Performance Tools

NERSC New User Training
Feb 16, 2024

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PEM

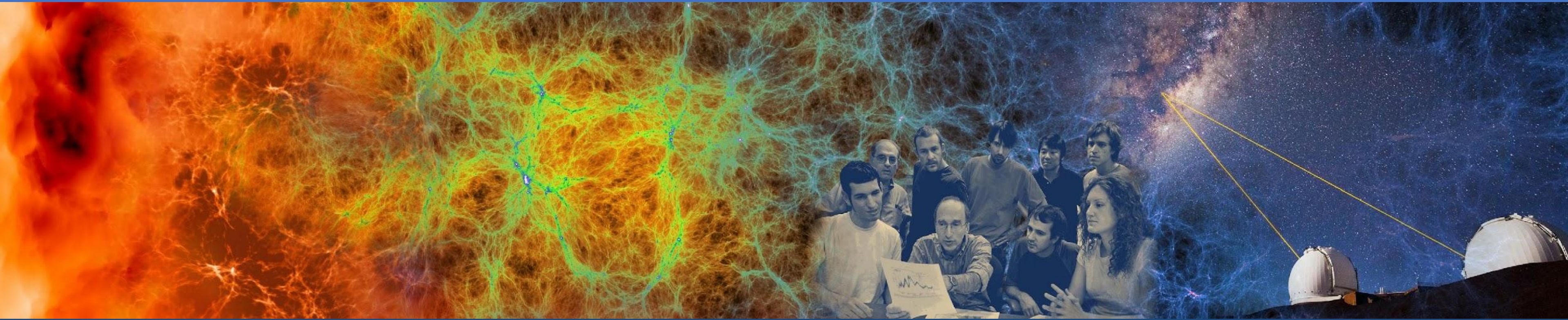
Performance tools available on Perlmutter

- **Profiling tools are used to measure and analyze code performance**
- **Metrics available help identify memory and compute bottlenecks**
- **List of profiling tools available on Perlmutter**

CrayPat Perftools, -lite, Reveal	CPU, GPU, MPI	cc, CC, ftn, omp
NVIDIA Nsight Systems, Compute	GPU	nvc++, nvcc, omp, oacc, python
Linaro MAP, Performance Reports	CPU and GPU	Diverse
Darshan I/O profiler	Data I/O	Diverse
Timemory	Profiling kit	Diverse

A lot more! Full list at https://docs.nersc.gov/tools/performance/

Nsight Systems



NVIDIA Nsight Systems

- **Nsight systems is a low overhead profiler**
- **Provides general broad description of GPU based applications**
- **Modules**
    - **cuda**
        - **required to load Nsight systems**
- **Application must be compiled by linking cuda libraries**
- **Supports:**
    - **cuda (nvcc, nvc++)**
    - **Kokkos (cuda, OpenMP)**
    - **OpenMP**
    - **OpenACC**

NVIDIA Nsight Systems steps

- **Profiling steps for an OpenMP Offload based application compiled using clang++**
- **Code run in `$SCRATCH`**
- **To visualize results, it is recommended to transfer profile files to local machine and use local install of Nsight Systems (available for free)**
- **Run steps are as follows:**

```
$ module unload darshan
$ module load PrgEnv-<required>
$ ...  compile your code  ...
$ salloc --nodes 1 --qos interactive --time 01:00:00 --C gpu --account=mxxxx
$ srun -n 1 nsys profile --stats=true ./test_snap.exe -ns 100
```

NVIDIA Nsight Systems steps

- **Generates text of profiling results**

CUDA API Statistics:

Time(%)	Total Time (ns)	Num Calls	Average	Minimum	Maximum	Name
83.9	6563435467	805	8153336.0	2413	44859498	cuStreamSynchronize
14.1	1100682085	33	33354002.6	2335	656900656	cuMemcpyHtoDAsync_v2
1.3	99718751	1	99718751.0	99718751	99718751	cuDevicePrimaryCtxRelease_v2
0.5	40948782	200	204743.9	26326	1158675	cuMemcpyDtoHAsync_v2
0.1	11082944	700	15832.8	6302	64274	cuLaunchKernel
0.1	6082361	17	357785.9	2668	2189898	cuMemAlloc_v2
0.0	858283	1	858283.0	858283	858283	cuModuleLoadDataEx
0.0	668654	32	20895.4	1345	353717	cuStreamCreate
0.0	654039	1	654039.0	654039	654039	cuModuleUnload
0.0	192187	32	6005.8	3933	21337	cuStreamDestroy_v2
0.0	159833	7	22833.3	14950	58247	cuMemcpyDtoH_v2
0.0	2250	1	2250.0	2250	2250	cuDevicePrimaryCtxSetFlags_v2

NVIDIA Nsight Systems steps

- **Kernel names may be mangled (eq: `__omp_offloading_70e68f56_5d00401c__ZN3SNA10compute_yiEPd_l471`)**

```
CUDA Kernel Statistics:

Time(%)  Total Time (ns)  Instances   Average    Minimum   Maximum                Name
-------  ---------------  ---------  ----------  --------  --------
-----------------------------------
   61.4       3946535611        100  39465356.1  39233639  44223639  __ZN3SNA10compute_yiEPd_l471
   17.5       1125861668        100  11258616.7  11178964  11771631  __ZN3SNA14compute_duidrjEv_l652
   16.3       1048090801        100  10480908.0  10082240  11828974  __ZN3SNA10compute_uiEv_l425
    3.8        243394690        100   2433946.9   2403145   2521384  __ZN3SNA14compute_deidrjEv_l577
    0.8         53957727        100    539577.3    535003    635610  __ZN3SNA14zero_uarraytotEv_l687
    0.1          8023377        100     80233.8     79007     93024  __ZN3SNA10compute_yiEPd_l460
    0.0          2334567        100     23345.7     22720     29376
__ZN3SNA17addself_uarraytotEd_l704
```

NVIDIA Nsight Systems steps

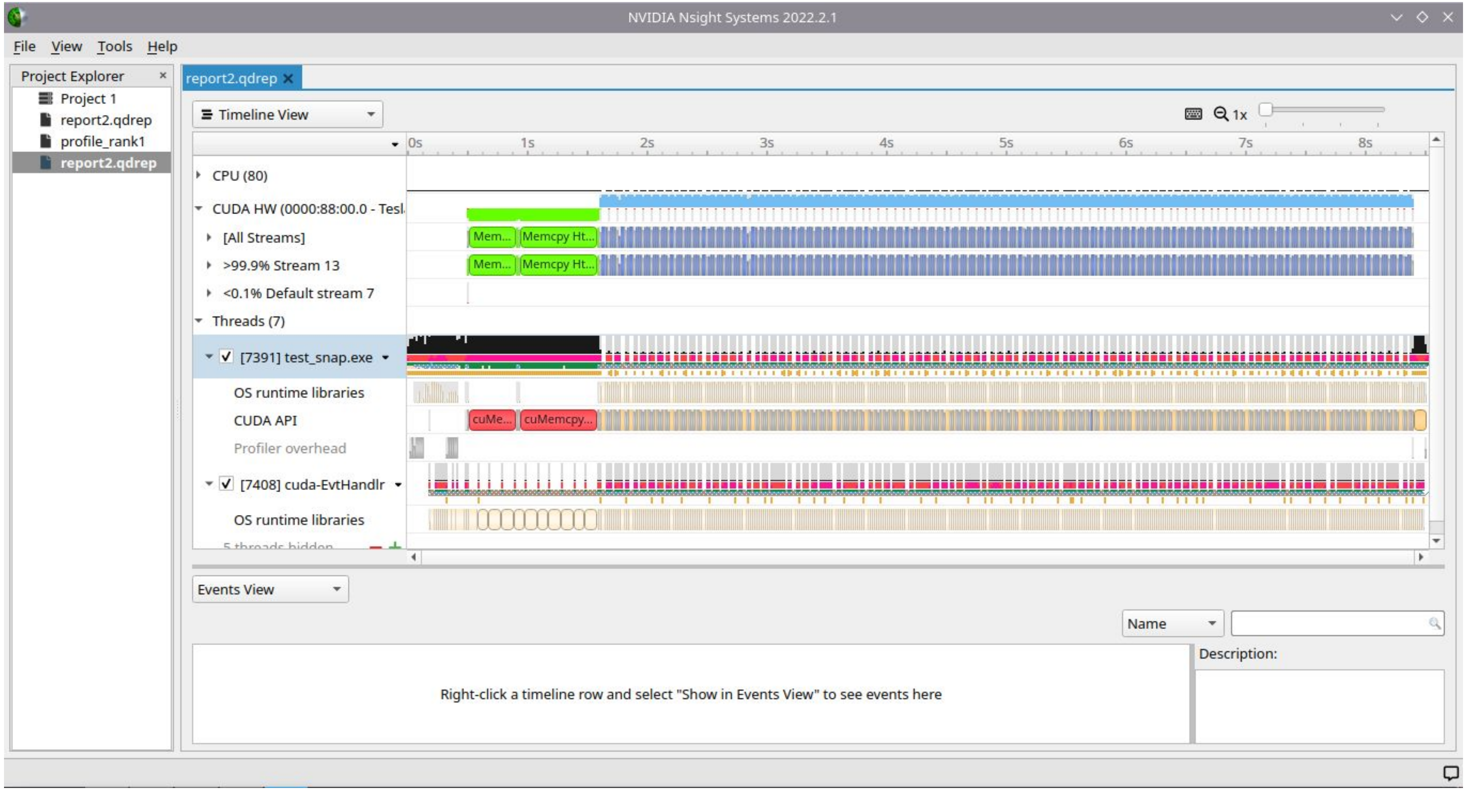
CUDA Memory Operation Statistics (by time):

