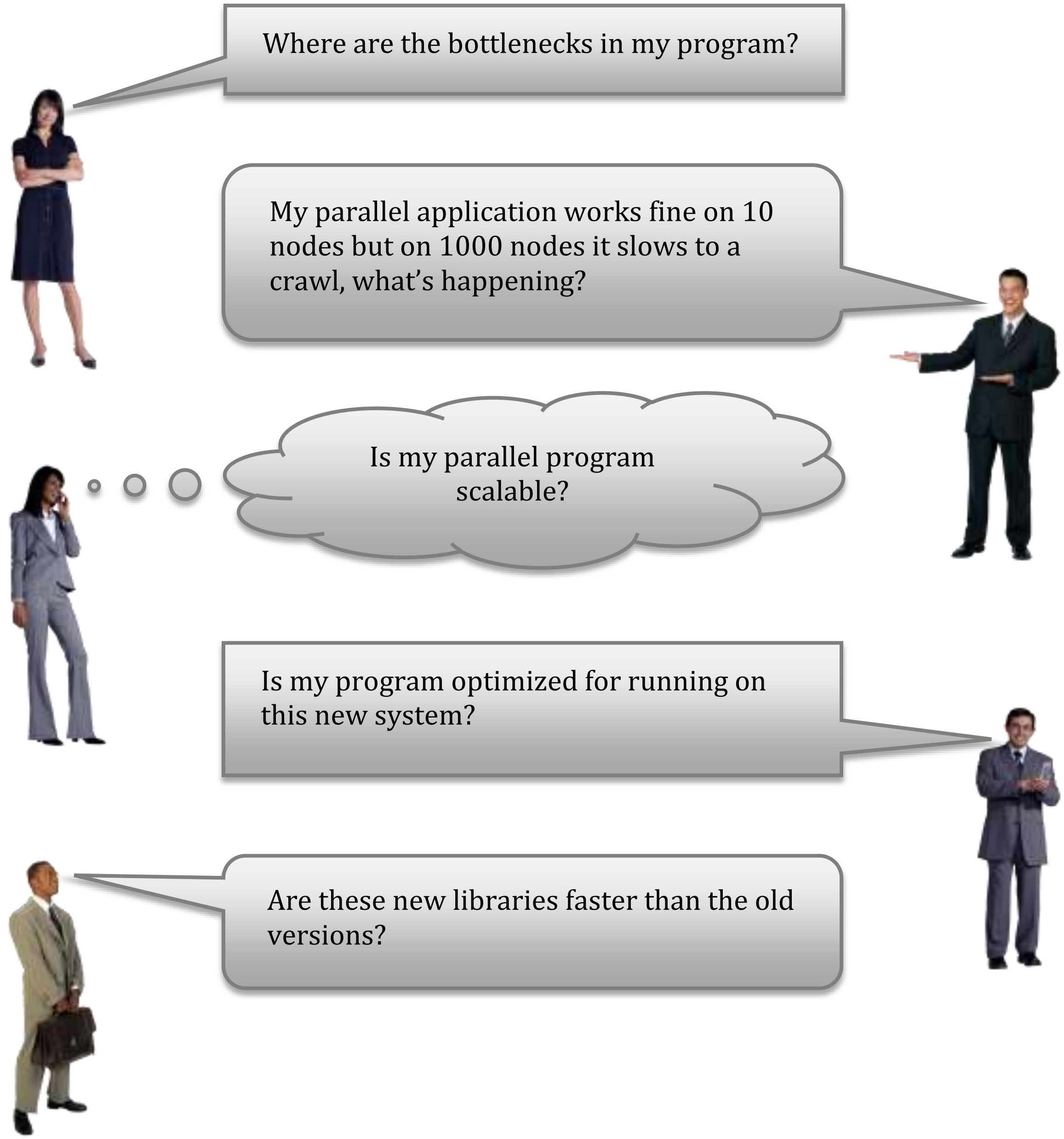
Open|SpeedShop User Manual

February 4, 2014
Version 2.1

Contributions from Krell Institute, LANL, LLNL, SNL

Table of Contents

Why do I need Performance Analysis?



All these questions can be answered by using Performance Analysis.

About this Manual

This manual will provide you with a basic understanding of performance analysis. You will learn how to plan and run Open|SpeedShop performance experiments on your applications.

This manual intends to give users an understanding of the general experiments available in Open|SpeedShop that can be used to analyze application code. There is extensive information provided about how to use the Open|SpeedShop experiments and how to view the performance information in informative ways. Hopefully this will allow users to start optimizing and analyzing the performance of application code.

Open|SpeedShop is a community effort by The Krell Institute with current direct funding from the Department of Energy's National Nuclear Security Administration (DOE NNSA). It builds on a broad list of community provided infrastructures, notably the Paradyn Project's Dyninst API and MRNet (Multicast Reduction Network) from the University of Wisconsin at Madison, the Libmonitor profiling tool, and the Performance Application Programming Interface (PAPI) from the University of Tennessee at Knoxville. Open|SpeedShop is an open source multi platform Linux performance tool which is targeted to support performance analysis of applications running on both single node and large scale IA64, IA32, EM64T, AMD64, PPC, Blue Gene and Cray XT/XE/XK platforms.

Open|SpeedShop is explicitly designed with usability in mind and is for application developers and computer scientists. The base functionality includes:

- Sampling Experiments
- Support for Call Stack Analysis
- Hardware Performance Counters
- MPI Profiling and Tracing
- I/O Profiling and Tracing
- Floating Point Exception Analysis
- Memory Function Tracing
- POSIX Thread Function Tracing
- NVIDIA CUDA Event Tracing

In addition, Open|SpeedShop is designed to be modular and extensible. It supports several levels of plug-ins, which allow users to add their own performance experiments.

Open|SpeedShop development is hosted by the Krell Institute. The infrastructure and base components of Open|SpeedShop are released as open source code primarily under LGPL. Highlights include:

- Comprehensive performance analysis for sequential, multithreaded, and MPI applications

- No need to recompile the user’s application.
- Supports both first analysis steps as well as deeper analysis options for performance experts
- Easy to use GUI and fully scriptable through a command line interface and Python
- Supports Linux Systems and Clusters with Intel and AMD processors
- Extensible through new performance analysis plugins ensuring consistent look and feel
- In production use on all major cluster platforms at LANL, LLNL, and SNL

Features include:

- Four user interface options: batch, command line interface, graphical user interface and Python scripting API.
- Supports multi-platform single system image (SSI) and traditional clusters.
- Scales to large numbers of processes, threads, and ranks.
- View performance data using multiple customizable views.
- Save and restore performance experiment data and symbol information for post experiment performance analysis.
- View performance data for all of application’s lifetime or smaller time slices.
- Compare performance results between processes, threads, or ranks between a previous experiment and current experiment.
- Interactive CLI help facility, which lists the CLI commands, syntax, and typical usage.
- Option to automatically group like-performing processes, threads, or ranks.
- Create MPI traces in OTF (Open Trace Format).

1 What is Performance Analysis?

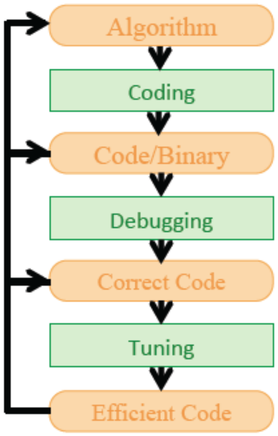
Performance Analysis, also called software profiling or performance tuning, is not only a way to measure the speed and efficiency of a program but also to identify bottlenecks in parallel applications. Software developers are facing new issues when writing code for massively parallel applications. There may be issues in code that does not become apparent until it is run on thousands (or tens of thousands, or hundreds of thousands, etc.…) of cores. Performance Analysis can be used to identify problems and tune applications for optimal speed and efficiency.

There are many aspects of a program that can be measured in order to analyze its performance. You can measure the time each function takes or the call paths within an application. There are a number of hardware counters available, like the number of floating point operations per second (FLOPS) performed or the number of data cache misses. You can monitor the I/O operations for a program to analyze its interaction with the file system.

Not only are there many possible things to measure about a program there are also different ways to measure them. You can instrument your program by adding performance routines to the source code, you can have a performance tool periodically take samples from a program as it runs, or you can preload certain library functions to monitor those calls.

There are a number of different performance tools that can help you measure the different performance aspects of your code. There are built in Unix commands like time or gprof that can give you some basic timing information. This manual describes how to use Open|SpeedShop, a robust performance tool capable of analyzing unmodified binaries. Throughout the manual will show real world examples of performance analysis using Open|SpeedShop.

2 How to use Performance Analysis



Performance analysis is an essential part of the development cycle, and should be included as early as possible. It can have an impact on the patterns used in message passing, or the layout of the data structures used and the algorithms themselves. Your end goal should be correct and efficient code. Typically one would measure the performance of some code and analyze the results. You then modify the code or algorithms as appropriate and repeat the measurements from before, analyzing the differences in successive runs to ensure an increase in performance.

The most basic performance analysis tool is the Unix “time” command, which can measure the CPU and wall clock time for an application. You could also keep track of application’s performance as you vary the input parameters. This type of performance analysis is very simple but has the disadvantage of the measurements being coarse grain and not allowing you to pinpoint any performance bottlenecks within the application.

Another performance analysis method is code integration (or instrumentation) of performance probes. This method allows a much finer grain analysis however it can be hard to maintain and required significant beforehand knowledge of what information to measure and record.

An alternative to the simple and coarse grain or complex and fine grain approach is the use of performance analysis tools. Performance Tools enable fine grain analysis that can be resulted to the source code and work universally across applications.

There are two ways performance analysis tools gather information from applications. One way is through statistical sampling, which periodically interrupts the execution of the program to record its location. Statistical distributions across all locations are reported, and data is typically aggregated over time. Time is the most common metric, but other metrics are possible. Statistical sampling is useful to get an overview of the applications performance, as it provides low and uniform overhead.

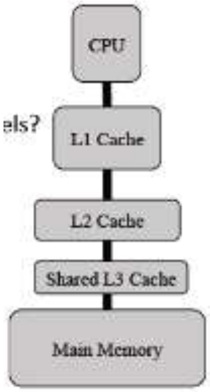
Event tracing is another way for performance analysis tools to gather information. In this case the tool can gather and store individual application events, for example, function invocations, MPI messages or I/O calls. The events recorded are typically time stamped and proved detailed per event information. This method can lead to huge data volumes and higher, potentially bursty overheads.

There are a number of different performance analysis tools, so how do you select the right one for your application? A tool must have the right features for what you are trying to measure. Keep in mind which questions you are looking to answer and how deep do you want to analyze the code. A tool must also match your application's workflow, and may need access to and knowledge about the source code and the machine environment. Other things to keep in mind when choosing a tool are having a local installation of the tool and the availability of local support for the tool. Getting started on Performance Analysis can be a challenging and sometimes overwhelming undertaking so it's a good idea to have some support system in place to help you through the hard parts.

Parts of this manual will focus on general performance analysis information, followed by many detailed examples using the Open|SpeedShop performance analysis tool. Open|SpeedShop has an easy to use GUI and command line options; it includes both sampling and tracing in a single framework and doesn't require recompilation of the application. It is extensible through user written plug-ins. Open|SpeedShop is also maintained and supported within the Tri-lab clusters, Blue Gene, and Cray platforms run by Lawrence Livermore, Los Alamos and Sandia National Laboratories. It is also available at a number of other laboratories and business around the world.

The following sections give a quick overview of what to look for in your Performance Analysis for different types of applications.

2.1 Sequential Code Performance Analysis

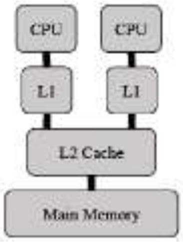


You should identify the most computationally intensive parts of your application. Find out where is your application spending most of its time: in modules or libraries, on particular statements in your code, or within certain functions. Check to make sure the most time is being spent in the computational kernels. Ask yourself if the amount of time that each section takes matches your intuition.

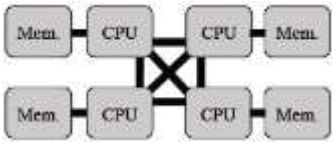
Explore the impact of the memory hierarchy. Check to see if your application has excessive data cache misses. Find out where your data is located. One can also assess the impact of the virtual memory Translation Lookaside Buffer (TLB) misses.

Check the interaction of you application with external resources by checking the efficiency of the I/O and looking at the time spent in system libraries.

2.2 Shared Memory Applications



Shared memory applications have a single shared storage that is accessible from any CPU. The programming models common to shared memory applications include threadsn (e.g. POSIX threads, and OpenMP.



The typical performance issues with shared memory applications include limited bus bandwidth where a bottleneck occurs when many CPUs are trying to access the same resources. There can be synchronization overhead associated with thread startup. There can be problems with not balancing the workload among threads properly, or most efficiently. There can be complications with Non-Uniform Memory Access (NUMA).

2.3 Message Passing Applications

Message passing applications use a distributed memory model with sequential or shared memory nodes coupled by a network. In this case data is exchanged using message passing via a Message Passing Interface (MPI).

The typical performance issues associated with message passing applications include long blocking times while waiting on data, or low messaging rates creating bottlenecks due to insufficient network bandwidth.

3 Introduction to Open|SpeedShop

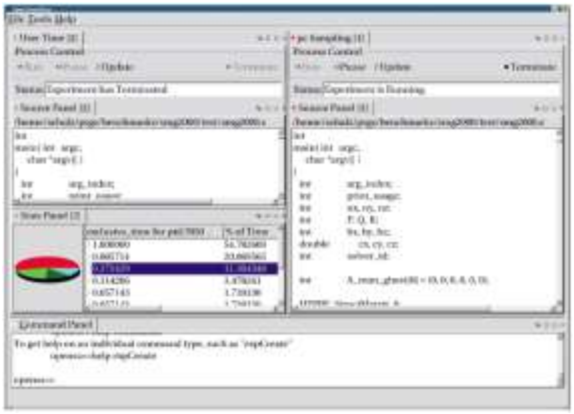
Open|SpeedShop is an open source performance analysis tool framework. It provides the most common performance analysis steps all in one tool. It is easily extendable by writing plugins to collect and display performance data. It also comes with built in experiments to gather and display several types of performance information.

Open|SpeedShop provides several flexible and easy ways to interact with it. There is a GUI to launch and examine experiments, a command line interface that provides the same access as the GUI, as well as python scripts. There are also convenience scripts that allow you to run standalone experiments on applications and examine the results at a later time.

The existing experiments for Open|SpeedShop all work on unmodified application binaries. Open|SpeedShop has been tested on a variety of Linux clusters and supports Cray and Blue Gene systems.

3.1 Basic Concepts, Interface, Workflow

Open|SpeedShop has three ways for the user to examine the results of a performance test, called experiments, a GUI, a command line interface or through python libraries. The user can also start experiments by using those three options or by an additional method of the command line launched convenience scripts. For example to launch one of the convenience scripts for the pcsamp experiment (Program Counter Sampling) the user executes the command osspcsamp "<application>", where <application> is the executable under study along with any arguments. The convenience scripts will then create a database for the results of that experiment.



The user can examine any database in the GUI with the command:

```
        openss –f <db file>
```

The GUI will proved some simple graphics to help you understand the results and will relate the data back to the source code when possible.

3.1.1 Common Terminology

Technical terms can have multiple and/or context sensitive meanings, therefore this section attempts to explain and clarify the meanings of the terms used in this document, especially with respect to the Open|SpeedShop tools.

Experiment: A set of collectors and executables bound together to generate performance information that can be viewed in human readable form.

Focused Experiment: The current experiment commands operate on. The user may run or view multiple experiments simultaneously and unless a particular experiment is specified directly, the focused experiment will be used. Experiments are given an enumeration, called an experiment id, for identification.

Component(s): A component is a somewhat self-contained code section of the Open|SpeedShop performance tool. This section of code does a set of specific related tasks for the tool. For example, the GUI component does all the tasks related to displaying Open|SpeedShop wizards, experiment creation, and results using a graphical user interface. The CLI component does similar functions but uses the interactive command line delivery method.

Collector: The portion of the tool containing logic that is responsible for the gathering of the performance metric. A collector is a portion of the code that is included in the experiment plugin.

Metric: The measurement, which the collector/experiment is gathering. A metric could be a time, an occurrence counter, or other entity, which reflects in some way on the application's performance and is gathered by a performance experiment at application runtime directly by the collector.

Offline: A link override mechanism that allows for gathering performance data using libMonitor to link Open|SpeedShop performance data gathering software components into the user application. For the Open|SpeedShop offline mode of operation, the application must be run from start up to completion. The performance results may be viewed after the application terminates normally.

Param: Each collector allows the user to set certain values that control the way a collector behaves. The parameter or **param** may cause the collector to perform various operations at certain time intervals or it may cause a collector to measure certain types of data. Although Open|SpeedShop provides a standard way to set a parameter, it is up to the individual collector to decide what to do with that information. Detailed documentation about the available parameters is part of the collector's documentation.

Framework: The set of API functions that allows the user interface to manage the creation and viewing of performance experiments. It is the interface between the user interface and the cluster support and dynamic instrumentation components.

Plugin: A portion (library) of the performance tool that can be loaded and included in the tool at tool start-up time. Development of the plugin uses a tool specific interface (API) so that the plugin, and the tool it is to be included in, know how to interact with each other. Plugins are normally placed in a specific directory so that the tool knows where to find the plugins.

Target: This is the application or part of the application one is running the experiment on. In order to fine tune what is being targeted, Open|SpeedShop gives target options that describes file names, host names, thread identifiers, rank identifiers and process identifiers.

3.1.2 Concept of an Experiment

Open|SpeedShop uses the concept of an experiment to describe the gathering of performance measurement data for a particular performance area of interest. Experiments consist of the collector responsible for the gathering of the measurements associated with the performance area of interest. The collector, which is a small dynamic or static object library, also contains functions that can interpret the gathered measurements, i.e., performance data, into a human understandable form. The experiment definition also includes the application being examined and how often the data will be gathered (the sampling rate). The application's symbol information is saved into the experiment output file so that performance reports can be generated from the performance data file alone. The application, itself, need not be present to view the performance data at a later time.

3.2 Performance Experiments Overview

Open|SpeedShop refers to the different performance measurements as experiments. Each experiment can measure and analyze different aspects of the code's performance. The experiment type, or type of data gathered, is chosen by the user. Any experiment can be applied to any application, with the exception of MPI specific experiments being applied to non-MPI applications.

Each experiment consists of collectors and views. The collectors define specific performance data sources, for example, program counter samples, call stack samples, hardware counters or tracing of library routines. Views specify how the performance data is aggregated and presented to the user. It is possible to implement multiple collectors per experiment.

3.2.1 Individual Experiment Descriptions

The following table provides a quick overview of the different experiment types that come with Open|SpeedShop.

Experiment	Experiment Description
pcsamp	Periodic sampling the program counters gives a low-overhead view of where the time is being spent in the user application.
usertime	Periodic sampling the call path allows the user to view inclusive and exclusive time spent in application routines. It also allows the user to see which routines called which routines. Several views are available, including the "hot" path.
hwc	Hardware events (including clock cycles, graduated instructions, instruction and data cache and TLB misses, floating-point operations) are counted at the machine instruction, source line and function levels.
hwcsamp	Similar to hwc, except that sampling is based on time, not PAPI event overflows. Up to six events may be sampled during the same experiment.
hwctime	Similar to hwc, except that call path sampling is also included.
io	Accumulated wall-clock durations of input/output (I/O) system calls: read, readv, write, writev, open, close, dup, pipe, creat and others. Show call paths for each unique I/O call path.
iop*	Lightweight I/O profiling: Accumulated wall-clock durations of I/O system calls: read, readv, write, writev, open, close, dup, pipe, creat and others, but individual call information is not recorded.
iot	Similar to io, except that more information is gathered, such as bytes moved, file names, etc.
mpi	Captures the time spent in and the number of times each MPI function is called. Show call paths for each MPI unique call path.
mpit	Records each MPI function call event with specific data for display using a GUI or a command line interface (CLI). Trace format option displays the data for each call, showing its start and end times.
mpiotf	Write MPI calls trace to Open Trace Format (OTF) files to allow viewing with Vampir or converting to formats of other tools.
fpe	Find where each floating-point exception occurred. A trace collects each with its exception type and the call stack contents. These measurements are exact, not statistical.
mem*	Captures the time spent in and the number of times each memory function is called. Show call paths for each memory function's unique call path
pthreads*	Captures the time spent in and the number of times each POSIX thread function is called. Show call paths for each POSIX thread function's unique call path
cuda*	Captures the NVIDIA CUDA events that occur during the application execution and report times spent for each event, along with the arguments for each event, in an event-by-event trace.

* Only available in Open|SpeedShop using CBTF collection mechanism (currently under development)

3.2.3 Sampling Experiments Descriptions

Program counter sampling (pcsamp) experiment, call path profiling (usertime) experiment, and the three hardware counter experiments (hwc, hwctime, hwcsamp) all use a form of sampling based performance information gathering techniques.

Program Counter Sampling (pcsamp) is used to record the Program Counter (PC) in the user application being monitored by interrupting the application at an user defined time interval, with the default being 100 times a second. This experiment provides a low overhead overview of the time distribution for the application. Its lightweight overview provides a good first step for analyzing the performance of an application.

The Call Path Profiling (usertime experiment) gathers both the PC sampling information and also records call stacks for each sample. This allows the later display of the call path information about the application as well as inclusive and exclusive timing data (see section 4.2). This experiment is used to find hot call paths (call paths that take the most time) and see who is calling whom.

The Hardware Counter experiments (hwc, hwctime, hwcsamp) access data like Cache and TLB misses. The experiments hwc and hwctime, sample a hardware counter events, based on an event threshold. The default event is PAPI_TOT_CYC overflows. Please see chapter 5 for more information on PAPI and hardware counter related experiments. Instead using a threshold, the hwcsamp experiment samples up to six events based on a sample time, similar to the usertime and pcsamp experiments. The hwcsamp experiment default events are PAPI_FP_OPS and PAPI_TOT_CYC.

3.2.4 Tracing Experiments Descriptions

The Input/Output tracing and profiling experiments (io, iot, iop), MPI Tracing Experiments (mpi, mpit, mpiotf), Memory tracing (mem), POSIX thread tracing (pthread), and the Floating Point Exception Tracing (fpe) all use a form of tracing or wrapping of the function names to record performance information. Tracing experiments do not use timers or thresholds to interrupt the application. Instead they intercept the function calls of interest by using a wrapper function that records timing and function argument information, calls the original function, and then records this information for later viewing with Open|SpeedShop's user interface tools.

The Input/Output tracing experiments (io, iot) record invocation of all POSIX I/O events. They both provide aggregated and individual timings and, in addition, the iot experiment also provides argument information for each call. To obtain a more lightweight overview of application I/O usage, use the I/O profiling experiment. The lightweight I/O experiment (iop) records the invocation of all POSIX I/O events, accumulating the information, but does not save individual call information like the io and iot experiments do. That allows the iop experiment database to be smaller and makes the iop experiment faster than the io and iot experiments.

The memory tracing experiment (mem) records invocation of all tracked memory function calls, also referred to as events. The mem experiment provides aggregated and individual timings and also provides argument information for each call.

The MPI Tracing Experiments (mpi, mpit, mpiotf) record invocation of all MPI routines as well as aggregated and individual timings. The mpit experiment provides argument information for each call. The mpiotf experiment creates Open Trace Format (OTF) output.

The Floating Point Exception Tracing (fpe) is triggered by any FPE caused by the application. It can help pinpoint numerical problem areas.

The POSIX thread tracing experiment (pthreads) records invocation of all tracked POSIX thread related function calls, also referred to as events. The pthreads experiment provides aggregated and individual timings and also provides argument information for each call.

3.2.5 Parallel Experiment Support

Open|SpeedShop supports MPI and threaded codes; it has been tested with a variety of MPI implementations. The thread support is based on POSIX threads and OpenMP is supported through POSIX threads. Open|SpeedShop reports the activity of the POSIX threads that represent the OpenMP threads, but currently doesn’t do any special processing for OpenMP specifically.

Any Open|SpeedShop experiment can be applied to any parallel application. This means you can run the program counter sampling experiment on a non-parallel application as well as a MPI or threaded application. The experiment data collectors are automatically applied to all tasks/threads. The default views aggregate (sum the performance data) across all tasks/threads but data from individual tasks/threads are available. The MPI calls are wrapped, and MPI function elapsed time and parameter information is displayed.

3.3 Running an Experiment

First think about what parameters you want to measure then choose the appropriate experiment to run. You may want to start by running the pcsamp experiment since it is a lightweight experiment and will give an overview of the timing for the entire application.

Once you have selected the experiment to run you can launch it with either the wizard in the GUI or by using the command line convenience scripts. For example say you have decided to run the pcsamp experiment on the Semi coarsening Multigrid Solver MPI application smg2000 (a good benchmark application). On the command line you would issue the command:

```
> osspcsamp “mpirun –np 256 smg2000 –n 65 65 65”
```

Where “mpirun –np 256 smg2000 –n 65 65 65” is a typical MPI application launching command you would normally use to launch the smg2000 application. mpirun, a MPI driver script or executable, is here used to launch smg2000 on 256 processors with “-n 65 65 65” is passed as an argument to smg2000. An example of a typical MPI smg2000 pcsamp experiment run along with the application and experiment output follows below:

```
> osspcsamp “mpirun –np 2 smg2000 –n 65 65 65”
```

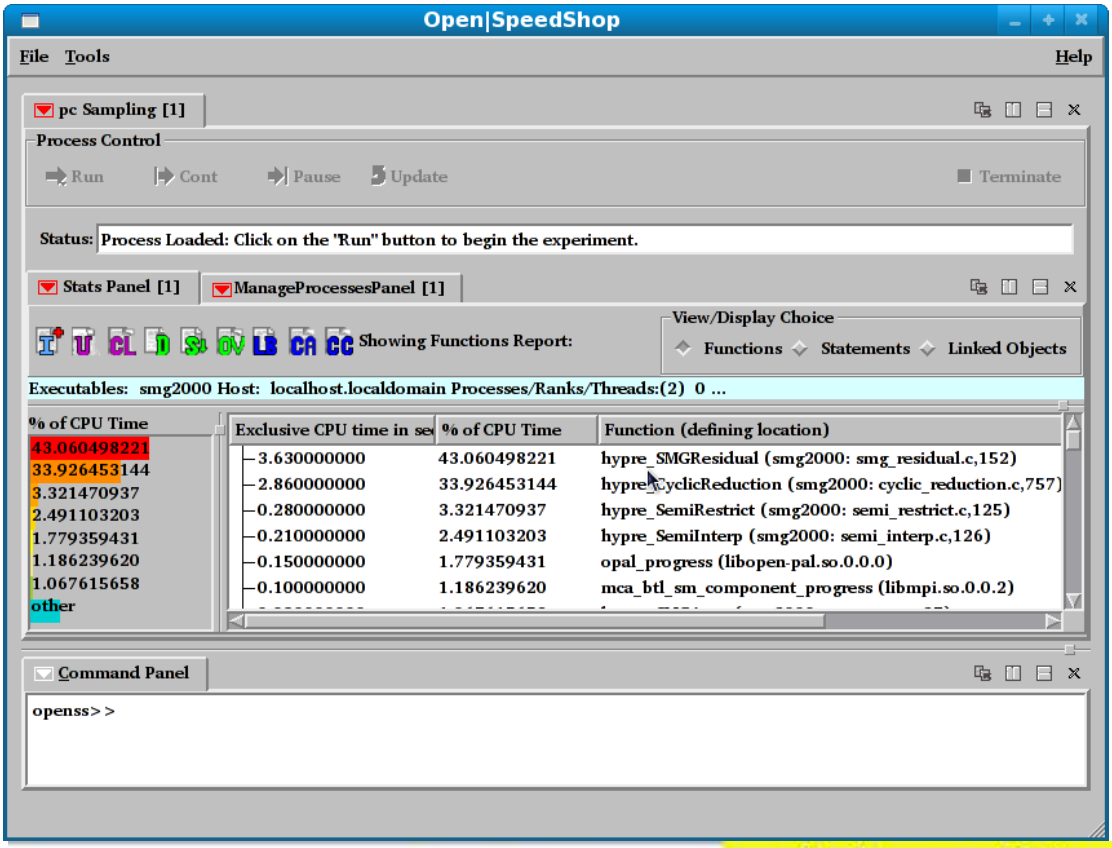
```
[openss]: pcsamp experiment using the pcsamp experiment default sampling rate: "100".
[openss]: Using OPENSS_PREFIX installed in /opt/OSS-mrnet
[openss]: Setting up offline raw data directory in /tmp/jeg/offline-oss
[openss]: Running offline pcsamp experiment using the command:
"mpirun -np 2 /opt/OSS-mrnet/bin/ossrun "./smg2000 -n 65 65 65" pcsamp"

Running with these driver parameters:
(nx, ny, nz) = (65, 65, 65)
(Px, Py, Pz) = (2, 1, 1)
(bx, by, bz) = (1, 1, 1)
(cx, cy, cz) = (1.000000, 1.000000, 1.000000)
(n_pre, n_post) = (1, 1)
dim = 3
solver ID = 0
=============================================
Struct Interface:
=============================================
Struct Interface:
 wall clock time = 0.049847 seconds
 cpu clock time = 0.050000 seconds
=============================================
Setup phase times:
=============================================
SMG Setup:
 wall clock time = 0.635208 seconds
 cpu clock time = 0.630000 seconds
=============================================
Solve phase times:
=============================================
SMG Solve:
 wall clock time = 3.987212 seconds
 cpu clock time = 3.970000 seconds
Iterations = 7
Final Relative Residual Norm = 1.774415e---07
[openss]: Converting raw data from /tmp/jeg/offline---oss into temp file X.0.openss
```

```
Processing raw data for smg2000
Processing processes and threads ...
Processing performance data ...
Processing functions and statements ...

[openss]: Restoring and displaying default view for:
 /home/jeg/DEMOS/demos/mpi/openmpi---1.4.2/smg2000/test/smg2000---pcsamp---1.openss
[openss]: The restored experiment identifier is: -x 1

Exclusive CPU time          % of CPU Time Function (defining location) in seconds.
  3.630000000               43.060498221 hypre_SMGResidual (smg2000: smg_residual.c,152)
  2.860000000               33.926453144 hypre_CyclicReduction (smg2000: cyclic_reduction.c,757)
  0.280000000                 3.321470937 hypre_SemiRestrict (smg2000: semi_restrict.c,125)
  0.210000000                 2.491103203 hypre_SemiInterp (smg2000: semi_interp.c,126)
  0.150000000                 1.779359431 opal_progress (libopen-pal.so.0.0.0)
  0.100000000                 1.186239620 mca_btl_sm_component_progress (libmpi.so.0.0.2)
  0.090000000                 1.067615658 hypre_SMGAxpy (smg2000: smg_axpy.c,27)
  0.080000000                 0.948991696 ompi_generic_simple_pack (libmpi.so.0.0.2)
  0.070000000                 0.830367734 __GI_memcpy (libc---2.10.2.so)
  0.070000000                 0.830367734 hypre_StructVectorSetConstantValues (smg2000:
struct_vector.c,537)
  0.060000000                 0.711743772 hypre_SMG3BuildRAPSym (smg2000: smg3_setup_rap.c,233)
```

When the application completes a default report will be printed on screen. The performance information gathered during execution of the experiment will be stored in a database called smg2000-pcsamp.openss. You can use the Open|SpeedShop GUI to analyze the data in detail. Run the openss command to load that database file or open the file directly using the "-f" option:

```
> openss –f smg2000-pcsamp.openss
```

Below we show basic examples of how to use the GUI to view the output database file created by the convenience script.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

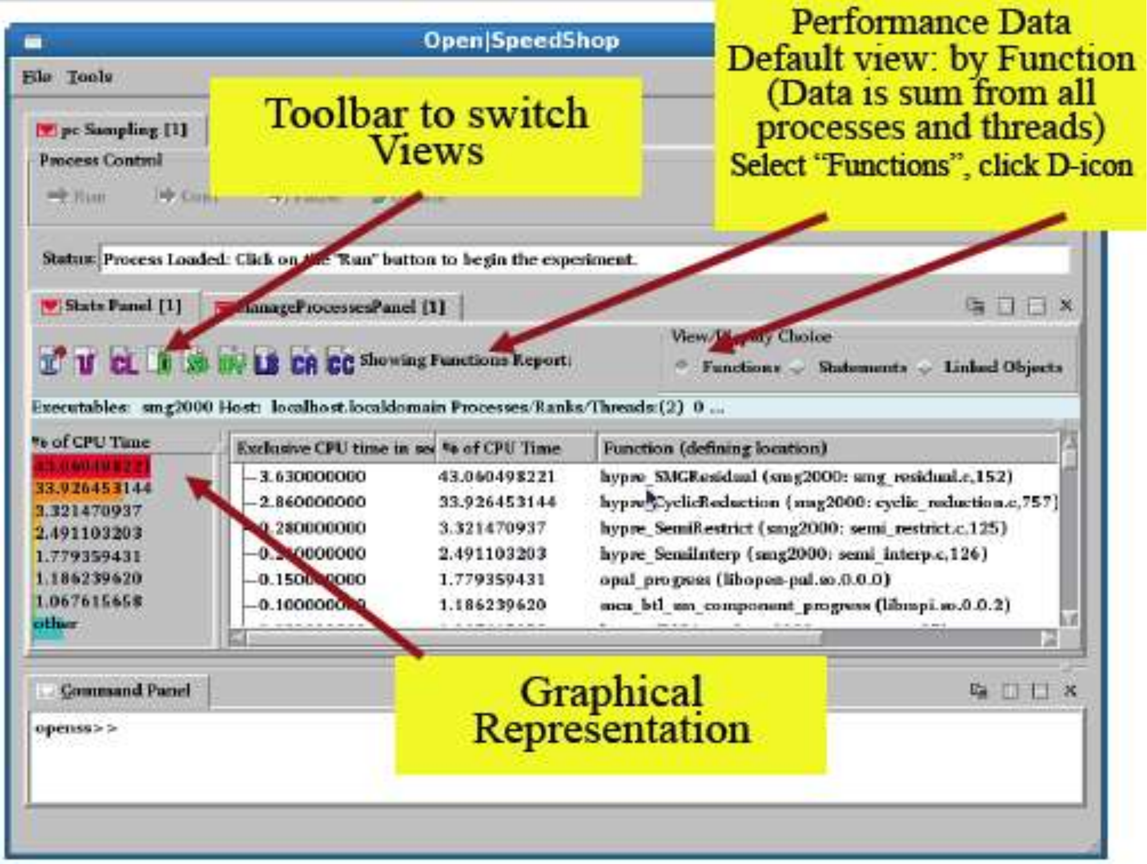
Showing Functions Report:

Executables: smg2000 Host: localhost.localdomain Processes/Ranks/Threads:(2) 0 ...

% of CPU Time
43.060498221
33.926453144
3.321470937
2.491103203
1.779359431
1.186239620
1.067615658
other

Exclusive CPU time in se	% of CPU Time	Function (defining location)
3.630000000	43.060498221	hypre_SMGResidual (smg2000: smg_residual.c,152)
2.860000000	33.926453144	hypre_CyclicReduction (smg2000: cyclic_reduction.c,757)
0.280000000	3.321470937	hypre_SemiRestrict (smg2000: semi_restrict.c,125)
0.210000000	2.491103203	hypre_SemiInterp (smg2000: semi_interp.c,126)
0.150000000	1.779359431	opal_progress (libopen-pal.so.0.0.0)
0.100000000	1.186239620	mca_btl_sm_component_progress (libmpi.so.0.0.2)

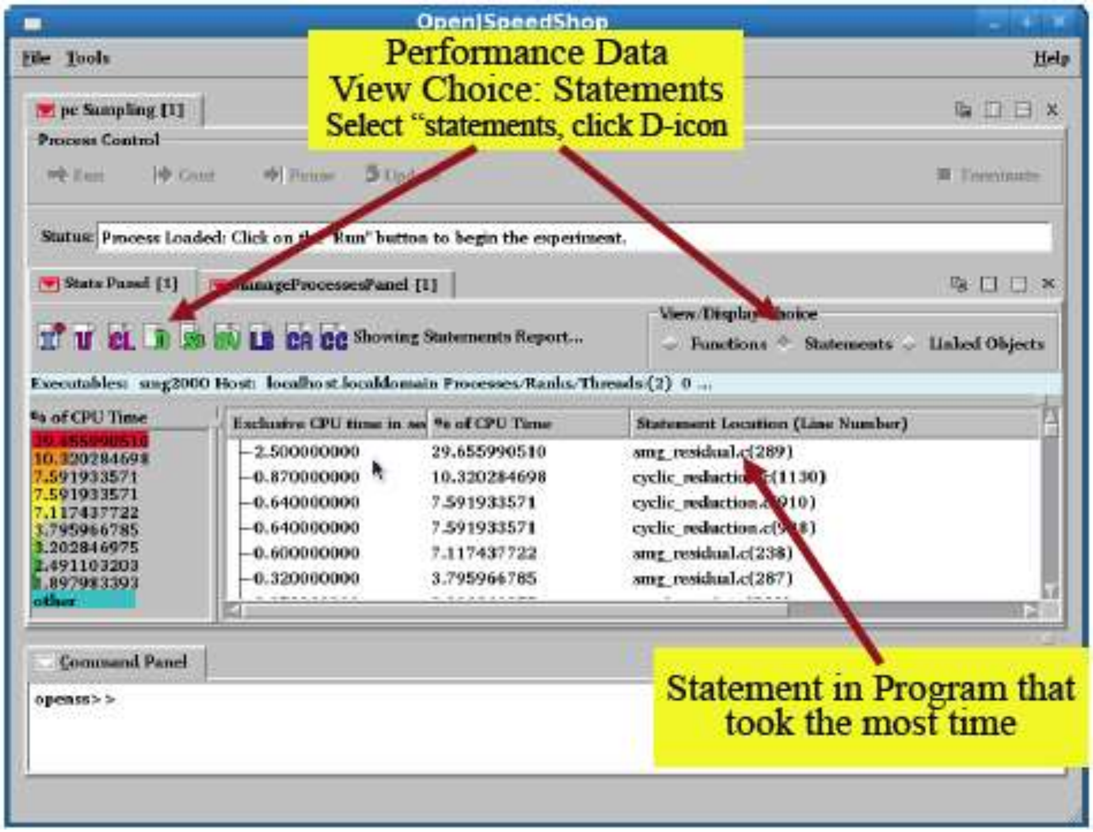
```
openss>>
```


Toolbar to switch Views

Performance Data
Default view: by Function
(Data is sum from all processes and threads)
Select "Functions", click D-icon

Graphical Representation

You can choose to view data for Functions, Statements or Linked Objects. To switch from one view type to another, first select the view granularity (Function, Statement, or Linked Object), then select the type of view. For the default views, select the "D" icon.



Performance Data View Choice: Statements
Select "statements, click D-icon

Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Statements Report...

Executables: smg2000 Host: localhost.localdomain Processes/Ranks/Threads:(2) 0 ...

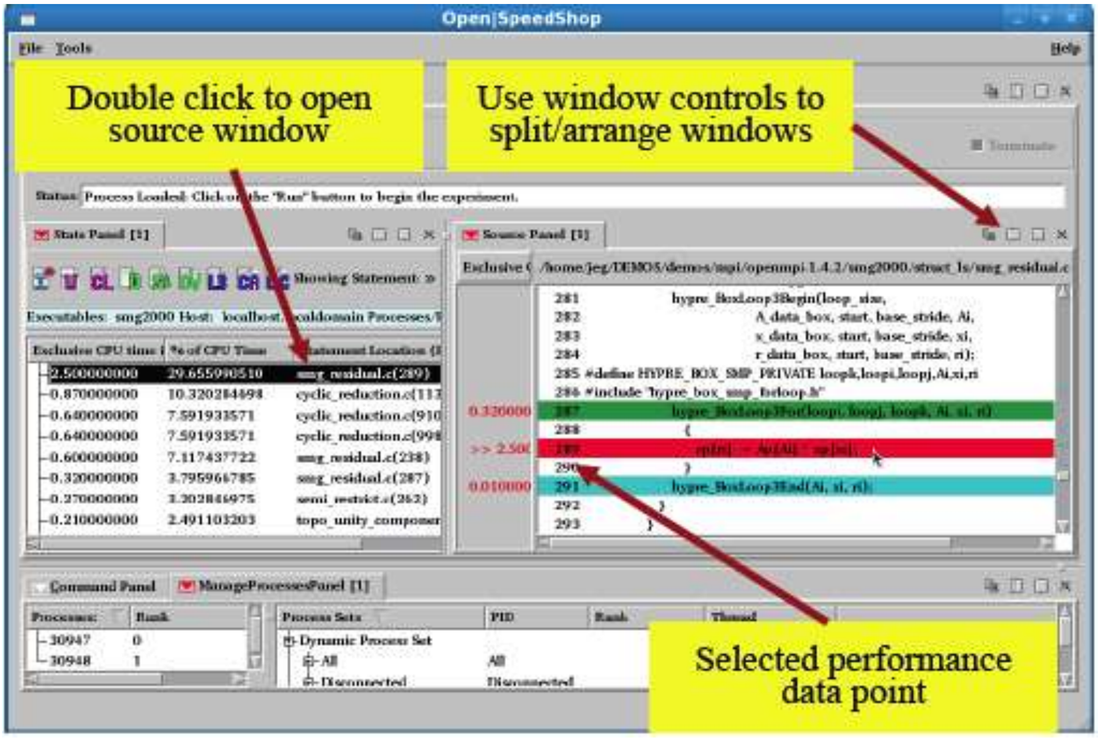
% of CPU Time
29.655990510
10.320284698
7.591933571
7.591933571
7.117437722
3.795966785
3.202846975
2.491103203
1.897983393
other

Exclusive CPU time in se	% of CPU Time	Statement Location (Line Number)
2.500000000	29.655990510	smg_residual.c(289)
0.870000000	10.320284698	cyclic_reduction.c(1130)
0.640000000	7.591933571	cyclic_reduction.c(910)
0.640000000	7.591933571	cyclic_reduction.c(9[illegible]8)
0.600000000	7.117437722	smg_residual.c(238)
0.320000000	3.795966785	smg_residual.c(287)

```
openss>>
```

Statement in Program that took the most time

You can manipulate the windows within the GUI and double click functions or statements to see the source code directly.



Double click to open source window

Use window controls to split/arrange windows

Selected performance data point

Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: smg2000 Host: localhost.localdomain Processes/T

```
Exclusive CPU time i  % of CPU Time   Statement Location (I
2.500000000           29.655990510    smg_residual.c(289)
0.870000000           10.320284698    cyclic_reduction.c(113
0.640000000           7.591933571     cyclic_reduction.c(910
0.640000000           7.591933571     cyclic_reduction.c(998
0.600000000           7.117437722     smg_residual.c(238)
0.320000000           3.795966785     smg_residual.c(287)
0.270000000           3.202846975     semi_restrict.c(262)
0.210000000           2.491103203     topo_unity_componen
```

Exclusive C /home/jeg/DEMOS/demos/mpi/openmpi-1.4.2/smg2000/struct_ls/smg_residual.c

```
           281                  hypre_BoxLoop3Begin(loop_size,
           282                                      A_data_box, start, base_stride, Ai,
           283                                      x_data_box, start, base_stride, xi,
           284                                      r_data_box, start, base_stride, ri);
           285 #define HYPRE_BOX_SMP_PRIVATE loopk,loopi,loopj,Ai,xi,ri
           286 #include "hypre_box_smp_forloop.h"
0.320000   287                  hypre_BoxLoop3For(loopi, loopj, loopk, Ai, xi, ri)
           288                     {
>> 2.500   289                        rp[ri] -= Ap[Ai] * xp[xi];
           290                     }
0.010000   291                  hypre_BoxLoop3End(Ai, xi, ri);
           292               }
           293            }
```

```
Processes:  Rank     Process Sets              PID           Rank   Thread
-30947      0        ⊟-Dynamic Process Set
-30948      1          ⊟-All                   All
                       ⊟-Disconnected          Disconnected
```

4 How to Gather and Understand Profiles

A profile is the aggregated measurements collected during the experiment. Profiles look at code sections over time. There are advantages to using profiles since they reduce the size of performance data and typically the data is collected with low overhead. So profiles can provide a good overview of the performance of an application.

The disadvantage of using a profile is that you are required to know beforehand how to aggregate the data collected. Also, since profiles provide more of an overview, they omit the performance details of individual events. There could also be an issue where selecting an inappropriate sampling frequency could skew the results of the profile.

Statistical Performance Analysis is a standard profiling technique, it involves interrupting the execution of the application in periodic intervals to record the location of the execution (Program Counter value). It can also be used to collect additional data like stack traces or hardware counters. Again the advantage of this method is its low overhead. It is good for getting an overview of the program and finding the hotspots (time intensive areas) within the program.

4.1 Program Counter Sampling Experiment

The sampling experiments available in Open|SpeedShop include Program Counter Sampling, Call Path Profiling and Hardware Counter. The Program Counter Sampling experiment (osspcsamp) provides approximate CPU time for each line and function in the program. The Call Path Profiling experiment (ossusertime) provides inclusive vs. exclusive CPU time (see section 4.2), and also includes call stacks. There is a number of Hardware Counter experiments (osshwc, osshwctime) that sample hardware counter overflows and osshwcsamp that can periodically sample up to six hardware counter events.

A flat profile will answer the basic question: “Where does my code spend its time?”. This will be displayed as a list of code elements with varying granularity, i.e. statements, functions and libraries (linked objects), with the time spent at each function. Flat profiling can be done through sampling, which allows us to avoid the overhead of direct measurements. We must ensure we request a sufficient number of samples (sampling rate) to get an accurate result.

