Interpreting perftools Performance Data

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Some Useful Experiments

- Identify slowest areas and notable bottlenecks of a program
  - Use `perftools-lite`
  - Good for examining performance characteristics of a program and for scaling analysis

- Focus on MPI communication
  - Use `perftools-lite` first to determine if MPI time is dominant or if there is a load imbalance between ranks
  - Use `perftools (pat_build –g mpi)` to collect more detailed MPI-specific information including MPI_SYNC time to detect late arrivers to collectives
  - Good for identifying source of imbalance and scaling analysis at targeted final job size

- Focus on loop optimization
  - Use `perftools-lite-loops`
  - Use `perftools-lite-hbm` for memory traffic analysis
  - Good for vectorizing, parallelizing and cache optimization

Cray Compiler Listings

- CCE provides loopmark, cross-references, compile options, and optimization messages in easy-to-read text files
- Just add the following flag to the application's Makefile:

```
-h list=a …
```

- Tip: For additional information on restructuring and optimization changes made by CCE, try `–h list=d` for decompiled code
- Use with perftools to understand top time consuming loop optimization information

Get Additional Information Without Re-running

- Generate full report
  - `user@login> pat_report my_data_directory+12s/ > rpt`

- Generate report with call tree (or by callers)
  - `user@login> pat_report –O calltree+src`

- Generate report without pruning
  - `user@login> pat_report –P`

- Show each MPI rank or each OpenMP thread in report
  - `user@login> pat_report –s pe=ALL`
  - `user@login> pat_report –s th=ALL`

Don’t See an Expected Function?

- To make the profile easier to interpret, samples are attributed to a caller that is either a user defined function, or a library function called directly by a user defined function

- To disable this adjustment, and show functions actually sampled, use the ‘`pat_report –P`’ option to disable pruning

- You should be able to see the caller/callee relationship with

  ‘`pat_report -P -O callers`’

Don’t See an Expected Function? (continued)

Why don’t I see a particular function in a report?

- Cray tools filter out data that may distract you
  - Use ‘`pat_report –T`’ to see functions that didn’t take much time

- Still don’t see it?
  - Check the compiler listing to see if the function was inlined

What is ETC Group in a Report?

- When a function is called that cannot be attributed to a user-defined parent function, it gets placed in ETC
- Try '`pat_report –P`'
- Note: pat_report depends on the accuracy of the DWARF issued by the compiler

How Do I See per-Rank or per-Thread Data?

- `$ pat_report –s pe=ALL`

- `$ pat_report –s th=ALL`

How Was Data Aggregated?

- Check the Notes before each table in the text report

```
Notes for table 1:

  This table shows functions that have significant exclusive sample
    hits, averaged across ranks.

  For further explanation, see the "General table notes" below,
    or use:  pat_report -v -O samp_profile ...

Table 1:  Profile by Function
```

When to Collect Counters

- Use to understand the “why” of a bottleneck

- Default set of counters are collected for whole program
  - Used to present memory and vector summary metrics

- User can choose to collect per function or per region of code with PAT_region API

Performance Counters Overview

- Cray supports raw counters, derived metrics and thresholds for:
  - Processor (core and uncore)
  - Network
  - Accelerator
  - Power

- Predefined groups
  - Groups together counters for experiments

- See *hwpc, nwpc, accpc, and rapl* man pages

CrayPat Runtime Options

- Runtime controlled through PAT_RT_XXX environment variables

- See intro_craypat(1) man page

- Examples of control
  - Enable full trace
  - Change number of data files created
  - Enable collection of HW, network or power counter events
  - Enable tracing filters to control trace file size (max threads, max call stack depth, etc.)