Time(%)	Total Time (ns)	Operations	Average	Minimum	Maximum	Operation
99.1	1098309937	33	33282119.3	1408	656553887	[CUDA memcpy HtoD]
0.9	10013795	207	48375.8	1696	99007	[CUDA memcpy DtoH]

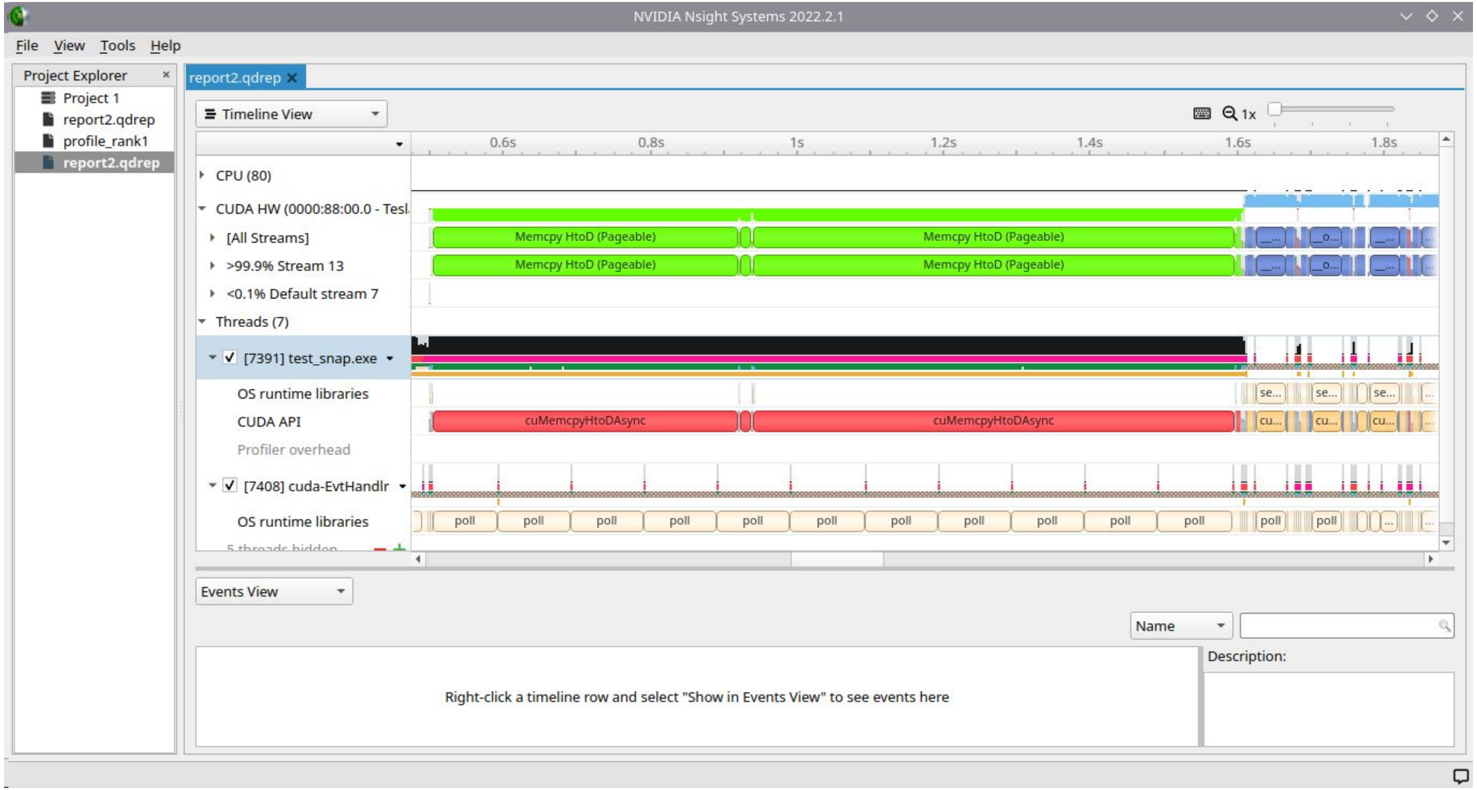
CUDA Memory Operation Statistics (by size in KiB):

Total	Operations	Average	Minimum	Maximum	Operation
2660577.207	33	80623.552	0.008	1589250.000	[CUDA memcpy HtoD]
121875.788	207	588.772	0.001	1218.750	[CUDA memcpy DtoH]

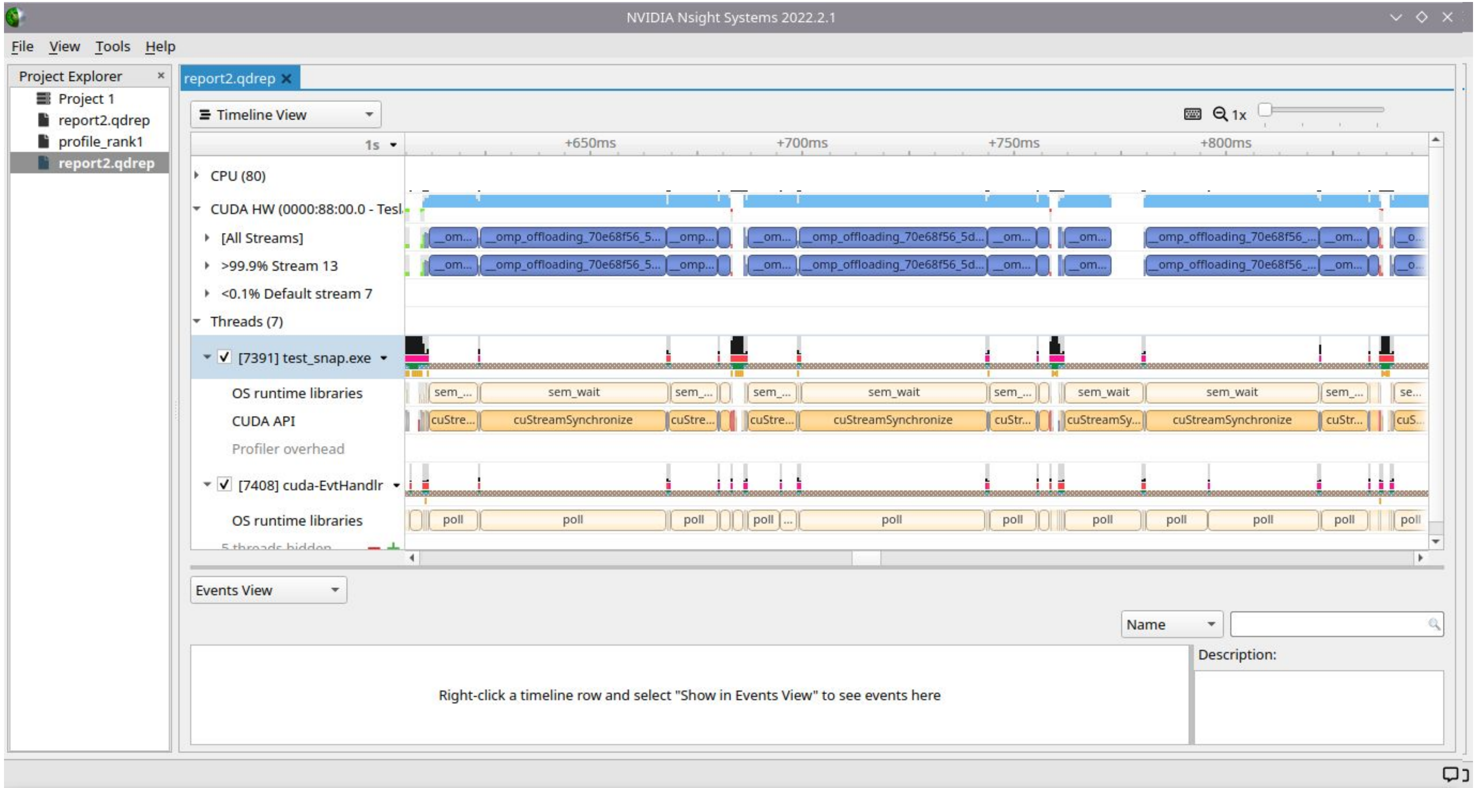
Visualizing results in NVIDIA Nsight Systems