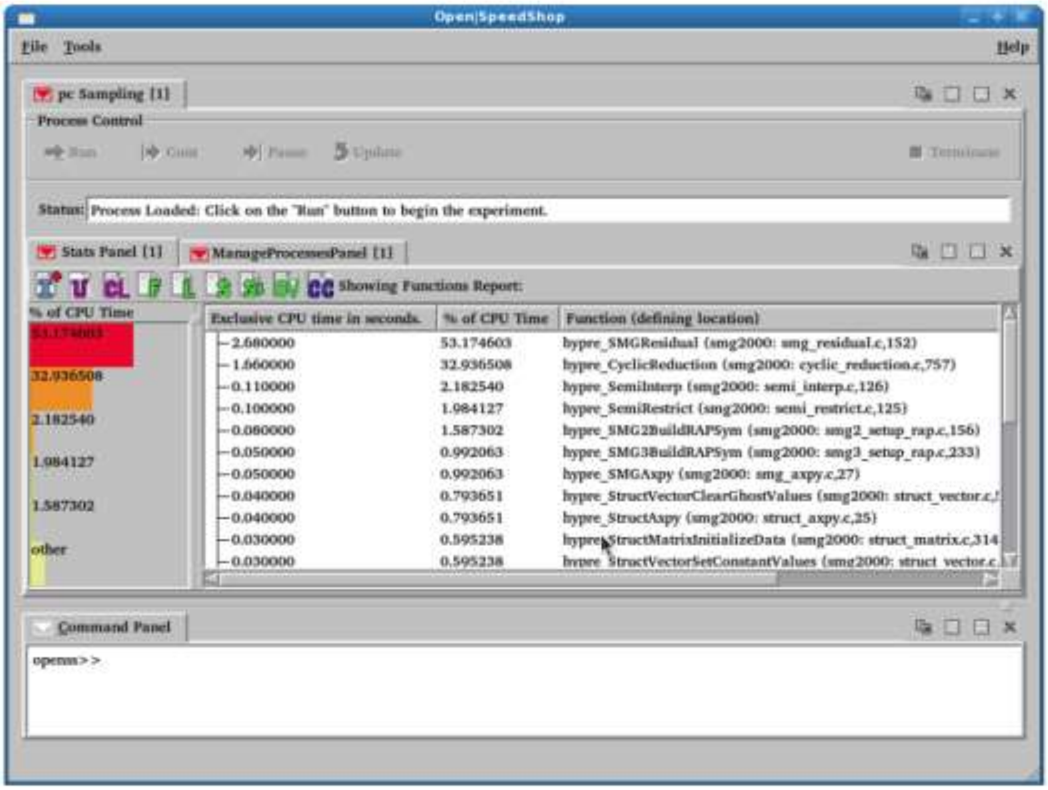
An example of flat profiling would be running the program counter sampling in Open|SpeedShop. We will run the convenience script on our test program smg2000:

```
> osspcsamp “mpirun –np 256 smg2000 –n 50 50 50”
```

It is recommended that you compile your code with the –g option in order to see the statements in the sampling. The pcsamp experiment also takes a sampling frequency as an optional parameter, the available parameters are high (200 samples per second), low (50 samples per second) and the default value is 100 samples per second. If we wanted to run the same experiment with the high sampling rate we would simply issue the command:

```
> osspcsamp “mpirun –np 256 smg2000 –n 50 50 50” high
```

We can view the results of this flat profile in the Open|SpeedShop GUI by using the “openss –f <database filename>” command.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Functions Report:

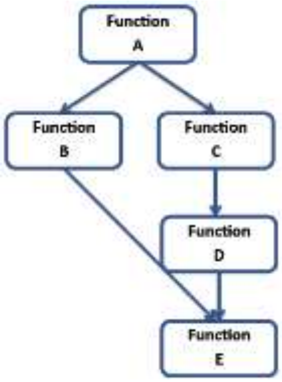
Exclusive CPU time in seconds.	% of CPU Time	Function (defining location)
2.680000	53.174603	hypre_SMGResidual (smg2000: smg_residual.c,152)
1.660000	32.936508	hypre_CyclicReduction (smg2000: cyclic_reduction.c,757)
0.110000	2.182540	hypre_SemiInterp (smg2000: semi_interp.c,126)
0.100000	1.984127	hypre_SemiRestrict (smg2000: semi_restrict.c,125)
0.080000	1.587302	hypre_SMG2BuildRAPSym (smg2000: smg2_setup_rap.c,156)
0.050000	0.992063	hypre_SMG3BuildRAPSym (smg2000: smg3_setup_rap.c,233)
0.050000	0.992063	hypre_SMGAxpy (smg2000: smg_axpy.c,27)
0.040000	0.793651	hypre_StructVectorClearGhostValues (smg2000: struct_vector.c,
0.040000	0.793651	hypre_StructAxpy (smg2000: struct_axpy.c,25)
0.030000	0.595238	hypre_StructMatrixInitializeData (smg2000: struct_matrix.c,314
0.030000	0.595238	hypre_StructVectorSetConstantValues (smg2000: struct_vector.c,

We can use this information to identify the critical regions. The profile shows computationally intensive code regions by displaying the time spent per function or per statement. While viewing this we must ask ourselves:

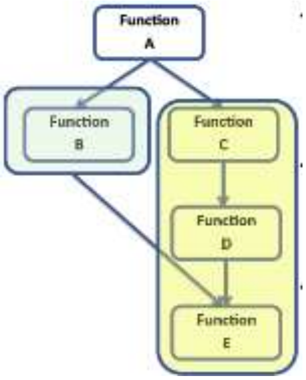
- “Are those the functions/statements that we expected to be taking the most time?”
- “Does this match the computational kernels?”
- “Are any runtime functions taking a lot of time?”

We want to identify any components that are bottlenecks. We can do this by viewing the profile aggregated by shared (linked) objects, making sure the correct or expected modules are present, then analyze the impact of those support and/or runtime libraries.

4.2 Call Path Profiling (usertime) Experiment



The call path profiling (usertime) experiment can add some information that is missing from the flat profiles. It is able to distinguish routines called from multiple callers, and understand the call invocation history. This provides context for the performance data. It also gathers stack traces for each performance sample and only aggregates samples with equal stack traces. For the user, this simplifies the view by showing the caller/callee relationship. It can also highlight the hot call paths, the paths through the application that take the most time.



The call path profiling experiment also provides inclusive and exclusive time. Exclusive time is the time spent inside a function only, for example function B. Whereas inclusive time is the time spend inside a function and its children, for example the full chain of function C, D and E.

The call path profiling experiment is similar to the program counter sampling experiment since it collects program counter information, except that it collects call stack information at every sample. There are, of course, tradeoffs with that, you obtain additional context information from the call stacks but there is now a higher overhead and necessarily lower sampling rate.

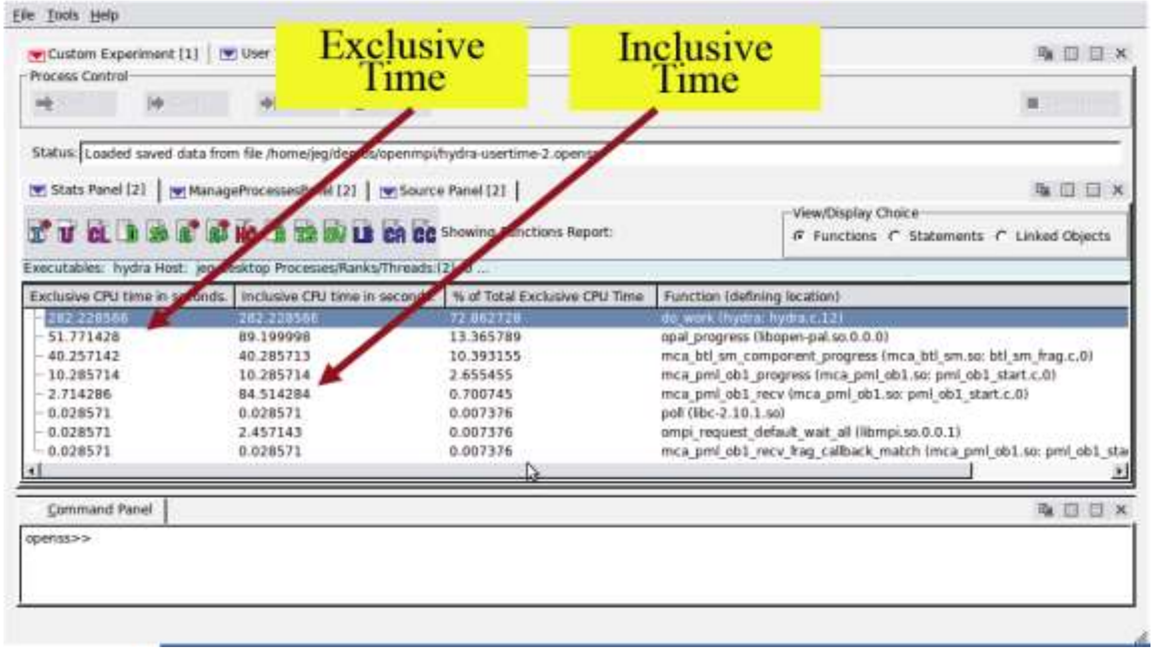
We can run the call path profiling experiment using the Open|SpeedShop convenience script on our test program smg2000:

```
> ossusertime “mpirun –np 256 smg2000 –n 50 50 50”
```

Again it is recommended that you compile your code with the –g option in order to see the statements in the sampling. The usertime experiment also takes a sampling frequency as an optional parameter, the available parameters are high (70 samples per second), low (18 samples per second) and the default value is 35 samples per second. Note that these sample rates are lower then the pcsamp experiment because of the increased amount of data being collected. If we wanted to run the same experiment with the low sampling rate we would simply issue the command:

```
> ossusertime “mpirun –np 256 smg2000 –n 50 50 50” low
```

We can view the results of this experiment in the Open|SpeedShop GUI. The view is similar to the pcsamp view but this time the inclusive CPU time is also shown.



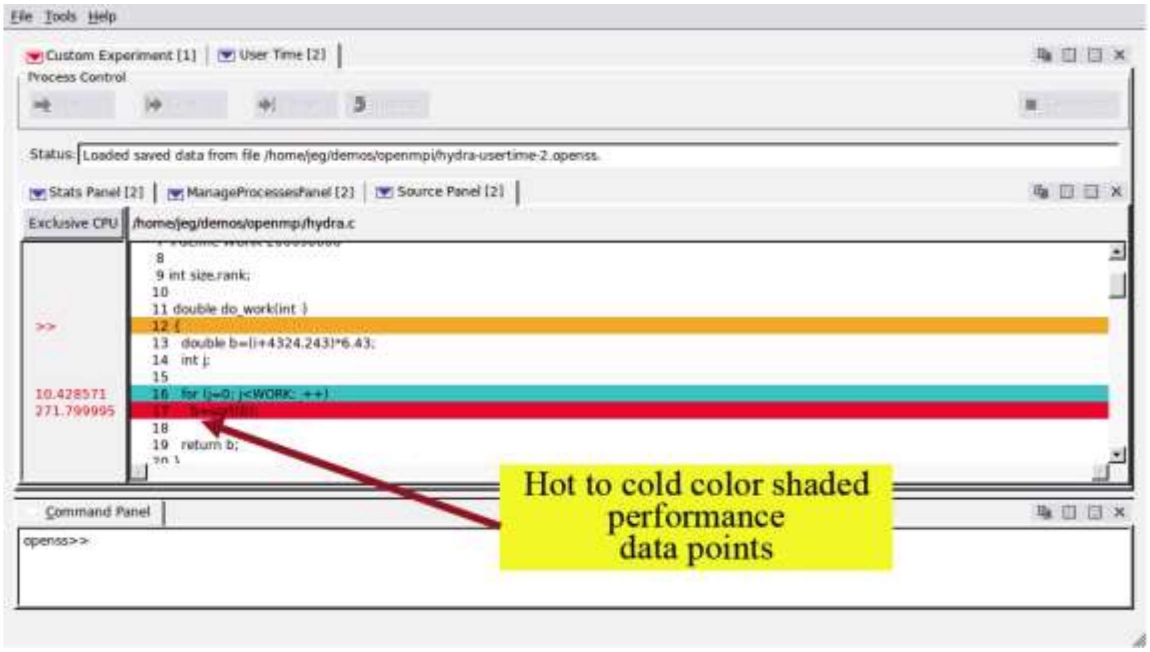
Status: Loaded saved data from file /home/jeg/demos/openmpi/hydra-usertime-2.openss

Executables: hydra Host: jeg-desktop Processes/Ranks/Threads:[2] 0 ...

Exclusive CPU time in seconds.	Inclusive CPU time in seconds.	% of Total Exclusive CPU Time	Function (defining location)
282.228566	282.228566	72.862728	do_work (hydra: hydra.c,12)
51.771428	89.199998	13.365789	opal_progress (libopen-pal.so.0.0.0)
40.257142	40.285713	10.393155	mca_btl_sm_component_progress (mca_btl_sm.so: btl_sm_frag.c,0)
10.285714	10.285714	2.655455	mca_pml_ob1_progress (mca_pml_ob1.so: pml_ob1_start.c,0)
2.714286	84.514284	0.700745	mca_pml_ob1_recv (mca_pml_ob1.so: pml_ob1_start.c,0)
0.028571	0.028571	0.007376	poll (libc-2.10.1.so)
0.028571	2.457143	0.007376	ompi_request_default_wait_all (libmpi.so.0.0.1)
0.028571	0.028571	0.007376	mca_pml_ob1_recv_frag_callback_match (mca_pml_ob1.so: pml_ob1_sta

```
openss>>
```

Below we see the Exclusive CPU time on highlighted lines that indicate relatively high CPU times.



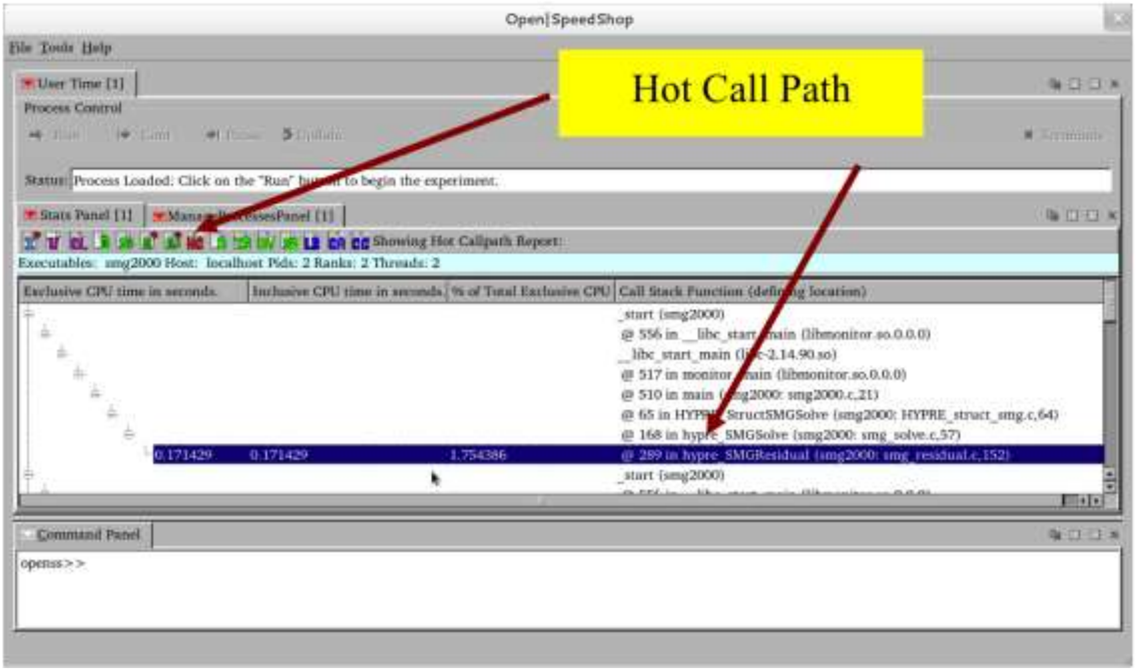
Status: Loaded saved data from file /home/jeg/demos/openmpi/hydra-usertime-2.openss.

/home/jeg/demos/openmp/hydra.c

```
                 
                 int size,rank;
                 
                 double do_work(int )
>>               {
                   double b=(i+4324.243)*6.43;
                   int j;
                 
10.428571          for (j=0; j<WORK; j++)
271.799995           b=sqrt(b);
                 
                   return b;
```

```
openss>>
```

While performance tools will point out potential bottlenecks and hot areas it is still up to the user to interpret most data in the correct context as well as note areas of the code you may want to probe further. If the inclusive and exclusive times are similar this means the child executions are insignificant (with respect to CPU time) and it may not be useful to profile below this layer. If the inclusive time is significantly greater then the exclusive time then you should focus your attention to the execution times of the children.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

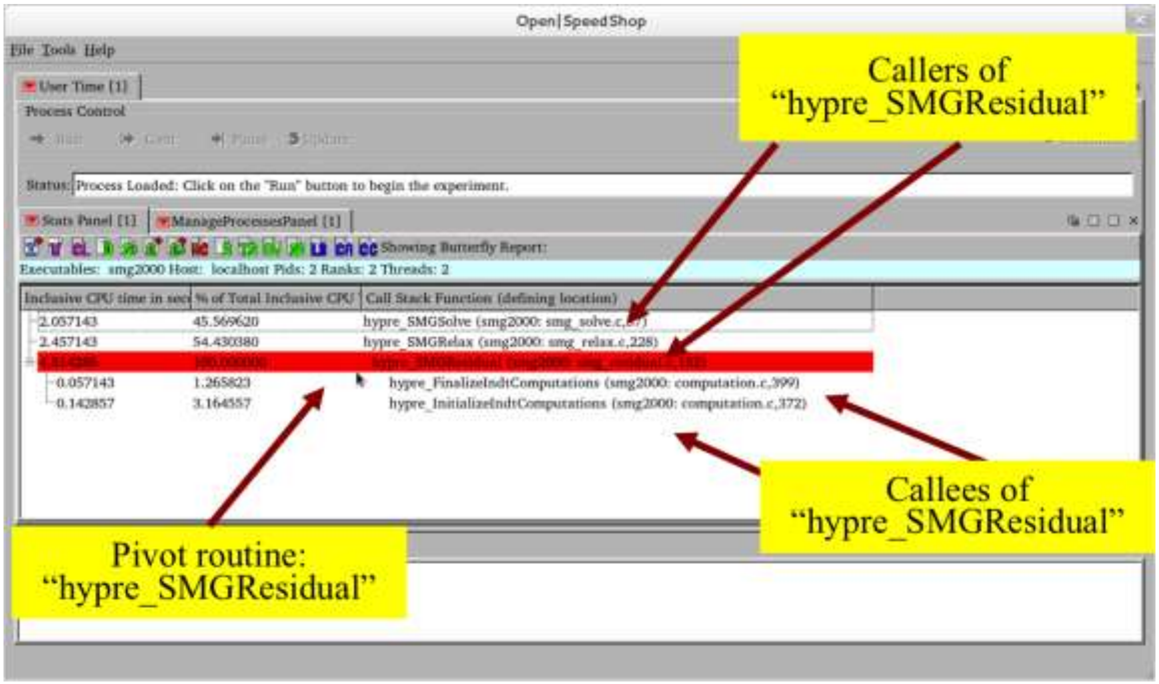
Showing Hot Callpath Report:

Executables: smg2000 Host: localhost Pids: 2 Ranks: 2 Threads: 2

Exclusive CPU time in seconds.	Inclusive CPU time in seconds.	% of Total Exclusive CPU	Call Stack Function (defining location)
			_start (smg2000)
			@ 556 in __libc_start_main (libmonitor.so.0.0.0)
			__libc_start_main (libc-2.14.90.so)
			@ 517 in monitor_main (libmonitor.so.0.0.0)
			@ 510 in main (smg2000: smg2000.c,21)
			@ 65 in HYPRE_StructSMGSolve (smg2000: HYPRE_struct_smg.c,64)
			@ 168 in hypre_SMGSolve (smg2000: smg_solve.c,57)
0.171429	0.171429	1.754386	@ 289 in hypre_SMGResidual (smg2000: smg_residual.c,152)
			_start (smg2000)

```
openss>>
```

The stack trace views in Open|SpeedShop are similar to the well-known Unix profiling tool gprof.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Butterfly Report:

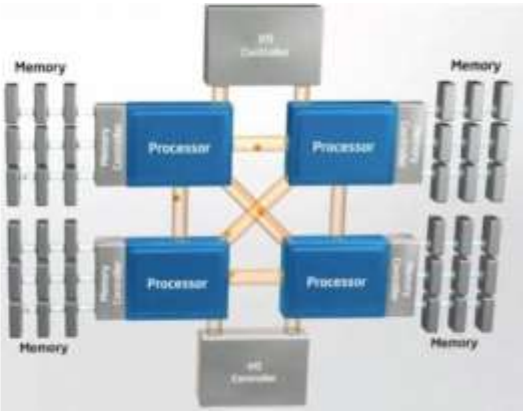
Executables: smg2000 Host: localhost Pids: 2 Ranks: 2 Threads: 2

Inclusive CPU time in seco	% of Total Inclusive CPU	Call Stack Function (defining location)
2.057143	45.569620	hypre_SMGSolve (smg2000: smg_solve.c,57)
2.457143	54.430380	hypre_SMGRelax (smg2000: smg_relax.c,228)
[illegible]	100.000000	hypre_SMGResidual (smg2000: smg_residual.c,152)
0.057143	1.265823	hypre_FinalizeIndtComputations (smg2000: computation.c,399)
0.142857	3.164557	hypre_InitializeIndtComputations (smg2000: computation.c,372)

5 How to Relate Data to Architectural Properties

So far we have been focusing mostly on timing. Timing information shows where your code spends its time by displaying hot functions/statements/libraries and hot call paths. But it doesn't show you why it is spending so much time in those areas. You need to know if the computationally intensive parts of the code are as efficient as they can be to reduce the time spent there or if there are resources that are constraining the execution of the code. These answers can be very platform dependent. Areas of bottlenecks can differ from system to system, and portability issues can cause a drop in performance. There may be a need to tune your code based on the architectural parameters of the system. In order to do this we will investigate the interaction between the application and the hardware to make sure there is an efficient use of hardware resources.

Modern memory system are complex, they can have deep hierarchies and explicitly managed memory. Systems can implement Non-Uniform Memory Access (NUMA) or streaming/prefetching methods. The key to memory is location. Are you accessing the same data repeatedly or are you accessing neighboring data. You will want to look at your codes read/write intensity, the prefetch efficiency, the cache miss rate at all levels, TLB miss rates and the overhead from NUMA.



Some system differences can affect the computational intensity like the cycles per instruction (CPI) or the number of floating point instructions. Other architectural features that can differ between systems include branches, the number of branches taken, the miss speculation or wrong branch prediction results.

If your code is using anything like single instruction multiple data (SIMD), any type of multimedia or streaming extensions the performance of all of these things could differ greatly from system to system.

General system-wide information including I/O busses, network counters, also power or temperature sensors; all could affect the performance of your code. But it can be difficult to relate this information to your source code.

Hardware performance counters are used to keep track of architectural features. Typically most features that are packaged inside the CPU allow counting hardware events transparently without any overhead. Newer platforms also provide system counters on things like network cards and switches or environmental sensors.

The drawback to hardware counters is that their availability differs between platforms and processor types. Even systems that allow the same counters may have slight semantic differences between platforms. In some cases access to hardware counters may require privileged access or kernel patches.

Performance Application Programming Interface (PAPI) allows access to hardware counters through APIs and simple runtime tools. You can find more information on PAPI at http://icl.cs.utk.edu/papi.

Open|SpeedShop provides three hardware counter experiments that are implemented on top of PAPI. It provides access to PAPI and native counters like data cache misses, TLB misses and bus accesses.

There are a few basic models to follow in hardware counter experiments. The first is thresholding, where the user selects a counter and the application runs until a fixed number of events have been reached on that counter. Then a PC sample is taken at that location every time the counter increases by the preset fixed number. The ideal threshold, the fixed number at which to monitor, is dependent on the application. Another model is a timer based sampling where the counters are checked at given time intervals.

Open|SpeedShop provides three hardware counter experiments, hwc for flat hardware counter profiles using a single hardware counter, hwctime for profiles with stack traces using a single hardware counter and hwcsamp for PC sampling with multiple hardware counters. Both osshwc and osshwctime support non-derived PAPI presets, all non-derived events are reported by “papi_avail –a”. You can also see the available events by running the experiments (osshwc or osshwctime) with no arguments. The experiments include all native events for that specific architecture. Some PAPI event names are listed in sections below, but please see the PAPI documentation for the full list.

The threshold you choose depends on the application, you want to balance overhead with accuracy. Remember a higher threshold will record less samples. Rare events need a smaller threshold or that information may be lost (never triggered and recorded). Frequent events should use a larger threshold, to reduce the overhead of collecting the information. Selecting the right threshold can take experience or some trial and error.

HINT: Running the sampling based hardware counter experiment, osshwcsamp, can help you get an idea for a threshold value to try when running the osshwc and osshwctime experiments which are threshold based. Since the ideal number of events (threshold) depends on the application and the selected counter, for events other than the default, the hwcsamp experiment can be used to get an overview of counter activity.

The default threshold is set to a very large value to match the default event (PAPI_TOT_CYC). For all other events, it is recommended that the user run hwcsamp first to get an idea of how many times a particular event occurs (the count of the event) during the life of the program. A reasonable threshold can be determined from the hwcsamp data by determining the average counts per thread of execution and then setting the hwc/hwctime threshold to some small fraction of that. For example, if you see 1333333333 PAPI_L1_DCM's over the life of the program when running the hwcsamp experiment and there were 524 processes used during the application run, the this is the formula you could use to find a reasonable threshold for the hwc and hwctime experiments when using the PAPI_L1_DCM event for the same application. So the formula that could be used is as follows:

> (Average counts per thread) / 1000 == Threshold for hwc/hwctime
> In this case:
> (1333333333/524)/1000 == 2544529/1000 == 2545

Using this formula one could use 2545 as the threshold value in hwc and hwctime for PAPI_L1_DCM and expect to get a reasonable data sample of that event.

5.1 Hardware Counter Sampling (hwcsamp) Experiment

The osshwcsamp experiment supports both derived and non-derived PAPI presets and is able to sample up to six counters at one time. Again you can check the available counters by running osshwcsamp with no arguments. All native events are available including architecture specific events listed in the PAPI documentation. Native events are also reported by papi_native_avail.

The hardware counter sampling experiment uses a sampling rate (instead of the threshold used in the previous experiments). But like the threshold, the sampling rate is depended on the application and must be balanced between overhead and accuracy. In this case the lower the sampling rate the less samples recorded.

The convenience script for this is experiment is:

```
> osshwcsamp “mpirun –np 256 smg2000 –n 50 50 50” <event_list> <sampling_rate>
```

Note if a counter does not appear in the output, there may be a conflict in the hardware counters. To find conflicts use

```
> papi_event_chooser PRESET <list_of_events>
```

Here is a list of some possible hardware counter combinations to use (list provided by Koushik Ghosh, LLNL).

For **Xeon** processors:	
PAPI_FP_INS, PAPI_LD_INS, PAPI_SR_INS	Load store info, memory bandwidth

	needs
PAPI_L1_DCM, PAPI_L1_TCA	L1 cache hit/miss ratios
PAPI_L2_DCM, PAPI_L2_TCA	L2 cache hit/miss ratios
LAST_LEVEL_CACHE_MISSES, LAST_LEVEL_CACHE_REFERENCES	L3 cache info
MEM_UNCORE_RETIRED:REMOTE_DRAM, MEM_UNCORE_RETIRED:LOCAL_DRAM	Local/nonlocal memory access
For **Opteron** processors:	
PAPI_FAD_INS, PAPI_FML_INS	Floating point add multiply
PAPI_FDV_INS, PAPI_FSQ_INS	Square root and divisions
PAPI_FP_OPS, PAPI_VEC_INS	Floating point and vector instructions
READ_REQUEST_TO_L3_CACHE:ALL_CORES, L3_CACHE_MISSES:ALL_CORES	L3 cache

When selecting PAPI events you must determine if they are a valid combination. In general combination that are valid will pass the test:

```
> papi_event_chooser PRESET event1 event2 … eventN
```

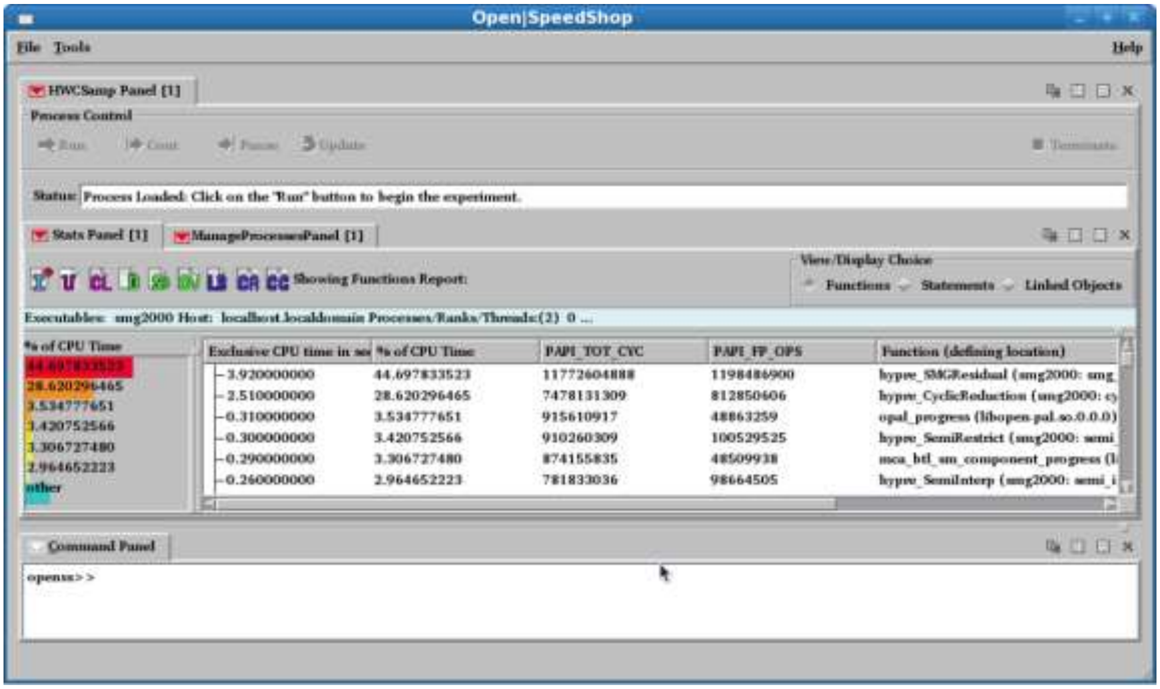
The output for a valid combination will contain:

```
event_chooser.c                    PASSED
```

Here is an example using PAPI to check if a three-event combination is valid.

```
> papi_event_chooser PRESET PAPI_FP_INS PAPI_LD_INS PAPI_SR_INS
--------------------------------------------------------------------------PAPI Version           :4.1.2.1
Vendor string and code        : GenuineIntel (1)
Model string and code         : Intel Nehalem (21)
CPU Revision         : 5.000000
…
…
PAPI_VEC_SP 0x80000069 No Single precision vector/SIMD instructions
PAPI_VEC_DP 0x8000006a No Double precision vector/SIMD instructions
--------------------------------------------------------------------------Total events reported: 44
event_chooser.c                    PASSED
```

Below shows the output of the osshwcsamp experiment with the counters for Total Cycles and Floating Point Operations.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: smg2000 Host: localhost.localdomain Processes/Ranks/Threads:(2) 0 ...

Exclusive CPU time in se	% of CPU Time	PAPI_TOT_CYC	PAPI_FP_OPS	Function (defining location)
3.920000000	44.697833523	11772604888	1198486900	hypre_SMGResidual (smg2000: smg
2.510000000	28.620296465	7478131309	812850606	hypre_CyclicReduction (smg2000: cy
0.310000000	3.534777651	915610917	48863259	opal_progress (libopen-pal.so.0.0.0)
0.300000000	3.420752566	910260309	100529525	hypre_SemiRestrict (smg2000: semi
0.290000000	3.306727480	874155835	48509938	mca_btl_sm_component_progress (l
0.260000000	2.964652223	781833036	98664505	hypre_SemiInterp (smg2000: semi_i

```
openss>>
```

Remember that you do not always need to use the Open|SpeedShop GUI to examine the output of experiments, you can also use the command line interface to view all of the same information. For example the same output from above can be seen on the command line:

```
> openss -cli -f smg2000-hwcsamp-1.openss

openss>>[openss]: The restored experiment identifier is: -x 1

openss>>expview

Exclusive CPU time          % of CPU Time    PAPI_TOT_CYC     PAPI_FP_OPS
Function (defining location) in seconds.
  3.920000000               44.697833523     11772604888 1198486900 hypre_SMGResidual (smg2000:
smg_residual.c,152)
  2.510000000               28.620296465     7478131309       812850606 hypre_CyclicReduction (smg2000:
cyclic_reduction.c, 757)
  0.310000000               3.534777651      915610917          48863259 opal_progress (libopen-
pal.so.0.0.0)
  0.300000000               3.420752566      910260309        100529525 hypre_SemiRestrict (smg2000:
semi_restrict.c,125)
  0.290000000               3.306727480      874155835          48509938 mca_btl...ress (libmpi.so.0.0.2)


openss>>expview -v linkedobjects

Exclusive CPU time           % of CPU Time    PAPI_TOT_CYC     PAPI_FP_OPS LinkedObject in seconds.
  7.710000000                87.315968290    22748513124             2396367480 smg2000
  0.610000000                  6.908267271      1789631493             126423208 libmpi.so.0.0.2
  0.310000000                  3.510758777       915610917                48863259 libopen-pal.so.0.0.0
  0.200000000                  2.265005663       521249939                46127342 libc-2.10.2.so
  8.830000000              100.0                25975005473             2617781289 Report Summary

openss>>
```

5.1.1 Hardware Counter Sampling (hwcsamp) experiment performance data gathering

The hardware counter sampling experiment convenience script is “osshwcsamp”. Use this convenience script in this manner to gather counter values for unique up to six (6) hardware counters:

```
osshwcsamp “how you normally run your application” <papi event list> < sampling rate>
```

5.1.1.1 Hardware Counter Sampling (hwcsamp) experiment parameters

The hwcsamp experiment is timer based not threshold based. What that means is a timer is used to periodically interrupt the processor. For the hwcsamp experiment, each time the timer interrupts the processor, the values of the hardware counter events specified will be read up and reset to 0 for the next timer cycle. This is repeated until the program finishes. Open|SpeedShop allows the user to control the sampling rate.

The following is an example of how to gather data for the smg2000 application on a Linux cluster platform using the osshwcsamp convenience script and specifying a specific set of PAPI hwc events. In the next example the user is choosing to only sample 45 times a second instead of the default 100 times a second. Why would you want to do this? One reason would be to save database size, a lower sampling rate may give an accurate portrayal of the application behavior.

```
> osshwcsamp “mpirun –np 256 smg2000 –n 50 50 50” PAPI_L1_DCM,PAPI_L2_DCA,PAPI_L2_DCM,PAPI_L3_DCA,PAPI_L3_TCM
```

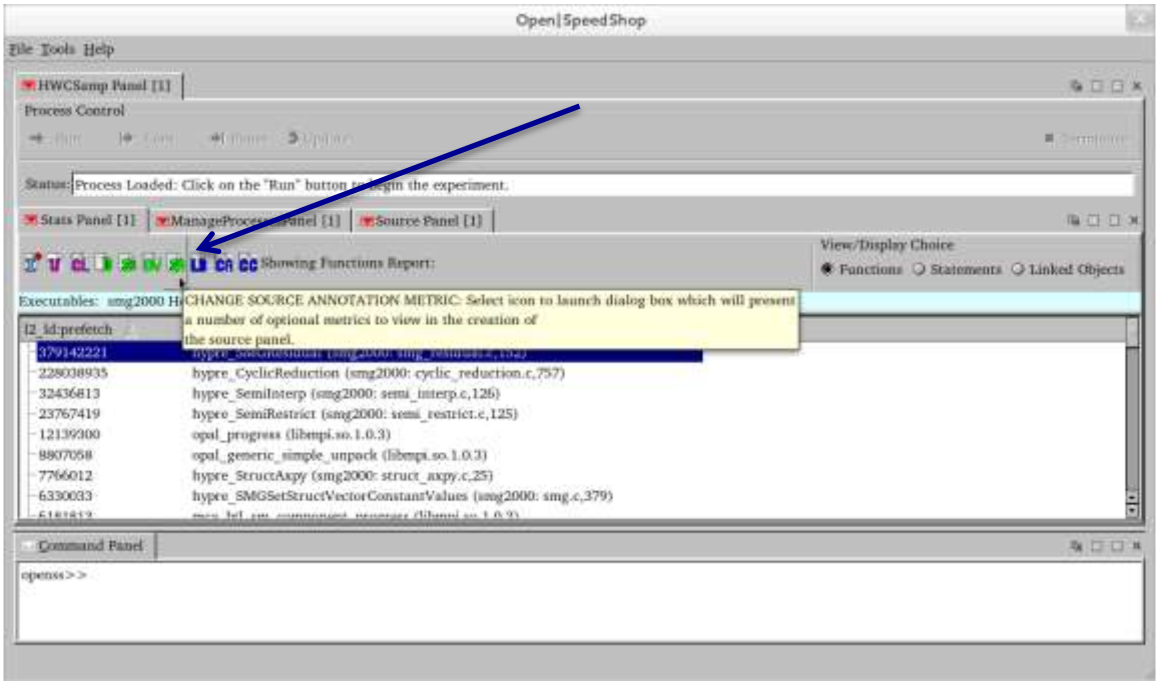
```
> osshwcsamp “mpirun –np 256 smg2000 –n 50 50 50” PAPI_L1_DCM,PAPI_L2_DCA,PAPI_L2_DCM 45
```

5.1.2 Hardware Counter Sampling (hwcsamp) experiment performance data viewing with GUI

To launch the GUI on any experiment, use “openss –f <database name>“.

5.1.2.1 Getting the PAPI counter as the GUIs Source Annotation Metric

In order to make one of the PAPI or native hardware counters the counter that will show up in the source view, one can click on the “SA” icon, which represents Source Annotation. This brings up an option dialogue that allows you to chose the source annotation metric.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Functions Report:

● Functions ○ Statements ○ Linked Objects

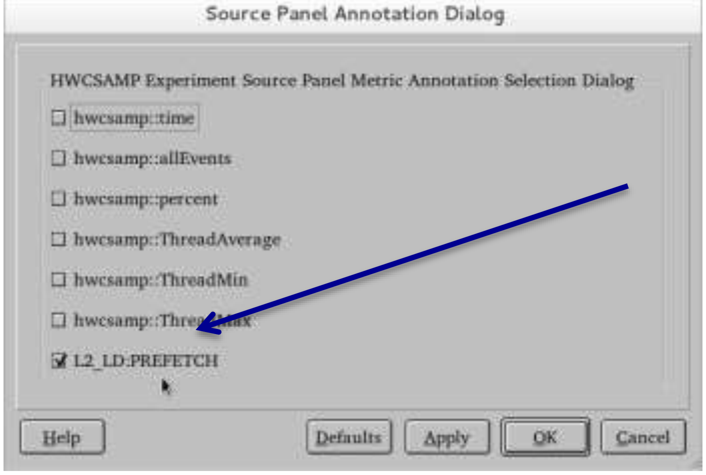
Executables: smg2000 H

CHANGE SOURCE ANNOTATION METRIC: Select icon to launch dialog box which will present a number of optional metrics to view in the creation of the source panel.

```
l2_ld:prefetch
379142221      hypre_SMGResidual (smg2000: smg_residual.c,152)
228038935      hypre_CyclicReduction (smg2000: cyclic_reduction.c,757)
32436813       hypre_SemiInterp (smg2000: semi_interp.c,126)
23767419       hypre_SemiRestrict (smg2000: semi_restrict.c,125)
12139300       opal_progress (libmpi.so.1.0.3)
8807058        opal_generic_simple_unpack (libmpi.so.1.0.3)
7766012        hypre_StructAxpy (smg2000: struct_axpy.c,25)
6330033        hypre_SMGSetStructVectorConstantValues (smg2000: smg.c,379)
```

```
openss>>
```

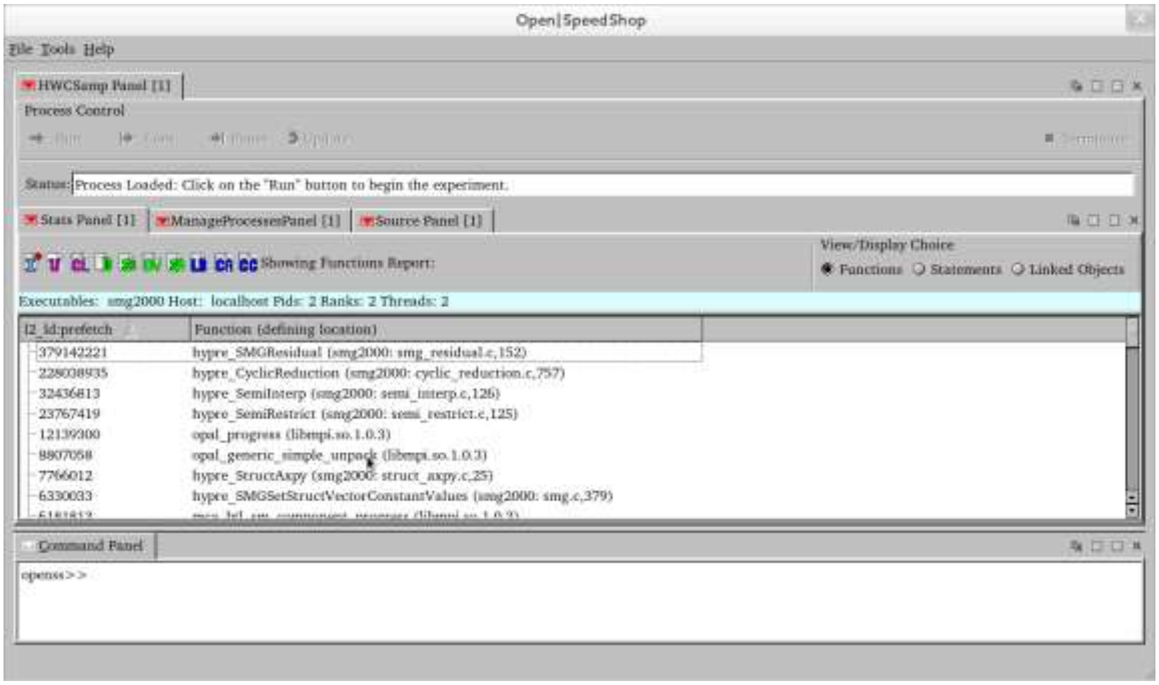
In this example the native counter we want to choose is L2_LD_PREFETCH. When we click to choose that counter and click on "OK" the Stats Panel view will regenerate and the source annotation metric will become L2_LD_PREFETCH.



