

Single Node Optimisation Profiling



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What is profiling?

- Analysing your code to find out the proportion of execution time spent in different routines.
- Essential to know this if we are going to target optimisation.
- No point optimising routines that don't significantly contribute to the overall execution time.
 - can just make your code less readable/maintainable

- Code profiling is the first step for anyone interested in performance optimisation
- Profiling works by instrumenting code at compile time
 - Thus it's (usually) controlled by compiler flags
 - Can reduce performance
- Standard profiles return data on:
 - Number of function calls
 - Amount of time spent in sections of code
- Also tools that will return hardware specific data
 - Cache misses, TLB misses, cache re-use, flop rate, etc...
 - Useful for in-depth performance optimisation

- Many profilers work by sampling the program counter at regular intervals (normally 100 times per second).
 - low overhead, little effect on execution time
- Builds a statistical picture of which routines the code is spending time in.
 - if the run time is too small ($< \sim 10$ seconds) there aren't enough samples for good statistics
- Tracing can get more detailed information by recording some data (e.g. time stamp) at entry/exit to functions
 - higher overhead, more effect on runtime
 - unrestrained use can result in huge output files

Standard Unix profilers

- Standard Unix profilers are `prof` and `gprof`
- Many other profiling tools use same formats
- Usual compiler flags are `-p` and `-pg`:
 - `ftn -p mycode.F90 -o myprog` for `prof`
 - `cc -pg mycode.c -o myprog` for `gprof`
- When code is run it produces instrumentation log
 - `mon.out` for `prof`
 - `gmon.out` for `gprof`
- Then run `prof/gprof` *on your executable program*
 - eg. `gprof myprog` (*not* `gprof gmon.out`)

Standard profilers

- **prof myprog** reads **mon.out** and produces this:

%Time	Seconds	Cumsecs	#Calls	msec/call	Name
32.4	0.71	0.71	14	50.7	relax_
28.3	0.62	1.33	14	44.3	resid_
11.4	0.25	1.58	3	83.	__f90_close
5.9	0.13	1.71	1629419	0.0001	_mcount
5.0	0.11	1.82	339044	0.0003	__f90_slr_i4
5.0	0.11	1.93	167045	0.0007	__inrange_single
2.7	0.06	1.99	507	0.12	_read
2.7	0.06	2.05	1	60.	MAIN_

Standard profilers

- **gprof** `myprog` reads `gmon.out` and produces something very similar
- **gprof** also produces a program calltree sorted by inclusive times
- Both profilers list all routines, including obscure system ones
 - Of note: `mcount()`, `_mcount()`, `moncontrol()`, `_moncontrol()` `monitor()` and `_monitor()` are all overheads of the profiling implementation itself
 - `_mcount()` is called every time your code calls a function; if it's high in the profile, it can indicate high function-call overhead
 - **gprof** assumes calls to a routine from different parents take the same amount of time – may not be true

The Golden Rules of profiling

- **Profile your code**
 - The compiler/runtime will **NOT** do all the optimisation for you.
- **Profile your code yourself**
 - Don't believe what anyone tells you. They're wrong.
- **Profile on the hardware you want to run on**
 - Don't profile on your laptop if you plan to run on ARCHER2.
- **Profile your code running the full-sized problem**
 - The profile will almost certainly be qualitatively different for a test case.
- **Keep profiling your code as you optimise**
 - Concentrate your efforts on the thing that slows your code down.
 - This will change as you optimise.
 - So keep on profiling.

- Can do both statistic sampling and function/loop level tracing.

Recommended usage:

1. Build and instrument code
2. Run code and get statistic profile
3. Re-instrument based on profile
4. Re-run code to get more detailed tracing

Example with CrayPAT

- Load performance tools software

```
module load perftools-lite
```

- Re-build application (keep .o files)

```
make clean  
make
```

- Application automatically instrumented for you
- Run the instrumented application to get top time consuming routines
 - You should get performance profiling in your Slurm output file
 - You should get a performance file <executable_name+93500-1088s>