How to Get List of Events for a Processor

- Run the following utility on a compute node:
  - papi_native_avail
  - papi_avail

- Use pat_help to see counter groups and derived metrics
  - user@login> `pat_help counters` *`processor_type`* `deriv`

- To collect performance counters
  - Set `PAT_RT_PERFCTR` environment variable to list of events or group prior to execution

Focus on Loop Optimization – Find Top Loops

- `$ module load perftools-lite-loops`
- Build program with CCE
  - Should see messages from CrayPat during build saying that it created an instrumented executable
  - Remember to add `-hlist=a` to build with CCE listing
  - Add `-hpl=/path_to_program_library/my_program.pl` if you want to use Reveal
- Run program
- Performance data sent to `STDOUT` and to directory with unique name

Example Loop Statistics

```
Inclusive and Exclusive Time in Loops
  Loop |  Loop Incl |  Loop Hit |  Loop |  Loop |  Loop |Function=/.LOOP[.]
  Incl |       Time |           | Trips | Trips | Trips | PE=HIDE
 Time% |            |           |   Avg |   Min |   Max |
|-----------------------------------------------------------------------------
| 99.4% | 333.895923 |         1 | 500.0 |   500 |   500 | les3d_.LOOP.3.li.216
| 98.7% | 331.721721 |       500 |   2.0 |     2 |     2 | les3d_.LOOP.4.li.272
| 26.5% |  89.032566 |     1,000 |  96.0 |    96 |    96 | fluxk_.LOOP.1.li.28
| 24.6% |  82.681435 |    96,000 |  97.0 |    97 |    97 | fluxk_.LOOP.2.li.29
| 24.2% |  81.356609 |     1,000 |  96.0 |    96 |    96 | fluxj_.LOOP.1.li.28
| 22.5% |  75.770180 |    96,000 |  97.0 |    97 |    97 | fluxj_.LOOP.2.li.29
| 22.5% |  75.458432 |     1,000 |  96.0 |    96 |    96 | fluxi_.LOOP.1.li.21
| 22.5% |  75.453469 |    96,000 |  96.0 |    96 |    96 | fluxi_.LOOP.2.li.22
| 18.9% |  63.574836 | 9,312,000 |  96.0 |    96 |    96 | visck_.LOOP.1.li.344
| 17.1% |  57.529187 | 9,312,000 |  96.0 |    96 |    96 | viscj_.LOOP.1.li.340
| 15.7% |  52.794857 | 9,216,000 |  97.0 |    97 |    97 | visci_.LOOP.1.li.782
|  5.0% |  16.924522 |     1,000 |  99.0 |    99 |    99 | extrapi_.LOOP.1.li.128
```

How to Identify Important Loops

- High inclusive time
- Create call tree with loops:
  - `user@login> pat_report –O calltree`

What About Memory Bandwidth?

- Phased in over perftools 7.0.0, 7.0.1, and 7.0.2 for Intel Xeon processors
- New default counter group with perftools-lite and perftools experiments
- New table for memory bandwidth by NUMA node in default lite and full reports
- Separate functionality from perftools-lite-hbm experiment which uses CCE, CrayPat, and Reveal to track memory traffic and associate with allocation sites

Example: Memory Bandwidth per NUMA

8 MPI ranks, 4 on each of 2 nodes

```
Table 1: Memory Bandwidth by Numanode

  Memory |    Local |   Remote |      Thread |   Memory |   Memory | Numanode
 Traffic |   Memory |   Memory |        Time |  Traffic |  Traffic | Node Id
  GBytes |  Traffic |  Traffic |             |   GBytes |        / | PE=HIDE
         |   GBytes |   GBytes |             |    / Sec |  Nominal |   Thread=HIDE
         |          |          |             |          |     Peak |
  39,429 |   39,429 |        0 |  990.218871 |    39.82 |    33.4% | Max of Numanode values
 |-----------------------------------------------------------------------------
 | 39,429 |   39,429 |        0 | 990.217439 |    39.82 |    33.4% | numanode.0
 ||----------------------------------------------------------------------------
 ||   39,429 | 39,429 |        0 | 990.217439 |    39.82 |    33.4% | nid.200
 ||   38,389 | 38,389 |        0 | 990.224163 |    38.77 |    32.5% | nid.205
 ||============================================================================
 | 38,857 |   38,857 |        0 | 990.218903 |    39.24 |    32.9% | numanode.1
 ||----------------------------------------------------------------------------
 ||   38,857 | 38,857 |        0 | 990.211194 |     39.24 |    32.9% | nid.200
 ||   38,528 | 38,528 |        0 | 990.226690 |     38.91 |    32.6% | nid.205
```