HWCSAMP Experiment Source Panel Metric Annotation Selection Dialog

☐ hwcsamp::time
☐ hwcsamp::allEvents
☐ hwcsamp::percent
☐ hwcsamp::ThreadAverage
☐ hwcsamp::ThreadMin
☐ hwcsamp::ThreadMax
☑ L2_LD:PREFETCH

The regenerated view now shows the results for only L2_LD:PREFETCH.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Functions Report:

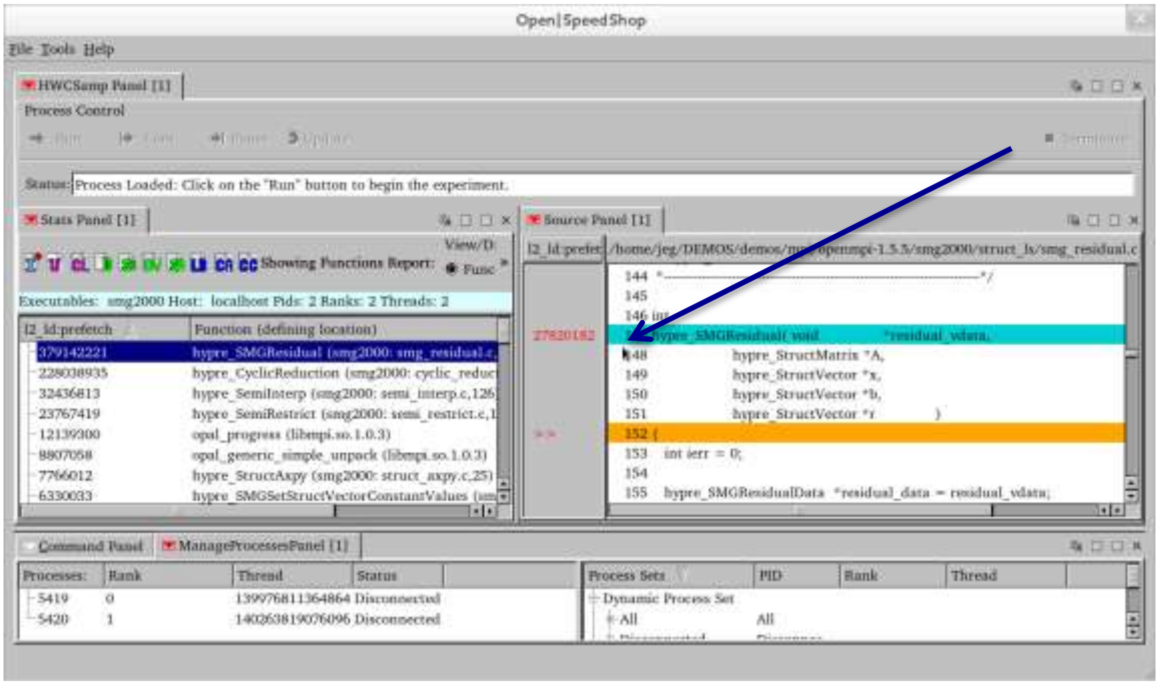
View/Display Choice: ● Functions ○ Statements ○ Linked Objects

Executables: smg2000 Host: localhost Pids: 2 Ranks: 2 Threads: 2

l2_ld:prefetch	Function (defining location)
379142221	hypre_SMGResidual (smg2000: smg_residual.c,152)
228038935	hypre_CyclicReduction (smg2000: cyclic_reduction.c,757)
32436813	hypre_SemiInterp (smg2000: semi_interp.c,126)
23767419	hypre_SemiRestrict (smg2000: semi_restrict.c,125)
12139300	opal_progress (libmpi.so.1.0.3)
8807058	opal_generic_simple_unpack (libmpi.so.1.0.3)
7766012	hypre_StructAxpy (smg2000: struct_axpy.c,25)
6330033	hypre_SMGSetStructVectorConstantValues (smg2000: smg.c,379)

```
openss>>
```

Now double clicking on the Stats Panel result line of choice will focus the source panel and use the PAPI or native counter that was chosen by using the Source Annotation dialog.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Functions Report:

Executables: smg2000 Host: localhost Pids: 2 Ranks: 2 Threads: 2

l2_ld:prefetch	Function (defining location)
379142221	hypre_SMGResidual (smg2000: smg_residual.c,
228038935	hypre_CyclicReduction (smg2000: cyclic_reduc
32436813	hypre_SemiInterp (smg2000: semi_interp.c,126
23767419	hypre_SemiRestrict (smg2000: semi_restrict.c,1
12139300	opal_progress (libmpi.so.1.0.3)
8807058	opal_generic_simple_unpack (libmpi.so.1.0.3)
7766012	hypre_StructAxpy (smg2000: struct_axpy.c,25)
6330033	hypre_SMGSetStructVectorConstantValues (sm

l2_ld:prefet /home/jeg/DEMOS/demos/mpi/openmpi-1.5.5/smg2000/struct_ls/smg_residual.c

```
               144 *-----------------------------------------------------------*/
               145
               146 int
27820182       147 hypre_SMGResidual( void               *residual_vdata,
               148                    hypre_StructMatrix *A,
               149                    hypre_StructVector *x,
               150                    hypre_StructVector *b,
               151                    hypre_StructVector *r            )
>>             152 {
               153    int ierr = 0;
               154
               155    hypre_SMGResidualData *residual_data = residual_vdata;
```

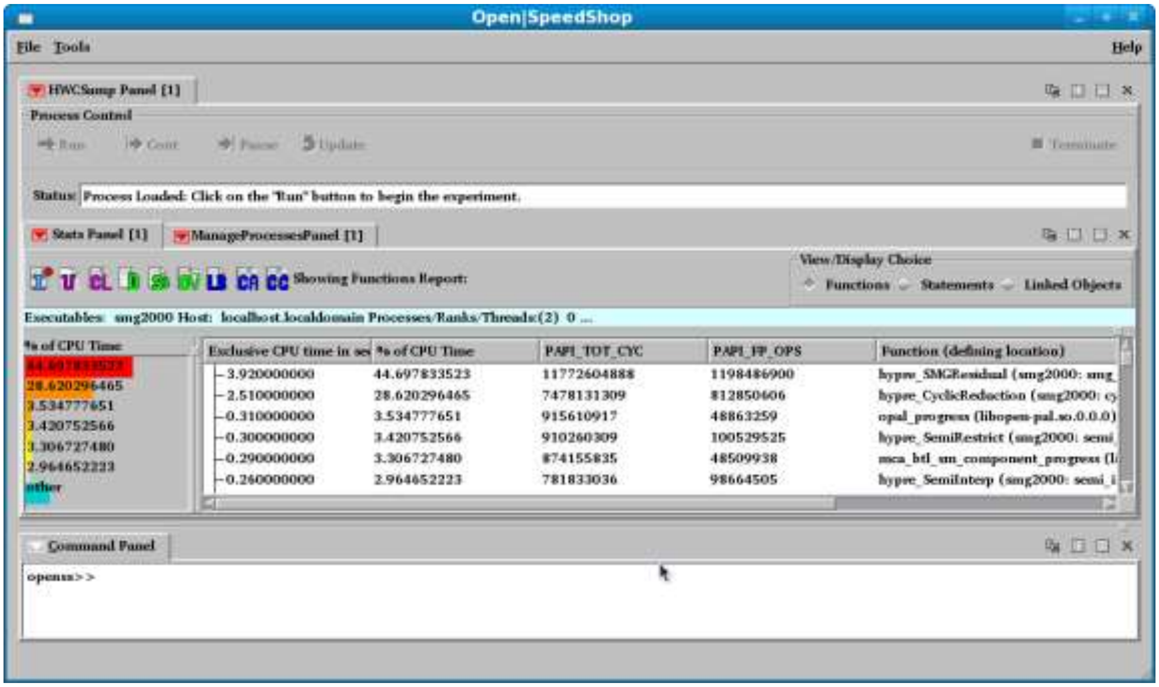
Processes:	Rank	Thread	Status
5419	0	139976811364864	Disconnected
5420	1	140263819076096	Disconnected

Process Sets	PID	Rank	Thread
Dynamic Process Set			
All	All		

5.1.2.2 Viewing Hardware Counter Sampling Data with the GUI

To launch the GUI on any experiment, use “openss –f <database name>“.

The GUI view below represents an example of the default view for the hardware counter sampling (hwcsamp) experiment. In the default view the first set of performance data shown is program counter exclusive time (where the program is statistically spending its time) and the percentage of time spent in each function of the program. The next information is the hardware counter event counts listed in columns by the hardware counter event. Column three represents the counts that were recorded for PAPI_TOT_CYC and column four represents the counts for PAPI_FP_OPS. What this view can indicate to the viewer is whether or not the specified hardware counter events are occurring and if they are, then how prevalent are they. With this information the user could isolate down to see exactly where a particular event is occurring by using the hwc or hwctime experiment These two experiments are threshold based. Which ultimately means you can map the performance data back to the source because the actual event triggered the recording of the counts of the event. This experiment, hwcsamp, is timer based, so Open|SpeedShop cannot take you exactly to the line of source where the hwc events are happening. hwcsamp is more of an overview experiment that tells the user which events are occurring to subsequently use hwc or hwctime to pinpoint where in the source the specified hardware counter event is occurring.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: smg2000 Host: localhost.localdomain Processes/Ranks/Threads:(2) 0 ...

Exclusive CPU time in se	% of CPU Time	PAPI_TOT_CYC	PAPI_FP_OPS	Function (defining location)
3.920000000	44.697833523	11772604888	1198486900	hypre_SMGResidual (smg2000: smg_
2.510000000	28.620296465	7478131309	812850606	hypre_CyclicReduction (smg2000: cy
0.310000000	3.534777651	915610917	48863259	opal_progress (libopen-pal.so.0.0.0)
0.300000000	3.420752566	910260309	100529525	hypre_SemiRestrict (smg2000: semi_
0.290000000	3.306727480	874155835	48509938	mca_btl_sm_component_progress (li
0.260000000	2.964652223	781833036	98664505	hypre_SemiInterp (smg2000: semi_i

```
openss>>
```

5.1.3 Hardware Counter Sampling (hwcsamp) experiment performance data viewing

To launch the CLI on any experiment, use “openss –cli –f <database name>“. The following example was run on the Yellowstone platform at NCAR/UCAR using the job script shown below.

5.1.3.1 Job Script and osshwcsamp command

```
#!/bin/csh
#
# LSF batch script to run an MPI application
#
#BSUB -P Pnnnnnnnn          # project code
#BSUB -W 00:30               # wall-clock time (hrs:mins)
#BSUB -n 64                  # number of tasks in job
#BSUB -R "span[ptile=4]"    # run 4 MPI tasks per node
#BSUB -J sweep3d-hwcsamp             # job name
#BSUB -o sweep3d-hwcsamp.%J.out       # output file name in which %J is replaced by the job ID
#BSUB -e sweep3d-hwcsamp.%J.err       # error file name in which %J is replaced by the job ID
#BSUB -q regular           # queue

module load openspeedshop

mkdir -p /glade/scratch/${USER}/sweep3d
rm -rf /glade/scratch/${USER}/sweep3d/hwcsamp
mkdir /glade/scratch/${USER}/sweep3d/hwcsamp
setenv OPENSS_RAWDATA_DIR /glade/scratch/${USER}/sweep3d/hwcsamp

setenv REQUEST_SUSPEND_HPC_STAT 1

echo "running (on compute node): osshwcsamp"
osshwcsamp "mpirun.lsf /glade/u/home/galaro/demos/sweep3d/orig/sweep3d.mpi"
PAPI_L1_DCM,PAPI_L1_ICM,PAPI_L1_TCM,PAPI_L1_LDM,PAPI_L1_STM
```

5.1.3.2 osshwcsamp experiment CLI Default view

```
openss -cli -f L1-64PE-sweep3d.mpi-hwcsamp.openss
openss>>[openss]: The restored experiment identifier is:  -x 1
openss>>expview -v summary

 Exclusive    % of CPU  papi_l1_dcm  papi_l1_icm  papi_l1_tcm papi_l1_ldm  papi_l1_stm  Function (defining location)
CPU time in Time
seconds.
824.870000   38.689781   8646497071   117738843    8764235914   8396159476  196649065  __libc_poll (libc-2.12.so)
799.300000   37.490443  46691996441   367096209  47059092650 46247555479   281624221  sweep (sweep3d.mpi:
sweep.f,2)
  75.000000    3.517807     782716992     10680760      793397752     757322217     20159725
PAMI::Interface::Context<PAMI::Context>::advance (libpami.so: ContextInterface.h,158)
 55.750000     2.614903     597583047       8038242     605621289
579127274    14647999  LapiImpl::Context::Advance<true, true, false> (libpami.so: Context.h,220)
 52.970000    2.484510    550761926    7569975    558331901 535841812    11563657  __libc_enable_asynccancel (libc-
2.12.so)
 49.850000    2.338169    518605433    6979361    525584794 502551336    12757207  _lapi_dispatcher<false> (libpami.so:
lapi_dispatcher.c,57)
 48.080000    2.255149    488545916    6784192    495330108 476065093     9649598  LapiImpl::Context::TryLock<true, true,
false> (libpami.so: Context.h,198)
 47.750000    2.239671    479947719    6732551    486680270 471343480     6436257  __libc_disable_asynccancel (libc-
2.12.so)
 26.680000    1.251401    275998769    3888499    279887268 269841454     4697170  udp_read_callback (libpamiudp.so:
lapi_udp.c,538)
 25.880000    1.213878   1522697263    12118336   1534815599 1507685061     9619348  __intel_ssse3_rep_memcpy
(libirc.so)
 21.960000    1.030014    223197680     3086626    226284306 215787794     5879517  _lapi_shm_dispatcher (libpami.so:
lapi_shm.c,2283)
```

```
 14.910000    0.699340    154744623    2075688    156820311 149803306    3979337  LapiImpl::Context::CheckContext
(libpami.so: CheckParam.cpp,21)
 13.990000    0.656188    151052863    2000330    153053193 146967548    3167039  LapiImpl::Context::Unlock<true, true,
false> (libpami.so: Context.h,204)
```

5.1.3.2 osshwcsamp experiment CLI Status command and view

```
openss>>expstatus

  Experiment definition
{ # ExpId is 1, Status is NonExistent, Saved database is L1-64PE-sweep3d.mpi-hwcsamp.openss
   Performance data spans 1:7.958138 mm:ss  from 2013/03/27 22:32:45 to 2013/03/27 22:33:53
  Executables Involved:
          sweep3d.mpi
 Currently Specified Components:
   -h ys6128 -p 2765 -t 47176895393312 -r 3 (sweep3d.mpi)
   -h ys6128 -p 2766 -t 47824321252896 -r 0 (sweep3d.mpi)
   -h ys6128 -p 2767 -t 47369830317600 -r 1 (sweep3d.mpi)
   -h ys6128 -p 2768 -t 47378742910496 -r 2 (sweep3d.mpi)
   -h ys6129 -p 22862 -t 47327259860512 -r 5 (sweep3d.mpi)
   -h ys6129 -p 22863 -t 47201888194080 -r 6 (sweep3d.mpi)
   -h ys6129 -p 22864 -t 47185544437280 -r 7 (sweep3d.mpi)
   ...
   -h ys6250 -p 11462 -t 47028080107040 -r 63 (sweep3d.mpi)
   -h ys6250 -p 11463 -t 47600632852000 -r 60 (sweep3d.mpi)
   -h ys6250 -p 11464 -t 47494028697120 -r 61 (sweep3d.mpi)
   -h ys6250 -p 11465 -t 47944527175200 -r 62 (sweep3d.mpi)
 Previously Used Data Collectors:
             hwcsamp
            Metrics:
   hwcsamp::exclusive_detail
       hwcsamp::percent
   hwcsamp::threadAverage
     hwcsamp::threadMax
     hwcsamp::threadMin
         hwcsamp::time
      Parameter Values:
   hwcsamp::event = PAPI_L1_DCM,PAPI_L1_ICM,PAPI_L1_TCM,PAPI_L1_LDM,PAPI_L1_STM
   hwcsamp::sampling_rate =  100
       Available Views:
             hwcsamp
                   }
```

5.1.3.3 osshwcsamp experiment CLI Load Balance command and view

```
openss>>expview -m loadbalance

 Max CPU  Rank    Min CPU  Rank    Average  Function (defining location)
    Time    of      Time    of   CPU Time
  Across   Max     Across   Min     Across
Ranks(s)        Ranks(s)        Ranks(s)
14.890000    28  10.950000    27  12.888594  __libc_poll (libc-2.12.so)
14.270000    47  11.780000    51  12.489062  sweep (sweep3d.mpi: sweep.f,2)
1.620000    43   0.840000    37   1.171875 PAMI::Interface::Context<PAMI::Context>::advance (libpami.so:
ContextInterface.h,158)
1.320000    16   0.570000     3   0.871094 LapiImpl::Context::Advance<true, true, false> (libpami.so: Context.h,220)
1.130000    60   0.500000     2   0.778906 _lapi_dispatcher<false> (libpami.so: lapi_dispatcher.c,57)
1.110000    35   0.520000    49   0.751250 LapiImpl::Context::TryLock<true, true, false> (libpami.so: Context.h,198)
1.030000    42   0.600000    12   0.827656 __libc_enable_asynccancel (libc-2.12.so)
0.950000    62   0.520000    38   0.746094 __libc_disable_asynccancel (libc-2.12.so)
0.700000     6   0.200000    59   0.343125 _lapi_shm_dispatcher (libpami.so: lapi_shm.c,2283)
0.630000    33   0.250000     0   0.404375 __intel_ssse3_rep_memcpy (libirc.so)
0.600000    18   0.270000    16   0.416875  udp_read_callback (libpamiudp.so:
```

5.1.3.4 osshwcsamp experiment CLI Linked Object command and view

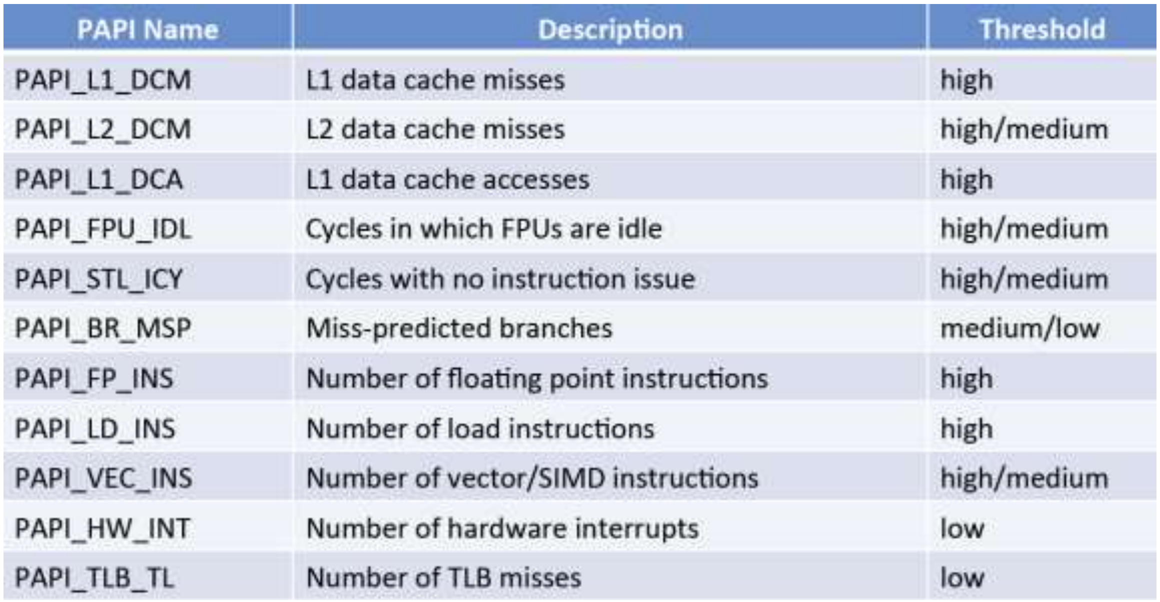
```
openss>>expview -v linkedobjects

 Exclusive    % of CPU  papi_l1_dcm  papi_l1_icm  papi_l1_tcm papi_l1_ldm  papi_l1_stm  LinkedObject
CPU time in Time
seconds.
 928.310000  43.541541   9818946796  133244862   9952191658   9543597734   215608918  libc-2.12.so
 811.920000  38.082373  47212355914  369525459  47581881373 46596204924   441601622  sweep3d.mpi
 311.490000  14.610157   3356646038   44875637   3401521675   3255300343    80090932  libpami.so
  29.640000   1.390237   1824778610   12931604   1837710214   1680978945   127174346  libirc.so
  26.930000   1.263127    287313329    3994016    291307345    281053971     4763152  libpamiudp.so
  22.250000   1.043616   1049603690    9037920   1058641610   1033650896    11422120  libpthread-2.12.so
   1.440000   0.067542     72649683     620083     73269766     71327993     1007704  libmpich.so.3.3
   0.020000   0.000938      1286256      23770      1310026      1232178        5222  ld-2.12.so
   0.010000   0.000469          327        394          721          313          13  librt-2.12.so
2132.010000 100.000000  63623580643  574253745  64197834388 62463347297   881674029  Report Summary
openss>>
```

5.2 Hardware Counter Experiment (hwc)

As an example we will run the osshwc experiment on our test program smg2000. The convenience script for this is experiment is:

```
> osshwc “mpirun –np 256 smg2000 –n 50 50 50” <counter> <threshold>
```

This is the same syntax as the osshwctime experiment. Note that if your output is empty, try lowering the <threshold> value, it is calculated by Open|SpeedShop by default. You can try lowering the threshold value if there have not been enough PAPI event occurrences to record. Also see the HINT in the osshwcsamp section above. You can run osshwcsamp and use a formula to create a reasonable threshold. Any counter reported by “papi_avail –a” that is not derived is available for use. You can also see the available counters by using the osshwc or osshwctime commands with no arguments. Native counters are listed in the PAPI documentation.



PAPI Name	Description	Threshold
PAPI_L1_DCM	L1 data cache misses	high
PAPI_L2_DCM	L2 data cache misses	high/medium
PAPI_L1_DCA	L1 data cache accesses	high
PAPI_FPU_IDL	Cycles in which FPUs are idle	high/medium
PAPI_STL_ICY	Cycles with no instruction issue	high/medium
PAPI_BR_MSP	Miss-predicted branches	medium/low
PAPI_FP_INS	Number of floating point instructions	high
PAPI_LD_INS	Number of load instructions	high
PAPI_VEC_INS	Number of vector/SIMD instructions	high/medium
PAPI_HW_INT	Number of hardware interrupts	low
PAPI_TLB_TL	Number of TLB misses	low

Note the Threshold indications are just for rough guidance and are dependent on the application. Also remember that not all counters will exist on all platforms, run osshwc with no arguments to see the available hardware counters available.

In the sections below, we show the outputs from the osshwc experiment, note that the default counter is the total cycles.

5.2.1 Hardware Counter Threshold (hwc) experiment performance data gathering

The hardware counter threshold experiment convenience script is “osshwc”. Use this convenience script in this manner to gather counter values for one unique hardware counter:

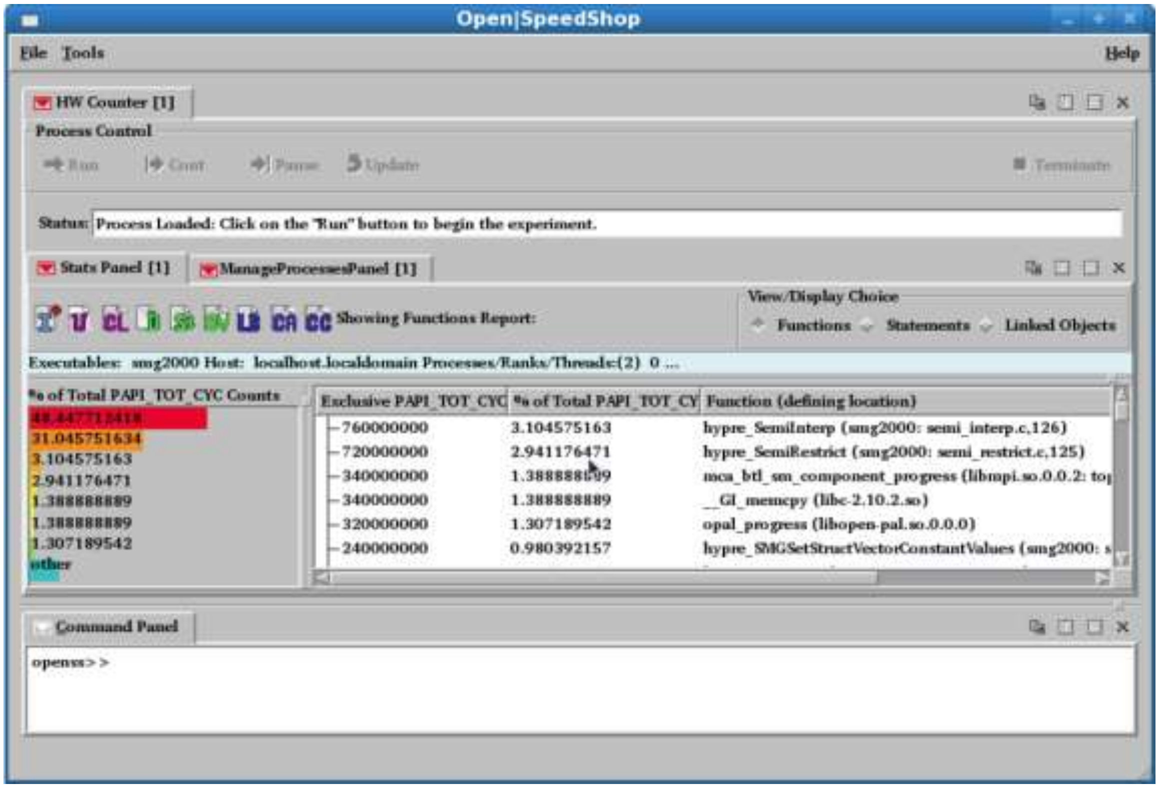
```
osshwc “how you normally run your application” <papi event > < threshold value>
```

tbd

5.2.2 Hardware Counter Threshold (hwc) experiment performance data viewing with GUI

To launch the GUI on any experiment, use “openss –f <database name>“.

This image shows the default view for the hwc experiment run with the smg2000 MPI application using PAPI_TOT_CYC as the hardware counter event. Double clicking on a line in the Stats Panel or on the bar chart will take the user to the source file and line represented by that line of performance information.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Functions Report:

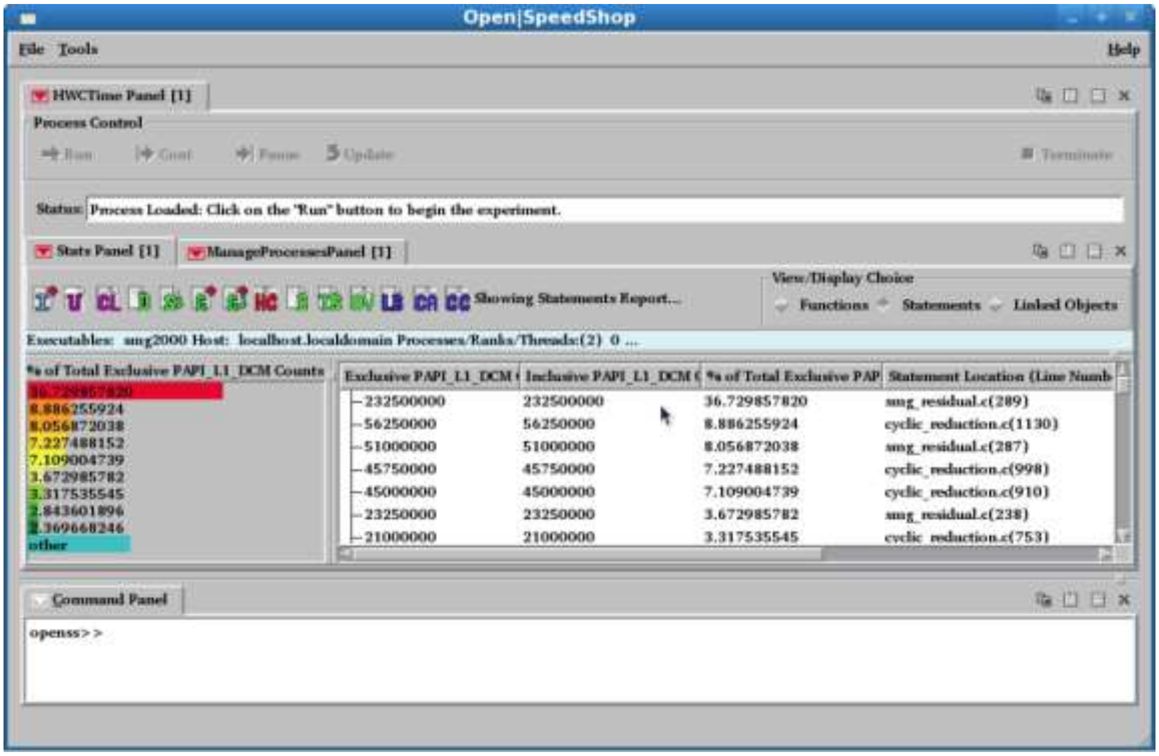
Executables: smg2000 Host: localhost.localdomain Processes/Ranks/Threads:(2) 0 ...

% of Total PAPI_TOT_CYC Counts
48.447712418
31.045751634
3.104575163
2.941176471
1.388888889
1.388888889
1.307189542
other

Exclusive PAPI_TOT_CYC	% of Total PAPI_TOT_CY	Function (defining location)
760000000	3.104575163	hypre_SemiInterp (smg2000: semi_interp.c,126)
720000000	2.941176471	hypre_SemiRestrict (smg2000: semi_restrict.c,125)
340000000	1.388888889	mca_btl_sm_component_progress (libmpi.so.0.0.2: to
340000000	1.388888889	__GI_memcpy (libc-2.10.2.so)
320000000	1.307189542	opal_progress (libopen-pal.so.0.0.0)
240000000	0.980392157	hypre_SMGSetStructVectorConstantValues (smg2000: s

```
openss>>
```

The next image displays the output from the osshwctime experiment where the counter is the L1 cache misses.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Statements Report...

Executables: smg2000 Host: localhost.localdomain Processes/Ranks/Threads:(2) 0 ...

% of Total Exclusive PAPI_L1_DCM Counts
36.729857820
8.886255924
8.056872038
7.227488152
7.109004739
3.672985782
3.317535545
2.843601896
2.369668246
other

Exclusive PAPI_L1_DCM (	Inclusive PAPI_L1_DCM (	% of Total Exclusive PAP	Statement Location (Line Numb
232500000	232500000	36.729857820	smg_residual.c(289)
56250000	56250000	8.886255924	cyclic_reduction.c(1130)
51000000	51000000	8.056872038	smg_residual.c(287)
45750000	45750000	7.227488152	cyclic_reduction.c(998)
45000000	45000000	7.109004739	cyclic_reduction.c(910)
23250000	23250000	3.672985782	smg_residual.c(238)
21000000	21000000	3.317535545	cyclic_reduction.c(753)

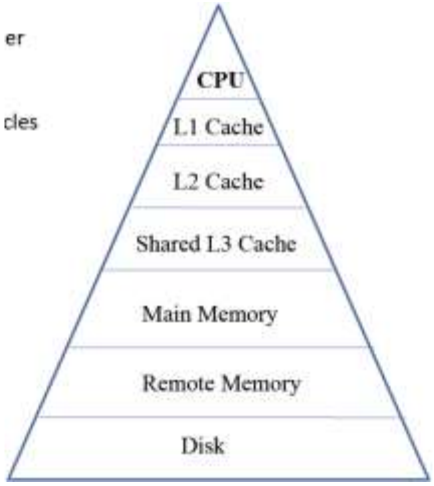
```
openss>>
```

5.2.3 Hardware Counter Threshold (hwc) experiment performance data viewing with CLI

To launch the CLI on any experiment, use “openss –cli –f <database name>“.

6 Hardware Performance Counters and Their Use

In this section we will explore the importance of simple Hardware Counter Metrics (HCM) through some easy to understand examples. We will also use a simple Matrix multiplication example to illustrate performance optimization.



The Memory Pyramid illustrates the impact of memory on the performance of an application. The closer the memory is to the CPU the faster, and smaller, it will be. Memory further away from the CPU is slower but larger. The most expensive operation is moving data. The application can only do useful work on the data at the top of the pyramid. For a given algorithm, serial performance is all about maximizing CPU flop rate and minimizing memory operations in scientific code. The table below shows the access latencies in clock cycles for the Nehalem Intel processor.

Memory	**Access latency in clock cycles**
L1	4
L2	9
L3	47
Main local NUMA	81
Main non-local NUMA	128

The following example uses BLAS operations to illustrate the impact of moving data. BLAS operations are Basic Linear Algebra Subprograms that proved library function calls for vectors and matrices. We use the Flops/Ops to understand how sections of the code relate to simple memory access patterns as typified by these BLAS operations. The following table show the number of Flops/Ops for each operation, where A, B and C are NxN Matrices; x and y are Nx1 Vectors; and k is a Scalar.

Level	Operation	# Memory Refs or Ops	# Flops	Flops/Ops	Comments on Flops/Ops
1	y = kx + y	3n	2n	2/3	Achieved in Benchmarks
2	y = Ax + y	n^2	$2n^2$	2	Achieved in Benchmarks
3	C = AB + C	$4n^2$	$2n^3$	n/2	Exceeds HW MAX

Below is an example of the BLAS Level 1 using the experiment osshwc (or osshwcsamp) to get the following PAPI counters: PAPI_FP_OPS, PAPI_TOT_CYC, PAPI_LD_INS, PAPI_ST_INS, PAPI_TOT_INS. Where the derived metrics of interest are: GLOPS (Giga Logical Operations per Second), Float_ops/cycle, Instructions/cycle, Loads/Cycle, Stores/Cycle, and Flops/memory Ops.

BLAS 1 Kernel: DAXPY; y = alpha * x + y

Kernel Code: (n=10,000) looped 1000,000 times for timing purposes

```
do i = 1, n
   y(i) = alpha * x(i) + y(i)
enddo
```

The following table shows the PAPI data for this example:

n	Mem Ref=3n	FLOPS Calc	Loop BLAS code	PAPI_LD_INS	PAPI_SR_INS	PAPI_FP_OPS	PAPI_TOT_CYCLE	PAPI_TOT_INS
10000	30000	20000	100000	1.02E+09	5.09E+08	1.03E+09	2.04E+09	2.43E+09

Code time sec	Code GFLOPS	FPC	IPC	LPC	SPC
6.4596E-06	3.096124	0.505386876	1.190989226	0.500489716	0.249412341
Error PAPI FLOPS	Error corrected FLOPS	Error Mem Refs	PAPI_GLOPS	PAPI FLOPS/OPS	Calc FLOPS/OPS
-93.80%	3.10%	-2.15%	3.195244288	0.673937178	0.6666667

The processors used in this example have a Floating Multiply-Add (FMADD) instruction set. Although this instruction performs two Floating Point operations, it is counted as one Floating Point instruction in PAPI. Because of this, there are situations where PAPI_FP_INS may produce fewer Floating Point counts then expected. In this example PAPI_FP_OPS was multiplied by 2 to match the theoretical, expected FLOP count. The formula for calculating Load Instructions was:

(2 vectors)*(vec_lecth)*(loop)*(bytes_per_word)*(8 bits_per_byte)/(128 bits_per_load)

What can the Hardware Counter Metrics tell us about the code performance? The set of useful metrics that can be calculated for functions are:

FLOPS/Memory Ops (FMO)	We would like this to be large which would imply good data locality. (Also called Computational Intensity or Ops/Refs)
FLOPS/Cycle (FPC)	Large values for floating point intensive codes suggests efficient CPU utilization.
Instructions/Cycle (IPC)	Large values suggest good balance with minimal stalls.
Loads/Cycle (LPC)	Useful for calculating FMO, may indicate good stride through arrays.
Stores/Cycle (SPC)	Useful for calculating FMO, may indicate good stride through arrays.

BLAS	Operation	Kernel	PAPI_GFLOPS	FMO	FPC	IPC	LPC	SPC
1	y=alpha*x+y	do loop	0.67	0.67	0.51	1.19	0.50	0.25

2	y=A*x+y	do loop	0.94	2.00	0.14	0.26	0.07	0.00
2	y=A*x+y	DGEMV	1.89		0.29	0.42	0.15	0.03
3	C=A*B+C	do loop(kji)	6.29		0.87	1.74	0.21	0.00
3	C=A*B+C	DGEMM	12.96		1.84	1.26	0.59	0.01

The following table shows single CPU simple code Hardware Counters for simple math kernels using the AMD Budapest Processor. Other hwc metrics that are useful are also shown.

Code	3D Fast Fourier Transforms; 256x256x256	Matrix Multiplication 500x500	QR Factorization N = 2350	HPCCG (linear system solver); sparseMV; 100x100x100
Computational Intensity; Ops/Ref	1.33	1.71	1.68	0.64
MFLOPS/papi	952	4159	3738	352
MFLOPS code	1370	4187	4000	276
Percent peak	19.8	86.7	77.9	7.3
fpOps/TLB miss	841.6515146	9040759.488	697703.964	14.05636016
fpOps/D1 cache miss	25.5290058	167.9364898	144.9081716	10.24364227
fpOps/DC_MISS	29.42427018	170.5178224	149.9578195	11.1702481
Ops/cycle	0.4	1.75	1.56	0.15

6.1 Using the Hardware counter experiments to find bottlenecks

6.1.1 How to find memory bandwidth bottlenecks using O|SS hwc experiments

TBD

6.1.2 How to find memory cache usage issues using O|SS hwc experiments

TBD

6.1.3 How to find load/store imbalance using O|SS hwc experiments

TBD

7 I/O Tracing and I/O Profiling

I/O could be a significant percentage of the execution time for an application and can depend on many things including Checkpoints, analysis output, visualization and I/O frequencies. The I/O pattern in the application also matters, whether it is N-to-1 or N-to-N and if there are simultaneous read or write requests. Certainly the nature of the application is also important to the I/O usage, if it is data intensive, traditional HPC with scalable data or out-of-core, that is, an application that works on data that is larger then the available system memory. The type of file system and striping available on the cluster: NFS, Lustre, Panasas or other Object Storage Targets (OSTs). What I/O libraries your code is using MPI-IO, hdf5, PLFS or others. Also the I/O is dependent on other jobs that are running and stressing the I/O subsystems.

The obvious thing to explore first while tuning your code is to try and use a parallel file system. Then optimize your code for I/O patterns. Match checkpoint I/O frequency to Mean Time Before Interrupt (MTBI) of the system. Make sure your code is using the appropriate libraries.

7.1 OOCORE Example

We will examine an example using the benchmarking application OOCORE, an out-of-core solver, from the Department of Defense High Performance Computing Modernization Program (DoD HPCMP). It is an out-of-core ScaLAPACK (Scalable LAPACK) benchmark from the University of Tennessee, Knoxville (UTK). It can be configured to be disk I/O intensive. It characterizes a very important class of HPC applications involving the use of Method of Moments (MOM) formulation for investigating electromagnetics (e.g. radar cross-section, antenna design). It solves dense matrix equations by LU (lower triangular, upper triangular), QR or Cholesky decomposition.

OOCORE is used by HPCMP to evaluate I/O system scalability. For our needs this application or similar out-of-core dense solver benchmarks help to point out the important points in performance analysis like I/O overhead minimization. The use of Matrix Multiply kernel which makes it possible to achieve close to peak performance of the machine if tuned well. It can highlight “blocking” which is very important to tune for deep memory hierarchies.

The following example was run on 16 cores on a Quad-Core, Quad-Socket Opteron IB cluster. We want to compare two different file systems, Lustre I/O with striping and NFS I/O. We use the ossio convenience script:

```
> ossio “srun –N 1 -n 16 ./testzdriver-std”
```

Sample Output from Lustre run:

```
TIME M N MB NB NRHS P Q Fact/SolveTime Error Residual
----------------------------------------------------------
WALL 31000 31000 16 16 1 4 4  1842.20 1611.59 4.51E+15 1.45E+11
DEPS = 1.110223024625157E---016
sum(xsol_i) = (30999.9999999873,0.000000000000000E+000)
sum|xsol_i-x_i| = (3.332285336962339E---006,0.000000000000000E+000)
sum|xsol_i-x_i|/M = (1.074930753858819E---010,0.000000000000000E+000)
sum|xsol_i-x_i|/(M*eps) = (968211.548505533,0.000000000000000E+000)
```

From output of two separate runs using Lustre and NFS:

LU Fact time with Lustre= 1842 secs;

```
   LU Fact time with NFS = 2655 secs
```

From the final times we see there is an 813 second penalty (more than 30%) if you do not use parallel file system like Lustre! The run time difference 75% of the 813 seconds is mostly I/O: (1360 + 99) – (847 + 7) = 605 seconds.

NFS Run				Lustre Run			
Min_t(sec)	Max_t(sec)	Avg_t(sec)	Function Call	Min_t(sec)	Max_t(sec)	Avg_t(sec)	Function Call
1102.380	1360.727	1261.310	__libc_read(/lib64/ libpthread-.5.so)	368.898	847.919	508.658	__libc_read(/lib64/ libpthread-.5.so)
31.192	99.444	49.018	__libc_write(/lib64/ libpthread-2.5.so)	6.270	7.896	6.850	__libc_write(/lib64/ libpthread-2.5.so)

7.2 Lustre Striping Commands

To set or get the Lustre file system (lfs) striping information you can use the following commands:

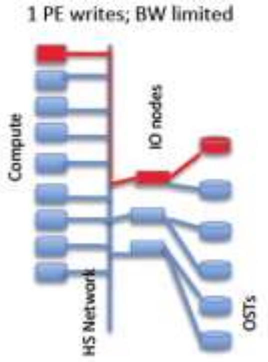
```
> lfs setstripe –s (size bytes; k, M, G) –c(cout; -1 all) –i (index; -1 round robin) <file | directory>
```

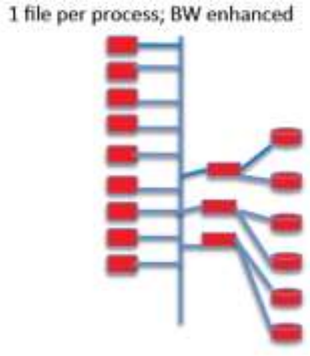
Typical defaults for setstripe are –s 1M –c 4 –i -1 (usually good to try first). File striping is set upon file create.

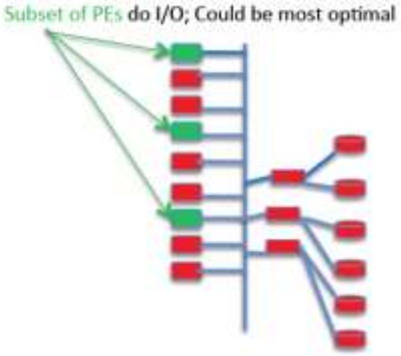
```
> lfs getstrip <file | directory>
```

Example for getstrip is:

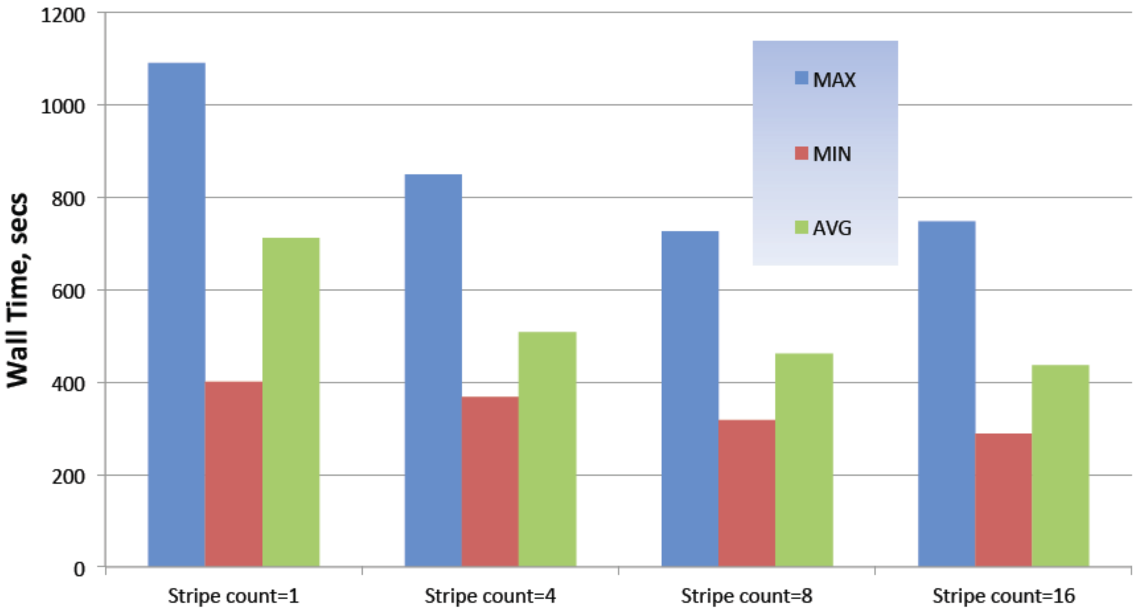
```
> lfs getstrip –verbose ./oss_lfs_strip_16 | grep stripe_count

stripe_count:  16 stripe_size:  1048576 strip_offset:  -1
```


1 PE writes; BW limited


1 file per process; BW enhanced

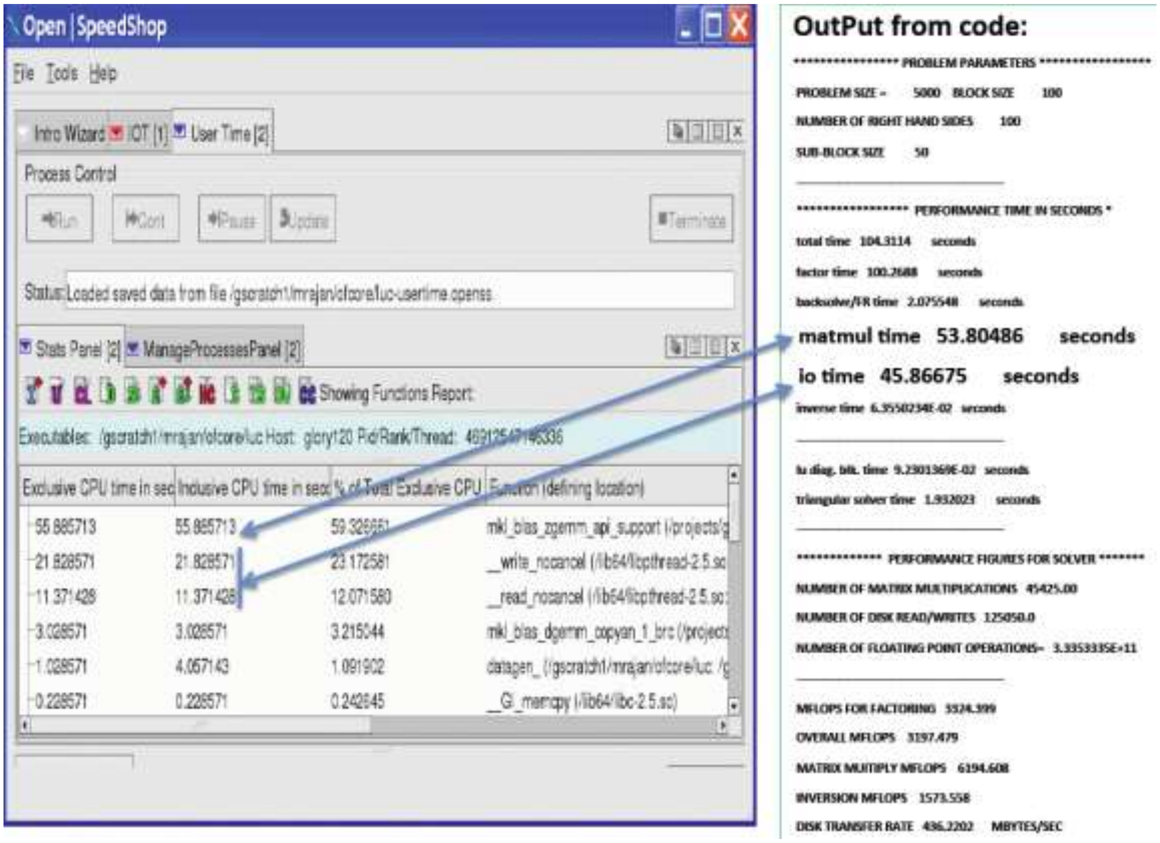

Subset of PEs do I/O; Could be most optimal

Using OOCORE I/O performance and the libc_read time from Open|SpeedShop, the following graph shows the output of an I/O experiment used to identify optimal lfs striping from load balance view (max, min and avg) for 16 way parallel run).