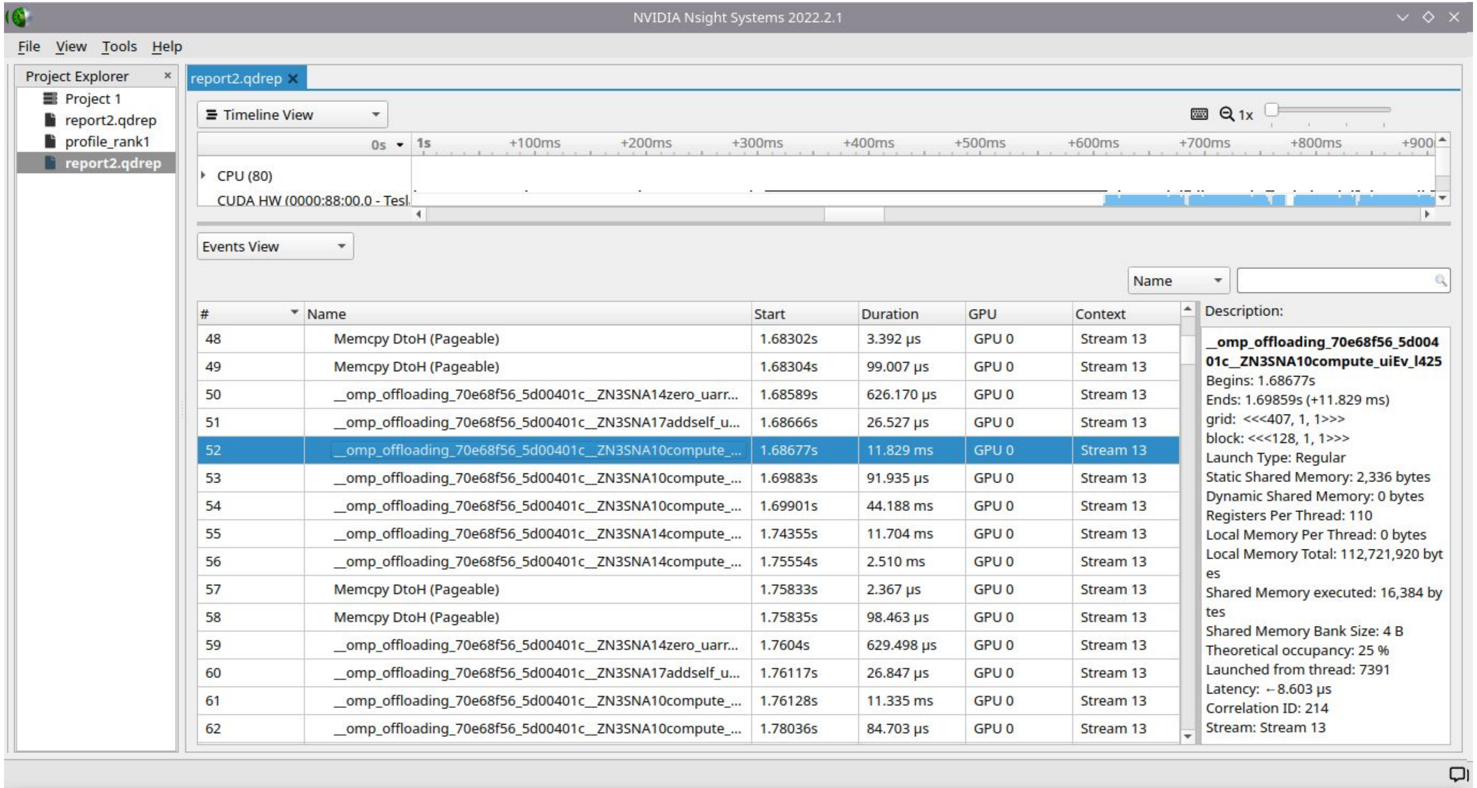
Visualizing results in NVIDIA Nsight Systems



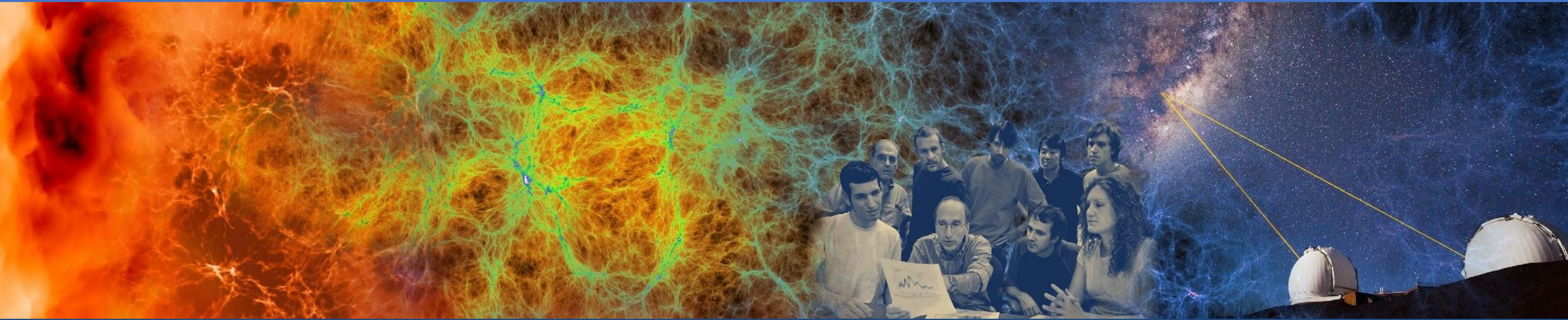
Visualizing results in NVIDIA Nsight Systems



Visualizing results in NVIDIA Nsight Systems



Nsight Compute



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NVIDIA Nsight Compute steps

- **Case 1: baseline**

```
{
#pragma omp target teams distribute parallel for
    for(int natom = 0; natom < num_atoms; ++natom)
        for(int nbor = 0; nbor < num_nbor; ++nbor)
            for(int j = 0; j < idxu_max; ++j)
            {
                compute();
            }
}
```

- **Exploit the ability to collapse nested *for* loops**
- **Case 2: collapse**

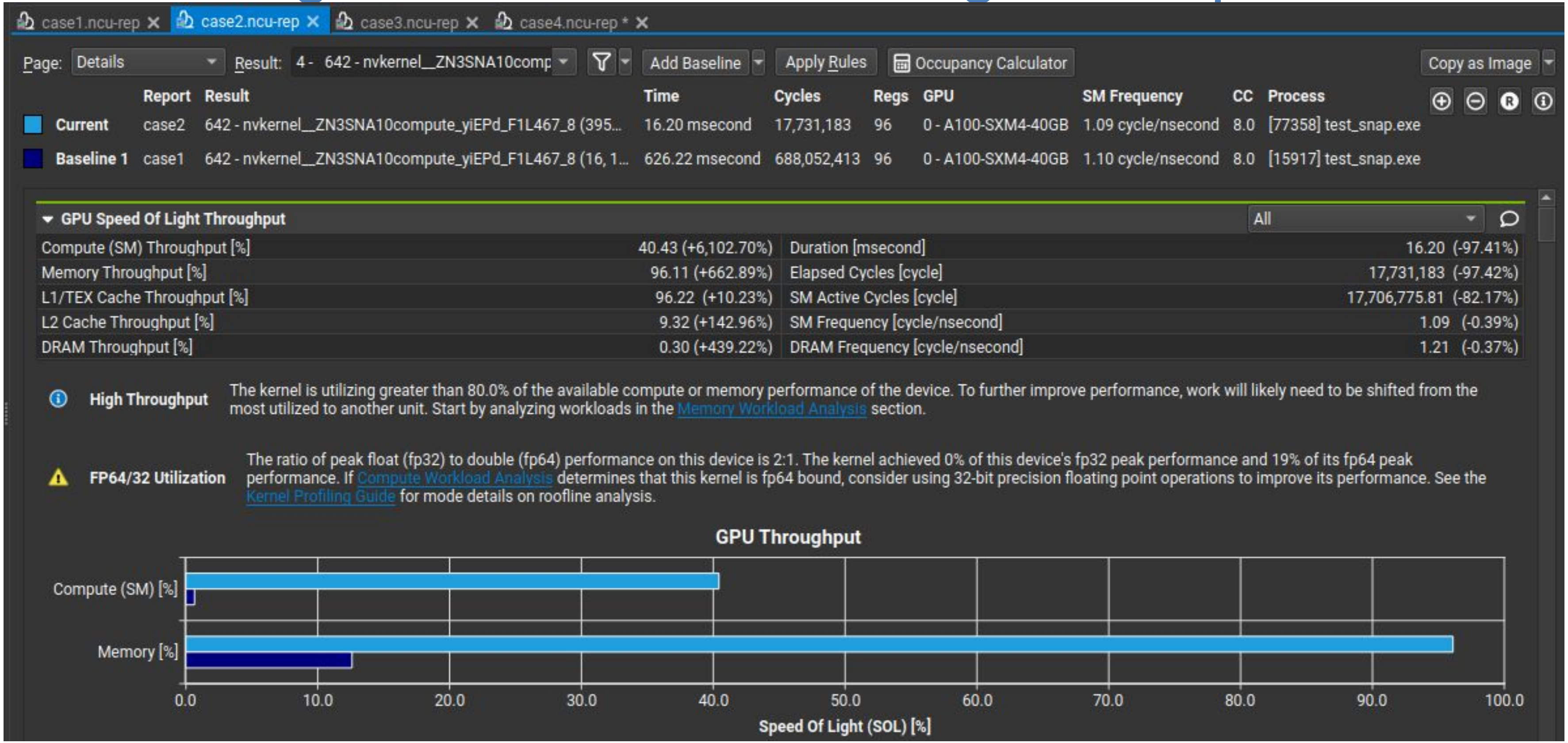
```
{
#pragma omp target teams distribute parallel for collapse(2)
    for(int natom = 0; natom < num_atoms; ++natom)
        for(int nbor = 0; nbor < num_nbor; ++nbor)
            for(int j = 0; j < idxu_max; ++j)
            {
                compute();
            }
}
```