Example with CrayPAT



CrayPat/X: Version 20.10.0 Revision 7ec62de47 09/16/20 16:57:54
Experiment: lite lite-samples

```
.....
Table 1: Profile by Function

  Samp% | Samp | Imb. | Imb. | Group
        |      | Samp | Samp% | Function=[MAX10]
        |      |      |      | PE=HIDE
-----|-----|-----|-----|-----
100.0% | 305.8 | -- | -- | Total
-----|-----|-----|-----|-----
 54.4% | 166.4 | -- | -- | MPI
-----|-----|-----|-----|-----
 51.6% | 157.8 | 24.2 | 13.4% | MPI_ALLTOALL
  1.4% |   4.4 |  5.6 | 56.4% | MPI_ALLREDUCE
-----|-----|-----|-----|-----
41.7% | 127.5 | -- | -- | USER
-----|-----|-----|-----|-----
 10.5% | 32.2 | 17.8 | 36.0% | riemann_
  9.9% | 30.4 | 20.6 | 40.7% | parabola_
  4.8% | 14.8 | 11.2 | 43.5% | sweepz_
  4.6% | 13.9 | 10.1 | 42.3% | remap_
  3.5% | 10.7 |  9.3 | 46.7% | sweepy_
  2.3% |  7.0 |  9.0 | 56.4% | paraset_
  1.8% |  5.4 |  9.6 | 64.4% | evolve_
  1.4% |  4.2 |  5.8 | 58.0% | states_
-----|-----|-----|-----|-----
  3.0% |  9.1 | -- | -- | ETC
=====
```

Program invocation:
/lus/cls01095/work/z19/z19/adrianj/DistributedStream/src/./distributed_streams

For a complete report with expanded tables and notes, run:
pat_report /lus/cls01095/work/z19/z19/adrianj/DistributedStream/src/distributed_streams+93500-1088s

For help identifying callers of particular functions:
pat_report -O callers+src /lus/cls01095/work/z19/z19/adrianj/DistributedStream/src/distributed_streams+93500-1088s
To see the entire call tree:
pat_report -O calltree+src /lus/cls01095/work/z19/z19/adrianj/DistributedStream/src/distributed_streams+93500-1088s

For interactive, graphical performance analysis, run:
app2 /lus/cls01095/work/z19/z19/adrianj/DistributedStream/src/distributed_streams+93500-1088s



```
Notes for table 2:

This table shows functions, and line numbers within 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+src ...

Table 2: Profile by Group, Function, and Line

  Samp% | Samp | Imb. | Imb. | Group
        |      | Samp | Samp% | Function=[MAX10]
        |      |      |      | Source
        |      |      |      | Line
        |      |      |      | PE=HIDE
-----|-----|-----|-----|-----
100.0% | 305.8 | -- | -- | Total
-----|-----|-----|-----|-----
 54.4% | 166.4 | -- | -- | MPI
-----|-----|-----|-----|-----
 51.6% | 157.8 | 24.2 | 13.4% | MPI_ALLTOALL
  1.4% |   4.4 |  5.6 | 56.4% | MPI_ALLREDUCE
-----|-----|-----|-----|-----
41.7% | 127.5 | -- | -- | USER
-----|-----|-----|-----|-----
 10.5% | 32.2 | -- | -- | riemann_
3| | | | Archer2Opt/VH1/src/riemann.f90
-----|-----|-----|-----|-----
4|||  3.4% | 10.5 |  9.5 | 47.6% | line.77
4|||  3.5% | 10.6 |  8.4 | 44.4% | line.78
-----|-----|-----|-----|-----
  9.9% | 30.4 | -- | -- | parabola_
3| | | | Archer2Opt/VH1/src/parabola.f90
-----|-----|-----|-----|-----
4|||  2.5% |  7.7 |  8.3 | 52.0% | line.45
4|||  1.9% |  6.0 |  6.0 | 50.8% | line.86
-----|-----|-----|-----|-----
  4.8% | 14.8 | -- | -- | sweepz_
3| | | | Archer2Opt/VH1/src/sweepz.f90
-----|-----|-----|-----|-----
4|||  1.3% |  4.0 |  6.0 | 60.5% | line.27
4|||  1.1% |  3.5 |  4.5 | 57.1% | line.33
-----|-----|-----|-----|-----
  4.6% | 13.9 | -- | -- | remap_
3| | | | Archer2Opt/VH1/src/remap.f90
  3.5% | 10.7 | -- | -- | sweepy_
3| | | | Archer2Opt/VH1/src/sweepy.f90
  2.3% |  7.0 | -- | -- | paraset_
3| | | | Archer2Opt/VH1/src/parabola.f90
  1.8% |  5.4 | -- | -- | evolve_
3| | | | Archer2Opt/VH1/src/evolve.f90
  1.4% |  4.2 | -- | -- | states_
3| | | | Archer2Opt/VH1/src/states.f90
-----|-----|-----|-----|-----
  3.0% |  9.1 | -- | -- | ETC
=====
```