7.3 Open|SpeedShop I/O Tracing and I/O Profiling

An example of how to use the Open|SpeedShop usertime experiment to profile I/O is shown below. This example compares Open|SpeedShop data to instrumentation data.



Status: Loaded saved data from file /gscratch1/mrajan/ofcore/luc-usertime.openss

Executables: /gscratch1/mrajan/ofcore/luc Host: glory120 Pid/Rank/Thread: 46912547146336

Exclusive CPU time in sec	Inclusive CPU time in sec	% of Total Exclusive CPU	Function (defining location)
55.885713	55.885713	59.326651	mkl_blas_zgemm_api_support (/projects/g
21.828571	21.828571	23.172581	__write_nocancel (/lib64/libpthread-2.5.so
11.371428	11.371428	12.071580	__read_nocancel (/lib64/libpthread-2.5.so:
3.028571	3.028571	3.215044	mkl_blas_dgemm_copyan_1_brc (/projects
1.028571	4.057143	1.091902	datagen_ (/gscratch1/mrajan/ofcore/luc: /g
0.228571	0.228571	0.242645	__GI_memcpy (/lib64/libc-2.5.so)

OutPut from code:

```
**************** PROBLEM PARAMETERS *****************
PROBLEM SIZE =      5000   BLOCK SIZE      100
NUMBER OF RIGHT HAND SIDES      100
SUB-BLOCK SIZE      50
_______________________________
***************** PERFORMANCE TIME IN SECONDS *
total time   104.3114     seconds
factor time   100.2688     seconds
backsolve/FR time   2.075548     seconds
matmul time   53.80486     seconds
io time   45.86675     seconds
inverse time  6.3550234E-02   seconds
_______________________________
lu diag. blk. time  9.2301369E-02   seconds
triangular solver time   1.932023     seconds
_______________________________
************* PERFORMANCE FIGURES FOR SOLVER *******
NUMBER OF MATRIX MULTIPLICATIONS   45425.00
NUMBER OF DISK READ/WRITES  125050.0
NUMBER OF FLOATING POINT OPERATIONS=   3.3353335E+11
_______________________________
MFLOPS FOR FACTORING   3324.399
OVERALL MFLOPS   3197.479
MATRIX MULTIPLY MFLOPS   6194.608
INVERSION MFLOPS   1573.558
DISK TRANSFER RATE  436.2202     MBYTES/SEC
```

Open|SpeedShop also has an iot experiment for extended I/O Tracing. It will record each event in chronological order, and collect additional information like function parameters and function return values. You should use the extended I/O tracing when you want to trace the exact order of events. Or when you want to see the return values or bytes that were read or written.

Beware of serial I/O in applications, illustrated in the code below (code from Mike Davis, Cray Inc.).

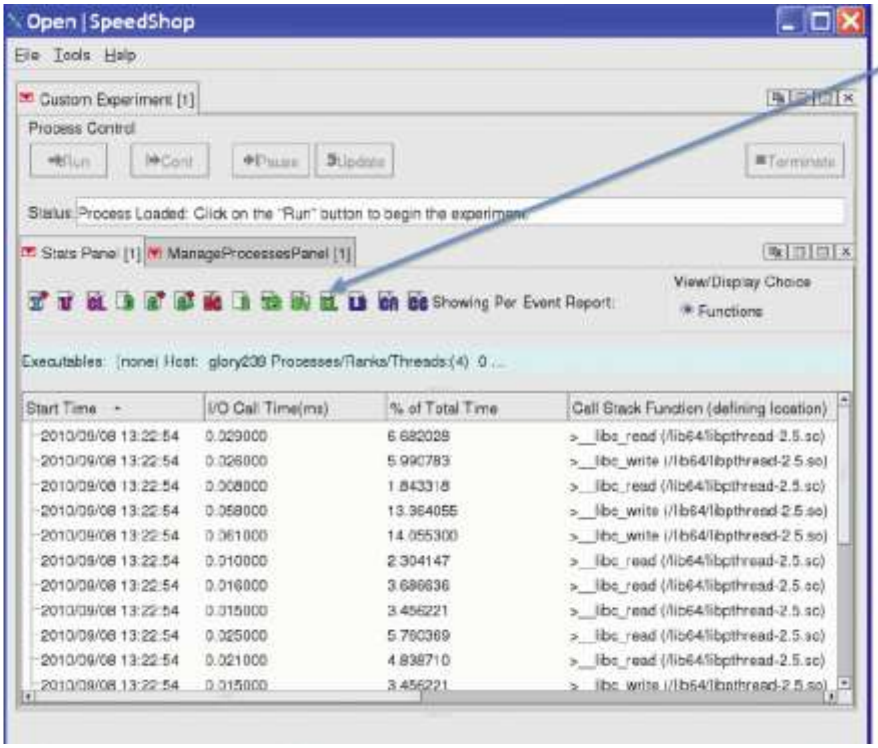
```
#include <stdio.h>
#include <stdlib.h>
#include <mpi.h>
#define VARS_PER_CELL 15

/*** Write a single restart file from many MPI processes */

int write_restart (
MPI_Comm comm    /// MPI communicator
, int num_cells  /// number of cells on this process
, double *cellv  /// cell vector
){
int rank;       // rank of this process within comm
int size;       // size of comm
int tag;        // for MPI_Send, MPI_Recv
int baton;      // for serializing I/O
FILE *f;        // file handle for restart file
```

```
/**
*
Procedure:
* Get MPI parameters
*/

MPI_Comm_rank(comm, &rank);
MPI_Comm_size(comm, &size);
tag = 4747;

if(rank == 0)
{
/**
* Rank 0 create a fresh restart file,
* and start the serial I/O;
*write cell data, then pass the baton to rank 1
*/

f = fopen ("restart.dat", "wb");
fwrite(cellv, num_cells, VARS_PER_CELL *sizeof (double), f);
fclose(f);
MPI_Send(&baton, 1, MPI_INT, 1, tag, comm);
} else {
/**
* Ranks 1 and higher wait for previous rank to complete I/O,
* then append its cell data to the restart file,
* then pass the baton to the next rank
*/

MPI_Recv(&baton, 1, MPI_INT, rank -1, tag, comm, MPI_STATUS_IGNORE);
f = fopen("restart.dat", "ab");
fwrite(cellv, num_cells, VARS_PER_CELL *sizeof (double), f);
fclose(f);
if(rank < size -1) {
  MPI_Send(&baton, 1, MPI_INT, rank + 1, tag, comm);
 }
}

/**
* All ranks have posted to the restart file;
* return to caller
*/

return 0;
}
```

```
int main(int argc, char *argv[]) {
  MPI_Comm comm;
  int comm_rank;
  int comm_size;
  int num_cells;
  double *cellv;
  int i;
  MPI_Init (&argc, &argv);
  MPI_Comm_dup(MPI_COMM_WORLD, &comm);
  MPI_Comm_rank(comm, &comm_rank);
  MPI_Comm_size(comm, &comm_size);

  /**
  * Make the cells be distributed somewhat evenly across ranks
  */
```

```
  num_cells = 5000000 + 2000 * (comm_size /2 - comm_rank);
  cellv = (double *) malloc (num_cells * VARS_PER_CELL * sizeof (double));

  for (i =  0; i < num_cells * VARS_PER_CELL; i++){

     cellv[i] = comm_rank;
  }

  write_restart(comm, num_cells, cellv);
  MPI_Finalize ();
  return 0;
}
```

Below shows the output of the Open|SpeedShop iot experiment on the serial I/O code:



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: (none) Host: glory238 Processes/Ranks/Threads:(4) 0 ...

Start Time	I/O Call Time(ms)	% of Total Time	Call Stack Function (defining location)
2010/09/08 13:22:54	0.029000	6.682028	>__libc_read (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.026000	5.990783	>__libc_write (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.008000	1.843318	>__libc_read (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.058000	13.364055	>__libc_write (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.061000	14.055300	>__libc_write (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.010000	2.304147	>__libc_read (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.016000	3.686636	>__libc_read (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.015000	3.456221	>__libc_read (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.025000	5.760369	>__libc_read (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.021000	4.838710	>__libc_read (/lib64/libpthread-2.5.so)
2010/09/08 13:22:54	0.015000	3.456221	>__libc_write (/lib64/libpthread-2.5.so)

SHOWS EVENT BY EVENT LIST: Clicking on this gives each call to a I/O function being traced as shown.

Below is a graphical trace view of the same data showing serialization of fwrite() (THE RED BARS for each PE) with another tool.

We can run the io or iot experiment convenience scripts on smg2000 application:

```
> ossio[t] "mpirun –np 256 smg2000 –n 50 50 50" [default | <list of I/O functions>]
```

Where by default the I/O function list to trace is all, the specific functions are: creat, creat64, dup, dup2, lseek, lseek64, open, open64, pipe, pread, pread64, pwrite, pwrite64, read, readv, write, writev.

Things to remember with I/O: Avoid writing to one file from all MPI tasks. If you need to do it make sure distinct offsets for each PE starts at a stripe boundary. Use buffered I/O if you must do this.

If each process writes it's own file then the parallel file system attempts to load balance the OST taking advantage of the stripe characteristics. Meta data server overhead can often create severe I/O problems. Minimize the number of files accessed per PE and minimize each PE doing operations like seek, open, close, stat that involve inode information. I/O time is usually not measured even in applications that keep some function profile. Open|SpeedShop can shed light on time spent in I/O using the io and iot experiments.

7.3 Open|SpeedShop I/O Tracing General Usage

The Open|SpeedShop *io* and *iot* I/O function tracing experiments wrap the most common I/O functions, record the time spent in each I/O function, record the call path along which I/O function was called, record the time spent along each call path to an I/O function, and record the number of times each function was called. In addition the *iot* experiment also records information about each individual I/O function call. The values of the arguments and the return value from the I/O function are recorded.

7.3.1 I/O Base Tracing (io) experiment

The base I/O tracing experiment gathers data for the following I/O functions: close, creat, creat64, dup, dup2, lseek, lseek64, open, open64, pipe, pread, pread64, pwrite, pwrite64, read, readv, write, and writev. It is a trace type experiment that wraps the real I/O calls and records information before and after calling the real I/O functions. This, base, I/O experiment records the basic I/O information as stated in the introductory section, but does not record the arguments to each call. That is done in the extended (iot) experiment.

7.3.1.1 I/O Base Tracing (io) experiment performance data gathering

The base I/O tracing (io) experiment convenience script is "ossio". Use this convenience script in this manner to gather base I/O tracing performance data:

```
ossio "how you normally run your application" <list of I/O function(s)>
```

The following is an example of how to gather data for the IOP application on a Linux cluster platform using the ossio convenience script. It gathers performance data for all the I/O functions because there is no list I/O functions specified after the quoted application run command.

```
ossio  "srun -n 512 ./IOR"
```

7.3.1.2 I/O Base Tracing (io) experiment performance data viewing with CLI

To launch the CLI on any experiment, use "openss –cli –f <database name>".

7.3.1.3 I/O Base Tracing (io) experiment performance data viewing with GUI

To launch the GUI on any experiment, use “openss –f <database name>“.

7.3.2 I/O Extended Tracing (iot) experiment

7.3.2.1 I/O Extended Tracing (iot) experiment performance data gathering

The extended I/O tracing (iot) experiment convenience script is “ossiot”. Use this convenience script in this manner to gather extended I/O tracing performance data:

```
ossiot “how you normally run your application” <list of I/O function(s)>
```

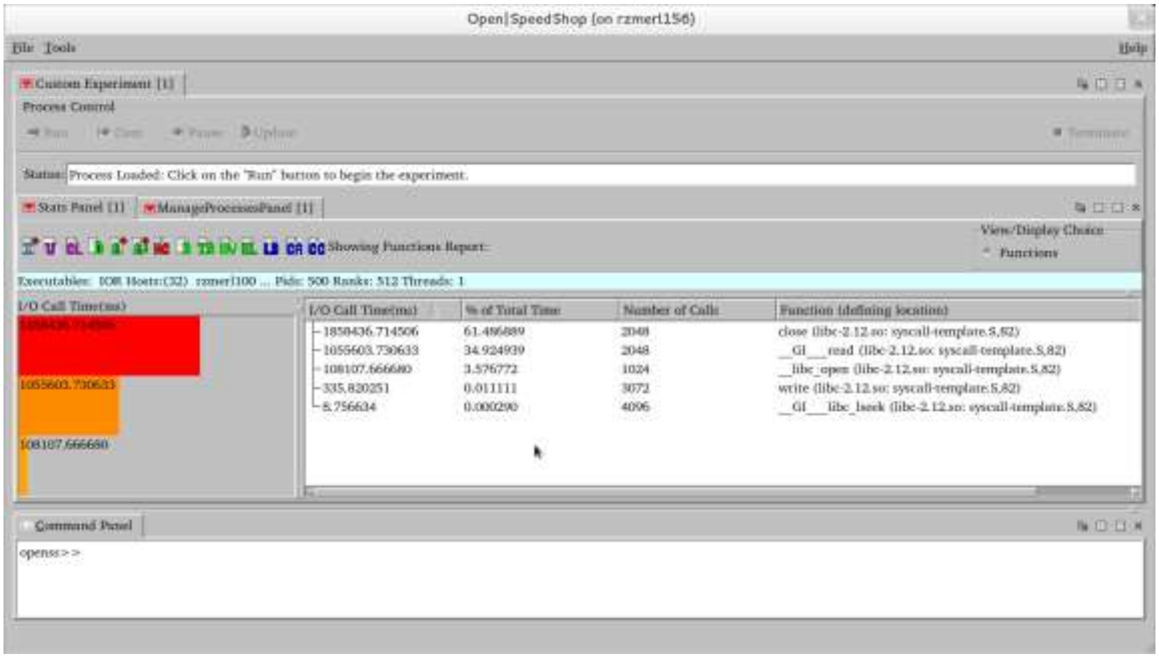
The following is an example of how to gather data for the IOP application on a Linux cluster platform using the ossiot convenience script. It gathers performance data for all the I/O functions because there is no list I/O functions specified after the quoted application run command.

```
ossiot  "srun -n 512 ./IOR"
```

7.3.2.2 I/O Extended Tracing (iot) experiment performance data viewing with GUI

To launch the GUI on any experiment, use “openss –f <database name>“.

This is the default GUI view for the iot experiment. This view give a summary of the I/O functions that were called, how many times they were called and the amount of time spent in each function. The percentage of the total I/O time is also attributed to each I/O function. The time is aggregated (totaled) across all the threads, ranks, or processes that were part of the application. The functions that called the I/O functions are available by choosing one of the call path views.



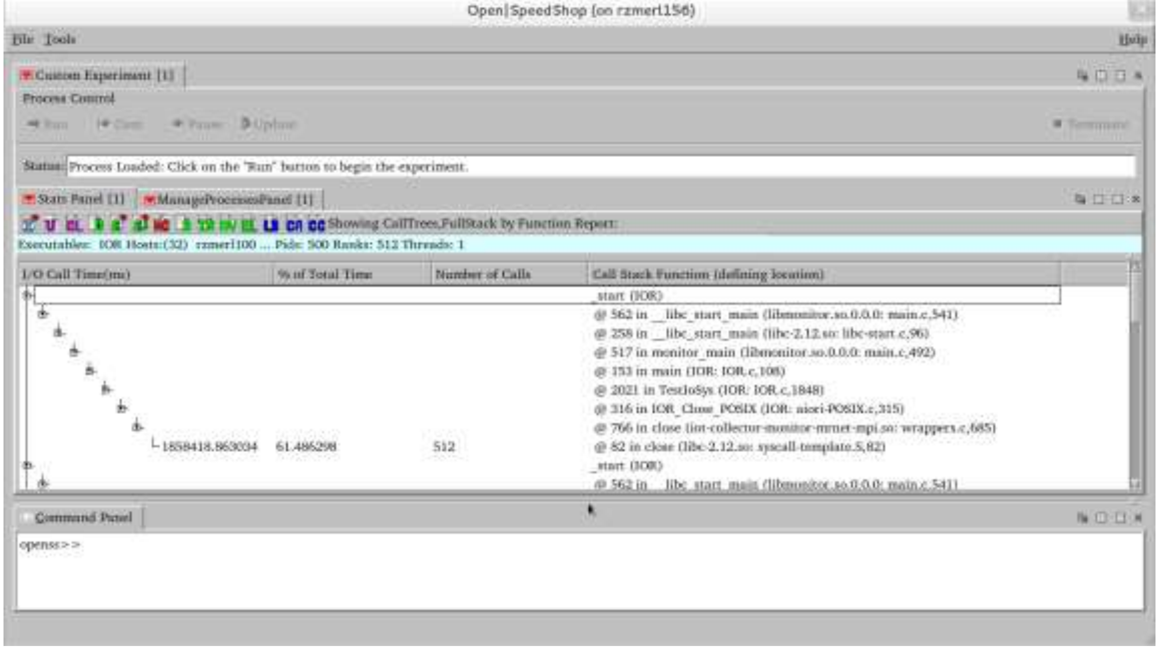
Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Functions Report:

Executables: IOR Hosts:(32) rzmerl100 ... Pids: 500 Ranks: 512 Threads: 1

I/O Call Time(ms)	% of Total Time	Number of Calls	Function (defining location)
1858436.714506	61.486889	2048	close (libc-2.12.so: syscall-template.S,82)
1055603.730633	34.924939	2048	__GI___read (libc-2.12.so: syscall-template.S,82)
108107.666680	3.576772	1024	__libc_open (libc-2.12.so: syscall-template.S,82)
335.820251	0.011111	3072	write (libc-2.12.so: syscall-template.S,82)
8.756634	0.000290	4096	__GI___libc_lseek (libc-2.12.so: syscall-template.S,82)

Here the user has chosen the C+ view icon and the Stats Panel now shows all the call paths in the users application. This view shows the every possible call paths through the source to all the I/O functions that were called during the execution of this application. From this one could validate that this is expected behavior and if not find where the I/O in this application is not behaving as expected.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

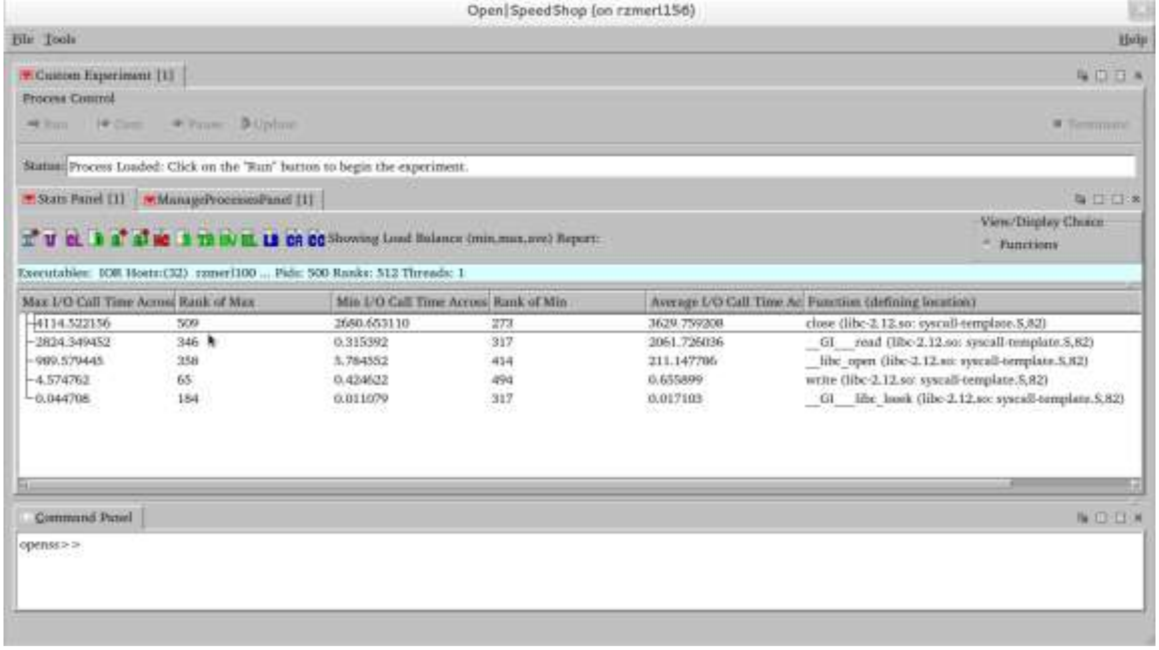
Showing CallTrees,FullStack by Function Report:

Executables: IOR Hosts:(32) rzmerl100 ... Pids: 500 Ranks: 512 Threads: 1

I/O Call Time(ms)	% of Total Time	Number of Calls	Call Stack Function (defining location)
			_start (IOR)
			@ 562 in __libc_start_main (libmonitor.so.0.0.0: main.c,541)
			@ 258 in __libc_start_main (libc-2.12.so: libc-start.c,96)
			@ 517 in monitor_main (libmonitor.so.0.0.0: main.c,492)
			@ 153 in main (IOR: IOR.c,108)
			@ 2021 in TestIoSys (IOR: IOR.c,1848)
			@ 316 in IOR_Close_POSIX (IOR: aiori-POSIX.c,315)
			@ 766 in close (iot-collector-monitor-mrnet-mpi.so: wrappers.c,685)
1858418.863034	61.486298	512	@ 82 in close (libc-2.12.so: syscall-template.S,82)
			_start (IOR)
			@ 562 in __libc_start_main (libmonitor.so.0.0.0: main.c,541)

This view is the load balance view, which gives the min, max, average values for the I/O function call time across all the ranks in this application. In this view we are seeing some wide ranges between the min and max values for some of the I/O functions. It may be useful to see if we can identify the ranks by using the Cluster

Analysis view.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

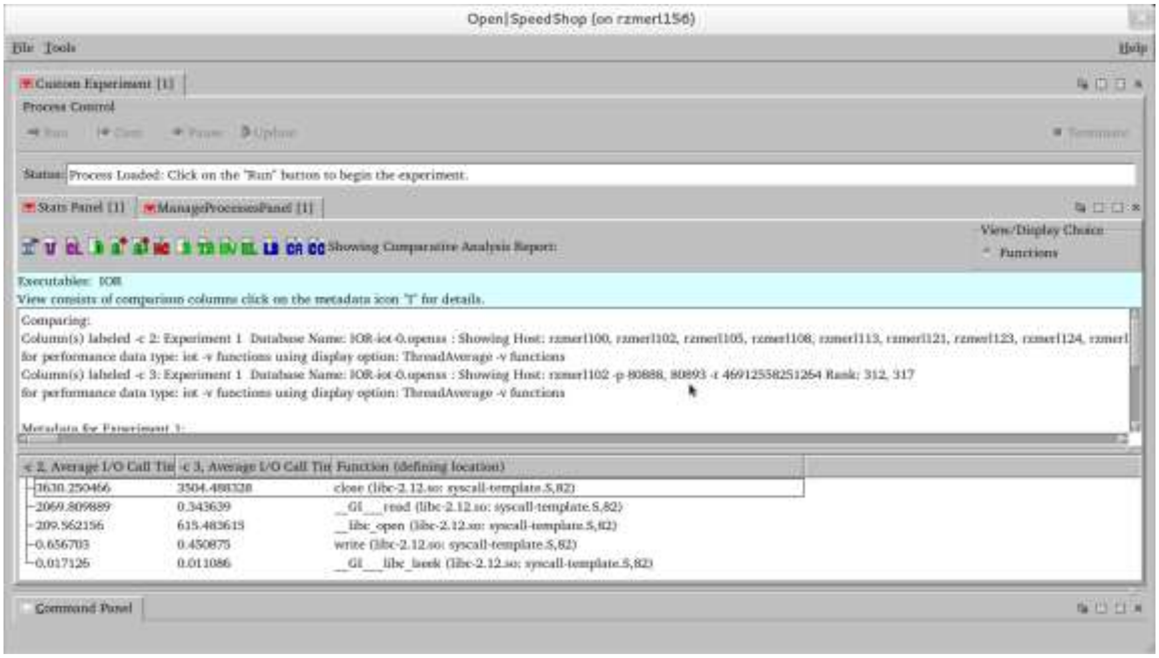
Showing Load Balance (min,max,ave) Report:

Executables: IOR Hosts:(32) rzmerl100 ... Pids: 500 Ranks: 512 Threads: 1

Max I/O Call Time Acros	Rank of Max	Min I/O Call Time Across	Rank of Min	Average I/O Call Time Ac	Function (defining location)
4114.522156	509	2680.653110	273	3629.759208	close (libc-2.12.so: syscall-template.S,82)
2824.349452	346	0.315392	317	2061.726036	__GI___read (libc-2.12.so: syscall-template.S,82)
989.579445	358	5.784552	414	211.147786	__libc_open (libc-2.12.so: syscall-template.S,82)
4.574762	65	0.424622	494	0.655899	write (libc-2.12.so: syscall-template.S,82)
0.044708	184	0.011079	317	0.017103	__GI___libc_lseek (libc-2.12.so: syscall-template.S,82)

```
openss>>
```

This view, generated by choosing CA icon, the shows that there are two groups of ranks where the I/O is performing in similar manner. For group 2 (labeled –c 3 below), there are two ranks where the rest of the 512 ranks perform like group 1 (labeled –c 2 below). Investigation by examining ranks 312 or 317 by comparing it to one of the ranks in the other group could shed some light on why group 2 is not similar to the rest. This may or may not be significant, but is here for illustration.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Comparative Analysis Report:

Executables: IOR
View consists of comparison columns click on the metadata icon "I" for details.

Comparing:
Column(s) labeled -c 2: Experiment 1 Database Name: IOR-iot-0.openss : Showing Host: rzmerl100, rzmerl102, rzmerl105, rzmerl108, rzmerl113, rzmerl121, rzmerl123, rzmerl124, rzmerl
for performance data type: iot -v functions using display option: ThreadAverage -v functions
Column(s) labeled -c 3: Experiment 1 Database Name: IOR-iot-0.openss : Showing Host: rzmerl102 -p 80888, 80893 -t 46912558251264 Rank: 312, 317
for performance data type: iot -v functions using display option: ThreadAverage -v functions

Metadata for Experiment 1:

-c 2, Average I/O Call Tin	-c 3, Average I/O Call Tin	Function (defining location)
3630.250466	3504.488328	close (libc-2.12.so: syscall-template.S,82)
2069.809889	0.343639	__GI___read (libc-2.12.so: syscall-template.S,82)
209.562156	615.483615	__libc_open (libc-2.12.so: syscall-template.S,82)
0.656703	0.450875	write (libc-2.12.so: syscall-template.S,82)
0.017126	0.011086	__GI___libc_lseek (libc-2.12.so: syscall-template.S,82)

7.3.2.3 I/O Extended Tracing (iot) experiment performance data viewing with CLI

To launch the CLI on any experiment, use “openss –cli –f <database name>“.

The command line interface (CLI) can provide the same data options as the graphical user interface (GUI) views. Here are some examples of the performance data that can be viewed and the commands in order to generate the CLI views.

```
>openss -cli -f IOR-iot-0.openss

openss>>[openss]: The restored experiment identifier is:  -x 1
openss>>expview

     I/O Call      % of  Number  Function (defining location)
     Time(ms)      Total      of
                    Time   Calls
1858436.714506  61.486889    2048  close (libc-2.12.so: syscall-template.S,82)
1055603.730633  34.924939    2048  __GI___read (libc-2.12.so: syscall-template.S,82)
  108107.666680   3.576772    1024  __libc_open (libc-2.12.so: syscall-template.S,82)
        335.820251   0.011111    3072  write (libc-2.12.so: syscall-template.S,82)
            8.756634   0.000290    4096  __GI___libc_lseek (libc-2.12.so: syscall-template.S,82)
openss>>expview -m loadbalance

   Max I/O  Rank      Min I/O  Rank  Average I/O  Function (defining location)
  Call Time    of    Call Time    of    Call Time
    Across   Max       Across   Min       Across
  Ranks(ms)          Ranks(ms)          Ranks(ms)
4114.522156   509  2680.653110   273  3629.759208  close (libc-2.12.so: syscall-template.S,82)
2824.349452   346         0.315392   317   2061.726036  __GI___read (libc-2.12.so: syscall-template.S,82)
  989.579445   358         5.784552   414     211.147786  __libc_open (libc-2.12.so: syscall-template.S,82)
       4.574762    65         0.424622   494         0.655899  write (libc-2.12.so: syscall-template.S,82)
       0.044708   184         0.011079   317         0.017103  __GI___libc_lseek (libc-2.12.so: syscall-template.S,82)
openss>>expview -v calltrees,fullstack

     I/O Call      % of  Number  Call Stack Function (defining location)
     Time(ms)      Total      of
                    Time   Calls
                                  _start (IOR)
                                  > @ 562 in __libc_start_main (libmonitor.so.0.0.0: main.c,541)
                                  >> @ 258 in __libc_start_main (libc-2.12.so: libc-start.c,96)
                                  >>> @ 517 in monitor_main (libmonitor.so.0.0.0: main.c,492)
                                  >>>> @ 153 in main (IOR: IOR.c,108)
                                  >>>>> @ 2021 in TestIoSys (IOR: IOR.c,1848)
                                  >>>>>> @ 316 in IOR_Close_POSIX (IOR: aiori-POSIX.c,315)
                                  >>>>>>> @ 766 in close (iot-collector-monitor-mrnet-mpi.so: wrappers.c,685)
1858418.863034  61.486298     512  >>>>>>>> @ 82 in close (libc-2.12.so: syscall-template.S,82)
                                  _start (IOR)
                                  > @ 562 in __libc_start_main (libmonitor.so.0.0.0: main.c,541)
                                  >> @ 258 in __libc_start_main (libc-2.12.so: libc-start.c,96)
                                  >>> @ 517 in monitor_main (libmonitor.so.0.0.0: main.c,492)
                                  >>>> @ 153 in main (IOR: IOR.c,108)
                                  >>>>> @ 2173 in TestIoSys (IOR: IOR.c,1848)
                                  >>>>>> @ 2611 in WriteOrRead (IOR: IOR.c,2562)
                                  >>>>>>> @ 251 in IOR_Xfer_POSIX (IOR: aiori-POSIX.c,224)
                                  >>>>>>>> @ 223 in read (iot-collector-monitor-mrnet-mpi.so: wrappers.c,137)
1055603.730633  34.924939    2048  >>>>>>>>> @ 82 in __GI___read (libc-2.12.so: syscall-template.S,82)
                                  _start (IOR)
                                  > @ 562 in __libc_start_main (libmonitor.so.0.0.0: main.c,541)
                                  >> @ 258 in __libc_start_main (libc-2.12.so: libc-start.c,96)
```

```
                 >>> @ 517 in monitor_main (libmonitor.so.0.0.0: main.c,492)
                 >>>> @ 153 in main (IOR: IOR.c,108)
                 >>>>> @ 2004 in TestIoSys (IOR: IOR.c,1848)
                 >>>>>> @ 104 in IOR_Create_POSIX (IOR: aiori-POSIX.c,74)
                 >>>>>>> @ 670 in open64 (iot-collector-monitor-mrnet-mpi.so: wrappers.c,608)
 103350.518692   3.419380     512  >>>>>>>> @ 82 in __libc_open (libc-2.12.so: syscall-template.S,82)
                 _start (IOR)
                 > @ 562 in __libc_start_main (libmonitor.so.0.0.0: main.c,541)
                 >> @ 258 in __libc_start_main (libc-2.12.so: libc-start.c,96)
                 >>> @ 517 in monitor_main (libmonitor.so.0.0.0: main.c,492)
                 >>>> @ 153 in main (IOR: IOR.c,108)
                 >>>>> @ 2161 in TestIoSys (IOR: IOR.c,1848)
                 >>>>>> @ 195 in IOR_Open_POSIX (IOR: aiori-POSIX.c,173)
                 >>>>>>> @ 670 in open64 (iot-collector-monitor-mrnet-mpi.so: wrappers.c,608)
   4757.147988   0.157392     512  >>>>>>>> @ 82 in __libc_open (libc-2.12.so: syscall-template.S,82)
                 _start (IOR)
                 > @ 562 in __libc_start_main (libmonitor.so.0.0.0: main.c,541)
                 >> @ 258 in __libc_start_main (libc-2.12.so: libc-start.c,96)
                 >>> @ 517 in monitor_main (libmonitor.so.0.0.0: main.c,492)
                 >>>> @ 153 in main (IOR: IOR.c,108)
                 >>>>> @ 2013 in TestIoSys (IOR: IOR.c,1848)
                 >>>>>> @ 2608 in WriteOrRead (IOR: IOR.c,2562)
                 >>>>>>> @ 244 in IOR_Xfer_POSIX (IOR: aiori-POSIX.c,224)
                 >>>>>>>> @ 321 in write (iot-collector-monitor-mrnet-mpi.so: wrappers.c,239)
    316.176763   0.010461    2048  >>>>>>>>> @ 82 in write (libc-2.12.so: syscall-template.S,82)
```

7.4 Open|SpeedShop Lightweight I/O Profiling General Usage

The Open|SpeedShop *iop* I/O function profiling experiment wraps the most common I/O functions, records the time spent in each I/O function, record the call path along which I/O function was called, record the time spent along each call path to an I/O function, and record the number of times each function was called.

7.4.1 I/O Profiling (iop) experiment performance data gathering

The I/O Profiling (iop) experiment convenience script is "ossiop". Use this convenience script in this manner to gather lightweight I/O profiling performance data:

```
ossiop "how you normally run your application"
```

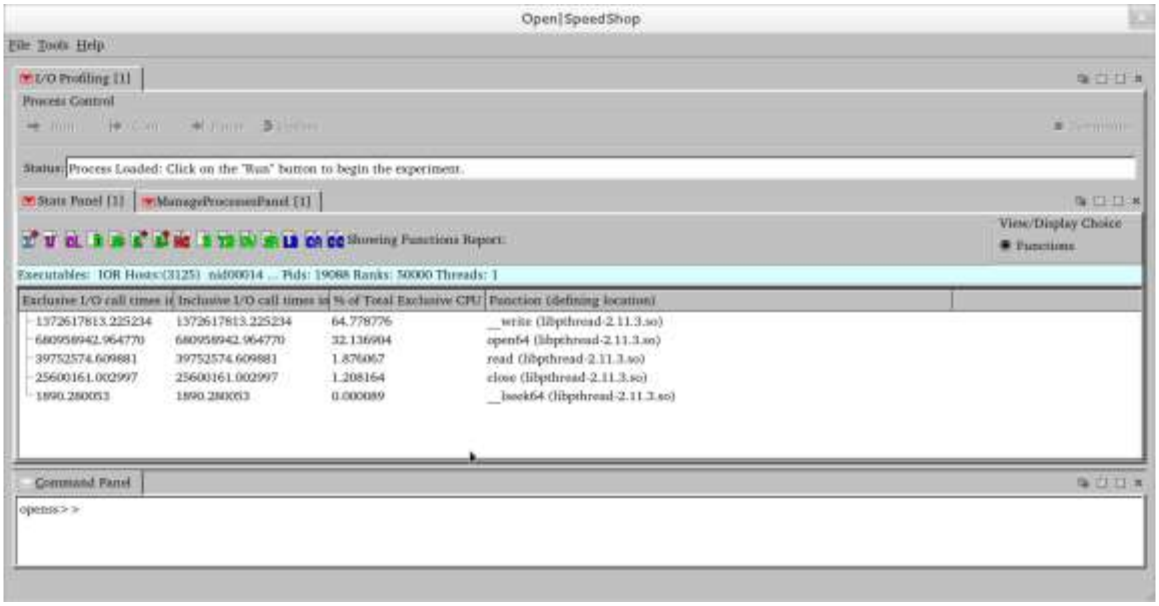
The following is an example of how to gather data for the IOP application on the Cray platform using the ossiop convenience script.

```
ossiop "aprun -n 64 ./IOR"
```

7.4.2 I/O Profiling (iop) experiment performance data viewing with GUI

To launch the GUI on any experiment, use "openss –f <database name>".

The first image below, shows the default view for the iop experiment run on a 50000 rank IOR application job. The performance information in the default view is the time spent in I/O functions and the percentage of time spent in each I/O function.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

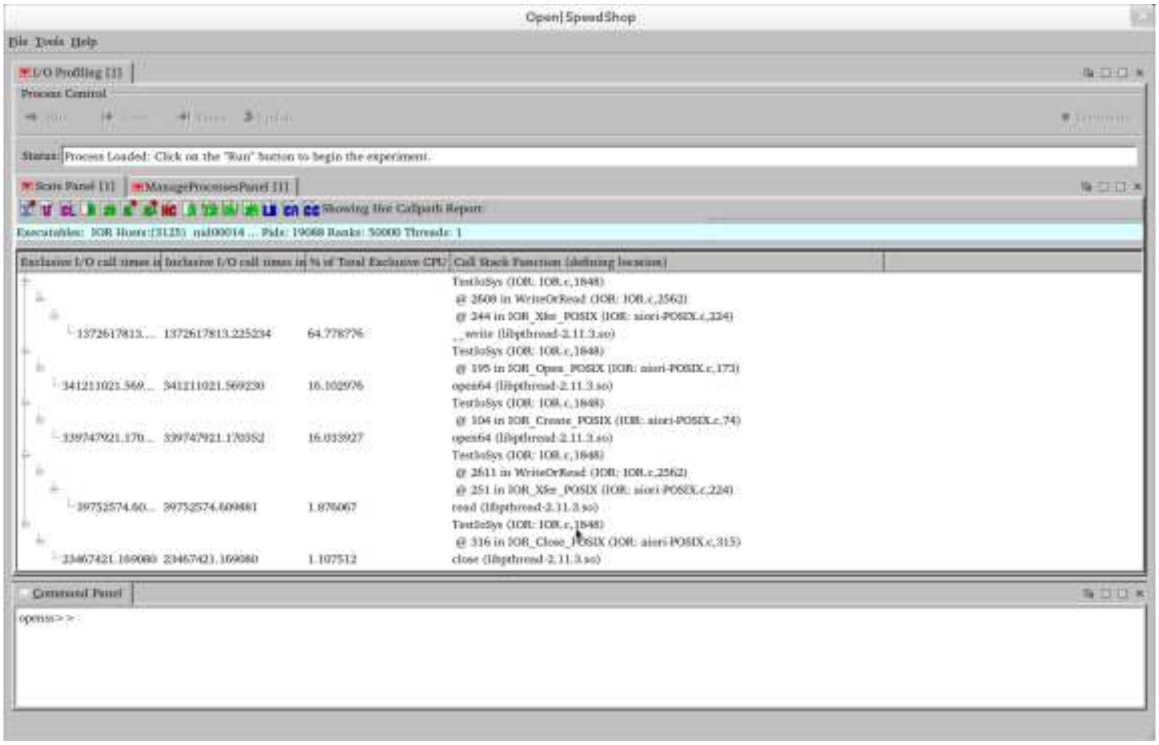
Showing Functions Report:

Executables: IOR Hosts:(3125) nid00014 ... Pids: 19088 Ranks: 50000 Threads: 1

Exclusive I/O call times i	Inclusive I/O call times in	% of Total Exclusive CPU	Function (defining location)
1372617813.225234	1372617813.225234	64.778776	__write (libpthread-2.11.3.so)
6809589942.964770	6809589942.964770	32.136904	open64 (libpthread-2.11.3.so)
39752574.609881	39752574.609881	1.876067	read (libpthread-2.11.3.so)
25600161.002997	25600161.002997	1.208164	close (libpthread-2.11.3.so)
1890.280053	1890.280053	0.000089	__lseek64 (libpthread-2.11.3.so)

```
openss>>
```

In the image below, the hot call path view for the iop experiment run on a 50000 rank IOR application job is displayed. The performance information in the hot call path view is the top five call paths to each of the I/O functions that took the most time, time spent in I/O functions and the percentage of time spent in each I/O function.

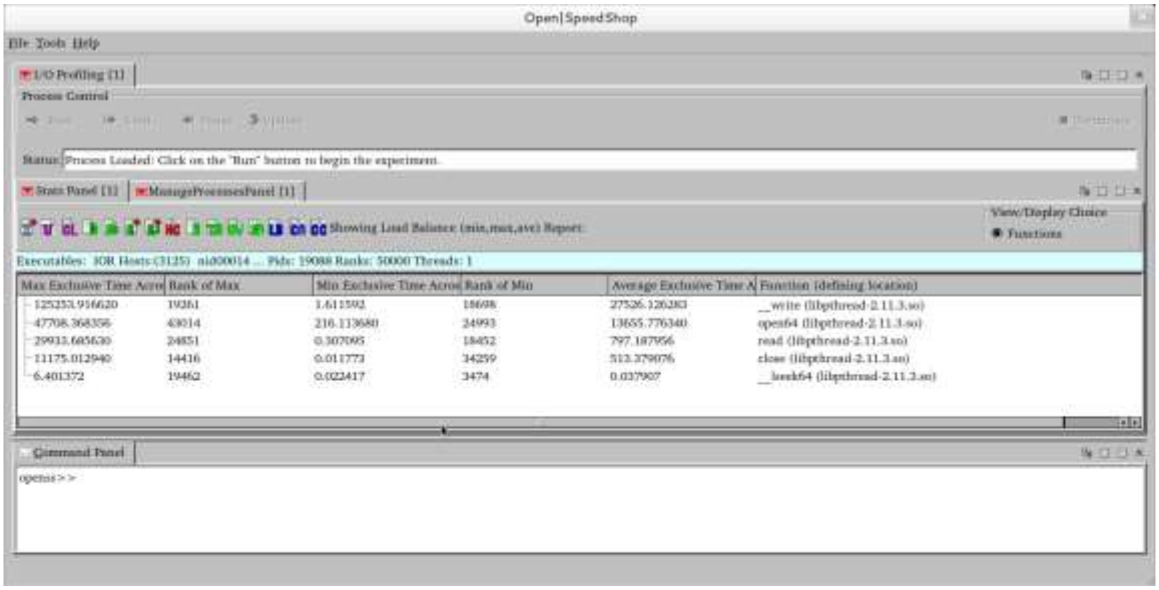


Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: IOR Hosts:(3125) nid00014 ... Pids: 19088 Ranks: 50000 Threads: 1

Exclusive I/O call times i	Inclusive I/O call times in	% of Total Exclusive CPU	Call Stack Function (defining location)
1372617813....	1372617813.225234	64.778776	TestIoSys (IOR: IOR.c,1848) @ 2608 in WriteOrRead (IOR: IOR.c,2562) @ 244 in IOR_Xfer_POSIX (IOR: aiori-POSIX.c,224) __write (libpthread-2.11.3.so)
341211021.569...	341211021.569230	16.102976	TestIoSys (IOR: IOR.c,1848) @ 195 in IOR_Open_POSIX (IOR: aiori-POSIX.c,173) open64 (libpthread-2.11.3.so)
339747921.170...	339747921.170352	16.033927	TestIoSys (IOR: IOR.c,1848) @ 104 in IOR_Create_POSIX (IOR: aiori-POSIX.c,74) open64 (libpthread-2.11.3.so)
39752574.60...	39752574.609481	1.876067	TestIoSys (IOR: IOR.c,1848) @ 2611 in WriteOrRead (IOR: IOR.c,2562) @ 251 in IOR_Xfer_POSIX (IOR: aiori-POSIX.c,224) read (libpthread-2.11.3.so)
23467421.169080	23467421.169080	1.107512	TestIoSys (IOR: IOR.c,1848) @ 316 in IOR_Close_POSIX (IOR: aiori-POSIX.c,315) close (libpthread-2.11.3.so)

This image shows the min, max, average time spent in each of the I/O functions showing the rank of the minimum value and the rank of the maximum value for each of the I/O functions. This view indicates if there is an imbalance relative to the I/O in the application being run. This may or may not be expected.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: IOR Hosts:(3125) nid00014 ... Pids: 19088 Ranks: 50000 Threads: 1

Max Exclusive Time Acro	Rank of Max	Min Exclusive Time Acros	Rank of Min	Average Exclusive Time A	Function (defining location)
125253.916620	19261	1.611592	18698	27526.126283	__write (libpthread-2.11.3.so)
47708.368356	43014	216.113680	24993	13655.776340	open64 (libpthread-2.11.3.so)
29933.685630	24851	0.307095	18452	797.187956	read (libpthread-2.11.3.so)
11175.012940	14416	0.011773	34259	513.379076	close (libpthread-2.11.3.so)
6.401372	19462	0.022417	3474	0.037907	__lseek64 (libpthread-2.11.3.so)

7.4.3 I/O Profiling (iop) experiment performance data viewing with CLI

To launch the CLI on any experiment, use “openss –cli –f <database name>“.