NVIDIA Nsight Compute

- **Nsight compute allows a deeper dive for profiling GPU based applications**
- **Modules**
  - **cuda**
    - **required to load Nsight compute**
- **To visualize results, it is recommended to transfer profile files to local machine and use local install of Nsight Compute (available for free) or use NX (https://docs.nersc.gov/connect/nx/)**

```
$ module unload darshan
$ module load PrgEnv-<required>
$ ...  compile your code  ...
$ salloc --nodes 1 --qos interactive --time 01:00:00 --C gpu --account=mxxxx
$ dcgmi profile --pause
$ srun -n 1 ncu -o profile_snap --set full ./test_snap.exe -ns 100
```

Visualizing results in NVIDIA Nsight Compute



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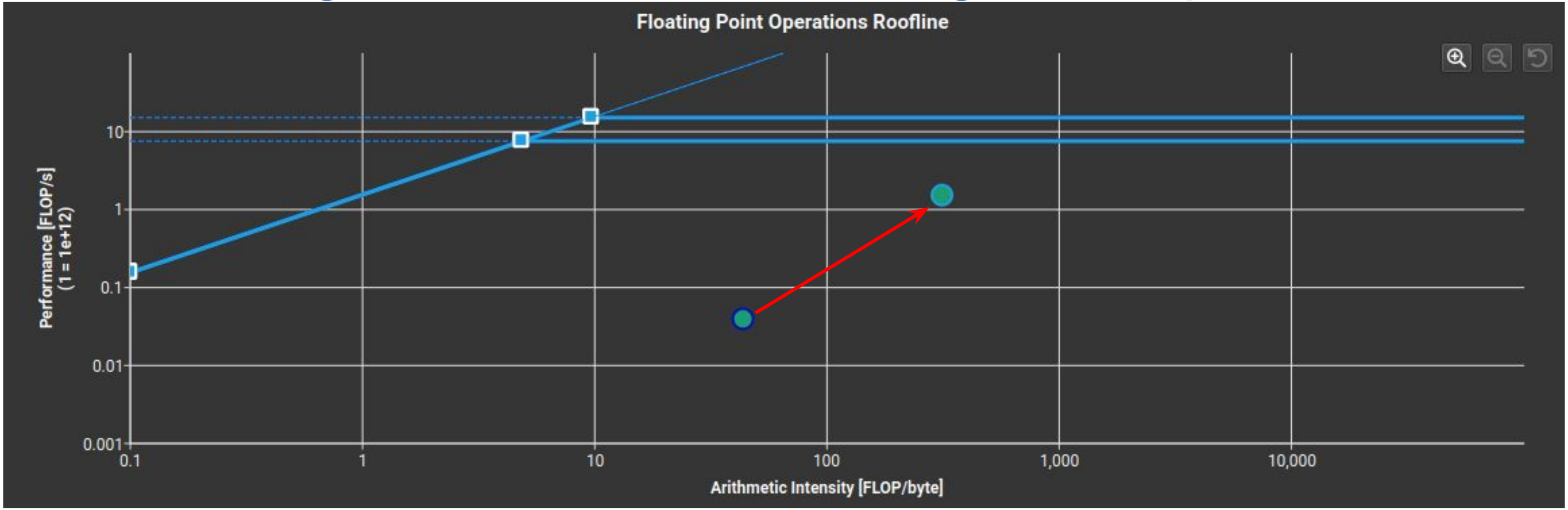
Visualizing results in NVIDIA Nsight Compute



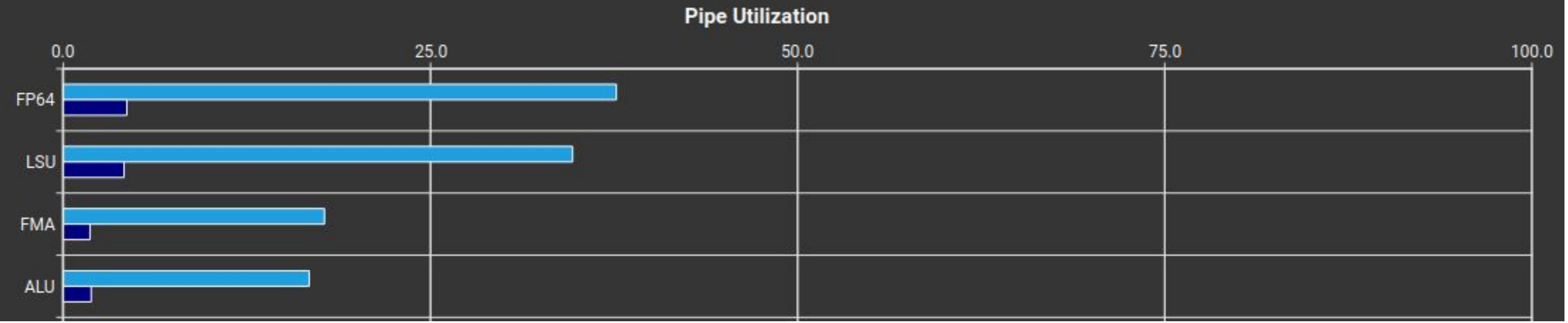
- **Improvement in AI and Performance due to atom and neighbor loop fusing**

Visualizing results in NVIDIA Nsight Compute

Compute Workload Analysis

Executed Ipc Elapsed [inst/cycle]	1.62 (+6,197.40%)	SM Busy [%]	40.48 (+810.22%)
Executed Ipc Active [inst/cycle]	1.62 (+809.91%)	Issue Slots Busy [%]	40.48 (+810.22%)
Issued Ipc Active [inst/cycle]	1.62 (+810.22%)		

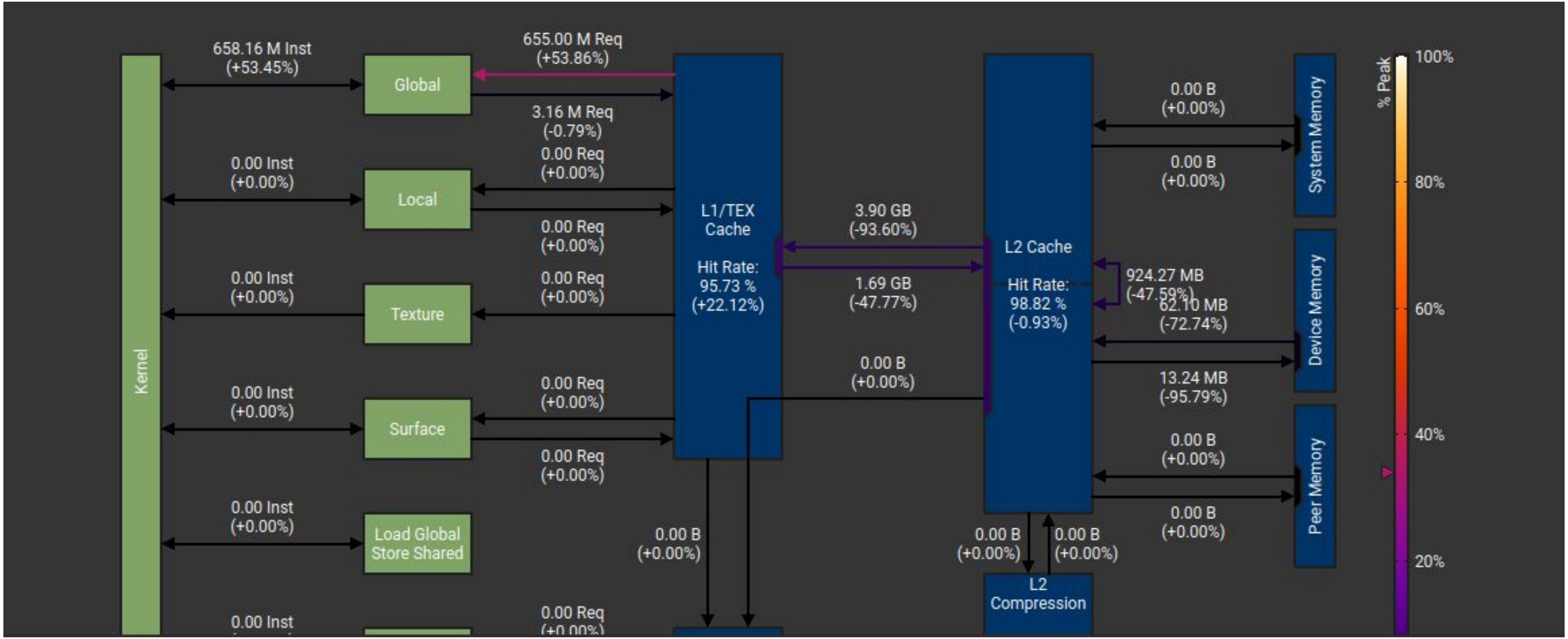
Balanced No pipeline is over-utilized.