Example with CrayPAT

- Load performance tools software
`module load perftools`
- Re-build application (keep .o files)
`make clean`
`make`
- Instrument application for automatic profiling analysis
 - You should get an instrumented program a.out+pat
`pat_build -O apa a.out`
- Run the instrumented application (...+pat) to get top time consuming routines
 - You should get a performance file ("`<sdatafile>.xf`") or multiple files in a directory `<sdatadir>`

Example with CrayPAT (2/2)

- Generate text report and an .apa instrumentation file
`pat_report [<sdatafile>.xf | <sdatadir>]`
- Inspect the .apa file and sampling report whether additional instrumentation is needed
 - See especially sites “Libraries to trace” and “HWPC group to collect”
- Instrument application for further analysis (a.out+apa)
`pat_build -O <apafilename>.apa`
- Run application (...+apa)
- Generate text report and visualization file (.ap2)
`pat_report -o my_text_report.txt <data>`
- View report in text and/or with Cray Apprentice²
`app2 <datafile>.ap2`

Finding single-core hotspots

- Remember: pay attention only to user routines that consume significant portion of the total time
- View the key hardware counters, for example
 - L1 and L2 cache metrics
 - use of vector (SSE/AVX) instructions

- CrayPAT has mechanisms for finding “the” hotspot in a routine (e.g. in case the routine contains several and/or long loops)
 - CrayPAT API
 - Possibility to give labels to “PAT regions”
 - Loop statistics (works only with Cray compiler)
 - Compile & link with CCE using -h profile_generate
 - pat_report will generate loop statistics if the flag is enabled

USER / remap_

Time%		25.2%	
Time		15.801180	secs
Imb. Time		2.582609	secs
Imb. Time%		14.7%	
Calls	0.026M/sec	460,800.0	calls
CPU_CLK_UNHALTED:THREAD_P		77,964,376,624	
CPU_CLK_UNHALTED:REF_P		2,689,572,161	
DTLB_LOAD_MISSES:MISS_CAUSES_A_WALK		20,626,569	
DTLB_STORE_MISSES:MISS_CAUSES_A_WALK		17,745,058	
L1D:REPLACEMENT		2,753,483,367	
L2_RQSTS:ALL_DEMAND_DATA_RD		1,912,839,218	
L2_RQSTS:DEMAND_DATA_RD_HIT		1,757,495,428	
FP_COMP_OPS_EXE:SSE_SCALAR_DOUBLE		1,597	
FP_COMP_OPS_EXE:SSE_FP_SCALAR_SINGLE		1,556,036,610	
FP_COMP_OPS_EXE:X87		1,878,388,524	
FP_COMP_OPS_EXE:SSE_PACKED_SINGLE		302,976,589	
SIMD_FP_256:PACKED_SINGLE		5,003,127,724	
User time (approx)	17.476 secs	47,202,147,918 cycles	100.0% Time
CPU_CLK	2.90GHz		
HW FP Ops / User time	2,556.183M/sec	44,671,354,883 ops	11.8% peak(DP)
Total SP ops	2,448.698M/sec	42,792,964,761 ops	
Total DP ops	107.485M/sec	1,878,390,122 ops	
MFLOPS (aggregate)	61,348.39M/sec		
D2 cache hit,miss ratio	94.4% hits	5.6% misses	
D2 to D1 bandwidth	6,680.690MiB/sec	122,421,709,963 bytes	
Average Time per Call		0.000034 secs	
CrayPat Overhead : Time	11.4%		

Flat profile data

HW counter
values

Derived
metrics

Hardware performance counters

- CrayPAT can interface with HWPCs
 - Gives extra information on how hardware is behaving
 - Very useful for understanding (& optimising) application performance
- Provides information on
 - hardware features, e.g. caches, vectorisation and memory bandwidth
- Available on per-program and per-function basis
 - Per-function information only available through tracing
- Number of simultaneous counters limited by hardware
 - 2 counters available with AMD Rome processors
 - If you need more, you'll need multiple runs
- Most counters accessed through the PAPI interface
 - Either native counters or derived metrics constructed from these

Hardware counters selection

- HWPCs collected using CrayPAT
 - Compile and instrument code for profiling as before
- Set PAT_RT_PERFCTR environment variable at runtime
 - e.g. in the job script
 - Hardware counter events are not collected by default (except with APA)
- `export PAT_RT_PERFCTR=...`
 - either a list of named PAPI counters
 - or `<set number>` = a pre-defined (and useful) set of counters
 - recommended way to use HWPCs
 - there are 8 groups to choose from
 - To see them:
 - `pat_help -> counters -> rome -> groups`
 - `man hwpc`
 - `more`
`/opt/cray/pe/perftools/23.09.0/share/counters/CounterGroups.amd_fam23mod49`