Examine NUMA Traffic

Table 3: Memory Bandwidth by Numanode (limited entries shown)

Memory Traffic GBytes	Local Memory Traffic GBytes	Remote Memory Traffic GBytes	Thread Time	Memory Traffic GBytes / Sec	Memory Traffic / Nominal Peak	Numanode Node Id=[max3,min3] PE=HIDE
172.95	171.48	1.48	19.755654	8.75	11.4%	numanode.0
172.77	171.48	1.30	19.414237	8.90	11.6%	nid.68
172.09	170.61	1.48	19.071340	9.02	11.7%	nid.63
171.20	169.93	1.27	17.631761	9.71	12.6%	nid.62
162.51	161.07	1.43	19.675857	8.26	10.8%	nid.71
162.28	160.82	1.46	19.730793	8.22	10.7%	nid.72
161.75	160.29	1.46	19.755654	8.19	10.7%	nid.70
168.69	166.81	1.89	19.781479	8.53	11.1%	numanode.1
168.69	166.81	1.89	19.454144	8.67	11.3%	nid.62
167.74	166.03	1.71	19.476164	8.61	11.2%	nid.63
166.66	164.88	1.78	19.225409	8.67	11.3%	nid.61
161.68	160.07	1.61	19.781479	8.17	10.6%	nid.71
161.60	159.99	1.62	19.642791	8.23	10.7%	nid.70
157.32	156.01	1.31	18.036118	8.72	11.4%	nid.72

Example traffic from pure MPI run

Example Traffic From an MPI+OpenMP Run

Table 3: Memory Bandwidth by Numanode (limited entries shown)

Memory Traffic GBytes	Local Memory Traffic GBytes	Remote Memory Traffic GBytes	Thread Time	Memory Traffic GBytes / Sec	Memory Traffic / Nominal Peak	Numanode Node Id=[max3,min3] PE=HIDE Thread=HIDE
184.47	173.59	10.89	11.578777	15.93	20.7%	numanode.0
183.50	173.59	9.91	11.569322	15.86	20.7%	nid.63
182.61	172.40	10.21	11.578777	15.77	20.5%	nid.61
178.55	167.75	10.80	11.563156	15.44	20.1%	nid.71
178.10	168.14	9.96	11.562097	15.40	20.1%	nid.62
178.08	168.07	10.01	11.564512	15.40	20.1%	nid.68
178.01	167.20	10.82	11.572032	15.38	20.0%	nid.70
60.36	14.73	45.62	9.073119	6.65	8.7%	numanode.1
60.36	14.73	45.62	9.072693	6.65	8.7%	nid.63
59.88	14.33	45.55	9.071553	6.60	8.6%	nid.62
59.48	14.19	45.29	9.068044	6.56	8.5%	nid.68
58.78	13.70	45.08	9.069259	6.48	8.4%	nid.70
58.67	13.87	44.81	9.071591	6.47	8.4%	nid.69
58.53	13.86	44.67	9.067146	6.46	8.4%	nid.71

Controls for Report Generation

perftools-lite:

- Optionally run pat_report on the data directory from login node
  - `export PAT_RT_REPORT_CMD=pat_report,-Q0`
  - Reduces job execution time, but disables parallel pat_report execution

perftools-lite or perftools:

- For a quick preview of performance data, use subset of data to generate a report
  - `user@login> pat_report -Q1` ← report from 1st ap2 file
  - `user@login> pat_report –Q3` ← report from 1st, middle, and last file

Controlling Instrumentation

- Record Subset of PEs during execution
  - It works again! (we found that it was broken last year)
  - Example: export PAT_RT_EXPFILE_PES=0,4,5,10