Memory Workload Analysis All

Memory Throughput [Gbyte/second]	4.65 (+437.23%)	Mem Busy [%]	96.11 (+662.89%)
L1/TEX Hit Rate [%]	95.73 (+22.12%)	Max Bandwidth [%]	67.65 (+1,374.25%)
L2 Hit Rate [%]	98.82 (-0.93%)	Mem Pipes Busy [%]	36.19 (+5,451.48%)
L2 Compression Success Rate [%]	0 (+0.00%)	L2 Compression Ratio	0 (+0.00%)

Visualizing results in NVIDIA Nsight Compute



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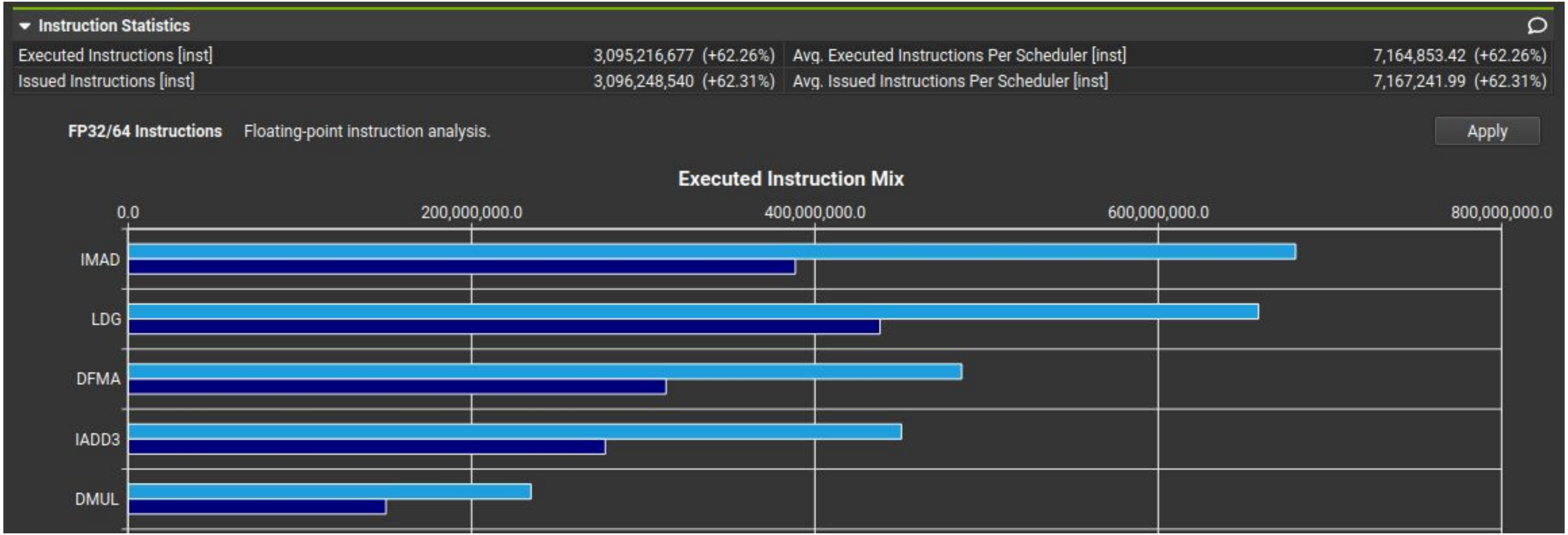
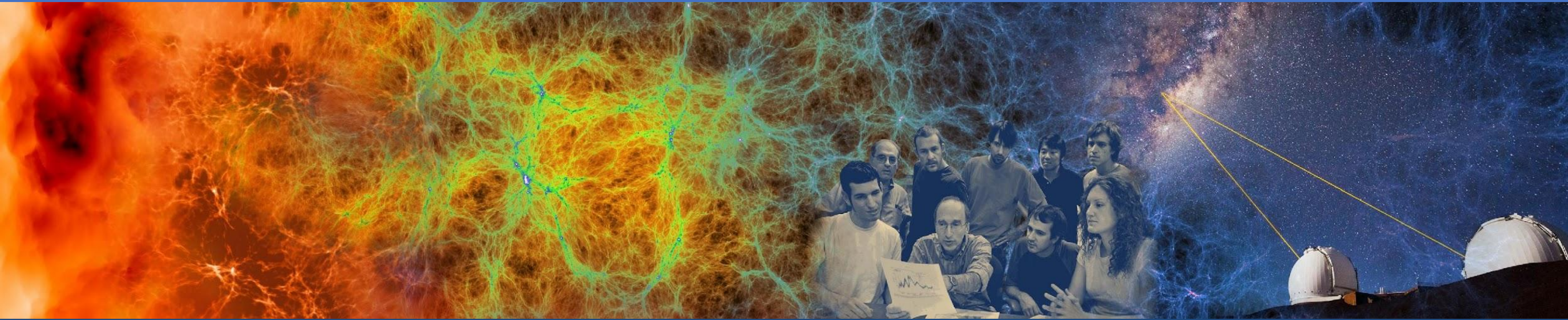
Visualizing results in NVIDIA Nsight Compute



CrayPAT



CrayPAT (Perftools)

- CrayPat specifically for use on Cray machines
- GUI and TUI tools
- Modules
  - perftools-base
    - required to load perftools or perftools-lite
  - perftools (full suite)
  - perftools-lite (fast, specific)
    - Additional perftools-lite modules (events, gpu, loops, hbm)
    - perftools-lite-gpu (GPU kernel and data movement with an even profile)

CrayPAT (Perftools-lite) steps

- **Profiling steps for a Jacobi solver written in Fortran with MPI and OpenMP**
- **Code must be run in `$SCRATCH` (or set an `env` to run it from elsewhere)**
- **Object (`*.o`) files must be created in a separate step and remain present**
- **To visualize, use App2, launch terminal with X forwarding or use NX (https://docs.nersc.gov/connect/nx/)**
- **Run steps are as follows:**

```
$ module load perftools-lite
$ module load PrgEnv-cray
$ ftn -c -fopenmp jacobi_mpiomp.F90
$ ftn -fopenmp -o jacobi_mpiomp jacobi_mpiomp.o
$ salloc --nodes 4 --qos interactive --time 01:00:00 --C cpu --account=mxxxx
$ srun -n 32 --cpu-bind=cores ./jacobi_mpiomp
```

CrayPAT (Perftools-lite) results

```
################################################################
#                                                              #
#            CrayPat-lite Performance Statistics               #
#                                                              #
################################################################

CrayPat/X:  Version 22.06.0 Revision 4b5ab6256  05/21/22 02:03:49
Experiment:                  lite  lite-samples
Number of PEs (MPI ranks):     32
Numbers of PEs per Node:        8  PEs on each of  4  Nodes
Numbers of Threads per PE:      2
Number of Cores per Socket:    64
Execution start time:  Wed Sep 21 11:00:59 2022
System name and speed:  nid005666  2.334 GHz (nominal)
AMD   Milan               CPU  Family: 25  Model:  1  Stepping:  1
Core Performance Boost:  64 PEs have CPB capability



Avg Process Time:      7.13 secs
High Memory:        6,850.6 MiBytes     214.1 MiBytes per PE
I/O Read Rate:    14.231151 MiBytes/sec
I/O Write Rate:   11.174613 MiBytes/sec
```

CrayPAT (Perftools-lite) results

```
Notes for table 1:

  This table shows functions that have significant exclusive sample
    hits, averaged across ranks.
  For further explanation, use:  pat_report -v -O samp_profile ...

Table 1:  Profile by Function

  Samp% |  Samp | Imb. |  Imb. | Group
        |       | Samp | Samp% |  Function=[MAX10]
        |       |      |       |   PE=HIDE
        |       |      |       |    Thread=HIDE

 100.0% | 687.2 |   -- |    -- | Total
|--------------------------------------------------------
|  70.3% | 483.0 |   -- |    -- | USER
||-------------------------------------------------------
||  53.3% | 366.3 | 16.7 |  4.5% | jacobi_mpiomp_.LOOP@li.61
||  16.8% | 115.7 | 34.3 | 23.6% | compute_diff_.LOOP@li.261
||=======================================================
|  22.3% | 153.4 |   -- |    -- | ETC
||-------------------------------------------------------
||  20.9% | 143.3 | 32.7 | 19.2% | __cray_memcpy_ROME
||=======================================================
|   6.3% |  43.4 |   -- |    -- | MPI
||-------------------------------------------------------
||   4.6% |  31.3 | 13.7 | 31.3% | MPI_ALLREDUCE
||   1.7% |  11.5 | 16.5 | 60.8% | MPI_SENDRECV
|========================================================
```