The command line interface (CLI) can provide the same data options as the graphical user interface (GUI) views. Here are some examples of the performance data that can be viewed and the commands in order to generate the CLI views.

```
> openss -cli -f IOR-iop-1.openss
openss>>[openss]: The restored experiment identifier is:  -x 1
openss>>expview

  Exclusive    Inclusive      % of  Function (defining location)
   I/O call     I/O call      Total
   times in     times in  Exclusive
   seconds.     seconds.   CPU Time
38297.339900  38297.339900  96.460929  __write (libpthread-2.11.3.so)
 741.019727    741.019727   1.866434  open64 (libpthread-2.11.3.so)
 598.432332    598.432332   1.507294  read (libpthread-2.11.3.so)
  63.383924     63.383924   0.159647  close (libpthread-2.11.3.so)
   2.261454      2.261454   0.005696  __lseek64 (libpthread-2.11.3.so)

openss>>expview -v calltrees,fullstack

  Exclusive    Inclusive      % of  Call Stack Function (defining location)
   I/O call     I/O call      Total
   times in     times in  Exclusive
   seconds.     seconds.   CPU Time
                                     TestIoSys (IOR: IOR.c,1848)
                                     > @ 2608 in WriteOrRead (IOR: IOR.c,2562)
                                     >> @ 244 in IOR_Xfer_POSIX (IOR: aiori-POSIX.c,224)
38297.339900  38297.339900  96.460929  >>>__write (libpthread-2.11.3.so)
                                     TestIoSys (IOR: IOR.c,1848)
                                     > @ 2611 in WriteOrRead (IOR: IOR.c,2562)
                                     >> @ 251 in IOR_Xfer_POSIX (IOR: aiori-POSIX.c,224)
 598.432332    598.432332   1.507294  >>>read (libpthread-2.11.3.so)
                                     TestIoSys (IOR: IOR.c,1848)
                                     > @ 104 in IOR_Create_POSIX (IOR: aiori-POSIX.c,74)
 472.137142    472.137142   1.189189  >>open64 (libpthread-2.11.3.so)
                                     TestIoSys (IOR: IOR.c,1848)
                                     > @ 195 in IOR_Open_POSIX (IOR: aiori-POSIX.c,173)
 268.882585    268.882585   0.677245  >>open64 (libpthread-2.11.3.so)
                                     TestIoSys (IOR: IOR.c,1848)
                                     > @ 316 in IOR_Close_POSIX (IOR: aiori-POSIX.c,315)
  61.587482     61.587482   0.155123  >>close (libpthread-2.11.3.so)
                                     TestIoSys (IOR: IOR.c,1848)
                                     > @ 316 in IOR_Close_POSIX (IOR: aiori-POSIX.c,315)
   1.796442      1.796442   0.004525  >>close (libpthread-2.11.3.so)
                                     TestIoSys (IOR: IOR.c,1848)
                                     > @ 2608 in WriteOrRead (IOR: IOR.c,2562)
                                     >> @ 234 in IOR_Xfer_POSIX (IOR: aiori-POSIX.c,224)
   1.280113      1.280113   0.003224  >>>__lseek64 (libpthread-2.11.3.so)
                                     TestIoSys (IOR: IOR.c,1848)
                                     > @ 2611 in WriteOrRead (IOR: IOR.c,2562)
                                     >> @ 234 in IOR_Xfer_POSIX (IOR: aiori-POSIX.c,224)
   0.981341      0.981341   0.002472  >>>__lseek64 (libpthread-2.11.3.so)
```

In the above command line interface output, the expview command with no options gives the overview or summary view for all the ranks and threads. One can view the performance information for individual ranks (using –r <rank number>) or individual threads (using –t <thread number>) or individual processes (using –p <process id>). One can also give a range of ranks, threads, or processes using their respective option.

For the calltree view, the display is showing where the I/O function were called from in the users application source. In this example, most of I/O time was spent in the write I/O function along the path shown in the first individual calltree. The calltree with fullstack option forces the calltree view to not collapse any similar sub-trees, which makes the view more explicit. Without the fullstack option the calltrees would be more consolidated.

8 Applying Experiments to Parallel Codes

The ideal scenario for the execution of parallel code using pthreads or OpenMP is efficient threading, where all threads are assigned work that can execute concurrently. Or for MPI code, the job is properly load balanced so all MPI ranks do the same about of work and no MPI rank is stuck waiting.

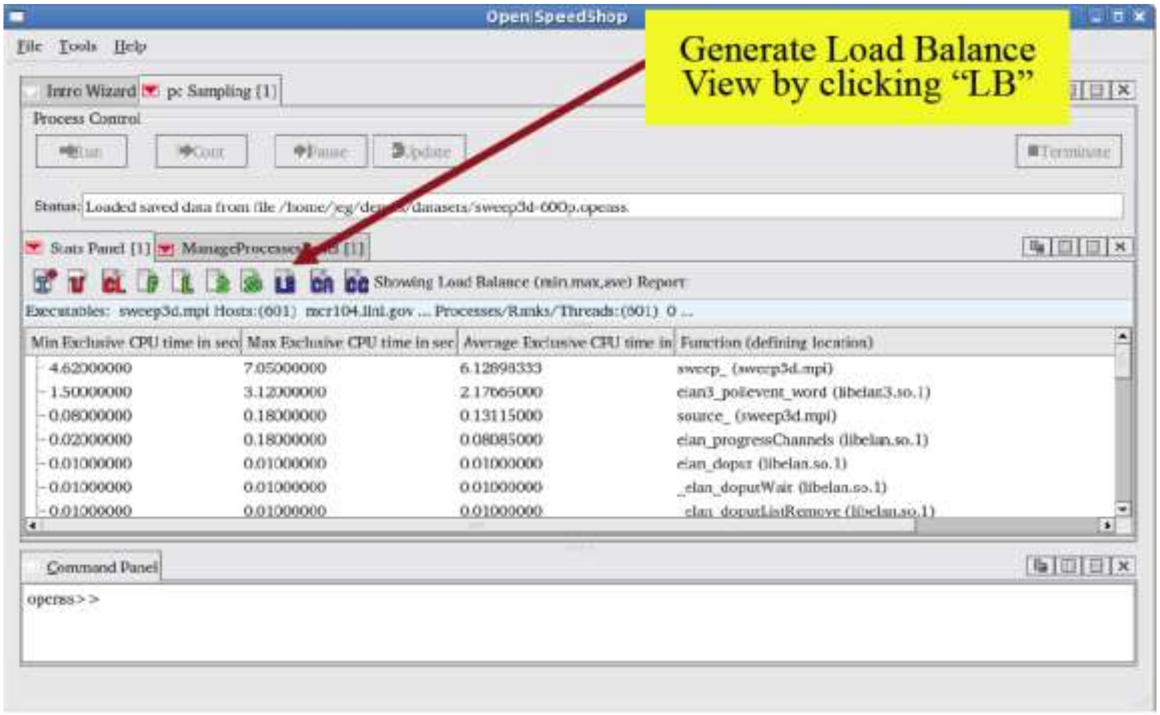
What are some things that can cause these ideal scenarios to fail? (taken from LLNL parallel processing tutorial) MPI jobs can become unbalanced if an equal amount of work was not assigned to each rank, possibly through the number of array operations not being equal for each rank or loop iterations not being evenly distributed. You can still have problems even if your work seems to be evenly distributed. For example if you evenly distribute a sparsely populated array then some ranks may end up with very little or no work while others will have a full workload. With adaptive grid models some ranks need to redefine their mesh while other don’t. With N-body simulations some work migrates to other ranks so those ranks will have more to do while the others have less.

Performance analysis can help you with load balancing and an even distribution of work. Tools like Open|SpeedShop are designed to work on parallel jobs. It supports threading and message passing and automatically tracks all ranks and thread during execution. It can also store the performance info per process, rank or thread for individual evaluation. All of the experiments for Open|SpeedShop can be run on parallel jobs, collectors are applied to all ranks on all nodes. The results of an experiment can be displayed as an aggregation across all ranks or threads, which is the default view, or you can select individual or groups of ranks or threads to view. There are also experiments specifically designed for tracing MPI function calls.

Open|SpeedShop has been tested with a variety of MPI versions including Open MPI, MVAPICH[2] and MPICH2 on Intel, Blue Gene, and Cray systems. Open|SpeedShop is able to identify the MPI task (rank info) through the MPIR interface for the online version or through PMPI preload for the offline version. To run MPI code with Open|SpeedShop just include the MPI launcher as part of the executable as normal, below are several examples:

```
> ossmpi  “mpirun –np  128 sweep3d.mpi”

> osspcsamp “mpirun –np 32 sweep3d.mpi”

> ossio “srun –N 4 –n 16 sweep3d.mpi”

> openss –offline –f “mpirun –np 128 sweep3d.mpi” hwctime

> openss –online –f “srun –N 8 –n 128 sweep3d.mpi” usertime
```

The default view for parallel applications is to aggregate the information collected across all ranks. You can manually include or exclude individual ranks, processes or threads to view their specific results. You can also compare ranks by using the Customize Stats panel View and creating a compare column for the process groups or individual ranks. Cluster analysis is also available, it can be used to find outliers, ranks that are performing very differently then the others. From the Stats Panel toolbar or context menu you can automatically create groups of similar performing ranks or threads. Through the Stat Panel Open|SpeedShop also provides common analysis functions designed for quick analysis of MPI applications. There are load balance views that calculate min, max and average values across ranks, processes or threads. The image below shows the Open|SpeedShop buttons for Load Balance and next to that Cluster Analysis.



Generate Load Balance View by clicking "LB"

Status: Loaded saved data from file /home/jeg/de[illegible]/datasets/sweep3d-600p.openss

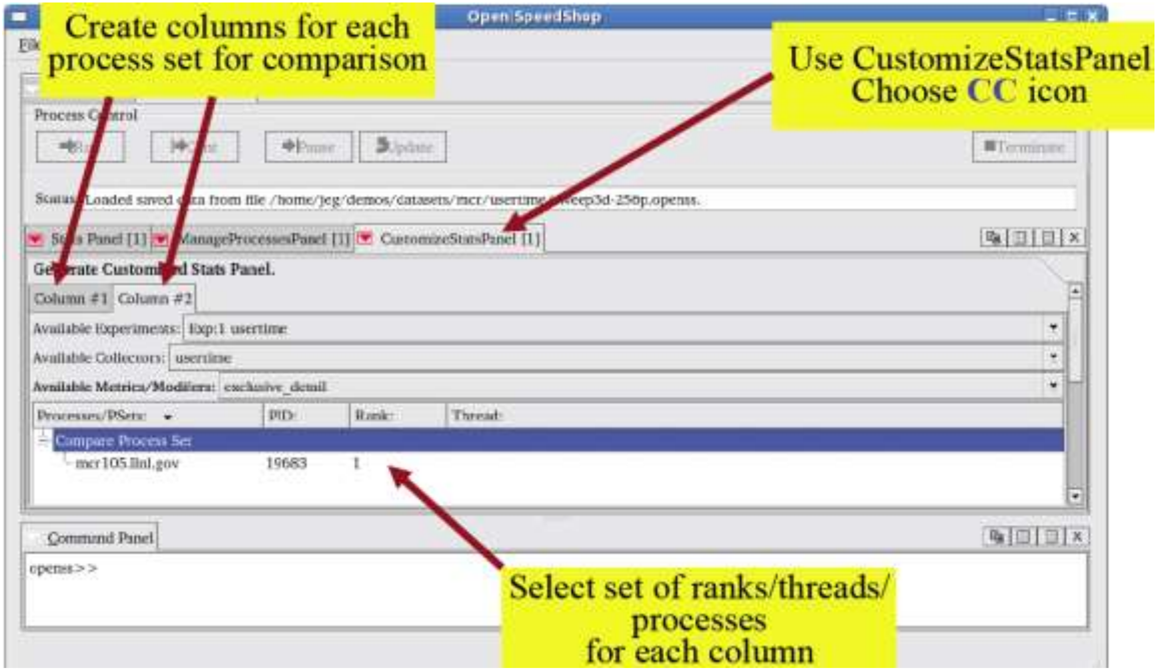
Showing Load Balance (min,max,ave) Report

Executables: sweep3d.mpi Hosts:(601) mcr104.llnl.gov ... Processes/Ranks/Threads:(601) 0 ...

Min Exclusive CPU time in sec	Max Exclusive CPU time in sec	Average Exclusive CPU time in	Function (defining location)
4.62000000	7.05000000	6.12898333	sweep_ (sweep3d.mpi)
1.50000000	3.12000000	2.17665000	elan3_pollevent_word (libelan3.so.1)
0.08000000	0.18000000	0.13115000	source_ (sweep3d.mpi)
0.02000000	0.18000000	0.08085000	elan_progressChannels (libelan.so.1)
0.01000000	0.01000000	0.01000000	elan_doput (libelan.so.1)
0.01000000	0.01000000	0.01000000	_elan_doputWait (libelan.so.1)
0.01000000	0.01000000	0.01000000	_elan_doputListRemove (libelan.so.1)

```
openss>>
```

Below we see the creation of a comparison between to ranks in Open|SpeedShop.



Status: Loaded saved data from file /home/jeg/demos/datasets/mcr/usertime/sweep3d-256p.openss.

Generate Customized Stats Panel.

Column #1 Column #2

Available Experiments: Exp:1 usertime

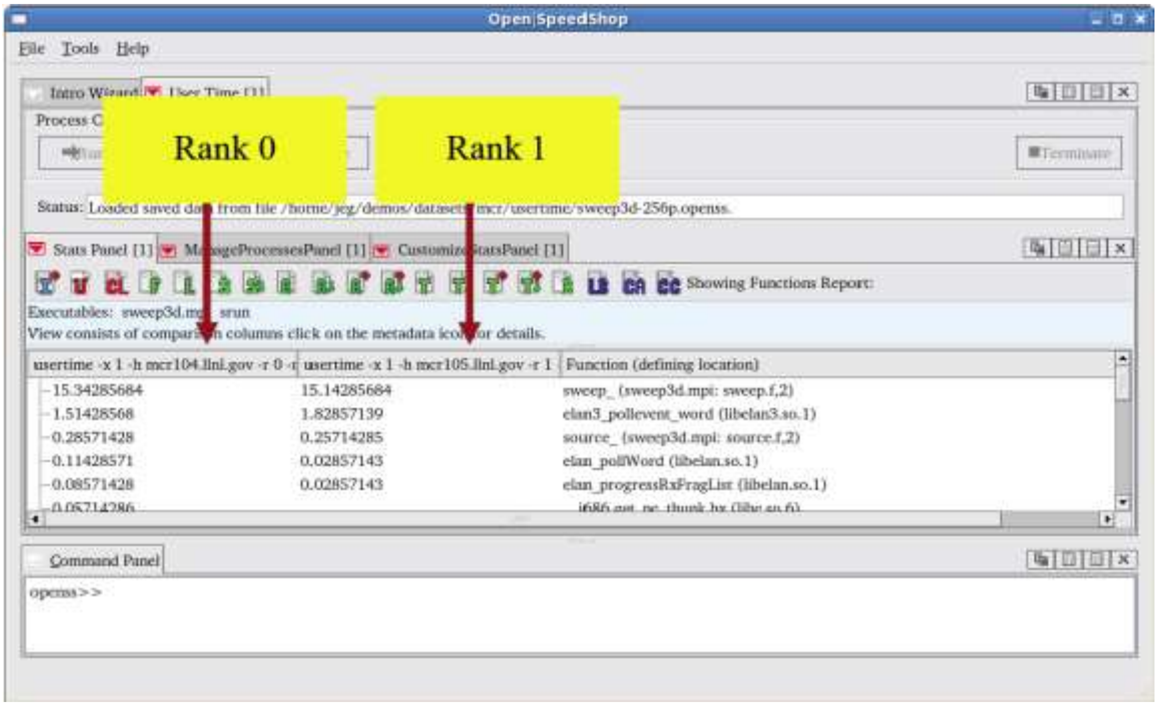
Available Collectors: usertime

Available Metrics/Modifiers: exclusive_detail

Processes/PSets:	PID:	Rank:	Thread:
Compare Process Set			
mcr105.llnl.gov	19683	1	

openss>>

Now we see those to ranks compared side by side in the statistics panel.



Status: Loaded saved data from file /home/jeg/demos/datasets/mcr/usertime/sweep3d-256p.openss.

Showing Functions Report:

Executables: sweep3d.mpi srun

View consists of comparison columns click on the metadata icon for details.

usertime -x 1 -h mcr104.llnl.gov -r 0 -r	usertime -x 1 -h mcr105.llnl.gov -r 1	Function (defining location)
15.34285684	15.14285684	sweep_ (sweep3d.mpi: sweep.f,2)
1.51428568	1.82857139	elan3_pollevent_word (libelan3.so.1)
0.28571428	0.25714285	source_ (sweep3d.mpi: source.f,2)
0.11428571	0.02857143	elan_pollWord (libelan.so.1)
0.08571428	0.02857143	elan_progressRxFragList (libelan.so.1)

openss>>

8.1 MPI Tracing Experiment

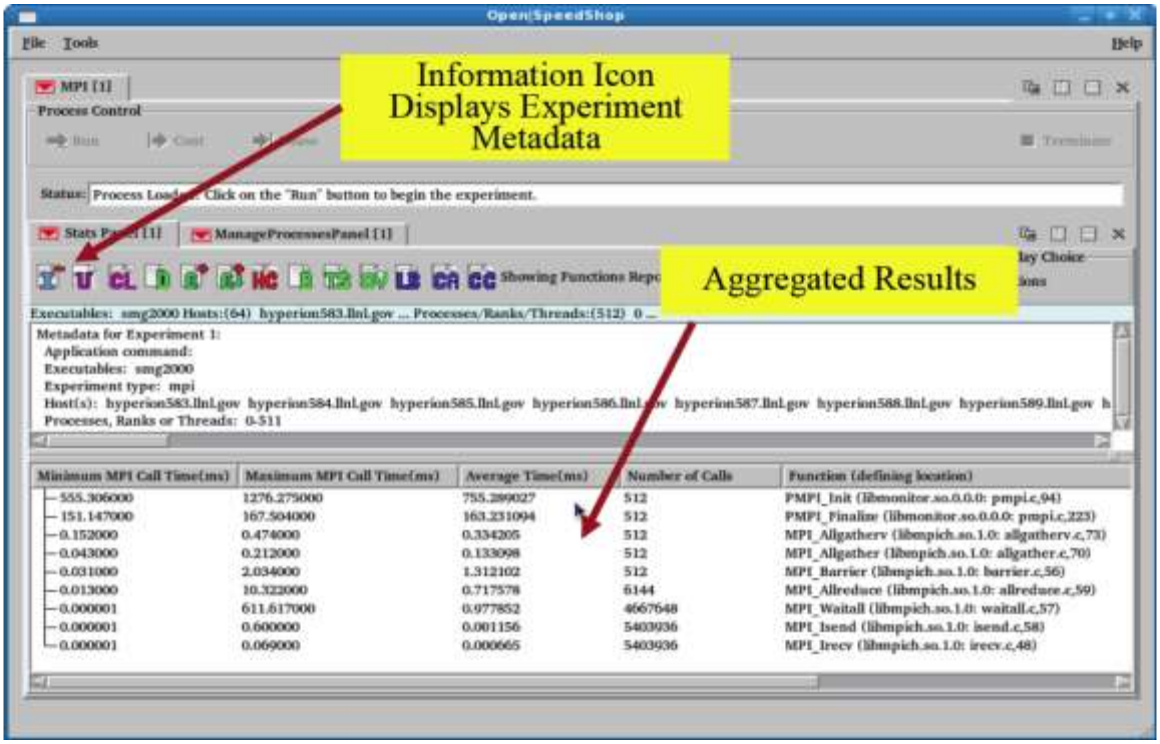
In this section we will go through an MPI tracing experiment with Open|SpeedShop. The experiment will be similar to the I/O tracing experiment; it will record all MPI call invocations. There are two MPI experiments and associated convenience scripts, ossmpi, which will record call times and ossmpit, which will record call times and arguments. Equal events will be aggregated to save space in the database as well as to reduce the overhead. There is one more MPI experiment that will save the full MPI traces in the Open Trace Format (OTF) with the convenience script ossmpiotf.

Again we will run experiment on the smg2000 application. The syntax for the experiment is:

```
> ossmpi[t] “srun –N 4 –n 32 smg2000 –n 50 50 50” [default | <list MPI functions> | mpi_category]
```

The default behavior is to trace all MPI functions, but a comma separated list of MPI functions can be giving if you only want to trace specific functions, e.g. MPI_Send, MPI_Recv,..., etc. You can also select an mpi_category to trace: "all”, "asynchronous_p2p”, "collective_com”, "datatypes”, "environment”, "graphs_contexts_comms”, "persistent_com”, "process_topologies”, and “synchronous_p2p”.

The image below shows the results of the MPI experiment in the default view.

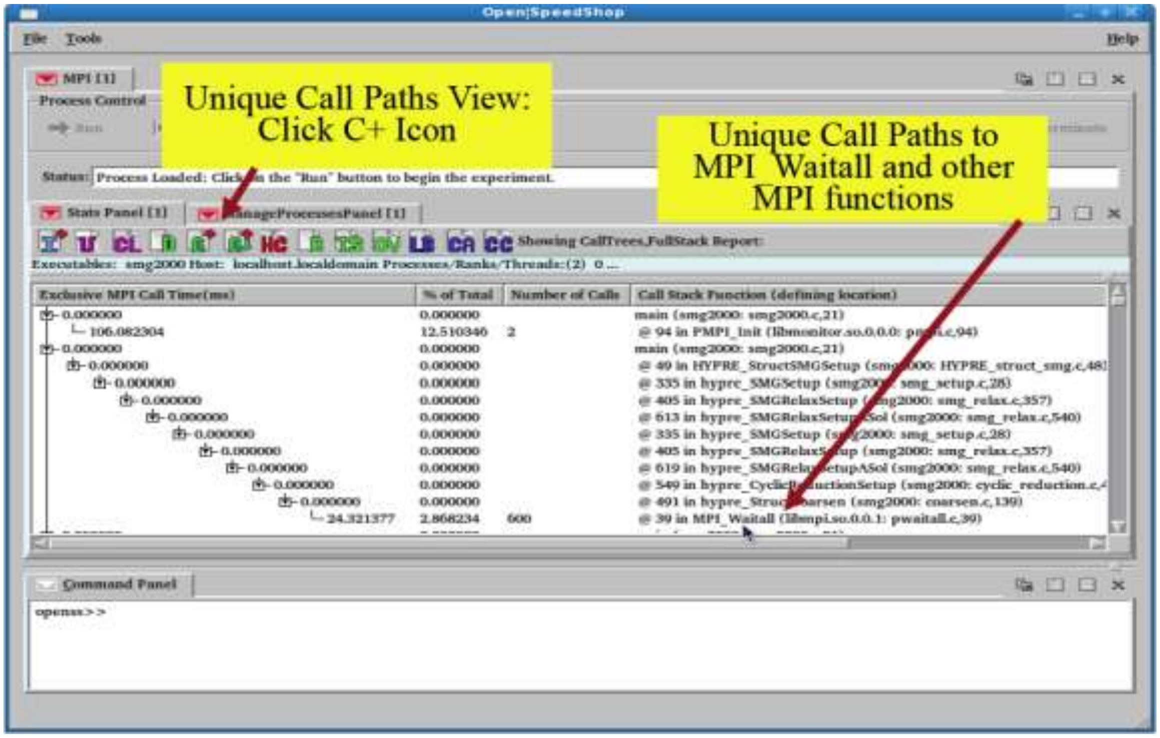


Status: Process Loaded: Click on the "Run" button to begin the experiment.

```
Executables:  smg2000 Hosts:(64)  hyperion583.llnl.gov ... Processes/Ranks/Threads:(512)  0 ...
Metadata for Experiment 1:
  Application command:
  Executables:  smg2000
  Experiment type:  mpi
  Host(s):  hyperion583.llnl.gov  hyperion584.llnl.gov  hyperion585.llnl.gov  hyperion586.llnl.gov  hyperion587.llnl.gov  hyperion588.llnl.gov  hyperion589.llnl.gov  h
  Processes, Ranks or Threads:  0-511
```

Minimum MPI Call Time(ms)	Maximum MPI Call Time(ms)	Average Time(ms)	Number of Calls	Function (defining location)
555.306000	1276.275000	755.289027	512	PMPI_Init (libmonitor.so.0.0.0: pmpi.c,94)
151.147000	167.504000	163.231094	512	PMPI_Finalize (libmonitor.so.0.0.0: pmpi.c,223)
0.152000	0.474000	0.334205	512	MPI_Allgatherv (libmpich.so.1.0: allgatherv.c,73)
0.043000	0.212000	0.133098	512	MPI_Allgather (libmpich.so.1.0: allgather.c,70)
0.031000	2.034000	1.312102	512	MPI_Barrier (libmpich.so.1.0: barrier.c,56)
0.013000	10.322000	0.717578	6144	MPI_Allreduce (libmpich.so.1.0: allreduce.c,59)
0.000001	611.617000	0.977852	4667648	MPI_Waitall (libmpich.so.1.0: waitall.c,57)
0.000001	0.600000	0.001156	5403936	MPI_Isend (libmpich.so.1.0: isend.c,58)
0.000001	0.069000	0.000665	5403936	MPI_Irecv (libmpich.so.1.0: irecv.c,48)

Next we see the MPI function call path view, shown below.



Unique Call Paths View: Click C+ Icon

Unique Call Paths to MPI_Waitall and other MPI functions

Status: Process Loaded: Click on the "Run" button to begin the experiment.

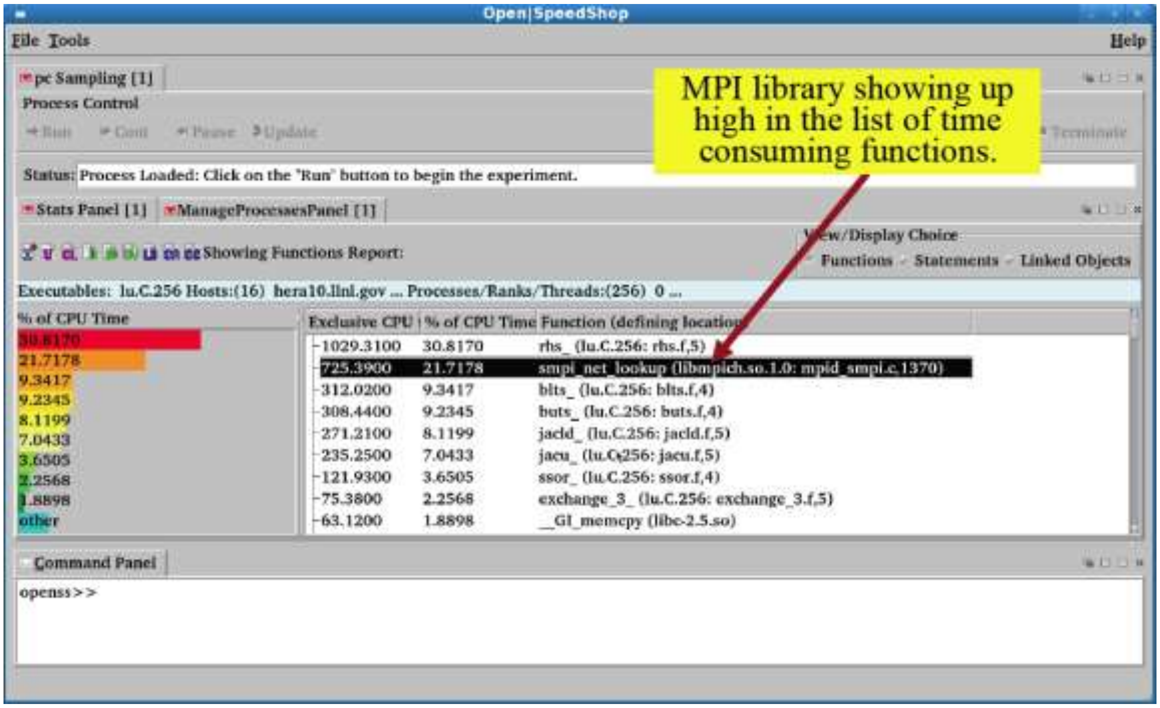
Showing CallTrees,FullStack Report:

Executables: smg2000 Host: localhost.localdomain Processes/Ranks/Threads:(2) 0 ...

```
Exclusive MPI Call Time(ms)   % of Total   Number of Calls   Call Stack Function (defining location)
-0.000000                     0.000000                       main (smg2000: smg2000.c,21)
 └ 106.082304                 12.510346    2                 @ 94 in PMPI_Init (libmonitor.so.0.0.0: p[illegible].c,94)
-0.000000                     0.000000                       main (smg2000: smg2000.c,21)
  -0.000000                   0.000000                       @ 49 in HYPRE_StructSMGSetup (smg2000: HYPRE_struct_smg.c,48)
    -0.000000                 0.000000                       @ 335 in hypre_SMGSetup (smg2000: smg_setup.c,28)
      -0.000000               0.000000                       @ 405 in hypre_SMGRelaxSetup (smg2000: smg_relax.c,357)
        -0.000000             0.000000                       @ 613 in hypre_SMGRelaxSetupASol (smg2000: smg_relax.c,540)
          -0.000000           0.000000                       @ 335 in hypre_SMGSetup (smg2000: smg_setup.c,28)
            -0.000000         0.000000                       @ 405 in hypre_SMGRelaxSetup (smg2000: smg_relax.c,357)
              -0.000000       0.000000                       @ 619 in hypre_SMGRelaxSetupASol (smg2000: smg_relax.c,540)
                -0.000000     0.000000                       @ 549 in hypre_CyclicReductionSetup (smg2000: cyclic_reduction.c,
                  -0.000000   0.000000                       @ 491 in hypre_StructCoarsen (smg2000: coarsen.c,139)
                   └ 24.321377 2.868234    600               @ 39 in MPI_Waitall (libmpi.so.0.0.1: pwaitall.c,39)
```

```
openss>>
```

Here is the default pcsamp view based on functions.



MPI library showing up high in the list of time consuming functions.

Status: Process Loaded: Click on the "Run" button to begin the experiment.

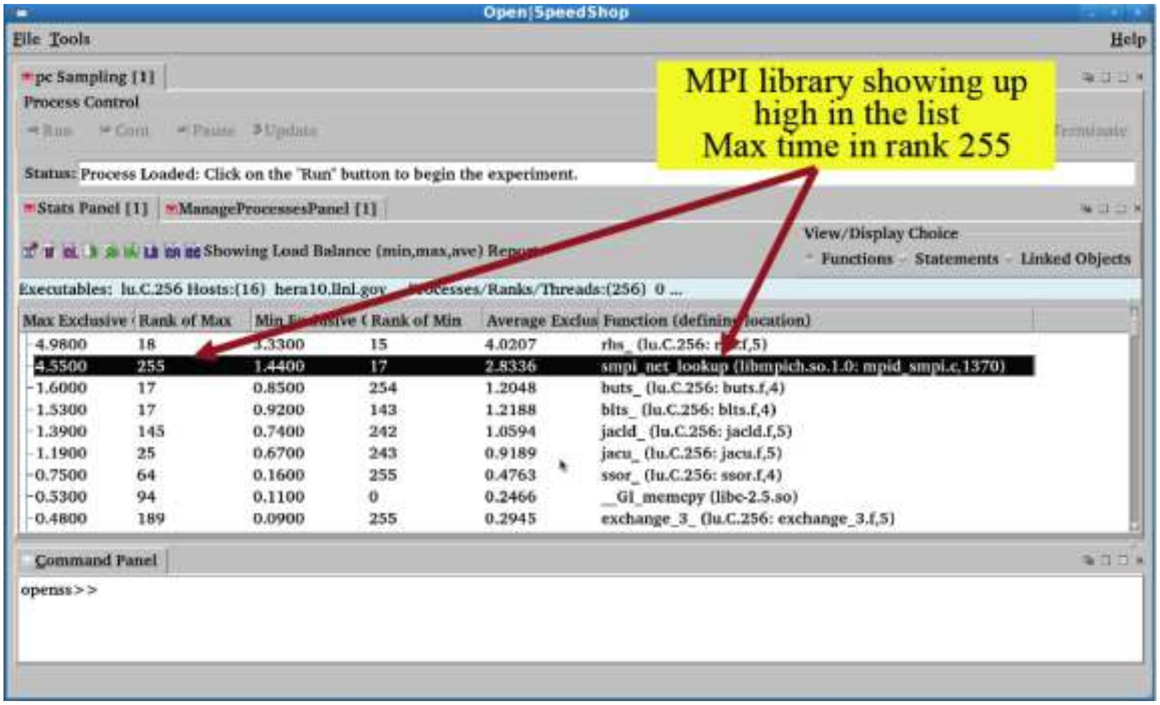
Showing Functions Report:

Executables: lu.C.256 Hosts:(16) hera10.llnl.gov ... Processes/Ranks/Threads:(256) 0 ...

```
Exclusive CPU  % of CPU Time  Function (defining location)
1029.3100      30.8170        rhs_ (lu.C.256: rhs.f,5)
725.3900       21.7178        smpi_net_lookup (libmpich.so.1.0: mpid_smpi.c,1370)
312.0200       9.3417         blts_ (lu.C.256: blts.f,4)
308.4400       9.2345         buts_ (lu.C.256: buts.f,4)
271.2100       8.1199         jacld_ (lu.C.256: jacld.f,5)
235.2500       7.0433         jacu_ (lu.C.256: jacu.f,5)
121.9300       3.6505         ssor_ (lu.C.256: ssor.f,4)
75.3800        2.2568         exchange_3_ (lu.C.256: exchange_3.f,5)
63.1200        1.8898         __GI_memcpy (libc-2.5.so)
```

```
openss>>
```

Here is the load balance view based on functions.



MPI library showing up high in the list
Max time in rank 255

Status: Process Loaded: Click on the 'Run' button to begin the experiment.

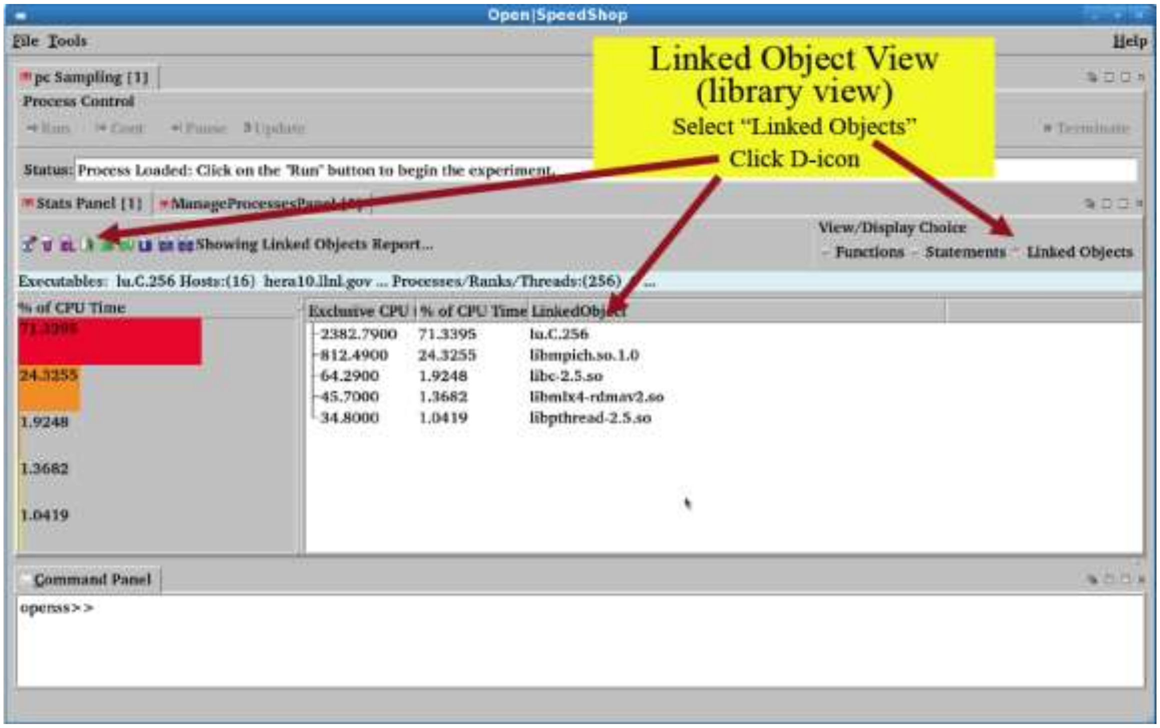
Showing Load Balance (min,max,ave) Report...

Executables: lu.C.256 Hosts:(16) hera10.llnl.gov ... Processes/Ranks/Threads:(256) 0 ...

Max Exclusive (	Rank of Max	Min Exclusive (	Rank of Min	Average Exclus	Function (defining location)
4.9800	18	3.3300	15	4.0207	rhs_ (lu.C.256: rhs.f,5)
4.5500	255	1.4400	17	2.8336	smpi_net_lookup (libmpich.so.1.0: mpid_smpi.c,1370)
1.6000	17	0.8500	254	1.2048	buts_ (lu.C.256: buts.f,4)
1.5300	17	0.9200	143	1.2188	blts_ (lu.C.256: blts.f,4)
1.3900	145	0.7400	242	1.0594	jacld_ (lu.C.256: jacld.f,5)
1.1900	25	0.6700	243	0.9189	jacu_ (lu.C.256: jacu.f,5)
0.7500	64	0.1600	255	0.4763	ssor_ (lu.C.256: ssor.f,4)
0.5300	94	0.1100	0	0.2466	__GI_memcpy (libc-2.5.so)
0.4800	189	0.0900	255	0.2945	exchange_3_ (lu.C.256: exchange_3.f,5)

```
openss>>
```

Here is the default view based on Linked Objects (libraries).



Linked Object View (library view)
Select "Linked Objects"
Click D-icon

Status: Process Loaded: Click on the 'Run' button to begin the experiment.

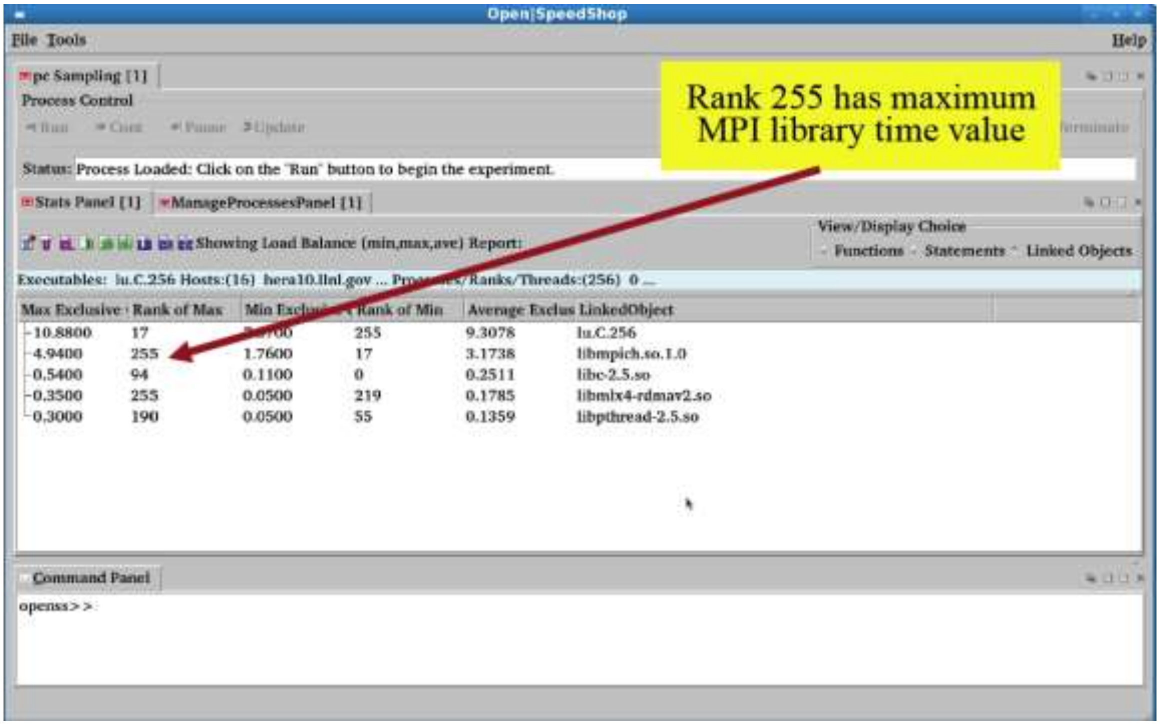
Showing Linked Objects Report...

Executables: lu.C.256 Hosts:(16) hera10.llnl.gov ... Processes/Ranks/Threads:(256) ...

Exclusive CPU	% of CPU Time	LinkedObject
2382.7900	71.3395	lu.C.256
812.4900	24.3255	libmpich.so.1.0
64.2900	1.9248	libc-2.5.so
45.7000	1.3682	libmlx4-rdmav2.so
34.8000	1.0419	libpthread-2.5.so

```
openss>>
```

Next we see the load balance view base on Linked Objects (libraries).



Rank 255 has maximum MPI library time value

Status: Process Loaded: Click on the "Run" button to begin the experiment.

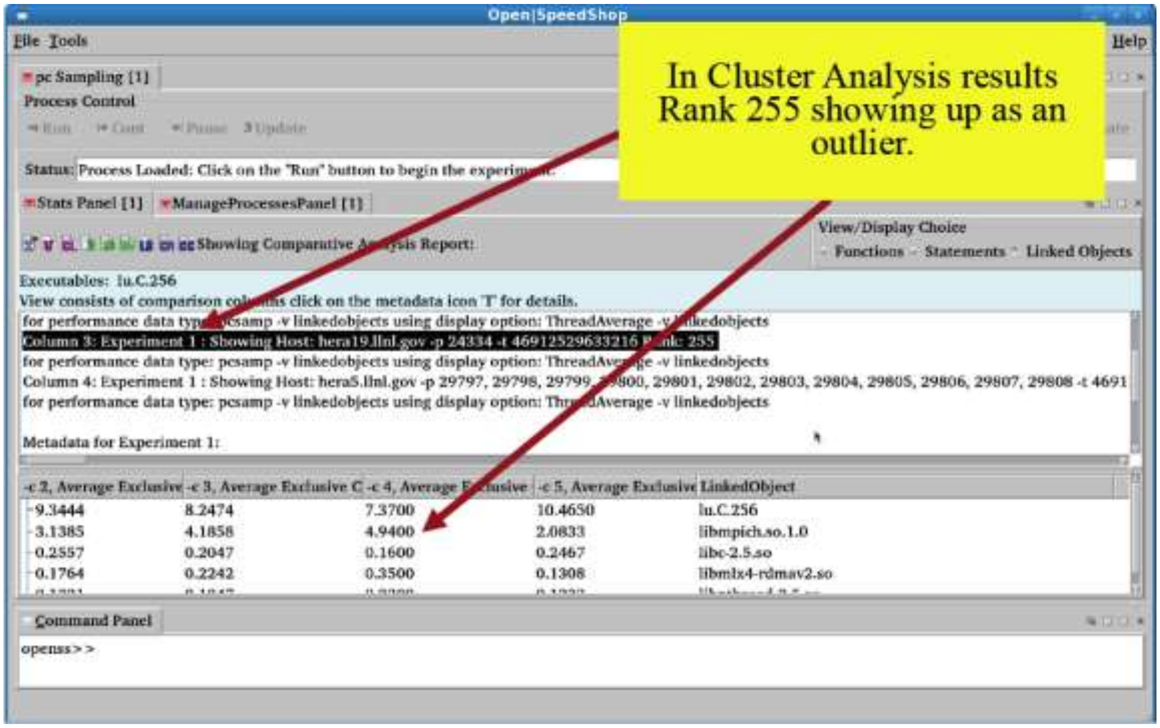
Showing Load Balance (min,max,ave) Report:

Executables: lu.C.256 Hosts:(16) hera10.llnl.gov ... Processes/Ranks/Threads:(256) 0 ...

Max Exclusive	Rank of Max	Min Exclusive	Rank of Min	Average Exclus	LinkedObject
10.8800	17	7.3700	255	9.3078	lu.C.256
4.9400	255	1.7600	17	3.1738	libmpich.so.1.0
0.5400	94	0.1100	0	0.2511	libc-2.5.so
0.3500	255	0.0500	219	0.1785	libmlx4-rdmav2.so
0.3000	190	0.0500	55	0.1359	libpthread-2.5.so

```
openss>>
```

Here we see the cluster analysis view based on Linked Objects.



In Cluster Analysis results Rank 255 showing up as an outlier.

Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Comparative Analysis Report:

Executables: lu.C.256

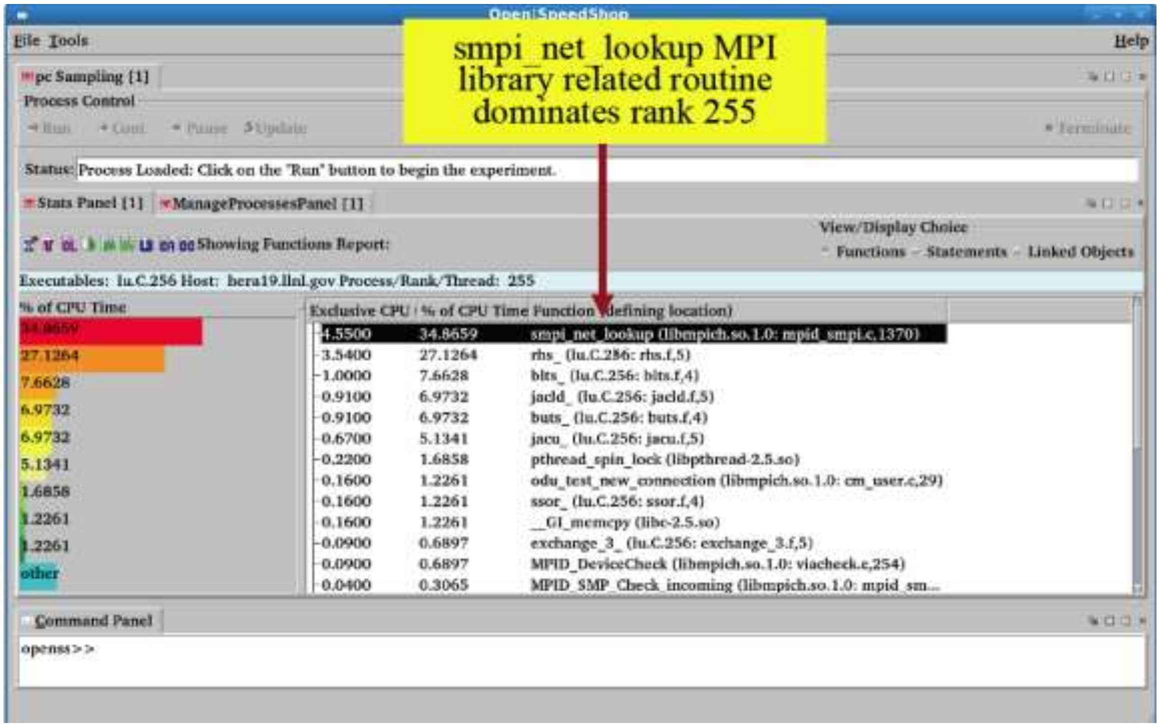
View consists of comparison columns click on the metadata icon 'I' for details.

```
for performance data type: pcsamp -v linkedobjects using display option: ThreadAverage -v linkedobjects
Column 3: Experiment 1 : Showing Host: hera19.llnl.gov -p 24334 -t 46912529633216 Rank: 255
for performance data type: pcsamp -v linkedobjects using display option: ThreadAverage -v linkedobjects
Column 4: Experiment 1 : Showing Host: hera5.llnl.gov -p 29797, 29798, 29799, 29800, 29801, 29802, 29803, 29804, 29805, 29806, 29807, 29808 -t 4691
for performance data type: pcsamp -v linkedobjects using display option: ThreadAverage -v linkedobjects

Metadata for Experiment 1:
```

-c 2, Average Exclusive	-c 3, Average Exclusive C	-c 4, Average Exclusive	-c 5, Average Exclusive	LinkedObject
9.3444	8.2474	7.3700	10.4650	lu.C.256
3.1385	4.1858	4.9400	2.0833	libmpich.so.1.0
0.2557	0.2047	0.1600	0.2467	libc-2.5.so
0.1764	0.2242	0.3500	0.1308	libmlx4-rdmav2.so

```
openss>>
```

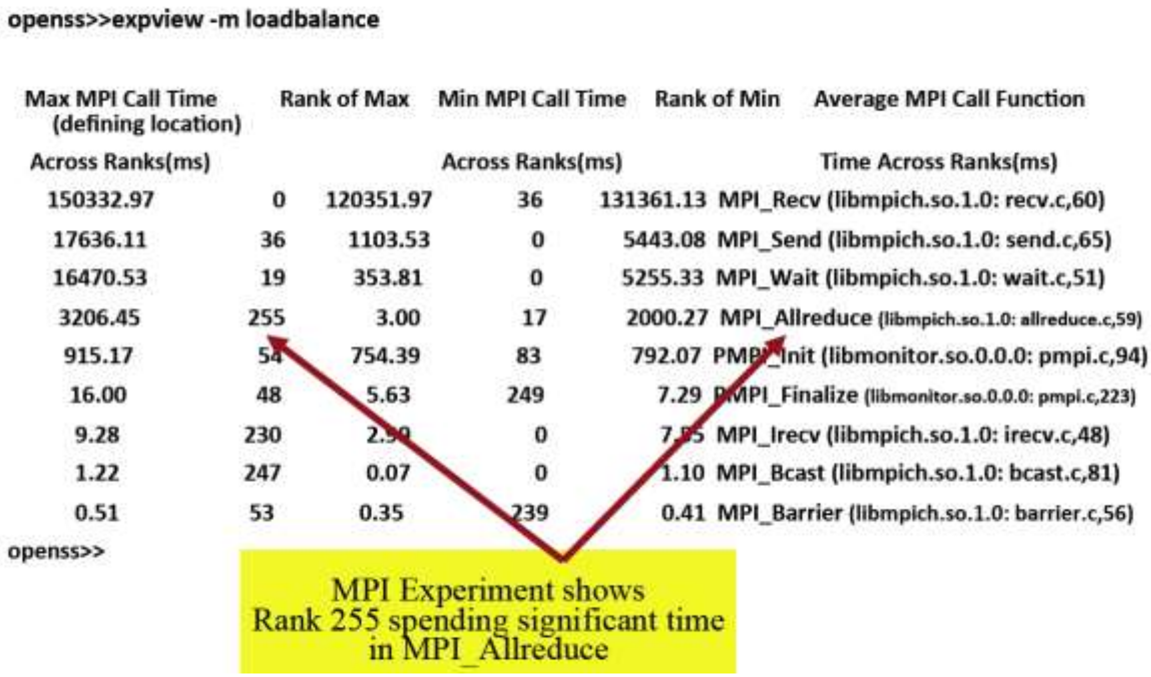
Here is the pcsamp view of Rank 255 performance data only.



smpi_net_lookup MPI library related routine dominates rank 255

```
Status: Process Loaded: Click on the "Run" button to begin the experiment.
Showing Functions Report:
Executables: lu.C.256 Host: hera19.llnl.gov Process/Rank/Thread: 255

% of CPU Time   Exclusive CPU  % of CPU Time  Function (defining location)
34.8659         4.5500         34.8659        smpi_net_lookup (libmpich.so.1.0: mpid_smpi.c,1370)
27.1264         3.5400         27.1264        rhs_ (lu.C.256: rhs.f,5)
7.6628          1.0000         7.6628         blts_ (lu.C.256: blts.f,4)
6.9732          0.9100         6.9732         jacld_ (lu.C.256: jacld.f,5)
6.9732          0.9100         6.9732         buts_ (lu.C.256: buts.f,4)
5.1341          0.6700         5.1341         jacu_ (lu.C.256: jacu.f,5)
1.6858          0.2200         1.6858         pthread_spin_lock (libpthread-2.5.so)
1.2261          0.1600         1.2261         odu_test_new_connection (libmpich.so.1.0: cm_user.c,29)
1.2261          0.1600         1.2261         ssor_ (lu.C.256: ssor.f,4)
other           0.1600         1.2261         __GI_memcpy (libc-2.5.so)
                0.0900         0.6897         exchange_3_ (lu.C.256: exchange_3.f,5)
                0.0900         0.6897         MPID_DeviceCheck (libmpich.so.1.0: viacheck.c,254)
                0.0400         0.3065         MPID_SMP_Check_incoming (libmpich.so.1.0: mpid_sm...

openss>>
```

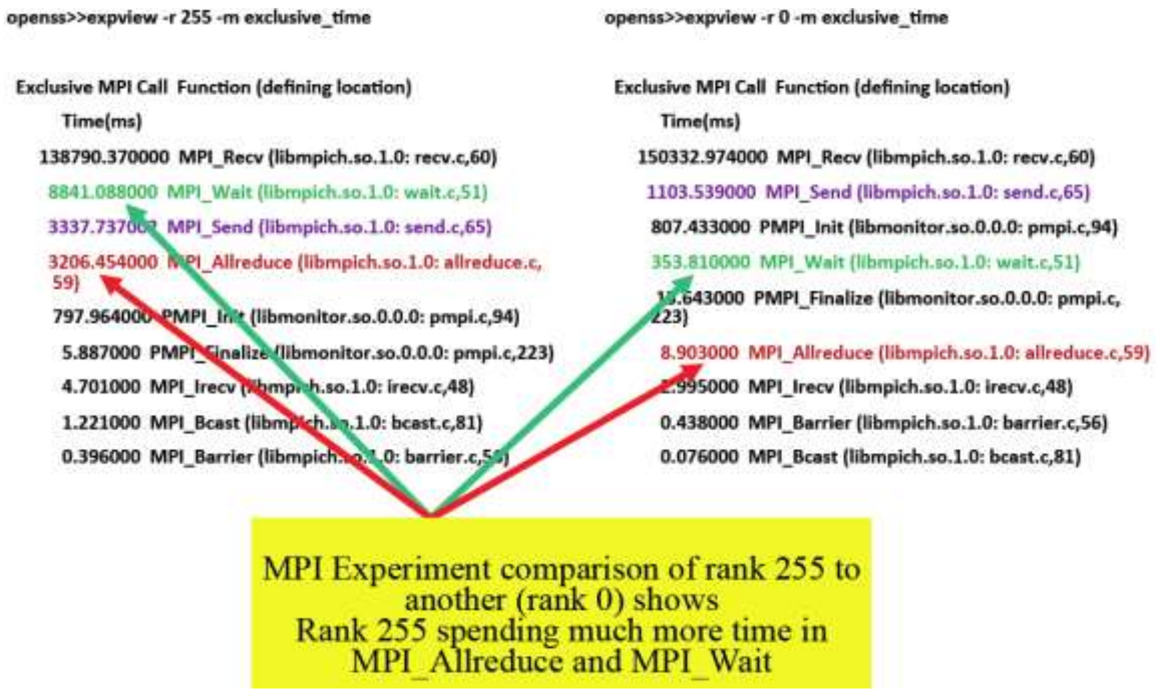
Below we examine Rank 255 further but this time using the load balance view in the Command Line Interface for Open|SpeedShop.



```
openss>>expview -m loadbalance

 Max MPI Call Time    Rank of Max  Min MPI Call Time  Rank of Min  Average MPI Call Function
  (defining location)
 Across Ranks(ms)                   Across Ranks(ms)               Time Across Ranks(ms)
  150332.97            0   120351.97        36     131361.13  MPI_Recv (libmpich.so.1.0: recv.c,60)
   17636.11           36     1103.53         0       5443.08  MPI_Send (libmpich.so.1.0: send.c,65)
   16470.53           19      353.81         0       5255.33  MPI_Wait (libmpich.so.1.0: wait.c,51)
    3206.45          255        3.00        17       2000.27  MPI_Allreduce (libmpich.so.1.0: allreduce.c,59)
     915.17           54      754.39        83        792.07  PMPI_Init (libmonitor.so.0.0.0: pmpi.c,94)
      16.00           48        5.63       249          7.29  PMPI_Finalize (libmonitor.so.0.0.0: pmpi.c,223)
       9.28          230        2.99         0          7.55  MPI_Irecv (libmpich.so.1.0: irecv.c,48)
       1.22          247        0.07         0          1.10  MPI_Bcast (libmpich.so.1.0: bcast.c,81)
       0.51           53        0.35       239          0.41  MPI_Barrier (libmpich.so.1.0: barrier.c,56)
openss>>
```

MPI Experiment shows Rank 255 spending significant time in MPI_Allreduce

Here we look at the difference between Rank 255 and Rank 0.

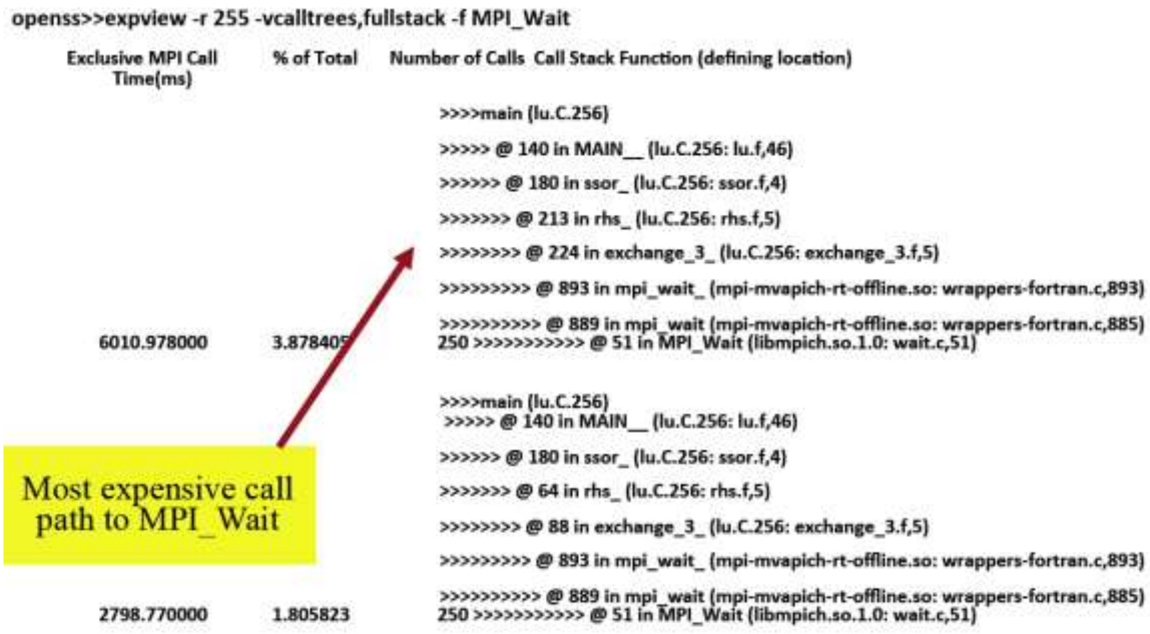


```
openss>>expview -r 255 -m exclusive_time

 Exclusive MPI Call  Function (defining location)
      Time(ms)
   138790.370000  MPI_Recv (libmpich.so.1.0: recv.c,60)
    8841.088000  MPI_Wait (libmpich.so.1.0: wait.c,51)
    3337.737000  MPI_Send (libmpich.so.1.0: send.c,65)
    3206.454000  MPI_Allreduce (libmpich.so.1.0: allreduce.c,
     59)
     797.964000  PMPI_Init (libmonitor.so.0.0.0: pmpi.c,94)
      5.887000  PMPI_Finalize (libmonitor.so.0.0.0: pmpi.c,223)
      4.701000  MPI_Irecv (libmpich.so.1.0: irecv.c,48)
      1.221000  MPI_Bcast (libmpich.so.1.0: bcast.c,81)
      0.396000  MPI_Barrier (libmpich.so.1.0: barrier.c,56)
```

```
openss>>expview -r 0 -m exclusive_time

 Exclusive MPI Call  Function (defining location)
      Time(ms)
   150332.974000  MPI_Recv (libmpich.so.1.0: recv.c,60)
    1103.539000  MPI_Send (libmpich.so.1.0: send.c,65)
     807.433000  PMPI_Init (libmonitor.so.0.0.0: pmpi.c,94)
     353.810000  MPI_Wait (libmpich.so.1.0: wait.c,51)
     15.643000  PMPI_Finalize (libmonitor.so.0.0.0: pmpi.c,
    223)
      8.903000  MPI_Allreduce (libmpich.so.1.0: allreduce.c,59)
      2.995000  MPI_Irecv (libmpich.so.1.0: irecv.c,48)
      0.438000  MPI_Barrier (libmpich.so.1.0: barrier.c,56)
      0.076000  MPI_Bcast (libmpich.so.1.0: bcast.c,81)
```

MPI Experiment comparison of rank 255 to another (rank 0) shows Rank 255 spending much more time in MPI_Allreduce and MPI_Wait

Next we see the hot call paths for MPI_Wait on Rank 255.



```
openss>>expview -r 255 -vcalltrees,fullstack -f MPI_Wait
    Exclusive MPI Call      % of Total     Number of Calls  Call Stack Function (defining location)
       Time(ms)

                                           >>>>main (lu.C.256)
                                           >>>>> @ 140 in MAIN__ (lu.C.256: lu.f,46)
                                           >>>>>> @ 180 in ssor_ (lu.C.256: ssor.f,4)
                                           >>>>>>> @ 213 in rhs_ (lu.C.256: rhs.f,5)
                                           >>>>>>>> @ 224 in exchange_3_ (lu.C.256: exchange_3.f,5)
                                           >>>>>>>>> @ 893 in mpi_wait_ (mpi-mvapich-rt-offline.so: wrappers-fortran.c,893)
                                           >>>>>>>>>> @ 889 in mpi_wait (mpi-mvapich-rt-offline.so: wrappers-fortran.c,885)
       6010.978000          3.878405       250 >>>>>>>>>>> @ 51 in MPI_Wait (libmpich.so.1.0: wait.c,51)

                                           >>>>main (lu.C.256)
                                            >>>>> @ 140 in MAIN__ (lu.C.256: lu.f,46)
                                           >>>>>> @ 180 in ssor_ (lu.C.256: ssor.f,4)
                                           >>>>>>> @ 64 in rhs_ (lu.C.256: rhs.f,5)
                                           >>>>>>>> @ 88 in exchange_3_ (lu.C.256: exchange_3.f,5)
                                           >>>>>>>>> @ 893 in mpi_wait_ (mpi-mvapich-rt-offline.so: wrappers-fortran.c,893)
                                           >>>>>>>>>> @ 889 in mpi_wait (mpi-mvapich-rt-offline.so: wrappers-fortran.c,885)
       2798.770000          1.805823       250 >>>>>>>>>>> @ 51 in MPI_Wait (libmpich.so.1.0: wait.c,51)
```

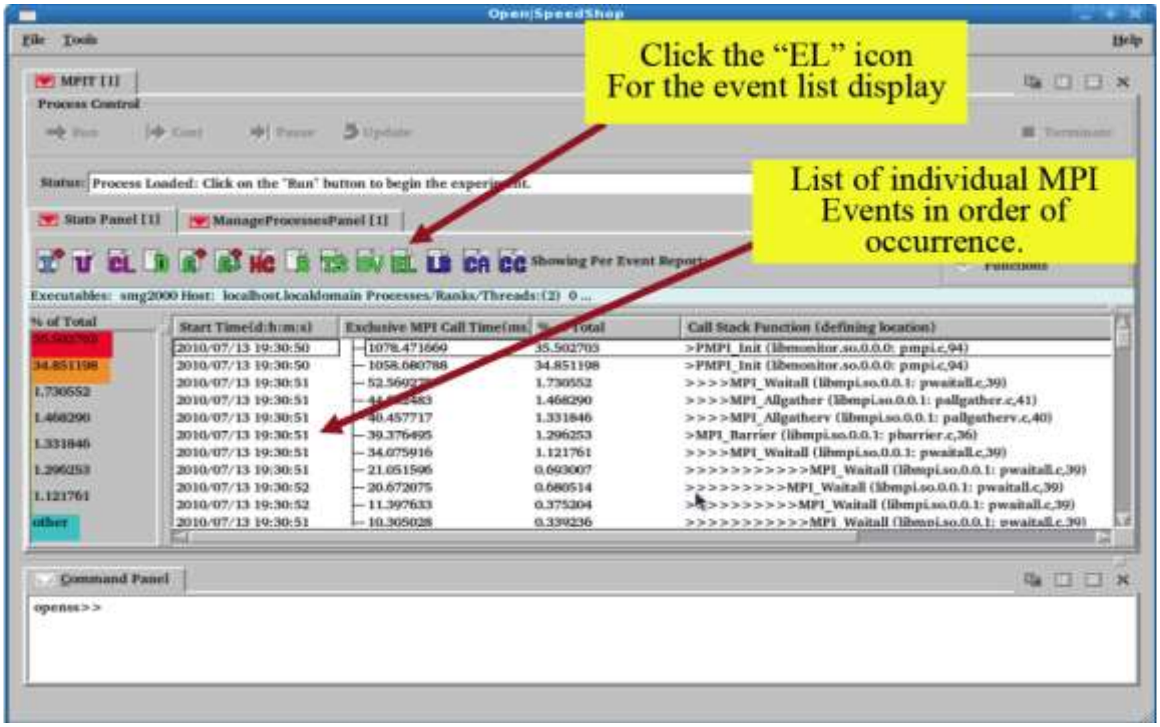
Most expensive call path to MPI_Wait

In this experiment we did program counter sampling to get an overview of the application. We noticed that smp_net_lookup showed up in function load balance view, which caused us to take a look at the linked object view. The load balance on the linked object showed some imbalance, so we looked at the cluster analysis view and found that rank 255 was an outlier.

We then took a closer look at rank 255 and saw that the pcsamp output shows most of the time was spent in smp_net_lookup. We used the MPI experiment to determine if we can get more clues and saw that a load balance view on the MPI experiment shows rank 255's MPI-Allreduce time is the highest of the 256 ranks. We then looked at rank 255 and a representative rank from the rest of the ranks and noted the differences in MPI_Wait, MPI_Send and MPI_Allreduce. We looked at the call paths to MPI_Wait to determine why the wait was occurring.

The mpit experiment has a performance information entry for each MPI function call. In addition to the time spent in each MPI function, information like source and destination rank, bytes sent or received are also available. You can selectively view the information you desire.

Below we see the default event view for an MPI application.



Click the "EL" icon
For the event list display

List of individual MPI
Events in order of
occurrence.

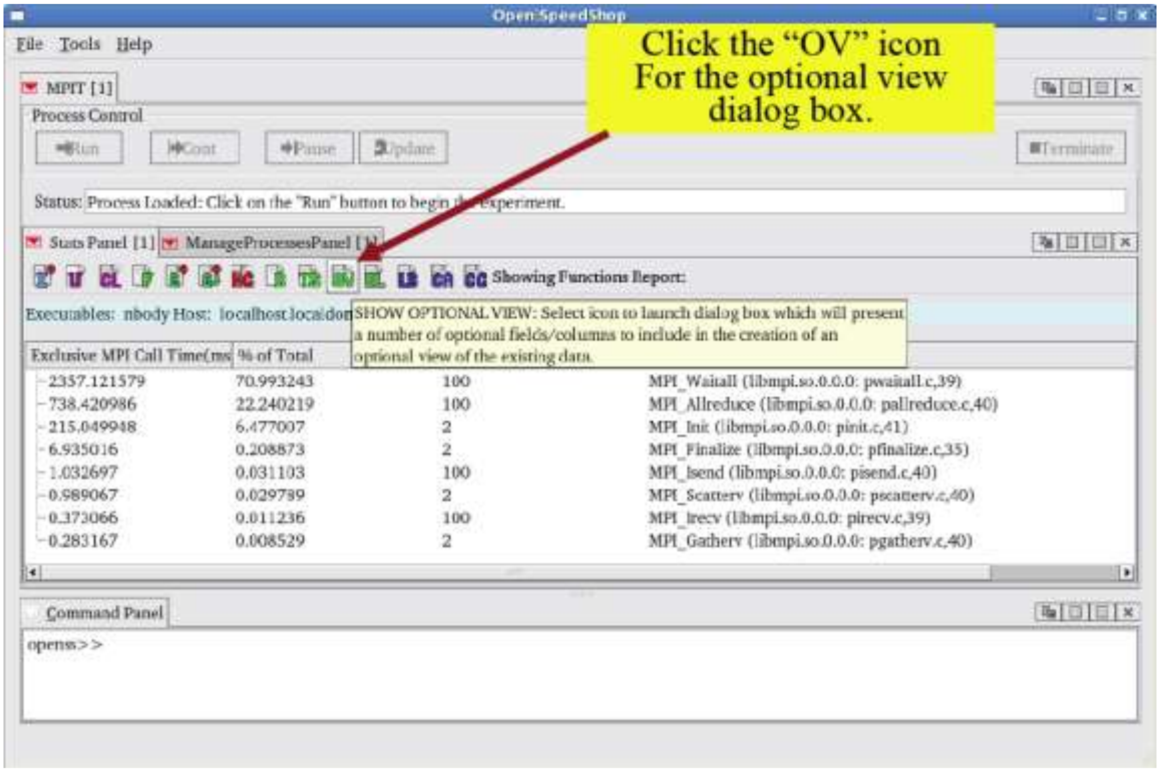
Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: smg2000 Host: localhost.localdomain Processes/Ranks/Threads:(2) 0 ...

Start Time(d:h:m:s)	Exclusive MPI Call Time(ms	% of Total	Call Stack Function (defining location)
2010/07/13 19:30:50	1078.471669	35.502703	>PMPI_Init (libmonitor.so.0.0.0: pmpi.c,94)
2010/07/13 19:30:50	1058.680788	34.851198	>PMPI_Init (libmonitor.so.0.0.0: pmpi.c,94)
2010/07/13 19:30:51	52.5692[illegible]	1.730552	>>>>MPI_Waitall (libmpi.so.0.0.1: pwaitall.c,39)
2010/07/13 19:30:51	44.[illegible]2483	1.468290	>>>>MPI_Allgather (libmpi.so.0.0.1: pallgather.c,41)
2010/07/13 19:30:51	40.457717	1.331846	>>>>MPI_Allgatherv (libmpi.so.0.0.1: pallgatherv.c,40)
2010/07/13 19:30:51	39.376495	1.296253	>MPI_Barrier (libmpi.so.0.0.1: pbarrier.c,36)
2010/07/13 19:30:51	34.075916	1.121761	>>>>MPI_Waitall (libmpi.so.0.0.1: pwaitall.c,39)
2010/07/13 19:30:51	21.051596	0.693007	>>>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwaitall.c,39)
2010/07/13 19:30:52	20.672075	0.680514	>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwaitall.c,39)
2010/07/13 19:30:52	11.397633	0.375204	>>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwaitall.c,39)
2010/07/13 19:30:51	10.305028	0.339236	>>>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwaitall.c,39)

```
openss>>
```

We can create our own event view with the OV button.



Click the "OV" icon For the optional view dialog box.

Status: Process Loaded: Click on the "Run" button to begin the experiment.

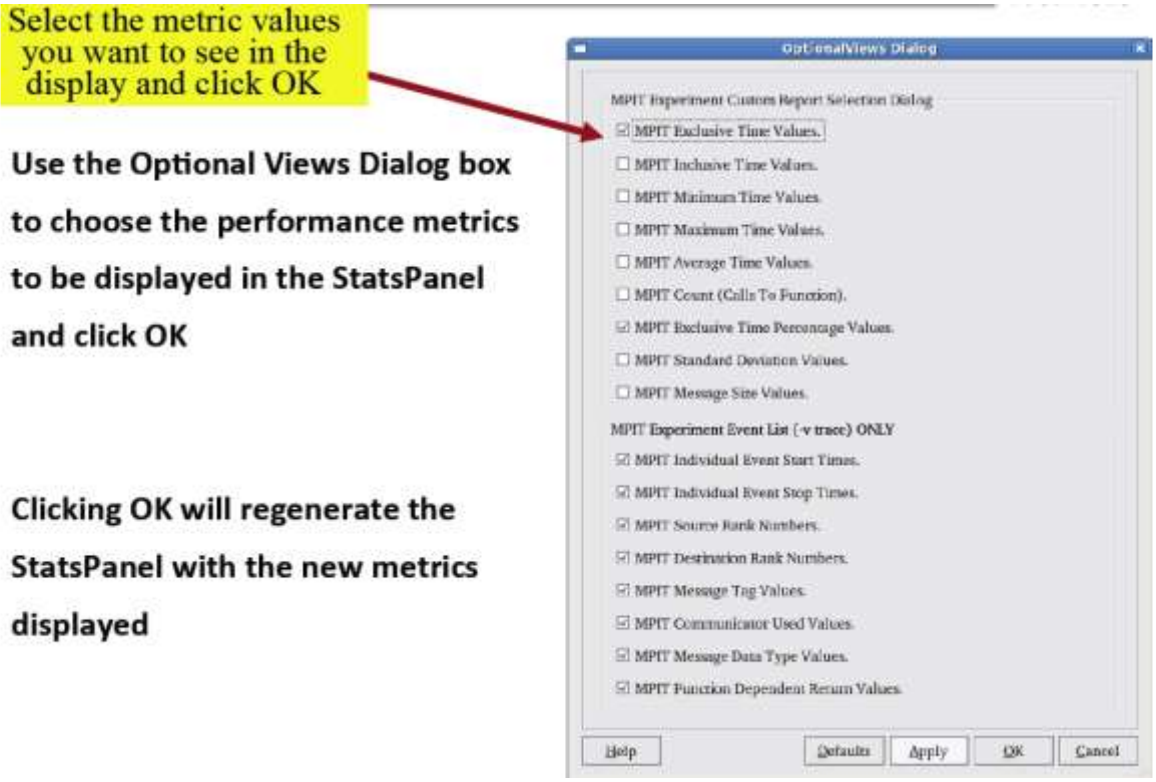
Executables: nbody Host: localhost.localdom

SHOW OPTIONAL VIEW: Select icon to launch dialog box which will present a number of optional fields/columns to include in the creation of an optional view of the existing data.

Exclusive MPI Call Time(ms	% of Total		
2357.121579	70.993243	100	MPI_Waitall (libmpi.so.0.0.0: pwaitall.c,39)
738.420986	22.240219	100	MPI_Allreduce (libmpi.so.0.0.0: pallreduce.c,40)
215.049948	6.477007	2	MPI_Init (libmpi.so.0.0.0: pinit.c,41)
6.935016	0.208873	2	MPI_Finalize (libmpi.so.0.0.0: pfinalize.c,35)
1.032697	0.031103	100	MPI_Isend (libmpi.so.0.0.0: pisend.c,40)
0.989067	0.029789	2	MPI_Scatterv (libmpi.so.0.0.0: pscatterv.c,40)
0.373066	0.011236	100	MPI_Irecv (libmpi.so.0.0.0: pirecv.c,39)
0.283167	0.008529	2	MPI_Gatherv (libmpi.so.0.0.0: pgatherv.c,40)

```
openss>>
```

You can use the views dialog box to choose what metric to display.



Select the metric values you want to see in the display and click OK

Use the Optional Views Dialog box to choose the performance metrics to be displayed in the StatsPanel and click OK

Clicking OK will regenerate the StatsPanel with the new metrics displayed

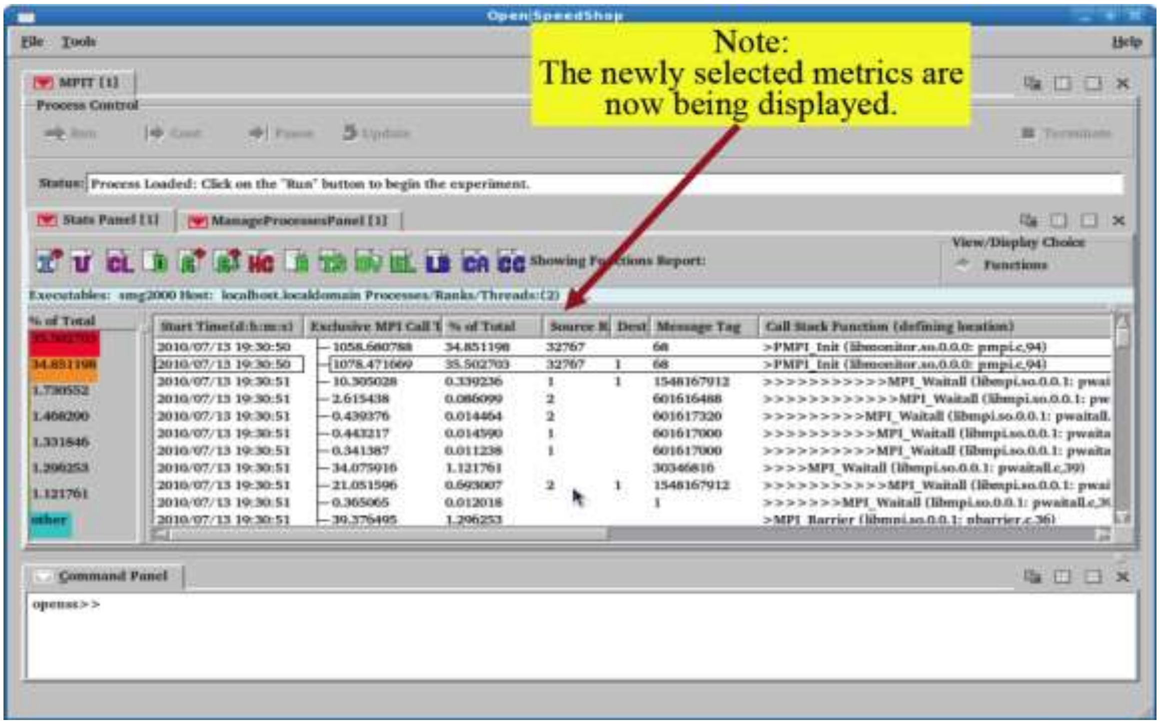
MPIT Experiment Custom Report Selection Dialog

- ☑ MPIT Exclusive Time Values.
- ☐ MPIT Inclusive Time Values.
- ☐ MPIT Minimum Time Values.
- ☐ MPIT Maximum Time Values.
- ☐ MPIT Average Time Values.
- ☐ MPIT Count (Calls To Function).
- ☑ MPIT Exclusive Time Percentage Values.
- ☐ MPIT Standard Deviation Values.
- ☐ MPIT Message Size Values.

MPIT Experiment Event List (-v trace) ONLY

- ☑ MPIT Individual Event Start Times.
- ☑ MPIT Individual Event Stop Times.
- ☑ MPIT Source Rank Numbers.
- ☑ MPIT Destination Rank Numbers.
- ☑ MPIT Message Tag Values.
- ☑ MPIT Communicator Used Values.
- ☑ MPIT Message Data Type Values.
- ☑ MPIT Function Dependent Return Values.

After choosing the event to view it will then be displayed.



Note:
The newly selected metrics are now being displayed.

Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Functions Report:

Executables: smg2000 Host: localhost.localdomain Processes/Ranks/Threads:(2)

% of Total
35.502703
34.851198
1.730552
1.408290
1.331846
1.296253
1.121761
other

Start Time(d:h:m:s)	Exclusive MPI Call T	% of Total	Source R	Dest	Message Tag	Call Stack Function (defining location)
2010/07/13 19:30:50	1058.680788	34.851198	32767		68	>PMPI_Init (libmonitor.so.0.0.0: pmpi.c,94)
2010/07/13 19:30:50	1078.471669	35.502703	32767	1	68	>PMPI_Init (libmonitor.so.0.0.0: pmpi.c,94)
2010/07/13 19:30:51	10.305028	0.339236	1	1	1548167912	>>>>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwai
2010/07/13 19:30:51	2.615438	0.086099	2		601616488	>>>>>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pw
2010/07/13 19:30:51	0.439376	0.014464	2		601617320	>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwaitall.
2010/07/13 19:30:51	0.443217	0.014590	1		601617000	>>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwaita
2010/07/13 19:30:51	0.341387	0.011238	1		601617000	>>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwaita
2010/07/13 19:30:51	34.075916	1.121761			30346816	>>>>MPI_Waitall (libmpi.so.0.0.1: pwaitall.c,39)
2010/07/13 19:30:51	21.051596	0.693007	2	1	1548167912	>>>>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwai
2010/07/13 19:30:51	0.365065	0.012018			1	>>>>>>>>MPI_Waitall (libmpi.so.0.0.1: pwaitall.c,3(
2010/07/13 19:30:51	39.376495	1.296253				>MPI_Barrier (libmpi.so.0.0.1: pbarrier.c,36)

```
openss>>
```

8.1.1 MPI Tracing Experiments performance data gathering

Much of this information is described above in the main MPI Tracing Experiments section, but for completeness, this is the convenience script description for running the MPI specific tracing expermeents.

```
> ossmpi[t] "srun –N 4 –n 32 smg2000 –n 50 50 50" [default | <list MPI functions> | mpi_category]
```

8.1.2 MPI Tracing Experiments performance data viewing with GUI

To launch the GUI on any experiment, use "openss –f <database name>".

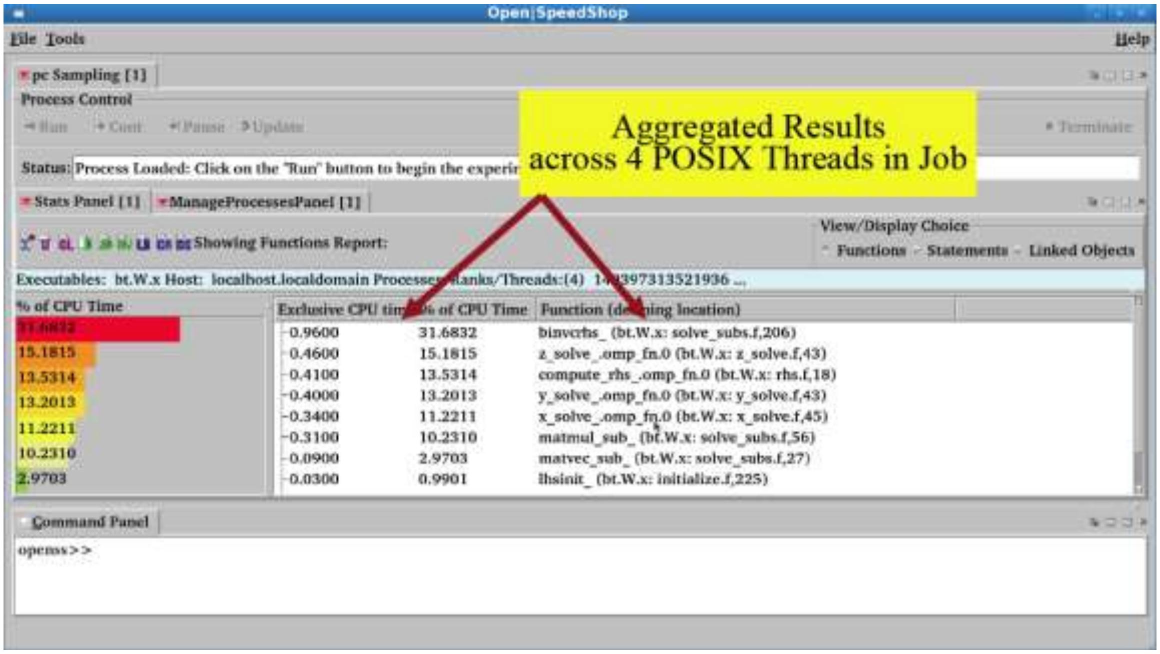
8.1.3 MPI Tracing Experiments performance data viewing with CLI

To launch the CLI on any experiment, use "openss –cli –f <database name>".

8.2 Threading Analysis Section

We just did an experiment that uses MPI but we can do a similar analysis on applications that use threads. To analyze a threaded application first we can run the pcsamp experiment to get an overview, then look at the load balance view to detect if there are any widely varying values and finally do cluster analysis to find any outliers.

The image below shows the default view for an application with 4 threads, the information displayed is the aggregated total from all threads.



Status: Process Loaded: Click on the "Run" button to begin the experi

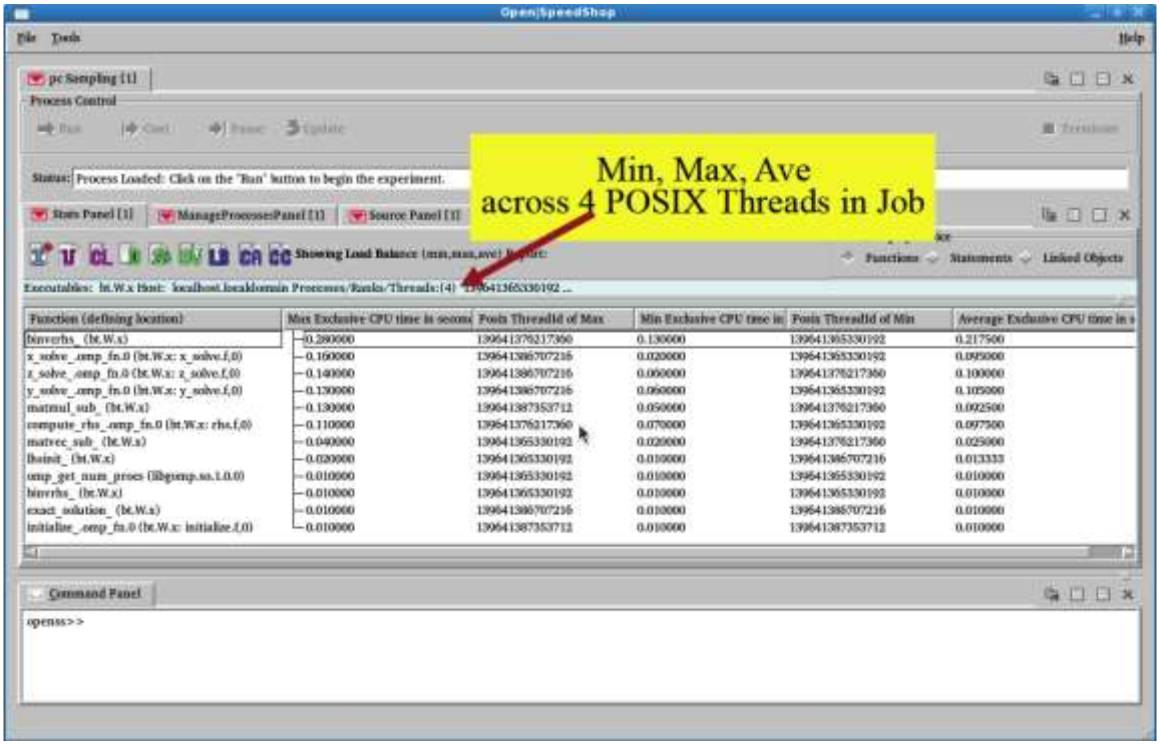
Showing Functions Report:

Executables: bt.W.x Host: localhost.localdomain Processes/Ranks/Threads:(4) 1[illegible]397313521936 ...

Exclusive CPU tim	% of CPU Time	Function (de ing location)
0.9600	31.6832	binvcrhs_ (bt.W.x: solve_subs.f,206)
0.4600	15.1815	z_solve_.omp_fn.0 (bt.W.x: z_solve.f,43)
0.4100	13.5314	compute_rhs_.omp_fn.0 (bt.W.x: rhs.f,18)
0.4000	13.2013	y_solve_.omp_fn.0 (bt.W.x: y_solve.f,43)
0.3400	11.2211	x_solve_.omp_fn.0 (bt.W.x: x_solve.f,45)
0.3100	10.2310	matmul_sub_ (bt.W.x: solve_subs.f,56)
0.0900	2.9703	matvec_sub_ (bt.W.x: solve_subs.f,27)
0.0300	0.9901	lhsinit_ (bt.W.x: initialize.f,225)

```
openss>>
```

Next we see the load balance view based on functions.



Min, Max, Ave
across 4 POSIX Threads in Job

Status: Process Loaded: Click on the "Run" button to begin the experiment.

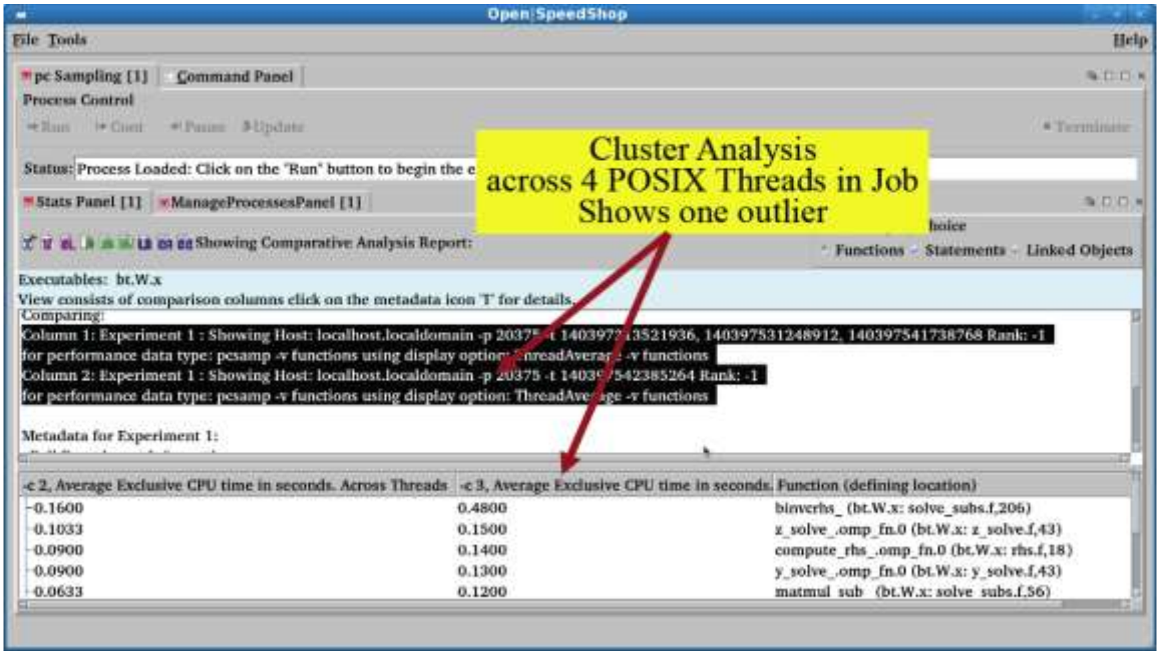
Showing Load Balance (min,max,ave) Report:

Executables: bt.W.x Host: localhost.localdomain Processes/Ranks/Threads:(4) 139641365330192 ...

Function (defining location)	Max Exclusive CPU time in secon	Posix ThreadId of Max	Min Exclusive CPU time in	Posix ThreadId of Min	Average Exclusive CPU time in s
binverhs_ (bt.W.x)	0.280000	139641376217360	0.130000	139641365330192	0.217500
x_solve_.omp_fn.0 (bt.W.x: x_solve.f,0)	0.160000	139641386707216	0.020000	139641365330192	0.095000
z_solve_.omp_fn.0 (bt.W.x: z_solve.f,0)	0.140000	139641386707216	0.060000	139641376217360	0.100000
y_solve_.omp_fn.0 (bt.W.x: y_solve.f,0)	0.130000	139641386707216	0.060000	139641365330192	0.105000
matmul_sub_ (bt.W.x)	0.130000	139641387353712	0.050000	139641376217360	0.092500
compute_rhs_.omp_fn.0 (bt.W.x: rhs.f,0)	0.110000	139641376217360	0.070000	139641365330192	0.097500
matvec_sub_ (bt.W.x)	0.040000	139641365330192	0.020000	139641376217360	0.025000
lhsinit_ (bt.W.x)	0.020000	139641365330192	0.010000	139641386707216	0.013333
omp_get_num_procs (libgomp.so.1.0.0)	0.010000	139641365330192	0.010000	139641365330192	0.010000
binvrhs_ (bt.W.x)	0.010000	139641365330192	0.010000	139641365330192	0.010000
exact_solution_ (bt.W.x)	0.010000	139641386707216	0.010000	139641386707216	0.010000
initialize_.omp_fn.0 (bt.W.x: initialize.f,0)	0.010000	139641387353712	0.010000	139641387353712	0.010000

```
openss>>
```

Then we look at a cluster analysis view based on functions.