- Don’t instrument select binaries when using perftools-lite
  - Good for applications that generate test or intermediate binaries with CMake and GNU Autotools
  - Use CRAYPAT_LITE_WHITELIST for binaries you DO want instrumented

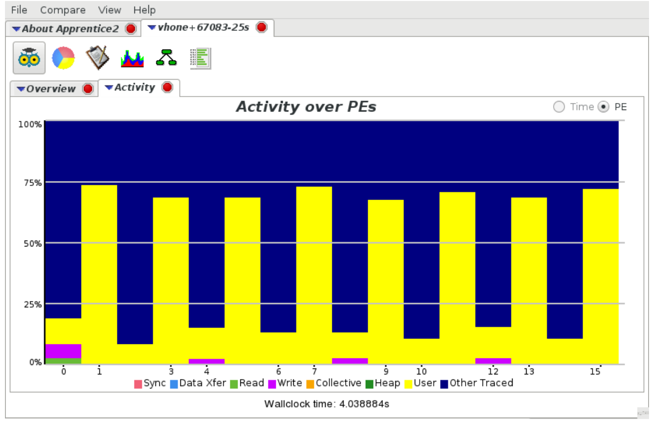
pat_run New!

Utility that allows you to profile un-instrumented, dynamically linked binaries with CrayPat!

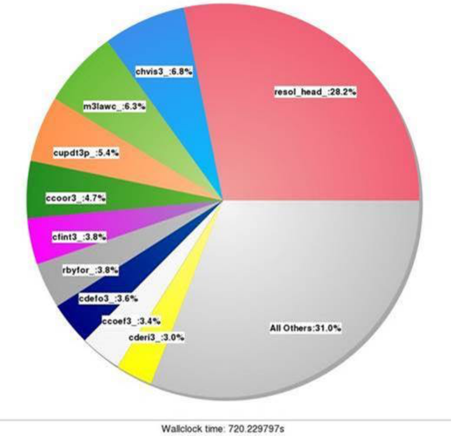
- Delivers Cray performance tools profiling information for codes that cannot easily be rebuilt
- Makes profiling possible for a wider set of HPC applications
- Available starting with perftools 7.0.1
- Initially targets Cray XC systems running CLE 6 or later

Using pat_run

- Insert before executable in run command
  - `user@login> srun –n 16 pat_run ./my_program`
  - `user@login> pat_report expdir > my_report`



- Use existing perftools capability
  - Optionally collect a different group of performance counters
    - `user@login> export PAT_RT_PERFCTR=1`
    - `user@login> aprun -n 16 pat_run ./my_program`
  - Perform other experiments, for example trace MPI routines
    - `user@login> pat_run -g mpi ./my_program`
  - Create additional views of the data with pat_report options, such as
    - `user@login> pat_report –P –O callers+src`



Example Advanced Capability

- Use pat_region API to mark regions in your code to profile
- Enable or disable specific function tracing based on name, size, …
- Choose additional predefined trace groups (blas, hdf5, ...)
- Adjust sampling rate (collect counters per sample, sample 1000 times a second, ….)
- Collect different performance counters (cache hierarchy, TLB misses, …)
- Customize data sorting, aggregation, or collection

