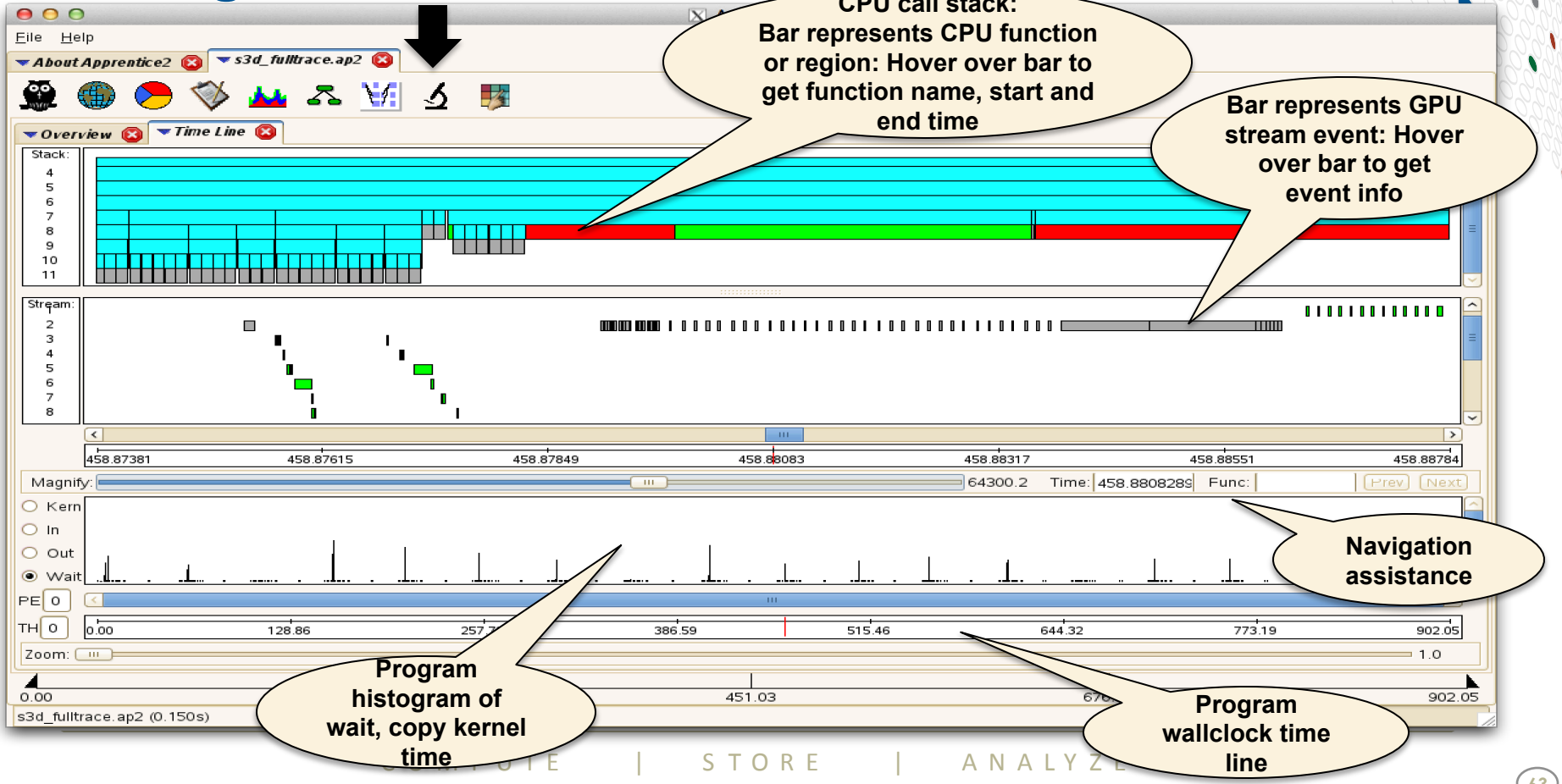
Example Accelerator Statistics

```
Table 1:  Time and Bytes Transferred for Accelerator Regions
  Host   |    Host   |     Acc   | Acc Copy  | Acc Copy  | Calls  |Calltree
 Time%   |    Time   |    Time   |       In  |      Out  |        | PE=HIDE
         |           |           | (MBytes)  | (MBytes)  |        |
 100.0% |    2.750 |    2.015 |  2812.760 |    13.568 |    103 |Total
|-------------------------------------------------------------------------------------------------------
| 100.0% |    2.750 |    2.015 |  2812.760 |    13.568 |    103 |lbm3d2p_d_
|        |          |          |           |           |        | lbm3d2p_d_.ACC_DATA_REGION@li.104
|||-----------------------------------------------------------------------------------------------------
3||  63.5% |    1.747 |    1.747 |  2799.192 |        -- |      1 |lbm3d2p_d_.ACC_COPY@li.104
3||  22.1% |    0.609 |    0.088 |    12.304 |    12.304 |     36 |streaming_
||||---------------------------------------------------------------------------------------------------
4|||  20.6% |    0.566 |    0.046 |    12.304 |    12.304 |     27 |streaming_exchange_
5|||        |          |          |           |           |        | streaming_exchange_.ACC_DATA_REGION@li.526
6|||  18.8% |    0.517 |       -- |        -- |        -- |      1 |  streaming_exchange_.ACC_DATA_REGION@li.
526(exclusive)
4|||   1.6% |    0.043 |    0.042 |        -- |        -- |      9 |streaming_.ACC_DATA_REGION@li.907
5|||   1.1% |    0.031 |    0.031 |        -- |        -- |      4 | streaming_.ACC_REGION@li.909
6|||   1.1% |    0.031 |       -- |        -- |        -- |      1 |  streaming_.ACC_REGION@li.909(exclusive)
||||=====================================================================================================
```

Apprentice2 Overview with GPU Data



GPU Program Timeline




CRAY
COMPUTE | STORE | ANALYZE
Thank You