CrayPAT (Perftools-lite) results

```
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, 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
        |       |      |       |      Thread=HIDE

 100.0% | 687.2 |   -- |    -- | Total
|-----------------------------------------------------------------------
|  70.3% | 483.0 |   -- |    -- | USER
||----------------------------------------------------------------------
||  53.3% | 366.3 |   -- |    -- | jacobi_mpiomp_.LOOP@li.61
3|        |       |      |       |  n/namehta4/Tutorial/jacobi_mpiomp.F90
||||--------------------------------------------------------------------
4|||  33.5% | 230.3 | 25.7 | 10.4% | line.63
4|||  19.4% | 133.0 | 13.0 |  9.2% | line.66
||||====================================================================
||  16.8% | 115.7 |   -- |    -- | compute_diff_.LOOP@li.261
3|        |       |      |       |  n/namehta4/Tutorial/jacobi_mpiomp.F90
||||--------------------------------------------------------------------
4|||   5.8% |  39.9 | 22.1 | 36.8% | line.263
4|||  11.0% |  75.4 | 23.6 | 24.6% | line.264
||======================================================================
|  22.3% | 153.4 |   -- |    -- | ETC
||----------------------------------------------------------------------
||  20.9% | 143.3 | 32.7 | 19.2% | __cray_memcpy_ROME
||======================================================================
|   6.3% |  43.4 |   -- |    -- | MPI
||----------------------------------------------------------------------
||   4.6% |  31.3 | 13.7 | 31.3% | MPI_ALLREDUCE
||   1.7% |  11.5 | 16.5 | 60.8% | MPI_SENDRECV
|=======================================================================
```

CrayPAT (Perftools-lite) results

```
Notes for table 3:

  This table shows functions that have the most significant exclusive
    time, taking for each thread the average time across ranks.
    The imbalance percentage is relative to the team observed to
    participate in execution.
    Use -s th=ALL to see individual thread values.
  For further explanation, use:  pat_report -v -O profile_th_pe ...

Table 3:  Profile by Function Group and Function

  Samp% |  Samp | Imb. |  Imb. | Team | Group
        |       | Samp | Samp% | Size |  Function=[MAX10]
        |       |      |       |      |   Thread=HIDE
        |       |      |       |      |    PE=HIDE

 100.0% | 687.2 |   -- |    -- |   -- | Total
|-----------------------------------------------------------------
|  70.3% | 483.0 |   -- |    -- |   -- | USER
||----------------------------------------------------------------
||  53.3% | 366.3 |  1.3 |  0.7% |    2 | jacobi_mpiomp_.LOOP@li.61
||  16.8% | 115.7 |  1.8 |  3.0% |    2 | compute_diff_.LOOP@li.261
||================================================================
|  22.3% | 153.4 |   -- |    -- |   -- | ETC
||----------------------------------------------------------------
||  20.9% | 143.3 |  4.5 |  6.3% |    2 | __cray_memcpy_ROME
||================================================================
|   6.3% |  43.4 |   -- |    -- |   -- | MPI
||----------------------------------------------------------------
||   4.6% |  31.3 |   -- |    -- |    1 | MPI_ALLREDUCE
||   1.7% |  11.5 |   -- |    -- |    1 | MPI_SENDRECV
|=================================================================
```

CrayPAT (Perftools-lite) results

```
Notes for table 3:
Notes for table 4:

  This table shows energy and power usage for the nodes with the
    maximum, mean, and minimum usage, as well as the sum of usage over
    all nodes.
    Energy and power for accelerators is also shown, if applicable.
  For further explanation, use:  pat_report -v -O program_energy ...

Table 4:  Program energy and power usage (from Cray PM)

   Node |       Node |   Process | Node Id
 Energy | Power (W) |      Time |  PE=HIDE
    (J) |            |           |   Thread=HIDE

 10,873 | 1,524.726 | 7.131116 | Total
|------------------------------------------------
|  2,730 |   382.878 | 7.130208 | nid.2
|  2,729 |   382.716 | 7.130610 | nid.1
|  2,707 |   379.554 | 7.132054 | nid.0
|  2,707 |   379.579 | 7.131592 | nid.3
|================================================
```

CrayPAT (Perftools-lite) results

```
Notes for table 6:

  This table show the average time and number of bytes written to each
    output file, taking the average over the number of ranks that
    wrote to the file.  It also shows the number of write operations,
    and average rates.
  For further explanation, use:  pat_report -v -O write_stats ...

Table 6:  File Output Stats by Filename

      Avg |       Avg |  Write Rate | Number |     Avg | Bytes/ | File Name=!x/^/(proc|sys)/
    Write |     Write | MiBytes/sec |     of | Writes |   Call |  PE=HIDE
 Time per |   MiBytes |             | Writer |    per |        |
   Writer |       per |             |  Ranks | Writer |        |
     Rank |    Writer |             |        |   Rank |        |
          |      Rank |             |        |        |        |
|-----------------------------------------------------------------------------
| 0.000091 | 0.002563 |   28.099071 |      1 |  101.0 |  26.60 | stdout
| 0.000062 | 0.000439 |    7.044082 |      6 |    7.5 |  61.33 | _UnknownFile_
|=============================================================================
Program invocation:  /pscratch/sd/n/namehta4/Tutorial/./jacobi_mpiomp

      |-------------------------------------------------
```

CrayPAT (Perftools-lite) results

```
Notes for table 1:

  This table shows functions that have significant exclusive time,
    averaged across ranks.
  For further explanation, use:  pat_report -v -O profile ...

Table 1:  Profile by Function Group and Function

  Time% |      Time | Imb. |  Imb. |     Calls | Group
        |           | Time | Time% |           |  Function=[MAX10]
                                                                    ^/(proc|sys)/
 100.0% | 0.651397 |   -- |    -- | 26,518.0 | Total
|------------------------------------------------------------------
|  98.0% | 0.638061 |   -- |    -- | 22,056.0 | CUDA
||-----------------------------------------------------------------
||  92.3% | 0.601155 |   -- |    -- |  2,000.0 | cudaLaunchKernel
||   4.5% | 0.029539 |   -- |    -- |  2,001.0 | cudaMemcpy
||=================================================================
|   1.8% | 0.011568 |   -- |    -- |       2.0 | USER
||-----------------------------------------------------------------
||   1.5% | 0.009741 |   -- |    -- |       1.0 | InitializeDataChunk
|==================================================================
```

CrayPAT (Perftools) steps

- **Similar to steps used for Perftools-lite**
- **Code must be run in `$SCRATCH`**
- **Object (`*.o`) files must be created in a separate step and maintained**
- **To visualize results using App2, launch terminal with X forwarding**
- **Run steps are as follows:**

```
$ pat_build -u -g mpi <name of exec>
```

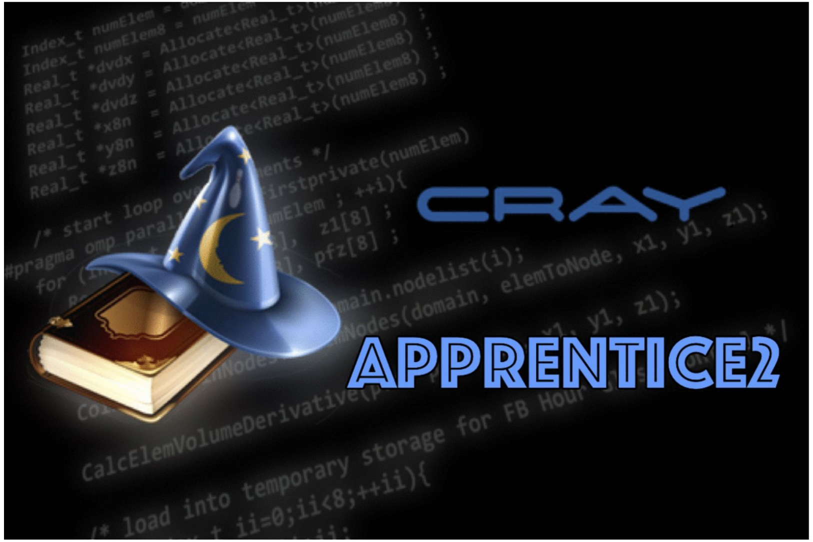
```
$ module unload darshan xalt
$ module load perftools
$ export PAT_RT_EXPDIR_NAME=./data_dir
$ ftn -c -fopenmp jacobi_mpiomp.F90
$ ftn -fopenmp -o jacobi_mpiomp jacobi_mpiomp.o
$ salloc --nodes 32 --qos interactive --time 01:00:00 --C cpu --account=mxxxx
$ pat_build -O apa jacobi_mpiomp
$ srun -n 32 ./jacobi_mpiomp+pat
```