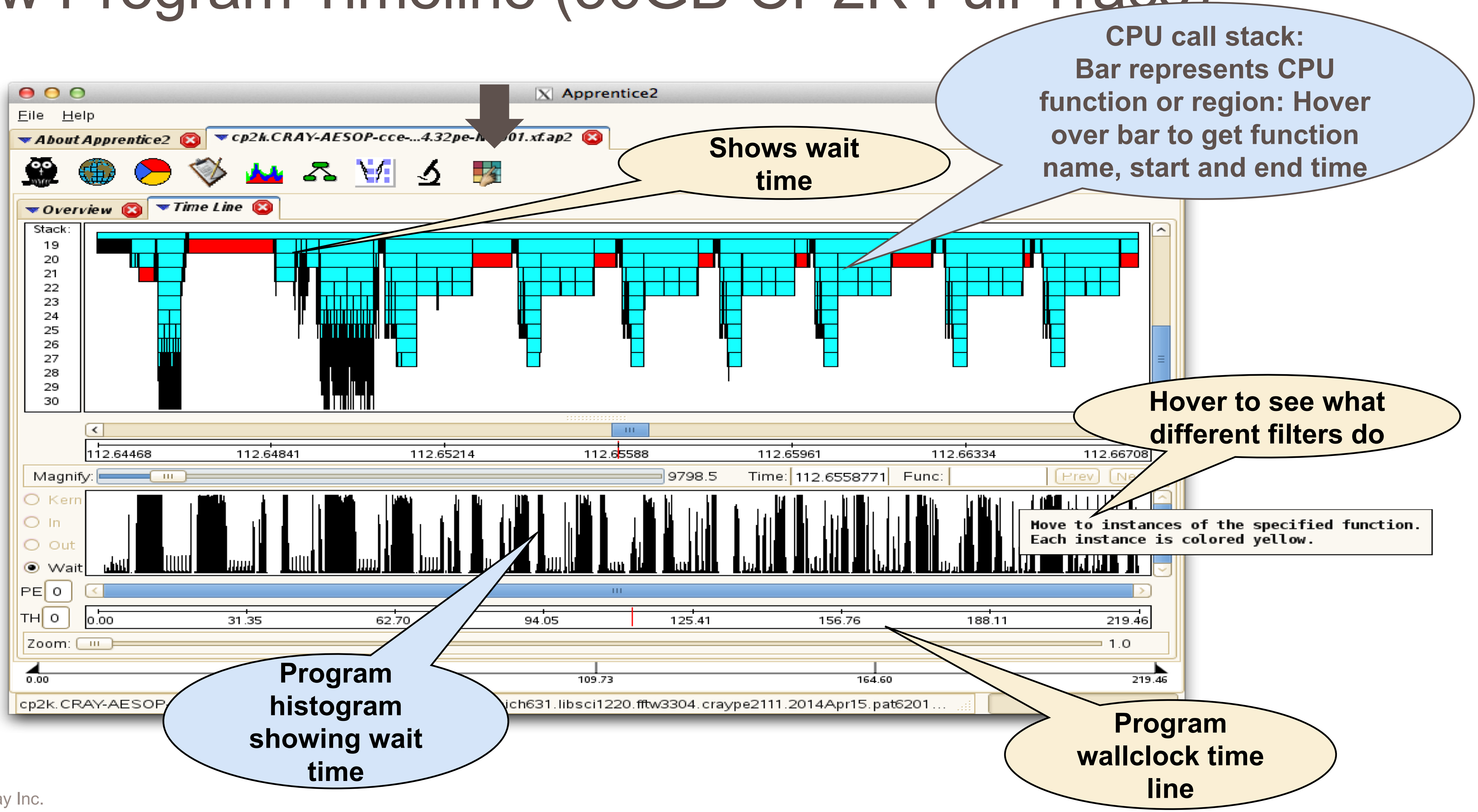
Creating a Timeline

- Can produce huge amounts of performance data
  - Adjust job size for shorter and smaller runs