Cluster Analysis
across 4 POSIX Threads in Job
Shows one outlier

Status: Process Loaded: Click on the "Run" button to begin the e

Showing Comparative Analysis Report:

Executables: bt.W.x
View consists of comparison columns click on the metadata icon 'I' for details.

```
Comparing:
Column 1: Experiment 1 : Showing Host: localhost.localdomain -p 2037[illegible] -t 140397[illegible]13521936, 140397531248912, 140397541738768 Rank: -1
for performance data type: pcsamp -v functions using display option: ThreadAverage -v functions
Column 2: Experiment 1 : Showing Host: localhost.localdomain -p 20375 -t 14039[illegible]542385264 Rank: -1
for performance data type: pcsamp -v functions using display option: ThreadAverage -v functions

Metadata for Experiment 1:
```

-c 2, Average Exclusive CPU time in seconds. Across Threads	-c 3, Average Exclusive CPU time in seconds.	Function (defining location)
0.1600	0.4800	binverhs_ (bt.W.x: solve_subs.f,206)
0.1033	0.1500	z_solve_.omp_fn.0 (bt.W.x: z_solve.f,43)
0.0900	0.1400	compute_rhs_.omp_fn.0 (bt.W.x: rhs.f,18)
0.0900	0.1300	y_solve_.omp_fn.0 (bt.W.x: y_solve.f,43)
0.0633	0.1200	matmul_sub_ (bt.W.x: solve_subs.f,56)

8.2.1 Threading Specific Experiment (pthreads)

An experiment specific to tracking POSIX thread function calls and analyzing those calls is also available in Open|SpeedShop. The experiment is called pthreads and it traces several POSIX thread related functions. Like all the other tracing experiments, number of calls, time spent in each function, the call paths to each POSIX thread function, and an event-by-event trace is available. Load balance and cluster analysis features are also available.

8.2.1.1 Threading Specific (pthreads) experiment performance data gathering

8.2.1.2 Threading Specific (pthreads) experiment performance data viewing with GUI

To launch the GUI on any experiment, use “openss –f <database name>“.

8.2.1.3 Threading Specific (pthreads) experiment performance data viewing with CLI

To launch the CLI on any experiment, use “openss –cli –f <database name>“.

8.2 NVIDIA CUDA Analysis Section

The Open|SpeedShop version with CBTF collection mechanisms supports tracing CUDA events in a NVIDIA CUDA based application. An event by event list of CUDA events and the event arguments are listed.

8.3.1 NVIDIA CUDA Tracing (cuda) experiment performance data gathering

To run the NVIDIA CUDA experiment, use the osscuda convenience script and specify the CUDA application as an argument. If there are no arguments to the application then no quotes are necessary, but they are placed here for consistency. The osscuda script will run the experiment by running the QTC application and will create an Open|SpeedShop database file with the results of the experiment. Viewing of the performance information can be done with the GUI or CLI.

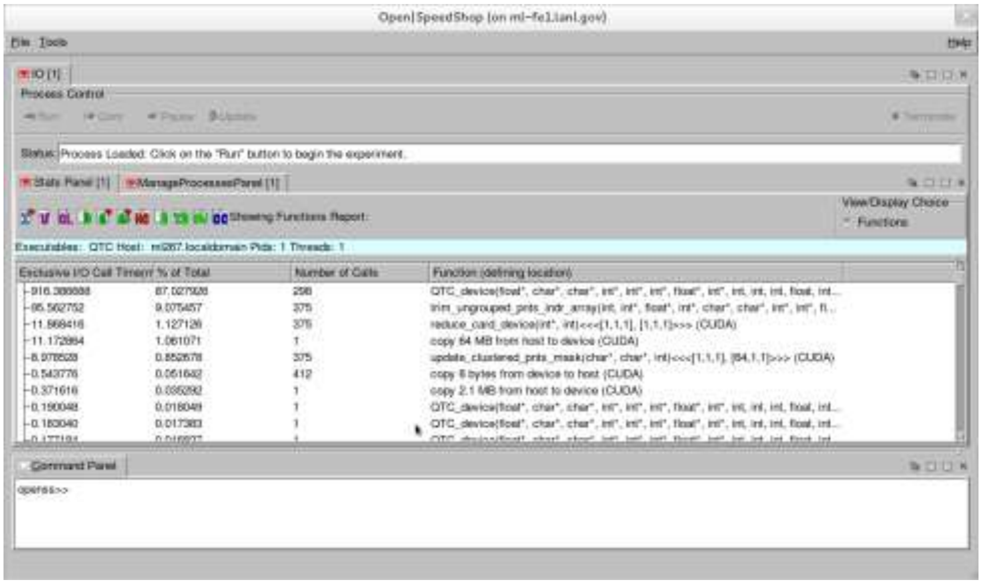
```
osscuda “./QTC”
```

8.3.2 NVIDIA CUDA Tracing (cuda) experiment performance data viewing with GUI

This section shows the default view for the NVIDIA CUDA experiment for the QTC application. Use the following command to open the GUI to see the QTC CUDA experiment performance information.

To launch the GUI on any experiment, use “openss –f <database name>“.

```
openss –f QTC-cuda.openss
```



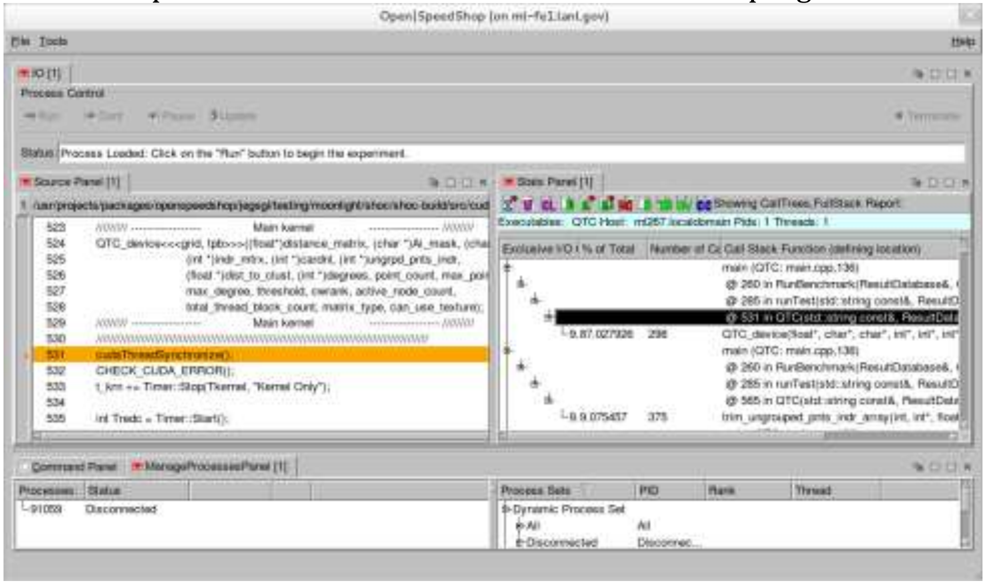
Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: QTC Host: ml267.localdomain Pids: 1 Threads: 1

Exclusive I/O Call Time(ms)	% of Total	Number of Calls	Function (defining location)
916.388888	87.027926	298	QTC_device(float*, char*, char*, int*, int*, int*, float*, int*, int, int, int, float, int...
95.562752	9.075457	375	trim_ungrouped_pnts_indr_array(int, int*, float*, int*, char*, char*, int*, int*, fl...
11.868416	1.127126	375	reduce_card_device(int*, int)<<<[1,1,1], [1,1,1]>>> (CUDA)
11.172884	1.061071	1	copy 64 MB from host to device (CUDA)
8.978528	0.852678	375	update_clustered_pnts_mask(char*, char*, int)<<<[1,1,1], [64,1,1]>>> (CUDA)
0.543776	0.051642	412	copy 8 bytes from device to host (CUDA)
0.371616	0.035292	1	copy 2.1 MB from host to device (CUDA)
0.190048	0.018049	1	QTC_device(float*, char*, char*, int*, int*, int*, float*, int*, int, int, int, float, int...
0.183040	0.017383	1	QTC_device(float*, char*, char*, int*, int*, int*, float*, int*, int, int, int, float, int...

```
openss>>
```

The view below is the statistics panel and source view panel showing the relationship of the statistics to the actual source in the program.



8.3.3 NVIDIA CUDA Tracing (cuda) experiment performance data viewing with CLI

To launch the CLI on any experiment, use “openss –cli –f <database name>“.

Here we show a trace view of the output from the osscuda experiment run. Note the –f CUDA is required do to the fact this is a prototype. This restriction will be removed in the future. This trace shows the actions taken during the execution of the CUDA application matmul on the Titan Cray platform at ORNL.

```
openss>>expview -v trace -f CUDA

  Start Time(d:h:m:s)  Exclusive      % of  Call Stack Function (defining location)
                  I/O Call     Total
                  Time(ms)
2013/08/21 18:31:21.611  11.172864  1.061071 >>>>>copy 64 MB from host to device (CUDA)
2013/08/21 18:31:21.622   0.371616  0.035292 >>>>>copy 2.1 MB from host to device (CUDA)
2013/08/21 18:31:21.623   0.004608  0.000438 >>>>>copy 16 KB from host to device (CUDA)
2013/08/21 18:31:21.623   0.003424  0.000325 >>>>set 4 KB on device (CUDA)
2013/08/21 18:31:21.623   0.003392  0.000322 >>>>set 137 KB on device (CUDA)
2013/08/21 18:31:21.623   0.120896  0.011481 >>>>compute_degrees(int*, int*, int, int)<<<[256,1,1], [64,1,1]>>> (CUDA)
2013/08/21 18:31:21.623  13.018784  1.236375 >>>>QTC_device(float*, char*, char*, int*, int*, int*, float*, int*, int, int, int, float, int, int, int, int,
bool)<<<[256,1,1], [64,1,1]>>> (CUDA)
2013/08/21 18:31:21.636   0.035232  0.003346 >>>>reduce_card_device(int*, int)<<<[1,1,1], [1,1,1]>>> (CUDA)
2013/08/21 18:31:21.636   0.002112  0.000201 >>>>>copy 8 bytes from device to host (CUDA)
2013/08/21 18:31:21.636   1.375616  0.130640 >>>>trim_ungrouped_pnts_indr_array(int, int*, float*, int*, char*, char*, int*, int*, float*, int*, int,
int, int, float, int, bool)<<<[1,1,1], [64,1,1]>>> (CUDA)
2013/08/21 18:31:21.638   0.001344  0.000128 >>>>>copy 260 bytes from device to host (CUDA)
2013/08/21 18:31:21.638   0.025600  0.002431 >>>>update_clustered_pnts_mask(char*, char*, int)<<<[1,1,1], [64,1,1]>>> (CUDA)
2013/08/21 18:31:21.638  11.724960  1.113503 >>>>QTC_device(float*, char*, char*, int*, int*, int*, float*, int*, int, int, int, float, int, int, int, int,
bool)<<<[256,1,1], [64,1,1]>>> (CUDA)
```

9 Memory Analysis Techniques

The Open|SpeedShop version with CBTF collection mechanisms supports tracing memory allocation and deallocation function calls in user applications. An event-by-event list of memory function call events and the memory function call event arguments are listed. The Open|SpeedShop experiment name for the memory analysis experiment is “mem”. The high water memory mark is not currently available but is coming in the future.

9.1 Memory Analysis Tracing (mem) experiment performance data gathering

To run the memory analysis experiment, use the ossmem convenience script and specify the application as an argument. If there are no arguments to the application then no quotes are necessary, but they are placed here for consistency. Using the sweep3d application as an example, here the ossmem script will apply the memory analysis experiment by running the sweep3d application with the Open|SpeedShop memory trace collector, gather the data and will create an Open|SpeedShop database file with the results of the experiment. Viewing of the performance information can be done with the GUI or CLI.

```
ossmem “mpirun –np 64 ./sweep3d.mpi”
```

9.2 Memory Analysis Tracing (mem) experiment performance data viewing with CLI

To launch the CLI on any experiment, use “openss –cli –f <database name>“.

Here we show a trace view of the output from the ossmem experiment run. This trace shows the default view and the load balance view for the execution of the sweep3d.mpi application on the Titan Cray platform at ORNL. The example below also contains an expcompare CLI command example where two of the programs ranks are compared against each other. This may be useful if there appears to be load imbalance when examining the –m loadbalance output.

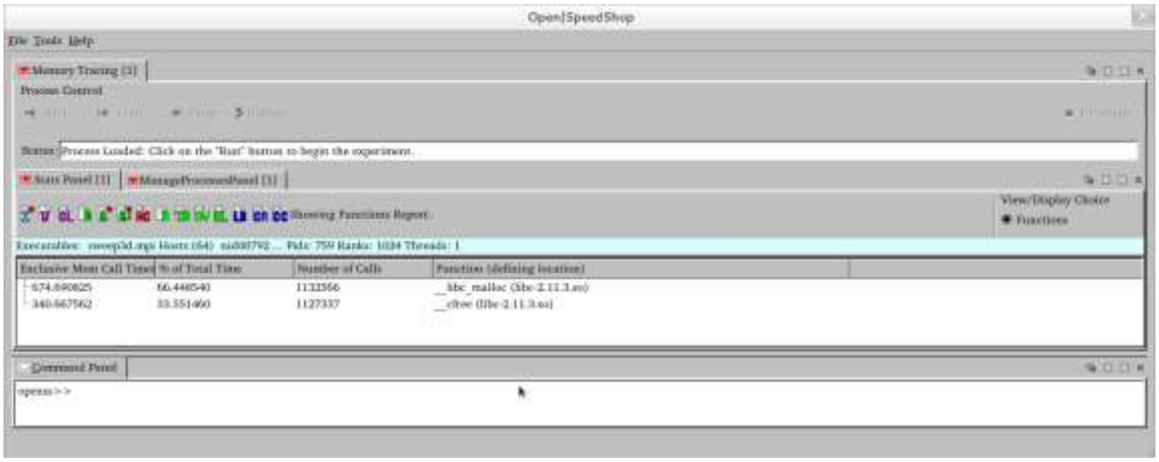
```
openss -cli -f sweep3d.mpi-mem-1.openss
openss>>[openss]: The restored experiment identifier is:  -x 1
openss>>expview

Exclusive      % of   Number  Function (defining location)
 Mem Call     Total      of
 Time(ms)      Time    Calls
674.690825  66.448540  1132566  __libc_malloc (libc-2.11.3.so)
340.667562  33.551460  1127337  __cfree (libc-2.11.3.so)
openss>>expview -m loadbalance

    Max  Rank       Min  Rank    Average  Function (defining location)
Exclusive          of  Exclusive    of  Exclusive Mem call   Max   Mem call   Min   Mem call
 time in             time in           time in
seconds.           seconds.          seconds.
  Across             Across            Across
```

```
Ranks(ms)       Ranks(ms)       Ranks(ms)
1.798064   33  0.193179  1023  0.658878  __libc_malloc (libc-2.11.3.so)
1.029151   48  0.076400  1001  0.332683  __cfree (libc-2.11.3.so)

openss>>expcompare -r 33  -r 1023

  -r 33,   -r 33, %  -r 33,                    -r 1023,   -r 1023,     -r  Function (defining location)
Exclusive   of Total  Number  Exclusive      % of   1023,
Mem Call      Time     of  Mem Call     Total  Number
Time(ms)           Calls   Time(ms)      Time     of
                                  Calls
1.798064  65.998580   3297   0.193179  65.455562    349 __libc_malloc (libc-2.11.3.so)
0.926334  34.001420   3292   0.101951  34.544438    346 __cfree (libc-2.11.3.so)
```

9.3 Memory Analysis Tracing (mem) experiment performance data viewing with GUI

To launch the GUI on any experiment, use "openss –f <database name>".

The first GUI view show below is the default view for the mem experiment. It shows the memory functions that were called in the application, how many times they were called, the time spent in each of the memory functions, and the percentage of the overall memory function time was spent in each of the memory functions. The paths to each memory, through the source, are available through the call path views.



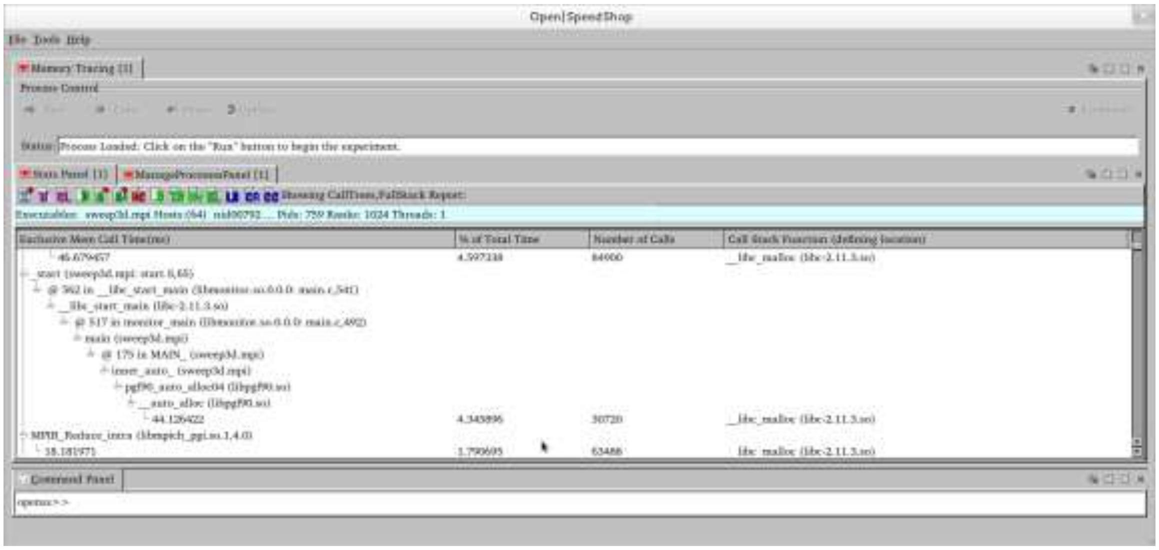
Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: sweep3d.mpi Hosts:(64) nid00792 ... Pids: 759 Ranks: 1024 Threads: 1

Exclusive Mem Call Time	% of Total Time	Number of Calls	Function (defining location)
674.890825	66.448540	1132566	__libc_malloc (libc-2.11.3.so)
340.667562	33.551460	1127337	__cfree (libc-2.11.3.so)

```
openss>>
```

In this (C+ icon) call path view we see the call paths to the memory functions called in this application.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

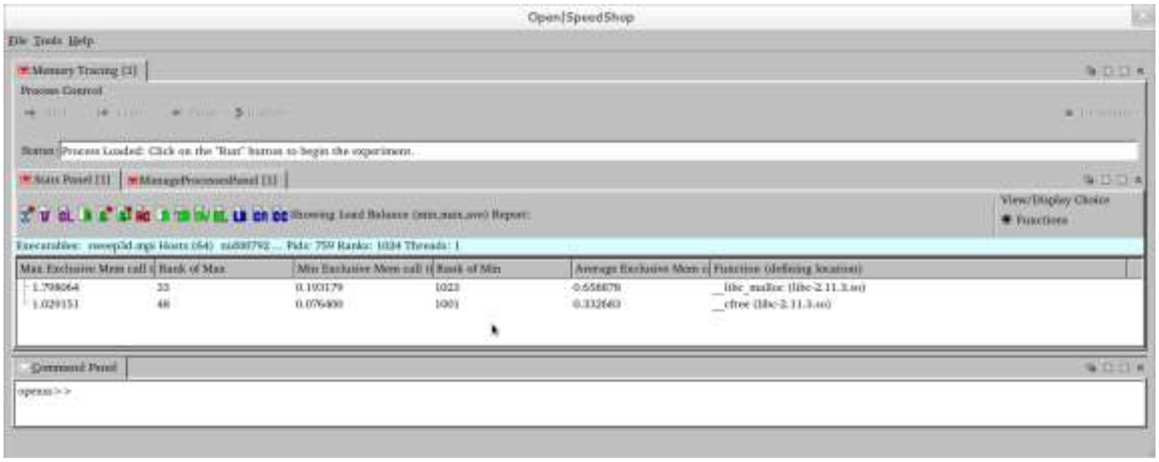
Showing CallTrees,FullStack Report:

Executables: sweep3d.mpi Hosts (64) nid00792 ... Pids: 759 Ranks: 1024 Threads: 1

```
Exclusive Mem Call Time(ms)                          % of Total Time   Number of Calls   Call Stack Function (defining location)
    └46.679457                                        4.597238          84000             __libc_malloc (libc-2.11.3.so)
 _start (sweep3d.mpi: start.S,65)
  @ 562 in __libc_start_main (libmonitor.so.0.0.0: main.c,541)
   __libc_start_main (libc-2.11.3.so)
    @ 517 in monitor_main (libmonitor.so.0.0.0: main.c,492)
     main (sweep3d.mpi)
      @ 175 in MAIN_ (sweep3d.mpi)
       inner_auto_ (sweep3d.mpi)
        pgf90_auto_alloc04 (libpgf90.so)
         __auto_alloc (libpgf90.so)
          └44.126422                                  4.345896          30720             __libc_malloc (libc-2.11.3.so)
 MPIR_Reduce_intra (libmpich_pgi.so.1.4.0)
  └18.181971                                          1.790695          63488             __libc_malloc (libc-2.11.3.so)
```

```
openss>>
```

In the view below, one has chosen the "LB" icon and generated the load balance view. This view shows the min, max, and average time across all the ranks in the application. The ranks of the min and max time values are also shown. If there is a significant difference between the min, max, and average time, there may be load imbalance. To identify the ranks, threads, or processes that are acting out of balance, use the cluster analysis feature activated by clicking on the "CA" icon.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Load Balance (min,max,ave) Report:

Executables: sweep3d.mpi Hosts (64) nid00792 ... Pids: 759 Ranks: 1024 Threads: 1

Max Exclusive Mem call t	Rank of Max	Min Exclusive Mem call t	Rank of Min	Average Exclusive Mem c	Function (defining location)
1.798064	33	0.103179	1023	0.658879	__libc_malloc (libc-2.11.3.so)
1.029151	48	0.076400	1001	0.332683	__cfree (libc-2.11.3.so)

```
openss>>
```

In this view, generated by clicking on the "CA" icon, we see that Open|SpeedShop has determined that there are four unique groups where the aggregate time for the groups differs enough to report this to the user. The columns in the Stats Panel display show the times that are reflective of each of the ranks in the group. The information (I+) icon can be used to view which ranks, etc. are included in each of the cluster groups.

Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Comparative Analysis Report:

Executables: sweep3d.mpi
View consists of comparison columns click on the metadata icon "I" for details.

Comparing:
Column(s) labeled -c 2: Experiment 1 Database Name: sweep3d.mpi-mem-1.openss : Showing Host: nid00792, nid00793, nid00822, nid00836, nid00837, nid00838, nid00839, nid02254, nid02255, nid02256, nid02257, ni
for performance data type: mem -v functions using display option: ThreadAverage -v functions
Column(s) labeled -c 3: Experiment 1 Database Name: sweep3d.mpi-mem-1.openss : Showing Host: nid00809, nid00822, nid00836, nid00837, nid00838, nid02258, nid02279, nid02359, nid02374, nid03002, nid03795, ni
for performance data type: mem -v functions using display option: ThreadAverage -v functions
Column(s) labeled -c 4: Experiment 1 Database Name: sweep3d.mpi-mem-1.openss : Showing Host: nid00792, nid00793, nid00808, nid00809, nid00822, nid00836, nid00837, nid00838, nid00839, nid02254, nid02255, ni
for performance data type: mem -v functions using display option: ThreadAverage -v functions

-c 2, Average Exclusive M	-c 3, Average Exclusive M	-c 4, Average Exclusive M	-c 5, Average Exclusive M	Function (defining location)
0.540977	0.845780	1.202530	1.615444	__libc_malloc (libc-2.11.3.so)
0.257331	0.482038	0.622866	0.901279	__cfree (libc-2.11.3.so)

openss>>

10 Advanced Analysis Techniques

Analyzing the results of a single performance experiment can be useful for debugging and tuning your code. But comparing the results of different experiments can show you how the performance of an application has changed. This is useful if you want to track how the performance varies for each new version of an application, or understanding how a different compiler or compiler options can affect the performance of your application. This also allows you to do scalability tests to see how the performance of your application scales with the number of processors. It's also helpful just to see the progress you have made while tuning your code.

Open|SpeedShop has options to allow you to compare performance data. You can use the Custom Compare Panel (CC icon) in the GUI or the osscompare convenience script.

```
> osscompare "db1.openss, db2.openss,…" [options]
```

This will produce a side-by-side comparison listing, you can compare up to 8 databases at once. You can see the osscompare man page for more details. Below is an example of comparing two different pcsamp experiments on the smg2000 application.

```
osscompare "smg2000-pcsamp.openss,smg2000-pcsamp-1.openss”

[openss]: Legend: -c 2 represents smg2000-pcsamp.openss
[openss]: Legend: -c 4 represents smg2000---pcsamp---1.openss
-c 2, Exclusive CPU-c 4, Exclusive CPU Function (defining location)
time in seconds.     time in seconds.
  3.870000000                    3.630000000 hypre_SMGResidual (smg2000:smg_residual.c,152)
  2.610000000                    2.860000000 hypre_CyclicReduction (smg2000:cyclic_reduc;on.c,757)
```

```
  2.030000000                    0.150000000 opal_progress (libopen-pal.so.0.0.0)
  1.330000000                    0.100000000 mca_btl_sm_component_progress (libmpi.so.0.0.2:
topo_unity_component.c,0)
  0.280000000                    0.210000000 hypre_SemiInterp (smg2000: semi_interp.c,126)
  0.280000000                    0.040000000 mca_pml_ob1_progress (libmpi.so.0.0.2: topo_unity_component.c, 0)
```

10.1 Comparison Script Argument Description

The Open|SpeedShop comparison script accepts a number of arguments. This section describes the acceptable options for those individual arguments. For a quick overview see section *14.4 osscompare: Compare Database Files*. As described above the osscompare script accepts at least two and up to eight comma separated database file names, enclosed in quotes as the mandatory argument. By default the compared metric is the primary metric produced by the experiment. For most experiments, the metric is exclusive time, however the hardware counter experiments use the count of the number of hardware counter overflows as the metric to be compared. These are the default or mandatory arguments to osscompare. The following sections describe the arguments for osscompare in more detail.

10.1.1 osscompare metric argument

The osscompare metric argument specifies the performance information type that Open|SpeedShop will use to compare against when looking at each database file in the compare database file list. To find the metric specifications that are legal and produce comparison outputs, one can open one of the database files with the Open|SpeedShop command line interface (CLI), and list the available metrics.

```
openss -cli -f smg2000-pcsamp.openss
  openss>>list -v metrics
  pcsamp::percent
  pcsamp::threadAverage
  pcsamp::threadMax
  pcsamp::threadMin
  pcsamp::time
```

You can use the output of the list metrics command as an argument to the osscompare command as shown in the examples below.

```
osscompare "smg2000-pcsamp.openss,smg2000-pcsamp-1.openss"
osscompare "smg2000-pcsamp.openss,smg2000-pcsamp-1.openss" percent
osscompare "smg2000-pcsamp.openss,smg2000-pcsamp-1.openss" threadMin
osscompare "smg2000-pcsamp.openss,smg2000-pcsamp-1.openss" threadMax
```

Some exceptions do apply. For example, some experiments such as usertime and hwctime have “details” type metrics output by the list metrics CLI command (list –v metrics). These will not work as a metric argument to osscompare.

For the hardware counter experiments: hwc and hwctime, you can use the actual PAPI event name in addition to the metric names output from the list metric command. The example database file was generated using the PAPI_TOT_CYC event.

```
openss -cli -f smg2000-hwc.openss
openss>>[openss]: The restored experiment identifier is:  -x 1
openss>>list -v metrics
hwc::overflows
hwc::percent
hwc::threadAverage
hwc::threadMax
hwc::threadMin
```

Here we show a couple osscompare examples where “hwc::overflows” can be used interchangeably with PAPI_TOT_CYC.

```
osscompare "smg2000-hwc.openss,smg2000-hwc-1.openss" hwc::overflows
osscompare "smg2000-hwc.openss,smg2000-hwc-1.openss" PAPI_TOT_CYC
```

10.1.2 osscompare rows of output argument

osscompare allows the user to specify how many lines of the comparison output to be output. The argument is optional and

```
"rows=nn" is defined as follows:
        "nn"    - Number of rows/lines of performance data output.
```

In this example, only ten (10) lines of comparison will be shown when the osscompare command is executed. It will be the most interesting, or top, ten lines.

```
osscompare "smg2000-hwc.openss,smg2000-hwc-1.openss" hwc::overflows rows=10
```

10.1.3 osscompare output name argument.

osscompare allows the user to specify the name to be used when writing out the comparison output files. The argument is optional and

```
"oname=<output file name>" is defined as follows:
        "output file name"    - Name given to the output files created for the comparison.
```

This argument is valid when the environment variable OPENSS_CREATE_CSV is set to 1. In this example, the comparison files created when the osscompare command is executed will be named smg_hwc_cmp.csv and/or smg_hwc_cmp.txt.

```
osscompare "smg2000-pcsamp.openss,smg2000-pcsamp-1.openss" oname=mar2013_pcsamp_cmp
```

This example will generate comparison files named using the specified oname specification.

```
8 -rw-rw-r--. 1 jeg jeg   4475 Mar 11 15:53 mar2013_pcsamp_cmp.compare.csv
8 -rw-rw-r--. 1 jeg jeg   4841 Mar 11 15:53 mar2013_pcsamp_cmp.compare.txt
```

10.1.4 osscompare view type or granularity argument.

osscompare allows an optional view type argument. It represents the granularity of the view. Open|SpeedShop allows for viewing performance data at three levels: linked object level, function level, and at the statement level. osscompare will produce output at one of those levels based on the view type argument where:

```
        "viewtype=<functions | statements | linkedobjects >" is defined as follows:
                  "functions"       - View type granularity is per function
                  "statements"      - View type granularity is per statement
                  "linkedobjects"   - View type granularity is per library (linked object)
```

This example will produce a side-by-side comparison for the statement level, not the default function level. So, this example will compare statement performance values in each of the two databases and produce a side-by-side comparison showing how each statement in the application differed from the two experiments.

```
osscompare "smg2000-pcsamp.openss,smg2000-pcsamp-1.openss" viewtype=statements
```

11 Open|SpeedShop User Interfaces

Throughout this manual we have been using the Open|SpeedShop GUI, we would encourage you to play around with the interface to become familiar with it. The GUI lets you peel-off and rearrange any panel. There are also context sensitive menus so you can right click on any location to access a different view or to activate additional panels.

If you prefer not to use the GUI there are three other options that all have equal functionality. First there is the command line interface that we have also seen throughout this manual, which you can launch with the –cli option:

```
> openss -cli
```

There is also the immediate command (batch) interface. This uses the –batch flag:

```
> openss –batch < openss_cmd_file
> openss –batch –f <exe> <experiment>
```

Lastly there is a python scripting API, so you can launch Open|SpeedShop commands within a python script.

```
> python openss_python_script_file.py
```

11.1 Command Line Interface Basics

The CLI offers an interactive command line interface with processing like gdb or dbx. There are several interactive commands that allow you to create experiments, provide you with process/thread control or enable you to view experiment results. You can find the full CLI documentation at http://www.openspeedshop.org/doc/cli_doc/ but here we will briefly cover some important points. Here is a quick overview of some commands (those marked with * are only available for the online version):

Experiment Creation • expcreate • expattach*	**Result Presentation** • expview • opengui
Experiment Control • expgo • expwait* • expdisable* • expenable*	**Misc. Commands** • help • list • log • record • playback • history • quit
Experiment Storage • expsave • exprestore	

The following is a simple example to create, run and view data from an experiment using the CLI.

> openss –cli	Open the CLI.
openss>> expcreate –f “mutatee 2000” pcsamp	Create an experiment using pcsamp with this application.
openss>> expgo	Run the experiment and create the database
openss>> expview	Display the default view of the performance data.

You can also get alternative views of the performance data within the CLI. The following is a list of some options to change the way the information is displayed.

help or help commands	Display CLI help text
expview	Show the default view for experiment
expview -v statements	Show time-consuming statements
expview -v loops	Show time-consuming loops
expview -v linkedobjects	Show time spent in libraries
expview -v calltrees,fullstack	See all unique call paths in the application.
expview -m loadbalance	See load balance across all the ranks/threads/processes in the experiment.
expview –r <rank_num>	See data for specific rank(s)
expcompare –r 1 –r 2 –m time	Compare rank 1 to rank 2 for metric equal to “time”. Other metrics are allowed. This is a usage example.
list –v metrics	See the list of optional performance data metrics.
list –v src	See the list of source files associated with experiment.
list –v obj	See the list of object files associated with experiment.

list –v ranks	See the list of ranks associated with experiment .
list –v hosts	See machine host names associated with experiment .
expview –m <metric>	See performance data for the metric specified .
expview –v calltrees,fullstack <experiment type> <number>	See <number> of call paths from the list of expensive call paths.
expview –v calltrees,fullstack usertime2	Shows the top two call paths in execution time.
expview <experiment-name><number>	Shows <number> of the functions from the list of the top time-consuming functions.
expview pcsamp2	Shows the two functions taking the most time.
expview –v statements <experiment-name><number>	Show <number> of the statements from the list of the top time-consuming statements

Remember if you want the GUI at any time just issue the command **opengui** in the CLI.

11.1.2 CLI Metric Expressions and Derived Types

Open|SpeedShop has the capability to create derived metric from the gathered metrics by using the metric expression math functionality in the command line interface (CLI). One can access the overview from the CLI by typing this help CLI command.

```
openss>>help metric_expression

  *********
<metric_expression> ::=<string> ( [<constant> ||<metric_expression> ] [ ,
[<constant> ||<metric_expression> ] ]* )

A user defined expression that uses metrics to compute a special value for display in a report.

User defined expression can be added to an<expMetric_list>.
A functional notation is used to build the desired expression and the following, simple, arithmetic operations are
available:
  Function    # arguments    returns
  --------    -----------    -------
  Uminus()     1    unary minus of the argument
  Abs()        1    Absolute value of the argument
  Add()        2    summation of the arguments
  Sub()        2    difference of the arguments
  Mult()       2    product of the arguments
  Div()        2    first argument divided by second
  Mod()        2    remainder of divide operation
  Min()        2    minimum of the arguments
  Max()          2    maximum of the arguments
  A_Add()      1    sum of all the data samples specified for the view
  A_Mult()     1    product of all the data samples specified for the view
  A_Min()      1    minimum of all the data samples specified for the view
  A_Max()      1    maximum of all the data samples specified for the view
  Sqrt()       1    square root of the argument
  Stdev()      3    standard deviation calculation
  Percent()    2    percent the first argument is of the second
  Condexp()    3    "C" expression: "(first argument) ? second argument : third argument"
  Header()     2    use the first argument as a column header for the display of the second
```

Note:

Integer and floating constants are supported as arguments as are the metric keywords associated with the experiment view.

Arguments to these functions can be<metric_expressions>, with the exception of the first argument of 'Header'.

The first argument of 'Header' must be a character string that is preceded with and followed by '\"'.

When the '-v summary' option is used, it is not generally possible to produce a meaningful column summary.
A summary is produced for Add(), Max(), Min(), Percent(), A_Add(), A_Max and A_Min().

Examples:

```
  expview hwc -m count,Header(\"percent of counts\",Percent(count,A_Add(count)) -v summary
  expview mpi -v butterfly -f MPI_Alltoallv -m time,Header("average time/count",Div(Mult(time,1000),counts))
```

To examine an example, we take the default view, expview command and add the capability to add the percentage that each function contributes to the total.

Add the header by using the “Header” phrase to create a header for the new data column that is being added.   The “Percent” phrase to create the arithmetic expression that divides the PAPI_L1_DCM counts (count) for each function by the total number of PAPI_L1_DCM counts in the application(A_Add(count)).

```
openss>>expview  -m count,Header(\"percent of counts\",Percent(count,A_Add(count)))

 Exclusive       percent  Function (defining location)
PAPI_L1_DCM  of counts
   Counts
 342000000   52.333588  hypre_SMGResidual (smg2000: smg_residual.c,152)
 207500000   31.752104  hypre_CyclicReduction (smg2000: cyclic_reduction.c,757)
   20500000     3.136955  hypre_SemiInterp (smg2000: semi_interp.c,126)
   15000000     2.295333  hypre_SemiRestrict (smg2000: semi_restrict.c,125)
     8500000     1.300689  pack_predefined_data (libmpi.so.0.0.3)
     7000000     1.071155  unpack_predefined_data (libmpi.so.0.0.3)
```

11.2 CLI Batch Scripting

If you have a known set of command you want to issue you can create a plain text file with CLI commands. For example we create a batch file that will create, run then view the pcsamp experiment run on the application fred.

```
# Create batch file commands
> echo expcreate –f fred pcsamp >> input.script
> echo expgo >> input.script
> echo expview pcsamp10 >> input.script
```

Now to run the batch file input.script we use the –batch option to openss.

```
> openss –batch < input.script
```

Note that currently, in this context, this interface is only supported via the online version of Open|SpeedShop, so it must have been build with the OPENSS_INSTRUMENTOR=mrnet options.

11.3 Python Scripting

The Open|SpeedShop python API allows users to execute the same interactive/batch commands directly through python. Users can intersperse the normal python code with commands to Open|SpeedShop. Currently this interface is only supported via the online version of Open|SpeedShop.

11.4 MPI_Pcontrol Support

Open|SpeedShop also supports the MPI_Pcontrol function. This feature allows the user to gather performance data only for sections of their code bounded by the MPI_Pcontrol calls. The MPI_Pcontrol must be added to the source code of the application. MPI_Pcontrol(1) enables the gathering of performance data and MPI_Pcontrol(0) disables the gathering. You must also set the Open|SpeedShop environment variable OPENSS_ENABLE_MPI_PCONTROL to 1 in order to activate the MPI_Pcontrol call recognition, otherwise it will be ignored. Optionally you can set the OPENSS_START_ENABLED environment variable to 1 to have performance data gathered until a MPI_Pcontrol(0) call is encountered. If OPENSS_START_ENABLED is no set no performance data will be gathered until a MPI_Pcontrol(1) call is encountered. Note that for OPENSS_START_ENABLED to have any effect OPENSS_ENABLE_MPI_PCONTROL must be set.

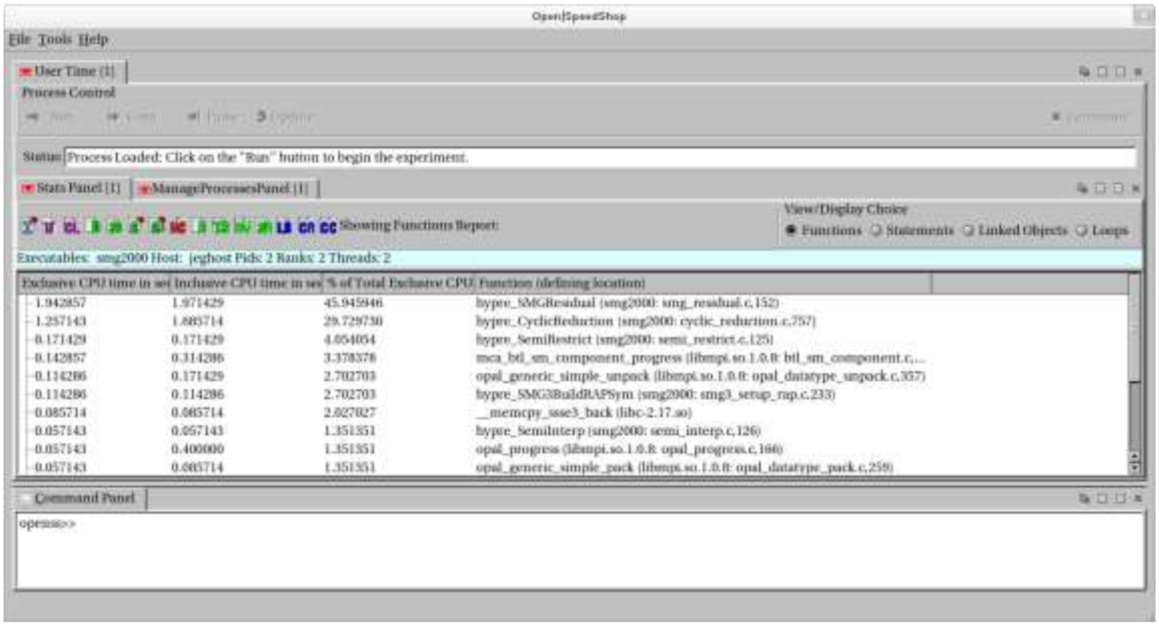
11.5 Graphical User Interface Basics

This section gives an overview of the OpenSpeedShop graphical user interface focusing on the basic functionality of the GUI.

To launch the GUI on any experiment, use “openss –f <database name>”.

11.5.1 Basic Initial View – Default View

Because this example usertime experiment default view has many of the icons and features of the other Open|SpeedShop experiments it is used here for illustration purposes.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: smg2000 Host: jeghost Pids: 2 Ranks: 2 Threads: 2

Exclusive CPU time in se	Inclusive CPU time in se	% of Total Exclusive CPU	Function (defining location)
1.942857	1.971429	45.945946	hypre_SMGResidual (smg2000: smg_residual.c,152)
1.257143	1.885714	29.729730	hypre_CyclicReduction (smg2000: cyclic_reduction.c,757)
0.171429	0.171429	4.054054	hypre_SemiRestrict (smg2000: semi_restrict.c,125)
0.142857	0.314286	3.378378	mca_btl_sm_component_progress (libmpi.so.1.0.8: btl_sm_component.c,...
0.114286	0.171429	2.702703	opal_generic_simple_unpack (libmpi.so.1.0.8: opal_datatype_unpack.c,357)
0.114286	0.114286	2.702703	hypre_SMG3BuildRAPSym (smg2000: smg3_setup_rap.c,233)
0.085714	0.085714	2.027027	__memcpy_ssse3_back (libc-2.17.so)
0.057143	0.057143	1.351351	hypre_SemiInterp (smg2000: semi_interp.c,126)
0.057143	0.400000	1.351351	opal_progress (libmpi.so.1.0.8: opal_progress.c,166)
0.057143	0.085714	1.351351	opal_generic_simple_pack (libmpi.so.1.0.8: opal_datatype_pack.c,259)

11.5.1.1 Icon ToolBar

The most used items that can be found in the StatsPanel menu that is found under the StatsPanel tab are also available in the StatsPanel ToolBar. The StatsPanel Toolbar is provided as a convenience. The following is a quick overview of the toolbar options. The contents of the toolbar vary by experiment, because some options don't make sense for all experiments. The following table describes the icons and the functionality they represent.

"I"	Information	This option shows the metadata for the experiment. Information such as the experiment type, processes, ranks, threads, hosts, and other experiment specific information is displayed.
"U"	Update	This option updates the information in the StatsPanel display. This can be used to display any new data that may have come from the nodes on which the application is running.
"CL"	Clear auxiliary information	Clear auxiliary information. If the user has chosen a time segment of the performance data or a specific function to view the data for. This option clears the settings for that and allows the next view selection to show data for the entire program again.
"D"	Default View	The default view icon shows the performance results based on the view choice granularity selection.
"S, down arrow"	Statements per Function	Show the performance results related back to the source statements in the application for the selected function. Highlight a function in the StatsPanel and click on this icon.
"C, plus sign"	Call paths w/o coalescing	Show all the calling paths in this application. Duplicate paths will not be coalesced. All of the calling paths will be shown in their entirety.
"C, plus	Call paths w/o	Show all the calling paths in this application for the selected function

sign, down arrow"	coalescing per Function	only. Highlight a function in the StatsPanel and click on this icon. Duplicate paths will not be coalesced. All of the calling paths will be shown in their entirety.
"HC"	Hot Call Path	Show the callpath in the application that took the most time. This is a short cut to find the "hot" call path.
"B"	Butterfly view	Show the butterfly view which displays the callers and callees of the selected function. Highlight a function in the StatsPanel and click on this icon. Then repeat to "drill" down into the callers and/or callees.
"TS"	Time Segment	Show a portion of the performance data results based on the time segment selected.
"OV"	Optional View	Use this dialog to select which performance metrics to be shown in the new performance data report.
“SA”	Source Annotation	Choose which metric to use in the source panel to annotate the source. Defaults are different for each experiment, but mostly: time.
"LB"	Load Balance	Show the load balance view, which displays the min, max, and average performance values for the application. Only available on threaded or multiple process applications.
"CA"	Cluster Analysis	Show the comparative analysis view which displays the output of a cluster analysis algorithm run against the threaded or multiple process performance analysis results for the user application. The goal of this view is to find outlying threads or processes and report the groups of like performing threads, processes, or ranks.
"CC"	Custom Compare	Raise the custom comparison panel which provides mechanisms allowing the user to create custom views of the performance analysis results. This allows the user to supplement the provided Open|SpeedShop views.