https://www.nersc.gov/assets/Uploads/Perftools-Reveal-Levesque-Sept2022.pdf

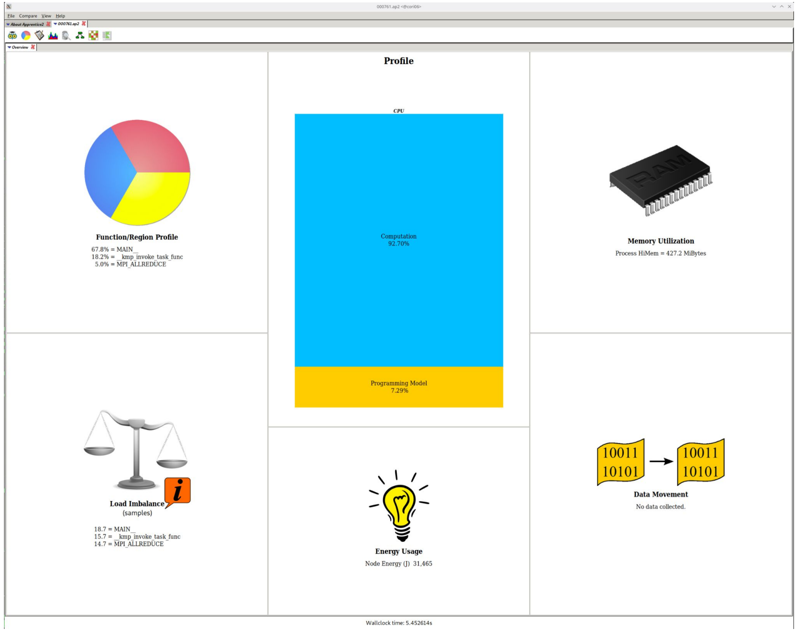
CrayPAT (Perftools) steps

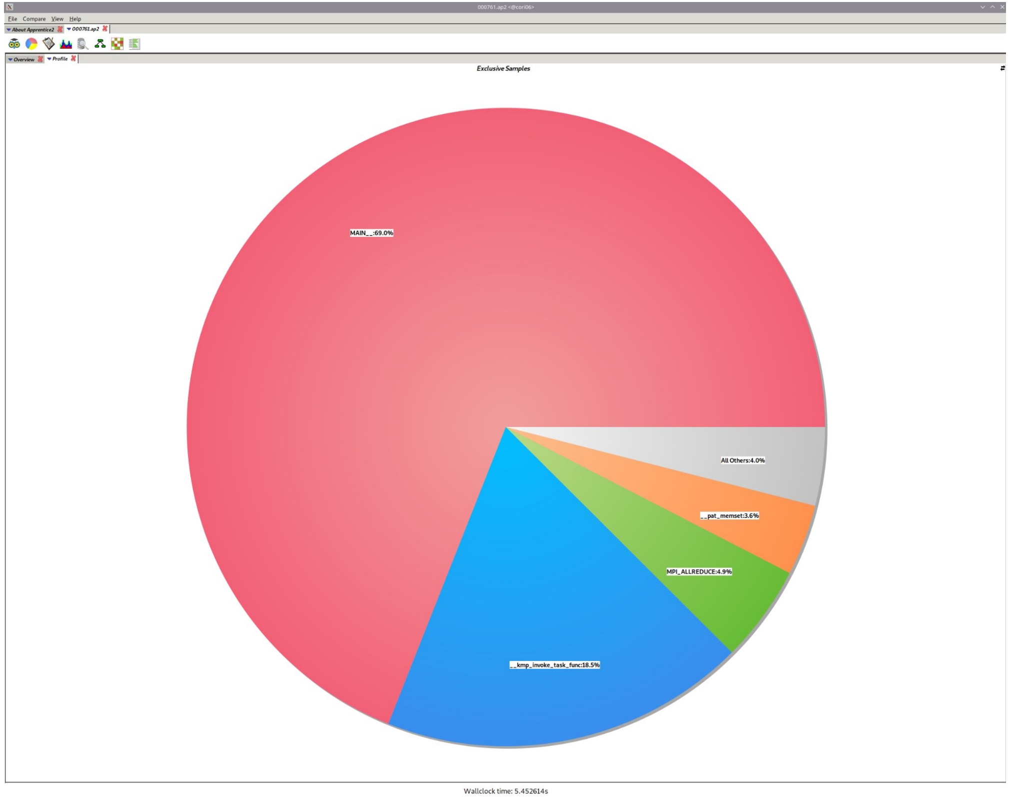
- **Running the +pat compiled binary will generate `.xf` files in the data_dir folder**
- **These `.xf2` files have to be converted to ap2 format to visualize using App2**
- **Run steps are as follows:**

```
$ cd ./data_dir
$ pat_report -f ap2 *.xf2
$ app2 result.ap2
```

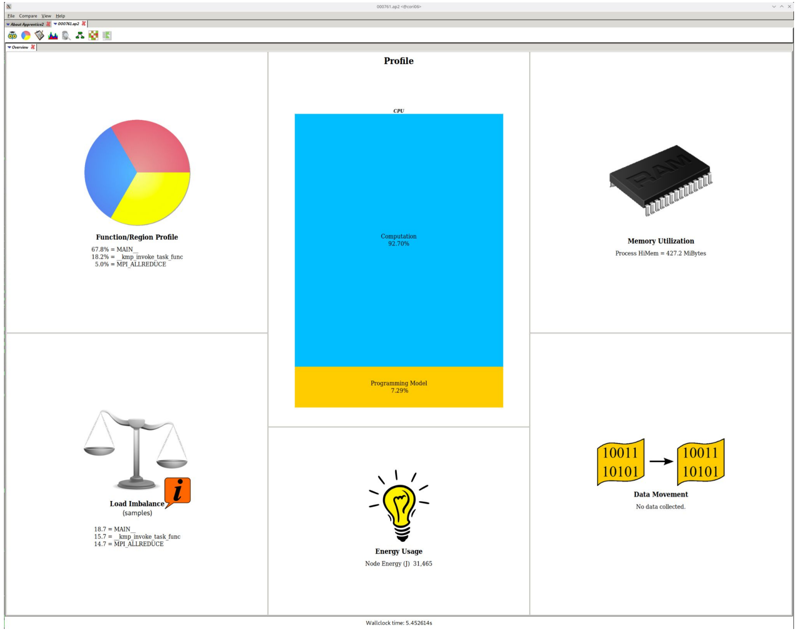


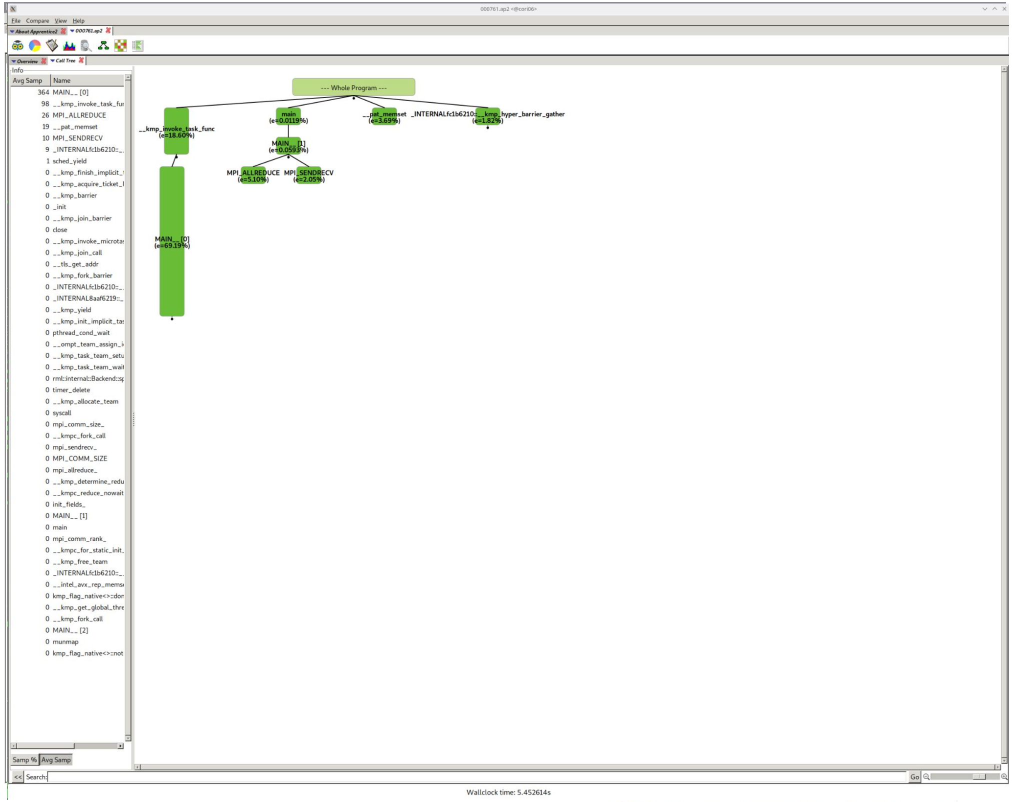
Visualizing CrayPAT (Perftools) results in App2