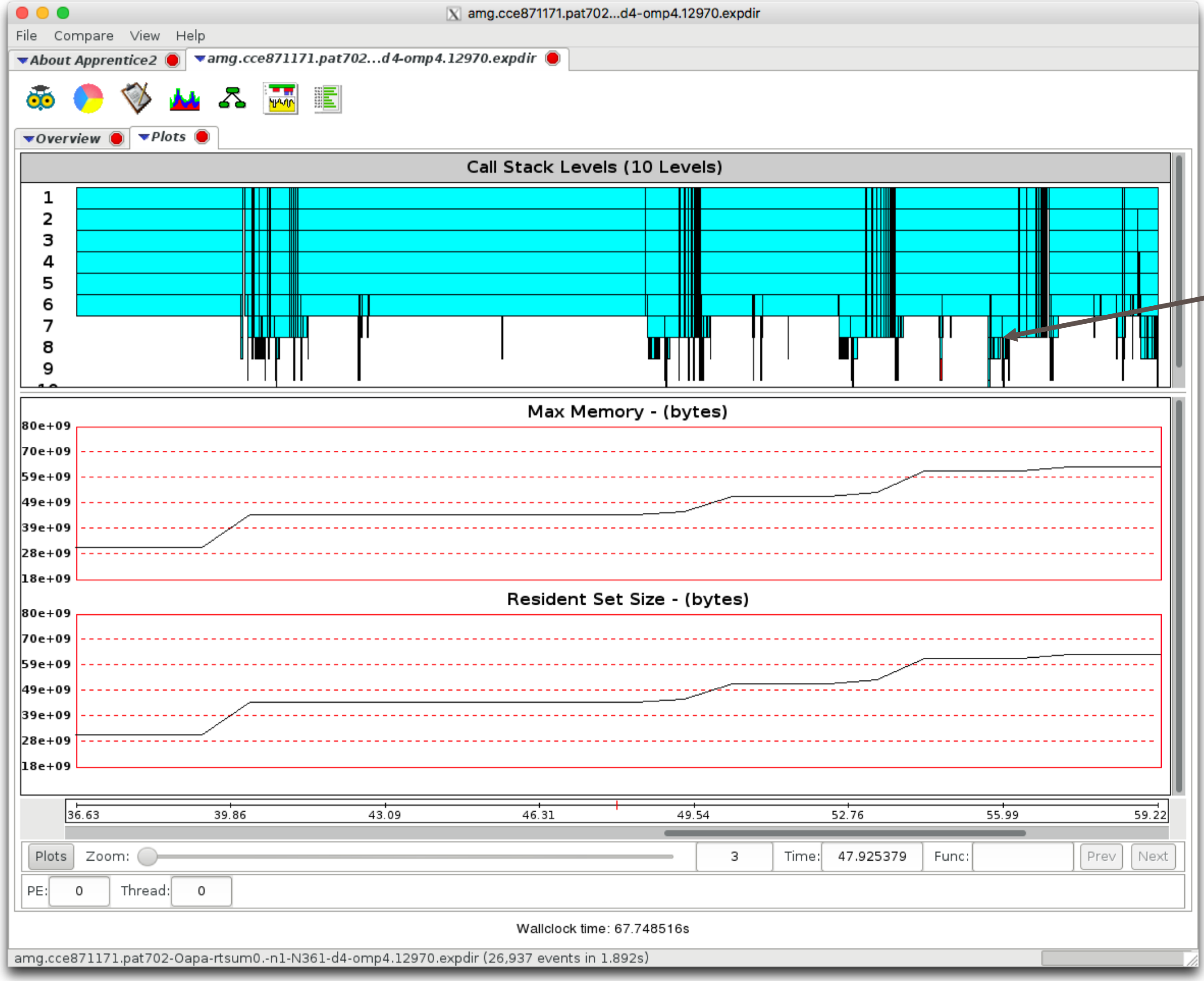
- Can be used with sampling and tracing (tracing is most common)
  - `perftools-lite-events` module
  - `pat_build –g mpi`
  - `pat_build –u –g mpi`

- To enable, set `PAT_RT_SUMMARY=0` `environment` variable at runtime

View Program Timeline (36GB CP2K Full Trace)



Memory High Water Over Time (Apprentice2)



Name:	MPI_Waitall
Start Time:	54.666761
End Time:	54.716777
Group:	MPI

Produced with:

```
pat_build ./my_program
PAT_RT_SAMPLING_DATA=memory
PAT_RT_SUMMARY=0
```

Summary of Cray Performance Tools

- Focus on whole program analysis
- Reduce the time investment associated with porting and tuning applications on new and existing Cray systems
- Provide easy-to-use interfaces complimented with a wealth of capability when you need it for analyzing the most critical production codes
- Offer analysis and recommendations that focus on areas that impact performance and scaling, such as
  - Imbalance
  - Communication overhead and inefficiencies
  - Vectorization and memory utilization efficiency