Technical term for
AMD Rome

Predefined AMD Rome HW Counter Groups

0: Summary with translation lookaside buffer activity

1: Summary with branch activity

default: mem_bw

default_samp: default

mem_bw: memory bandwidth

mem_bw_1: memory load bandwidth, stalls

mem_bw_2: memory load bandwidth, cycles

stalls: Dispatch stalls for load, store, fp

Example: mem_bw

USER / sweepy_

Time%	14.6%
Time	8.738150 secs
Imb. Time	3.077320 secs
Imb. Time%	27.2%
Calls	11.547 /sec
	100.0 calls
CPU_CLK_UNHALTED:THREAD_P	92,754,888,918
CPU_CLK_UNHALTED:REF_P	2,759,876,135
L1D:REPLACEMENT	1,813,741,166
L2_RQSTS:ALL_DEMAND_DATA_RD	1,891,459,700
L2_RQSTS:DEMAND_DATA_RD_HIT	1,644,133,800
LLC_MISSES	98,952,928
LLC_REFERENCES	690,626,471
User time (approx)	8.660 secs
	23,390,899,520 cycles
	100.0% Time
CPU_CLK	3.36GHz
D2 cache hit,miss ratio	86.4% hits
	13.6% misses
L3 cache hit,miss ratio	85.7% hits
	14.3% misses
D2 to D1 bandwidth	13,330.757MiB/sec
	121,053,420,792 bytes
Average Time per Call	0.087381 secs
CrayPat Overhead : Time	0.0% ...

Interpreting the performance numbers

- Performance numbers are an average over all ranks
 - explains non-integer values
- This does not always make sense
 - e.g. if ranks are not all doing the same thing:
 - Leader-worker schemes
 - MPMD apruns combining multiple, different programs
- Want them to only process data for certain ranks
 - `pat_report -sfilter_input='condition' ...`
 - `condition` should be an expression involving `pe`, e.g.
 - `pe<1024` for the first 1024 ranks only
 - `pe%2==0` for every second rank

OpenMP data collection and reporting

- Give finer-grained profiling of threaded routines
 - Measure overhead incurred entering and leaving
 - Parallel regions
 - `#pragma omp parallel`
 - Work-sharing constructs within parallel regions
 - `#pragma omp for`
- Timings and other data now shown per-thread
 - rather than per-rank
- OpenMP tracing enabled with `pat_build -gomp ...`
 - CCE: insert tracing points around parallel regions automatically
 - AMD, Gnu: need to use CrayPAT API manually

OpenMP data collection and reporting

- Load imbalance for hybrid MPI/OpenMP programs
 - now calculated across all threads in all ranks
 - imbalances for MPI and OpenMP combined
 - Can choose to see imbalance in each programming model separately
 - See next slide for details
- Data displayed by default in pat_report
 - no additional options needed
 - Report focuses on where program is spending its time
 - Assumes all requested resources should be used
 - you may have reasons not to want to do this, of course

Memory usage

- Knowing how much memory each rank uses is important:
 - What is the minimum number of cores I can run this problem on?
 - given there is 256GB (~254GB usable) of memory per node (128 cores)
 - Does memory usage scale well in the application?
 - Is memory usage balanced across the ranks in the application?
 - Is my application spending too much time allocating and freeing?

Heap statistics

Memory per rank

~254GB usable memory per node

Notes for table 5:

Table option:

-O heap_hiwater

Options implied by table option:

-d am@,ub,ta,ua,tf,nf,ac,ab -b pe=[mmm]

Too many allocs/frees?

Would show up as ETC time in CrayPAT report

This table shows only lines with Tracked Heap HiWater MBytes > 0.