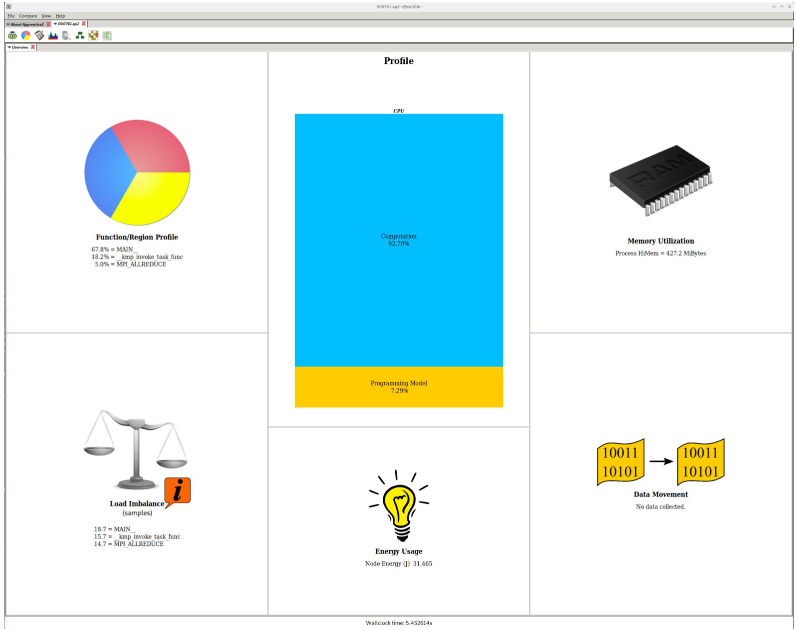


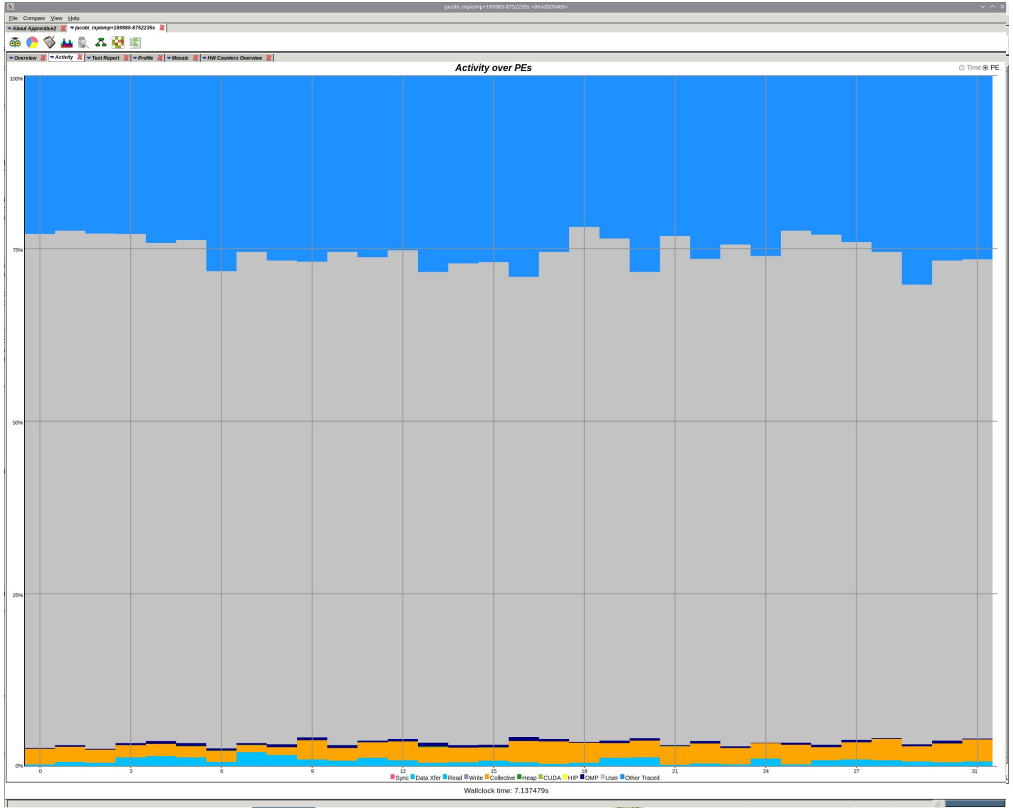
Visualizing CrayPAT (Perftools) results in App2





Visualizing CrayPAT (Perftools) results in App2





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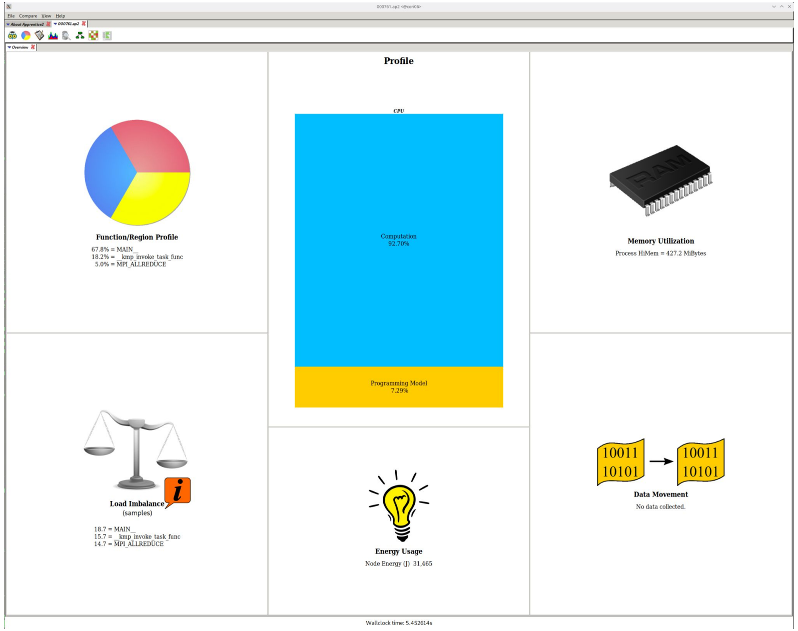
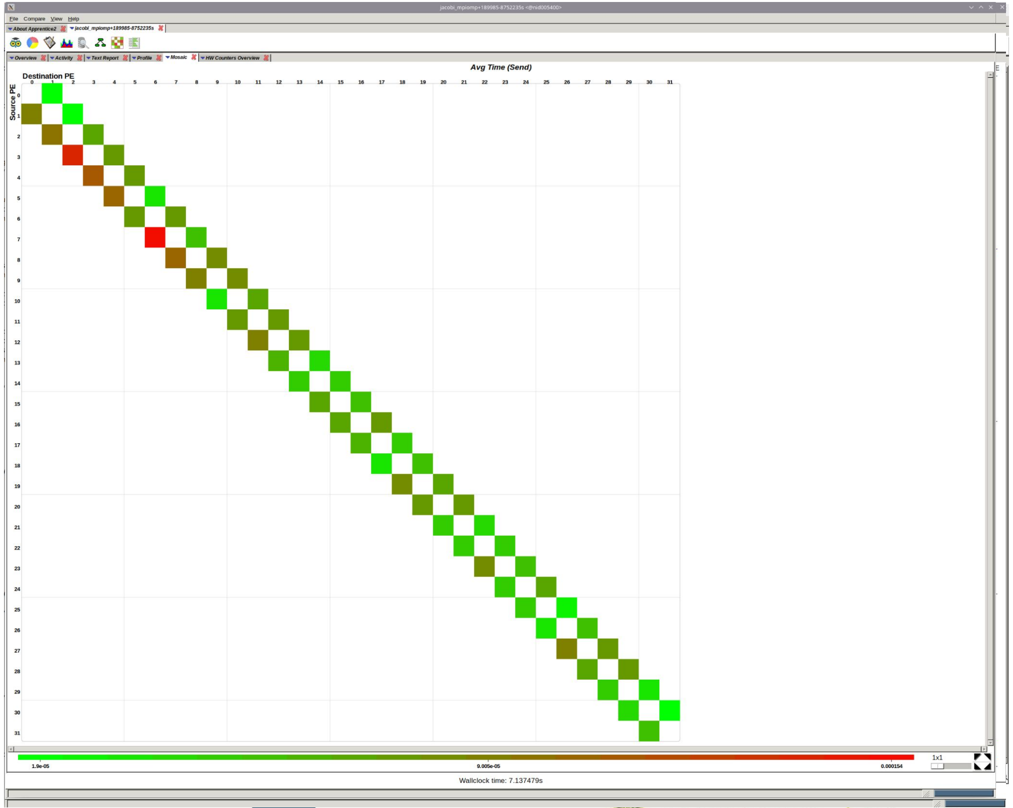
Visualizing CrayPAT (Perftools) results in App2





Thank You and Welcome to NERSC!