Table 5: Heap Stats during Main Program

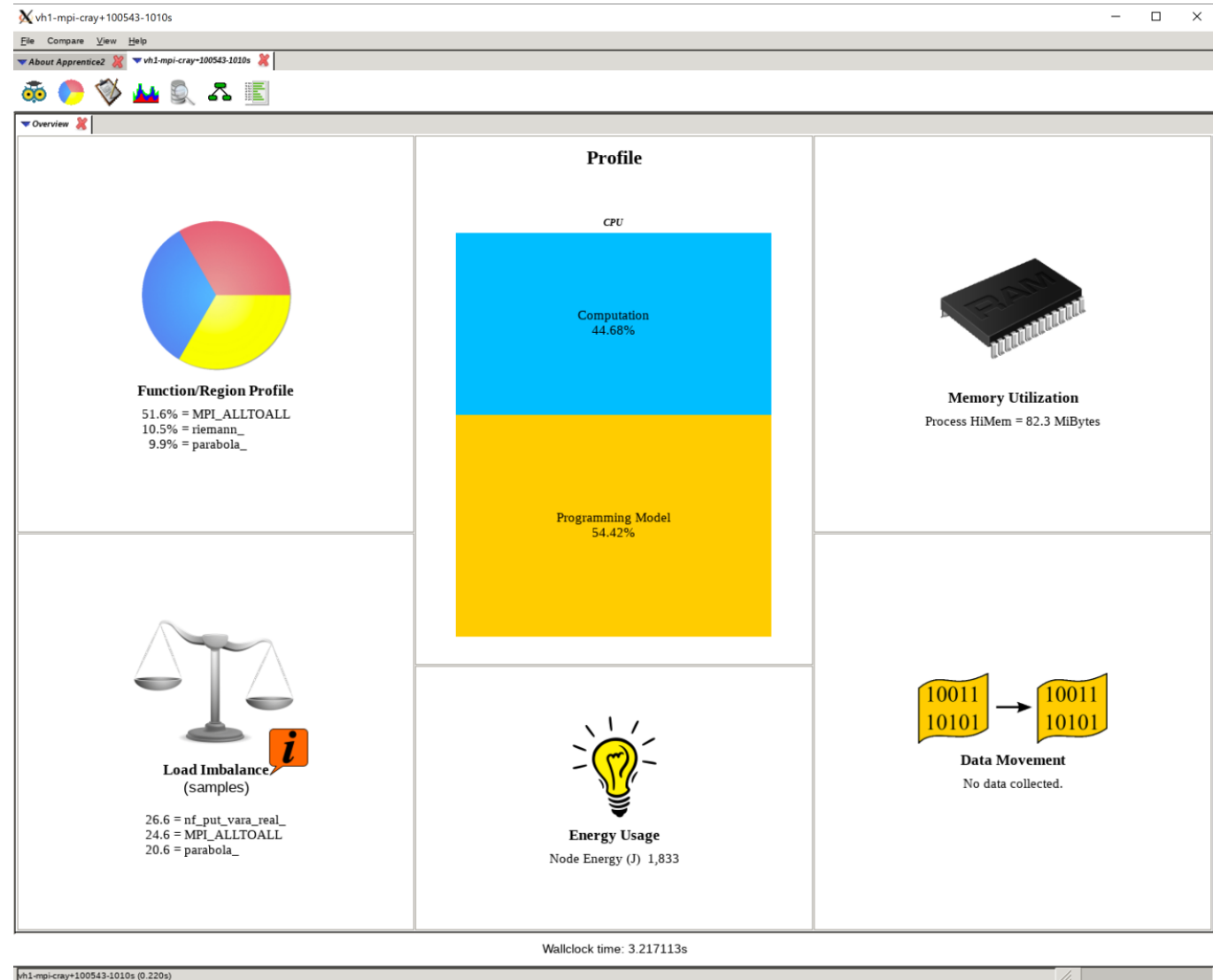
Tracked Heap HiWater MBytes	Total Allocs	Total Frees	Tracked Objects Not Freed	Tracked MBytes Not Freed	PE [mmm]
9.794	915	910	4	1.011	Total
9.943	1170	1103	68	1.046	pe.0
9.909	715	712	3	1.010	pe.22
9.446	1278	1275	3	1.010	pe.43

Memory leaks

Not usually a problem in HPC

Viewing data

- Apprentice 2 tool
 - GUI for exploring code/data
 - Insight summaries
- Can install desktop version
- **/opt/cray/pe/perftools**
/\$(current_version)/share
/desktop_installers/



Summary

- Profiling is essential to identify performance bottlenecks
 - even at single core level
- CrayPAT has some very useful extra features
 - can pinpoint and characterise the hotspot loops (not just routines)
 - hardware performance counters give extra insight into performance
 - well-integrated view of hybrid programming models
 - most commonly MPI/OpenMP
 - also CAF, UPC, SHMEM, pthreads, OpenACC, CUDA
 - information on memory usage
- And remember the **Golden Rules**
 - including the one about not believing what anyone tells you