11.5.1.2 View/Display Choice Selection

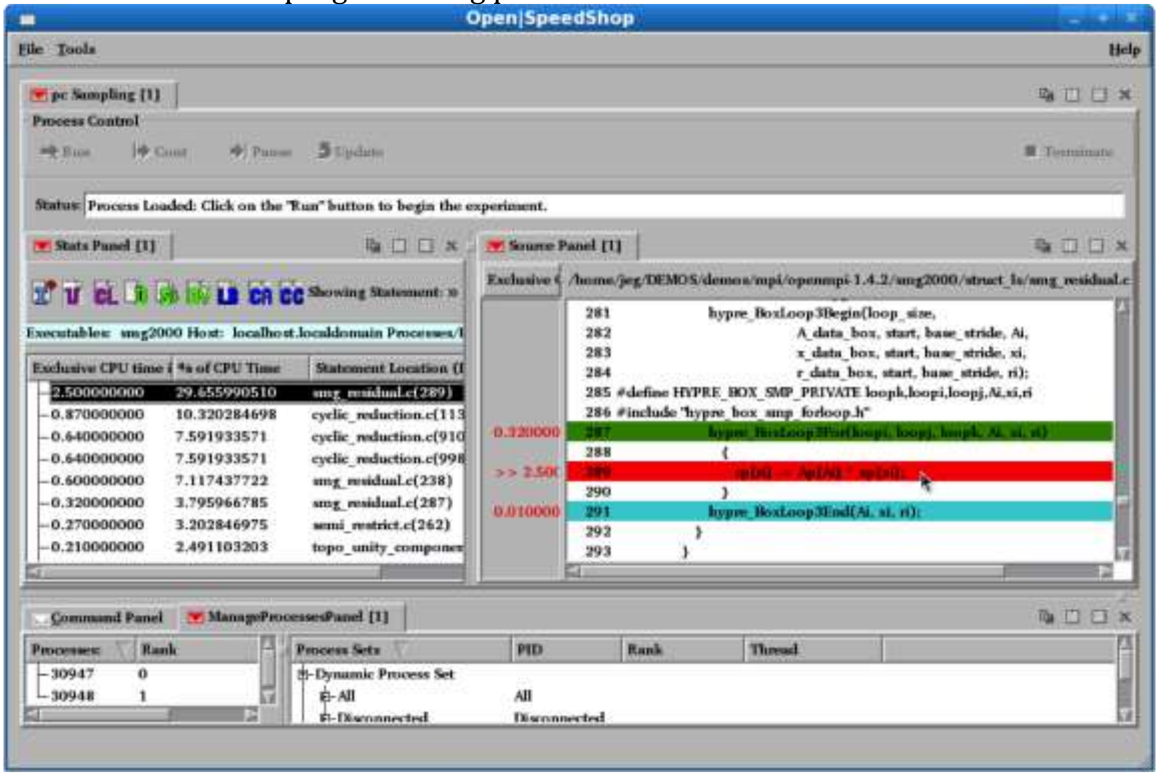
The View/Display Choice set of buttons allows users to choose what granularity to use for a particular display. The normal usage scenario, is to choose a view choice granularity and then select a view by choosing one of the icons described in the table above. The choices, as shown in the image below, are to see the performance data displayed:

- Per Function – Display the performance information relative to each function in the program that had performance data gathered during the experiment that was run.
- Per Statement – Display the performance information relative to each statement in the program that had performance data gathered during the experiment that was run
- Per Linked Object – Display the performance information relative to each library or linked object in the program that had performance data gathered during the experiment that was run.
- Per Loop – Display the performance information relative to each loop in the program that had performance data gathered during the experiment that was run. Note that the loop performance information is only shown for loops that actually were executed. There may be loops in the application that will not show up in the display because they did were not executed or had minimal time attributed to them.


View/Display Choice

● Functions ○ Statements ○ Linked Objects ○ Loops

The image below illustrates that double clicking on a line of statistical information in the Stats Panel will focus the source panel at the line of source representing the performance information and annotates the source with that information. Note the hot to cold color highlighting of the source. The higher the performance values are the hotter the color. Red is the hottest color, so source highlighted in red is taking the most time in the program being profiled.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Statement: »

Executables: smg2000 Host: localhost.localdomain Processes/I

Exclusive CPU time i	% of CPU Time	Statement Location (I
2.500000000	29.655990510	smg_residual.c(289)
0.870000000	10.320284698	cyclic_reduction.c(113
0.640000000	7.591933571	cyclic_reduction.c(910
0.640000000	7.591933571	cyclic_reduction.c(998
0.600000000	7.117437722	smg_residual.c(238)
0.320000000	3.795966785	smg_residual.c(287)
0.270000000	3.202846975	semi_restrict.c(262)
0.210000000	2.491103203	topo_unity_componen

Exclusive (/home/jeg/DEMOS/demos/mpi/openmpi-1.4.2/smg2000/struct_ls/smg_residual.c

```
           281             hypre_BoxLoop3Begin(loop_size,
           282                                 A_data_box, start, base_stride, Ai,
           283                                 x_data_box, start, base_stride, xi,
           284                                 r_data_box, start, base_stride, ri);
           285 #define HYPRE_BOX_SMP_PRIVATE loopk,loopi,loopj,Ai,xi,ri
           286 #include "hypre_box_smp_forloop.h"
0.320000   287             hypre_BoxLoop3For(loopi, loopj, loopk, Ai, xi, ri)
           288                {
>> 2.50(   289                   rp[ri] -= Ap[Ai] * xp[xi];
           290                }
0.010000   291             hypre_BoxLoop3End(Ai, xi, ri);
           292          }
           293       }
```

Processes	Rank
30947	0
30948	1

Process Sets	PID	Rank	Thread
Dynamic Process Set			
All	All		
Disconnected	Disconnected		

12 Special System Support

12.1 Cray and Blue Gene

When shared library support is limited the normal manner of running experiments in Open|SpeedShop doesn’t work. You must link the collectors into the static executable. Currently Open|SpeedShop has static support on Cray and the Blue Gene P/Q platforms. You must relink the application with the osslink command to add support for the collectors.

The osslink command is a script that will help with linking. Calls to it are usually embedded inside an application’s makefiles. The user generally needs to fine the target that creates the actual static executable and create a collector target that links in the selected collector. The following is an example for re-linking the smg2000 application.

```
smg2000: smg2000.o
  @echo "Linking" $@ "... "
  ${CC} –o smg2000 smg2000.o ${LFLAGS}

smg2000-pcsamp: smg2000.o
  @echo "Linking" $@ "... "
  osslink –v -c pcsamp ${CC} -o smg2000-pcsamp smg2000.o ${LFLAGS}

smg2000-usertime: smg2000.o
  @echo "Linking" $@ "... "
  osslink -v -c usertime ${CC} -o smg2000-usertime smg2000.o ${LFLAGS}

smg2000-hwcsamp: smg2000.o
  @echo "Linking" $@ "... "
  osslink -v -c hwcsamp ${CC} -o smg2000-hwcsamp smg2000.o ${LFLAGS}

smg2000-io: smg2000.o
  @echo "Linking" $@ "... "
  osslink -v -c io ${CC} -o smg2000-io smg2000.o ${LFLAGS}

smg2000-iot: smg2000.o
  @echo "Linking" $@ "... "
  osslink -v -c iot ${CC} -o smg2000-iot smg2000.o ${LFLAGS}

smg2000-mpi: smg2000.o
  @echo "Linking" $@ "... "
  osslink -v -c mpi ${CC} –o smg2000-mpi smg2000.o ${LFLAGS}
```

Running the re-linked executable will cause the application to write the raw data files to the location specified by the environment variable OPENSS_RAWDATA_DIR. Normally, in the cluster environment where shared executables are being run, the conversion from raw data to an Open|SpeedShop database is done under the hood. However, in this case you must use the ossutil command to create the database file manually. Of course you can add the ossutil command to a batch script to eliminate the step of manually issuing that command. Once you have the Open|SpeedShop database files create you can view them normally with the GUI or CLI.

Below is an example of a job script that will execute these steps for you.

```
#PBS -q debug
#PBS -N smg2000-pcsamp
...
# must have a clean raw data directory each run
rm -rf /home/USER/smg2000/test/raw
mkdir /home/USER/smg2000/test/raw

setenv OPENSS_RAWDATA_DIR /home/USER/smg2000/test/raw
setenv OPENSS_DB_DIR /home/USER/smg2000/test/

cd /home/jgalaro/smg2000/test

# needs –bb to have the original executable available
# when doing ossutil
aprun -bb -n 16 /home/USER/smg2000/test/smg2000-pcsamp

# creates a X.0.openss database file, please
# load the module pointing to openspeedshop before accessing ossutil
ossutil /home/jgalaro/smg2000/test/raw
```

There have been recent changes to the shared library support in Open|SpeedShop. Dynamic shared library support is now available in newer Cray and Blue Gene operating systems. There is support for both shared and static binaries on the Cray and on the Blue Gene Q platforms.

Also being worked on is a replacement mechanism for having to re-link the static binaries to insert the Open|SpeedShop collectors into the application. It will use the Dyninst binary rewriter to insert the collectors under the hood. Then you could use the same convenience scripts and interface for all types of applications.

12.1 Cray Specific Static aprun Information

Note, in the above execution of the statically linked executable that we need to add the –b option to the aprun call. The option is needed because Open|SpeedShop stores information about the executable location when it is running. Without the –b option the executable is run in a temporary location that is not available when the raw data information is being converted into the Open|SpeedShop database file.

13 Setup and Build for Open|SpeedShop

Open|SpeedShop is setup to work with the AMD Opteron or Athlon and the Intel x86, x86-64, and Itanium-2 architectures. It has been tested on many Linux Distributions include SLES, SUSE, RHEL, Fedora Core, CentOS, Debian, Ubuntu and many others. It has been installed on the IBM Blue Gene P/Q and the Cray XT/XE/XK systems. The OpenSpeedShop website contains information on special builds and usage instructions.

The source code for Open|SpeedShop is available for download at the Open|SpeedShop project home on Sourceforge:

http://sourceforge.net/projects/openss

Or CVS access is available at:

http://sourceforge.net/scm/?type=cvs&group_id=176777

Packages and additional information can be found on the Open|SpeedShop website:

http://www.openspeedshop.org/

13.1 Open|SpeedShop Cluster Install

Open|SpeedShop comes with a set of bash install scripts that will build Open|SpeedShop and any components it needs from source tarballs. First it will check to see if the correct supporting software is installed on your system, if the needed software isn't installed it will ask to build it for you. The only thing you need to do is provide a few arguments for the install script. For a normal setup you would just specify the directory to install in, what build task you want to do, and the location of your MPI and QT installs. For example:

```
./install-tool --build-offline --openss-prefix /opt/myoss --with-openmpi /opt/openmpi-1.5.5 –with-mvapich /opt/mvapich-1.1
```

After the install has successfully completed there are a few important environment variable you need to set. Again set OPENSS_PREFIX for the install location, the OPENSS_PLUGIN_PATH for the directory where the plugins are stored, if you installed with more then one MPI version you must specify which to use with OPENSS_MPI_IMPLEMENATION, lastly add the Open|SpeedShop bin directory to your PATH and lib64 directory to your LD_LIBRARY_PATH. Examples of the necessary environment variables that need to be set are as follows:

```
export OPENSS_PREFIX=/opt/myoss
export OPENSS_MPI_IMPLEMENTATION=openmpi
export OPENSS_PLUGIN_PATH=$OPENSS_PREFIX/lib64/openspeedshop
export LD_LIBRARY_PATH=$OPENSS_PREFIX/lib64:$LD_LIBRARY_PATH
export PATH=$OPENSS_PREFIX/bin:$PATH
```

13.2 Open|SpeedShop Blue Gene Platform Install

Please reference the OpenSpeedShop 2.1 Build and Install Guide.

13.3 Open|SpeedShop Cray Platform Install

Please reference the OpenSpeedShop 2.1 Build and Install Guide.

13.4 Execution Runtime Environment Setup

This section gives an example of a module file, softenv file and dotkit that can be used to set-up the Open|SpeedShop execution environments.

13.4.1 Example module file

This is an example of a module file used for a cluster installation. Use module load <filename of module file> to activate the Open|SpeedShop runtime environment.

```
#%Module1.0#############################################################
#########
## openss modulefile
##
proc ModulesHelp { } {
      global version openss
      puts stderr "\topenss - loads the OpenSpeedShop software & application environment"
      puts stderr "\n\tThis adds $oss/* to several of the"
      puts stderr "\tenvironment variables."
      puts stderr "\n\tVersion $version\n"
}
module-whatis   "loads the OpenSpeedShop runtime environment"
# for Tcl script use only
set    version        2.1
set    oss       /opt/OSS21

setenv        OPENSS_PREFIX                    $oss
setenv        OPENSS_DOC_DIR                   $oss/share/doc/packages/OpenSpeedShop
prepend-path   PATH                            $oss/bin
prepend-path   MANPATH                                 $oss/share/man

set unameexe  "/bin/uname"
if { [file exists $unameexe] } {
   set machinetype [ exec /bin/uname -m ]
   if { $machinetype == "x86" ||
       $machinetype == "i386" ||
       $machinetype == "i486" ||
       $machinetype == "i586" ||
       $machinetype == "i686" } {
```

```
    setenv  OPENSS_PLUGIN_PATH   $oss/lib/openspeedshop
    setenv DYNINSTAPI_RT_LIB $oss/lib/libdyninstAPI_RT.so
    prepend-path LD_LIBRARY_PATH $oss/lib
  }
  if { $machinetype == "x86_64" } {
    setenv  OPENSS_PLUGIN_PATH   $oss/lib64/openspeedshop
    setenv DYNINSTAPI_RT_LIB $oss/lib64/libdyninstAPI_RT.so
    prepend-path LD_LIBRARY_PATH $oss/lib64
  }
  if { $machinetype == "ia64" } {
    setenv  OPENSS_PLUGIN_PATH   $oss/lib/openspeedshop
    setenv DYNINSTAPI_RT_LIB $oss/lib/libdyninstAPI_RT.so
    prepend-path LD_LIBRARY_PATH $oss/lib
  }
}
```

13.4.2 Example softenv file

This is an example of a softenv file used for a Blue Gene/Q installation. Use the “resoft <filename of softenv file>” command to activate the Open|SpeedShop runtime environment.

```
# The OpenSpeedShop .soft file.
# Remember to type "resoft" after working on this file.

OSS = /home/projects/oss/oss
TARCH = bgq

# Set up OSS environment variables

# Find the executable portions of OpenSpeedShop (order is important here)
PATH += $OSS/$TARCH/bin
PATH += $OSS/bin

# Find the libraries for OpenSpeedShop (order is important here)
LD_LIBRARY_PATH += $OSS/$TARCH/lib64
LD_LIBRARY_PATH += $OSS/lib64

# Find the runtime collectors
OPENSS_PLUGIN_PATH = $OSS/$TARCH/lib64/openspeedshop

# Tell the tool what the application MPI implementation is
# Needed if supporting multiple implementations and running the "mpi", "mpit", or "mpiotf" experiments
OPENSS_MPI_IMPLEMENTATION = mpich2

# Paths to documentation and man pages
OPENSS_DOC_DIR = $OSS/share/doc/packages/OpenSpeedShop
MANPATH = $OSS/share/man

# Use the basic environment.
@default
```

13.4.3 Example dotkit file

This is an example of a dotkit file used for a 64-bit cluster platform installation and is not generalized to support different platforms other than the 64-bit cluster it was written for. Use the “use <filename of dotkit file>” command to activate the Open|SpeedShop runtime environment. Note: do not include the “.dk” portion of the filename when using the “use” command.

```
#c performance/profile
#d Open|Speedshop (Version 2.1)
dk_setenv OPENSS_PREFIX /usr/global/tools/openspeedshop/oss-dev/OSS21
dk_setenv OPENSS_PLUGIN_PATH $OPENSS_PREFIX/lib64/openspeedshop
dk_setenv OPENSS_DOC $OPENSS_PREFIX/share/doc/packages/OpenSpeedShop/
dk_alter PATH           $OPENSS_PREFIX/bin
dk_alter LD_LIBRARY_PATH $OPENSS_PREFIX/lib64

dk_setenv DYNINSTAPI_RT_LIB $OPENSS_PREFIX/lib64/libdyninstAPI_RT.so
dk_setenv XPLAT_RSH rsh
dk_setenv OPENSS_MPI_IMPLEMENTATION mvapich
dk_test `dk_cev OPENSS_RAWDATA_DIR` -eq 0 && dk_setenv OPENSS_RAWDATA_DIR
/p/lscratchb/${USER}
```

14 Additional Information and Documentation Sources

14.1 Final Experiment Overview

In the table below we match up a few general questions you may ask yourself with the experiments you may want to run in order to find the answer.

Where does my code spend most of its time?
• Flat profiles (pcsamp) • Getting inclusive/exclusive timings with callstacks (usertime) • Identifying hot callpaths (usertime + HP analysis)
How do I analyze cache performance?
• Measure memory performance using hardware counters (hwc) • Compare to flat profiles (custom comparison) • Compare multiple hardware counters (N x hwc, hwcsamp)
How to identify I/O problems?
• Study time spent in I/O routines (io, iot and lightweight iop) • Compare runs under different scenarios (custom comparisons)
How to identify memory problems?
• Study time spent in memory allocation/de-allocation routines (mem) • Look for load imbalance (LB view) and outliers (CA view)
How do I find parallel inefficiencies in OpenMP and/or threaded applications?
• Study time spent in POSIX thread routines (pthreads) • Look for load imbalance (LB view) and outliers (CA view)
How do I find parallel inefficiencies in MPI applications?
• Study time spent in MPI routines (mpi) • Look for load imbalance (LB view) and outliers (CA view)
How do I find parallel inefficiencies in NVIDIA CUDA applications?
• Study time spent in CUDA routines and the CUDA event execution trace. (cuda)

14.2 Additional Documentation

The python scripting API documentation can be found at http://www.openspeedshop.org/docs/pyscripting_doc or in the …/share/doc/packages/openspeedshop/pyscripting_doc folder in the install directory.

There are also man pages for openss and every convenience script. There's also a quick start guide that you can download from http://www.openspeedshop.org

There is also an Open|SpeedShop Forum where you can ask questions and read posts at http://www.openspeedshop.org/forums There is also an email list that you can send your questions to oss-questions@openspeedshop.org

15 Convenience Script Basic Usage Reference Information

This section provides a quick overview of the convenience scripts that can be used to either compare experiment data to other experiment data or to gather performance information for each of the various performance metric types that Open|SpeedShop supports.

15.1 Suggested Workflow

We recommend an **O|SS** workflow consisting of two phases. First, gathering the performance data using the convenience scripts. Then using the GUI or CLI to view the data.

15.2 Convenience Scripts

Users are encouraged to use the convenience scripts that hide some of the underlying options for running experiments. The full command syntax can be found in the User's Guide. The script names correspond to the experiment types and are: **osspcsamp, ossusertime, osshwc, osshwcsamp, osshwctime, ossio, ossiot, ossmpi, ossmpit, ossmpiotf, ossfpe** plus an **osscompare** script.

Note: Make sure to set **OPENSS RAWDATA DIR (See KEY ENVIRONMENT VARIABLES** section for info). When running Open|SpeedShop, use the same syntax that is used to run the application/executable outside of O|SS, but enclosed in quotes; e.g., Using an MPI with mpirun: **osspcsamp** "mpirun -np 512 ./smg2000" Using SLURM/srun: **osspcsamp** "srun -N 64 -n 512 ./smg2000 -n 5 5 5" Redirection to/from files inside quotes can be problematic, see convenience script "man" pages for more info.

15.3 Report and Database Creation

Running the pcsamp experiment on the sequential program named mexe: **osspcsamp** mexe results in a default report and the creation of a SQLite database file mexe-pcsamp.openss in the current directory; the report:

```
% CPU Time  CPU time   Function
48.990       11.650      f3 (mexe: m.c, 24)
33.478        7.960      f2 (mexe: m.c,15)
17.451        4.150      f1 (mexe: m.c,6)
 0.084        0.020      work(mexe:m.c,33)
```

To access alternative views in the GUI: **openss –f** mexe-pcsamp.openss loads the database file. Then use the GUI toolbar to select desired views; or, using the CLI: **openss –cli –f** mexe-pcsamp.openss to load the database file. Then use the **expview** command options for desired views.

15.4 osscompare: Compare Database Files

General form:
osscompare "<db_file1>, < db_file2>[,<db_file>...]" [time | percent | <other metrics>] [rows=nn] [viewtype=functions| statements | linkedobjects] > [oname = <csv filename>]

Where:

"<db_file>" represents an Open|SpeedShop database file created by running an Open|SpeedShop experiment on an application.

[time | percent | <other metrics>] represent the metric that the comparison will use to differentiate the performance information for each experiment database.

[rows=nn] indicates how many rows of output you want to have listed.

[viewtype=functions| statements | linkedobjects] select the granularity of the view output. The comparison is either done at the function, statement, or library view level. Function level is the default granularity.

[oname = <csv filename>] Name the output filename when comma separated list output is requested.

Example:

```
osscompare "smg-run1.openss,smg-run2.openss"
osscompare "smg-run1.openss,smg-run2.openss" percent rows=10
```

Please type "man osscompare" for more details.

15.5 osspcsamp: Program Counter Experiment

General form:
osspcsamp "<command> < args>" **[high | low | default |** <sampling rate>]

Sequential job example:

```
osspcsamp "smg2000 –n 50 50 50"
```

Parallel job example:

```
osspcsamp "mpirun –np 128 smg2000 –n 50 50 50"
```

Additional arguments:
high: twice the default sampling rate (samples per second)
low: half the default sampling rate
default: default sampling rate is 100
<sampling rate>: integer value sampling rate

15.6 ossusertime: Call Path Experiment

General form:
ossusertime "<command> < args>" [**high** | **low** | **default** | <sampling rate>]

Sequential job example:

```
ossusertime "smg2000 –n 50 50 50"
```

Parallel job example:

```
ossusertime "mpirun –np 64 smg2000 –n 50 50 50"
```

Additional arguments:

- **high:** twice the default sampling rate (samples per second)
- **low:** half the default sampling rate
- **default:** default sampling rate is 35
- <sampling rate>: integer value sampling rate

15.7 osshwc, osshwctime: HWC Experiments

General form:
osshwc[time] "<command> < args>" **[default |** <PAPI_event> | <PAPI threshold> | <PAPI_ event><PAPI threshold>]

Sequential job example:

```
osshwc[time] "smg2000 –n 50 50 50"
```

Parallel job example:

```
osshwc[time] "mpirun –np 128 smg2000 –n 50 50 50"
```

Additional arguments:

- **default:** event (PAPI_TOT_CYC), threshold (10000)
- <PAPI_event>: PAPI event name
- <PAPI threshold>: PAPI integer threshold

15.8 osshwcsamp: HWC Experiment

General form:
osshwcsamp "<command>< args>" **[default | <PAPI_event_list>| <sampling_rate>]**

Sequential job example:

```
osshwcsamp "smg2000 –n 50 50 50"
```

Parallel job examples:

```
osshwcsamp "mpirun –np 128 smg2000 –n 50 50 50"
osshwcsamp "srun –N 32 –n 128 sweep3d.mpi" PAPI_L1_DCM,PAPI_L1_DCA 200
```

Additional arguments:

- **default:** events(PAPI_TOT_CYC and PAPI_FP_OPS), sampling_rate is 100
- <PAPI_event_list>: Comma separated PAPI event list <sampling_rate>:Integer value sampling rate

15.9 ossio, ossiot: I/O Experiments

General form:
ossio[t] "<command> < args>" [**default** | f_t_list]

Sequential job example:

```
ossio[t] "smg2000 –n 50 50 50"
```

Parallel job example:

ossio[t] "mpirun –np 128 smg2000 –n 50 50 50"

Additional arguments:

default: trace all I/O functions

< f_t_list>: Comma-separated list of I/O functions to trace, one or more of the following: **close, creat, creat64, dup, dup2, lseek, lseek64, open, open64, pipe, pread, pread64, pwrite, pwrite64, read, readv, write, and writev**

15.10 ossmpi, ossmpit: MPI Experiments

General form:

ossmpi[t] "<mpirun><mpiargs><command><args>" [**default** | f_t_list]

Parallel job example:

ossmpi[t] "mpirun –np 128 smg2000 –n 50 50 50"

Additional arguments:

default: trace all MPI functions

<f_t_list>: Comma-separated list of MPI functions to trace, consisting of zero or more of: **MPI_Allgather, …. MPI_Waitsome** and/or zero or more of the MPI group categories:

MPI Category	Argument
All MPI Functions	all
Collective Communicators	collective_com
Persistent Communicators	persistent_com
Synchronous Point to Point	synchronous_p2p
Asynchronous Point to Point	asynchronous_p2p
Process Topologies	process_topologies
Groups Contexts Communicators	graphs_contexts_comms
Environment	environment
Datatypes	datatypes
MPI File I/O	fileio

15.11 ossfpe: FP Exception Experiment

General form:

ossfpe "<command> < args>" [**default** | f_t_list]

Sequential job example:

ossfpe "smg2000 –n 50 50 50"

Parallel job example:

ossfpe "mpirun –np 128 smg2000 –n 50 50 50"

Additional arguments:

default: trace all floating-point exceptions

<f_t_list>: Comma-separated list of exceptions to trace, consisting of one or more of:
inexact_result, division_by_zero, underflow, overflow, invalid_operation

15.12 ossmem: Memory Analysis Experiment

General form:
ossmem “<command> < args>” [**default** | f_t_list]

Sequential job example:

```
ossmem “smg2000 –n 50 50 50”
```

Parallel job example:

```
ossmem “mpirun –np 128 smg2000 –n 50 50 50”
```

Additional arguments:

default: trace all supported memory functions
<f_t_list>: Comma-separated list of exceptions to trace, consisting of one or more of: **malloc, free, memalign, posix_mem align, calloc and realloc**

15.13 osspthread: POSIX Thread Analysis Experiment

General form:
osspthread “<command> < args>” [**default** | f_t_list]

Sequential job example:

```
osspthread “smg2000 –n 50 50 50”
```

Parallel job example:

```
osspthread “mpirun –np 128 smg2000 –n 50 50 50”
```

Additional arguments:

default: trace all POSIX thread functions
<f_t_list>: Comma-separated list of exceptions to trace, consisting of one or more of:
pthread_create, pthread_mutex_init, pthread_mutex_destroy, pthread_mutex_lock, pthread_mutex_trylock, pthread_mutex_unlock, pthread_cond_init, pthread_cond_destroy, pthread_cond_signal, pthread_cond_broadcast, pthread_cond_wait, and pthread_cond_timedwait

15.14 osscuda: NVIDIA CUDA Tracing Experiment

General form:
osscuda “<command> < args>”

Sequential job example:

```
osscuda “eigenvalues --matrix-size=4096”
```

Parallel job example:

```
osscuda “mpirun -np 64 -npernode 1 lmp_linux -sf gpu < in.lj”
```

15.15 Key Environment Variables

EXECUTION RELATED VARIABLES	***DESCRIPTION***
OPENSS_RAWDATA_DIR	Used on cluster systems where a /tmp file system is unique on each node. It specifies the location of a shared file system path which is required for O|SS to save the "raw" data files on distributed systems. **OPENSS_RAWDATA_DIR="shared** file system path" Example: export **OPENSS_RAWDATA_DIR=/lustre4/fsys/userid**
OPENSS_ENABLE_MPI_PCONTROL	Activates the MPI_Pcontrol function recognition, otherwise MPI_Pcontrol function calls will be ignored by O|SS.
OPENSS_DATABASE_ONLY	When running the Open|SpeedShop convenience scripts only create the database file and do NOT put out the default report. Used to reduce the size of the batch file output files if user is not interested in looking at the default report.
OPENSS_RAWDATA_ONLY	When running the Open|SpeedShop convenience scripts only gather the performance information into the OPENSS_RAWDATA_DIR directory, but do NOT create the database file and do NOT put out the default report.
OPENSS_DB_DIR	Specifies the path to where O|SS will build the database file. On a file system without file locking enabled, the SQLite component cannot create the database file. This variable is used to specify a path to a file system with locking enabled for the database file creation. This usually occurs on lustre file systems that don't have locking enabled. **OPENSS_DB_DIR="file** system path" Example: export **OPENSS_DB_DIR=/opt/filesys/userid**
OPENSS_MPI_IMPLEMENTATION	Specifies the MPI implementation in use by the application; only needed for the mpi, mpit, and mpiotf experiments. These are the currently supported MPI implementations: **openmpi, lampi, mpich, mpich2, mpt, lam, mvapich, mvapich2.** For Cray, IBM, Intel MPI implementations, use **mpich2.** **OPENSS_MPI_IMPLEMENTATION="MPI** impl. name" Example: export **OPENSS_MPI_IMPLEMENTATION=openmpi** In most cases, O|SS can auto-detect the MPI in use.

16 Hybrid (openMP and MPI) Performance Analysis

For this example/tutorial we have run Open|SpeedShop convenience script on the NPB-MZ BT program and created a database file that has 4 ranks each of which has 4 underlying openMP threads.

What this example intends to show is that you can look at hybrid performance first at the MPI level and then can look under the MPI rank to see how the threads are performing. At the MPI level you can see load balance and outliers, then focus on a rank and look at load balance and outliers for the underlying threads. Within a terminal window we enter:

```
openss -f bt-mz.B.4-pcsamp-1.openss
```

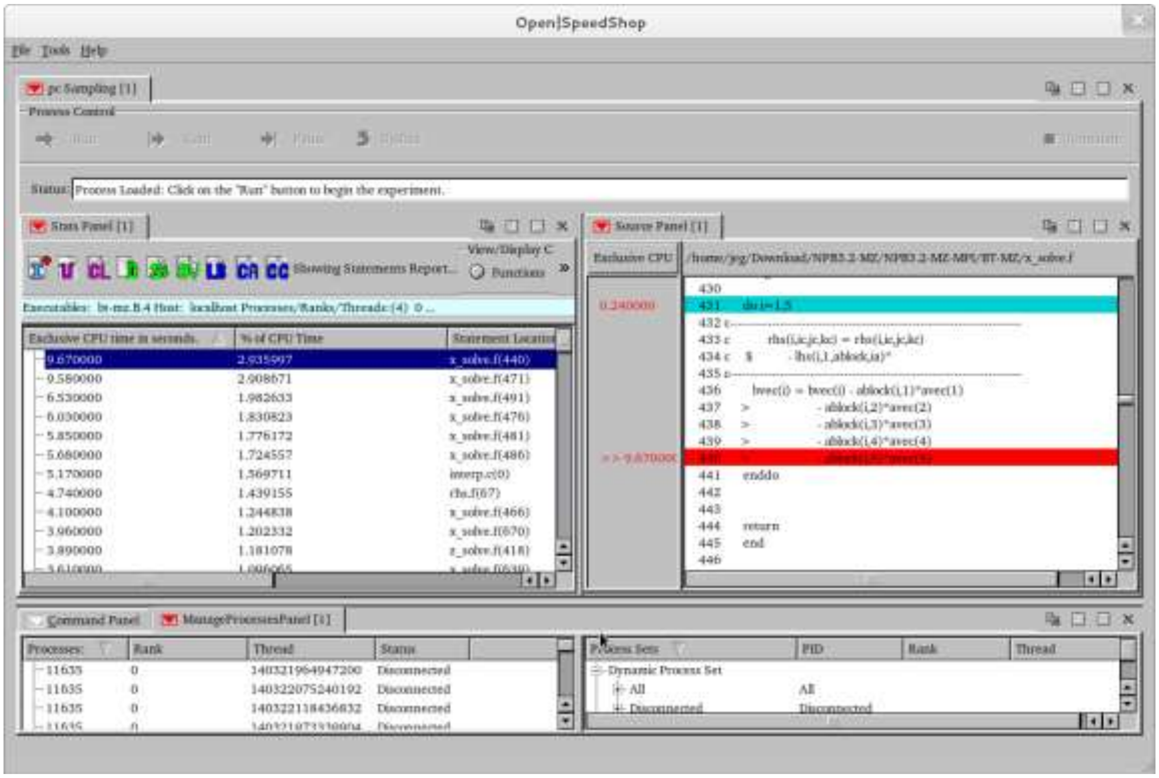
to bring up the Open|SpeedShop GUI.

In the GUI view below, we display the aggregated results for the application at the statement level granularity. When the default view first comes up the view is at the function level granularity. To switch to the statement level select the Statements button in the View/Display Choice section on the right hand side of the Stats Panel display and then click the “D” icon for default view. This will switch the Stats Panel view to statement level granularity.

Now the Stats Panel is displaying the statements that took the most time in the application run. For this execution of BT, the statement at line 440 took the most time. By double clicking on the statement, Open|SpeedShop focuses on the source for that line of the application source and highlights that line.

In the view below, we moved the ManageProcess panel tab to the lower panel and split the upper panel using the vertical splitter icon on the far right side of the original upper panel.

Note: Left mouse down and hold on the panel tab then slide the panel you want to move to another location on the Open|SpeedShop GUI or off onto other parts of your display.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: bt-mz.B.4 Host: localhost Processes/Ranks/Threads:(4) 0 ...

Exclusive CPU time in seconds.	% of CPU Time	Statement Location
9.670000	2.935997	x_solve.f(440)
9.580000	2.908671	x_solve.f(471)
6.530000	1.982633	x_solve.f(491)
6.030000	1.830823	x_solve.f(476)
5.850000	1.776172	x_solve.f(481)
5.680000	1.724557	x_solve.f(486)
5.170000	1.569711	interp.c(0)
4.740000	1.439155	rhs.f(67)
4.100000	1.244838	x_solve.f(466)
3.960000	1.202332	x_solve.f(670)
3.890000	1.181078	z_solve.f(418)

Exclusive CPU /home/jeg/Download/NPB3.2-MZ/NPB3.2-MZ-MPI/BT-MZ/x_solve.f

```
0.240000     431       do i=1,5
             432 c-----------------------------------------
             433 c        rhs(i,ic,jc,kc) = rhs(i,ic,jc,kc)
             434 c   $         - lhs(i,1,ablock,ia)*
             435 c-----------------------------------------
             436       bvec(i) = bvec(i) - ablock(i,1)*avec(1)
             437     >                 - ablock(i,2)*avec(2)
             438     >                 - ablock(i,3)*avec(3)
             439     >                 - ablock(i,4)*avec(4)
>>9.670000   440     >                 [illegible]
             441       enddo
             442
             443
             444       return
             445       end
             446
```

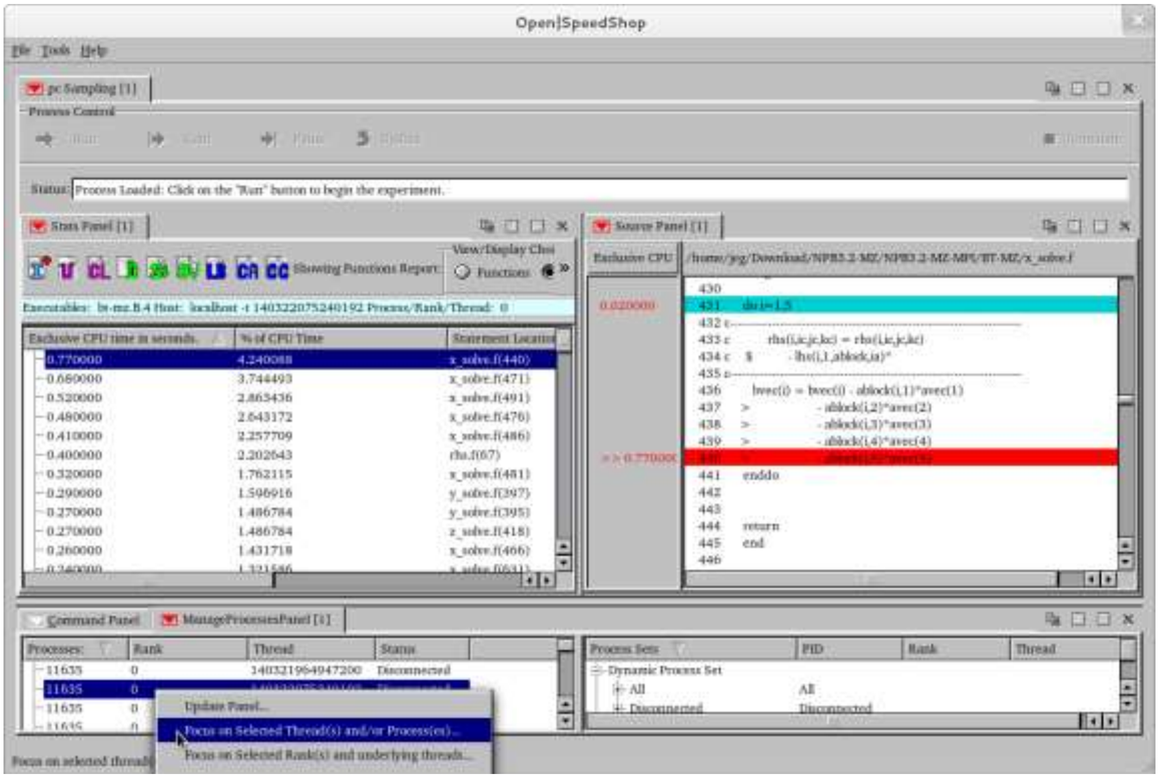
Processes:	Rank	Thread	Status
11635	0	140321964947200	Disconnected
11635	0	140322075240192	Disconnected
11635	0	140322118436832	Disconnected

Process Sets	PID	Rank	Thread
Dynamic Process Set			
All	All		
Disconnected	Disconnected		

16.1 Focus on individual Rank to get Load Balance for Underlying Threads

In the next view (below) we used the ManageProcess panel to highlight one rank and an individual thread within the rank to show only that threads performance data in the Stats Panel view.

Note: Use the focus on threads and processes Manage Process panel option to focus on individual threads within a rank. Right mouse button down on the Manage Process panel tab to see the options.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Executables: bt-mz.B.4 Host: localhost -t 140322075240192 Process/Rank/Thread: 0

Exclusive CPU time in seconds.	% of CPU Time	Statement Location
0.770000	4.240088	x_solve.f(440)
0.680000	3.744493	x_solve.f(471)
0.520000	2.863436	x_solve.f(491)
0.480000	2.643172	x_solve.f(476)
0.410000	2.257709	x_solve.f(486)
0.400000	2.202643	rhs.f(67)
0.320000	1.762115	x_solve.f(481)
0.290000	1.596916	y_solve.f(397)
0.270000	1.486784	y_solve.f(395)
0.270000	1.486784	z_solve.f(418)
0.260000	1.431718	x_solve.f(466)

Exclusive CPU | /home/jeg/Download/NPB3.2-MZ/NPB3.2-MZ-MPI/BT-MZ/x_solve.f

```
             430
0.020000     431    do i=1,5
             432 c-----------------------------------------------
             433 c        rhs(i,ic,jc,kc) = rhs(i,ic,jc,kc)
             434 c  $         - lhs(i,1,ablock,ia)*
             435 c-----------------------------------------------
             436       bvec(i) = bvec(i) - ablock(i,1)*avec(1)
             437    >              - ablock(i,2)*avec(2)
             438    >              - ablock(i,3)*avec(3)
             439    >              - ablock(i,4)*avec(4)
>>0.770000   440    >              [illegible]
             441    enddo
             442
             443
             444    return
             445    end
             446
```

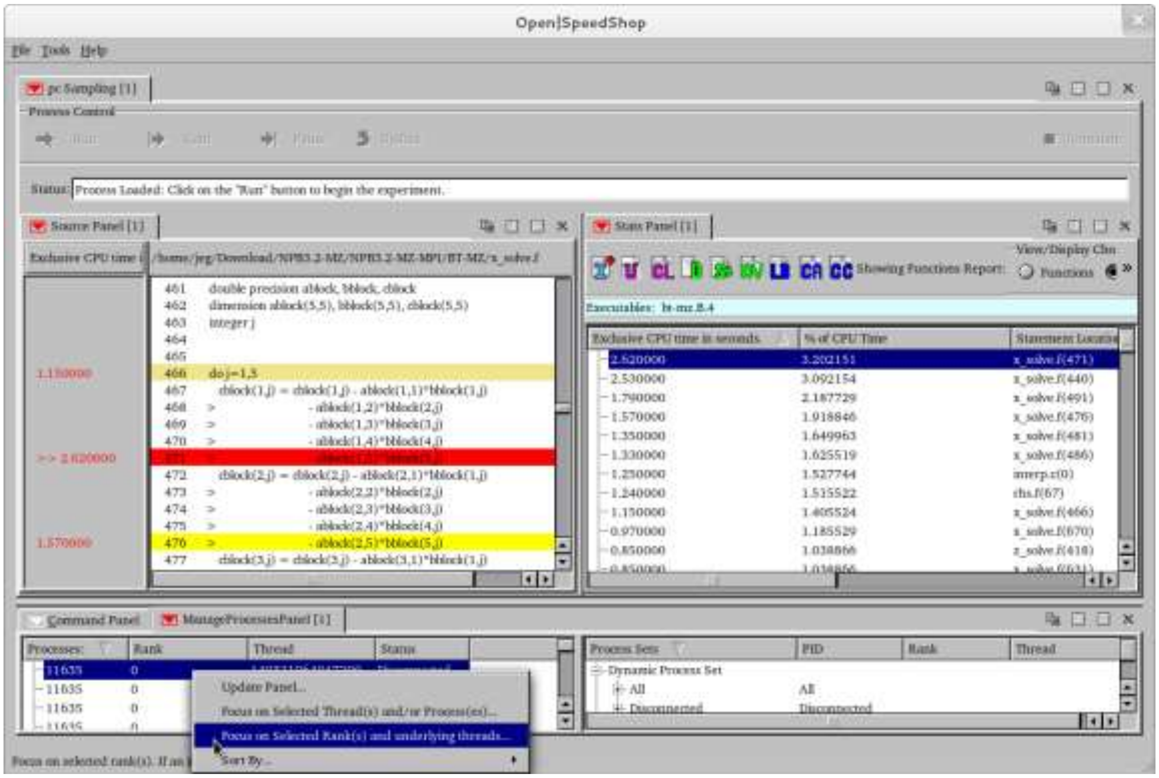
Processes:	Rank	Thread	Status
11635	0	140321964947200	Disconnected
11635	0		
11635	0		

Process Sets	PID	Rank	Thread
Dynamic Process Set			
All	All		
Disconnected	Disconnected		

Focus on selected thread

In the next GUI view, we used the ManageProcess panel to highlight one rank to show the performance data from all the threads that are executed under that particular rank in order to see only that performance data in the Stats Panel view.

Note: Use the "focus on selected rank and underlying threads" Manage Process panel option to focus on all the threads within a rank. Right mouse button down on the Manage Process panel tab to see the options.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

```
      double precision ablock, bblock, cblock
      dimension ablock(5,5), bblock(5,5), cblock(5,5)
      integer j


      do j=1,5
        cblock(1,j) = cblock(1,j) - ablock(1,1)*bblock(1,j)
     >                     - ablock(1,2)*bblock(2,j)
     >                     - ablock(1,3)*bblock(3,j)
     >                     - ablock(1,4)*bblock(4,j)
     >                     [illegible]
        cblock(2,j) = cblock(2,j) - ablock(2,1)*bblock(1,j)
     >                     - ablock(2,2)*bblock(2,j)
     >                     - ablock(2,3)*bblock(3,j)
     >                     - ablock(2,4)*bblock(4,j)
     >                     - ablock(2,5)*bblock(5,j)
        cblock(3,j) = cblock(3,j) - ablock(3,1)*bblock(1,j)
```

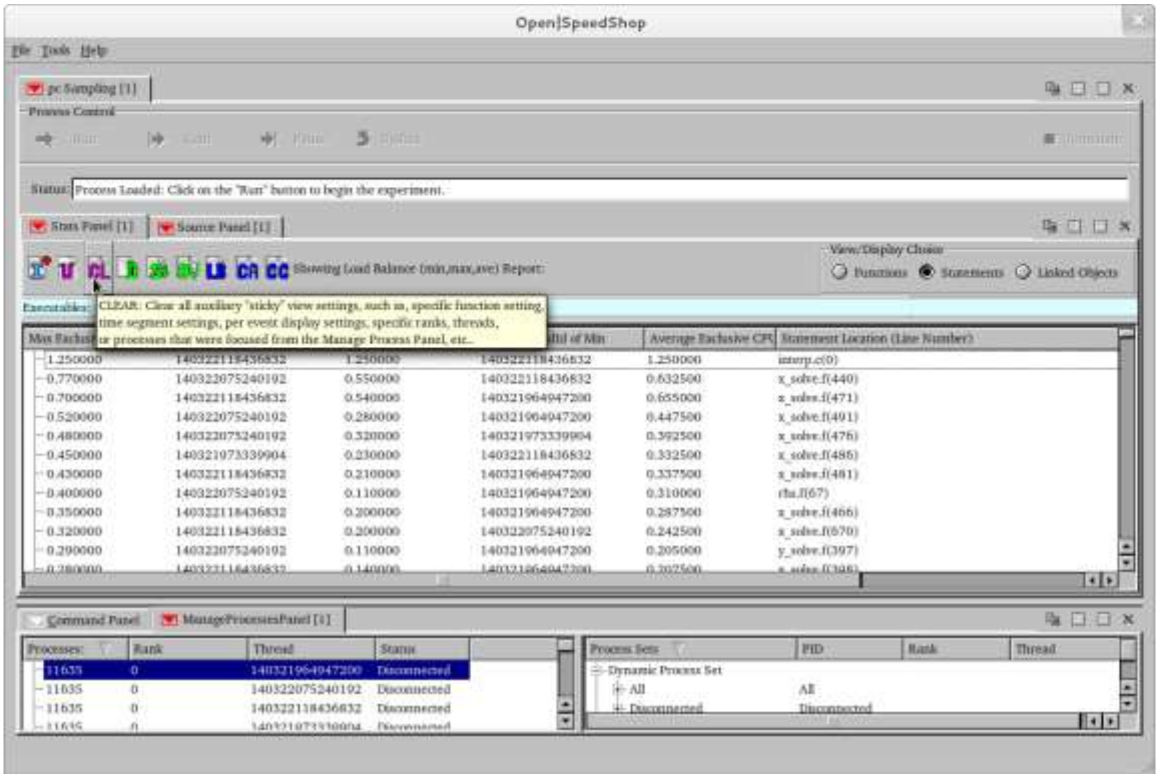
Executables: bt-mz.B.4

Exclusive CPU time in seconds	% of CPU Time	Statement Locatio
2.620000	3.202151	x_solve.f(471)
2.530000	3.092154	x_solve.f(440)
1.790000	2.187729	x_solve.f(491)
1.570000	1.918846	x_solve.f(476)
1.350000	1.649963	x_solve.f(481)
1.330000	1.625519	x_solve.f(486)
1.250000	1.527744	interp.c(0)
1.240000	1.515522	rhs.f(67)
1.150000	1.405524	x_solve.f(466)
0.970000	1.185529	x_solve.f(670)
0.850000	1.038866	z_solve.f(418)

Processes:	Rank	Thread	Status
11635	0		
11635	0		
11635	0		

16.2 Clearing Focus on individual Rank to get bank to default behavior

Note: Once you focus on individual or groups of ranks, e.g. venturing away from the default aggregated views, then you need to use the "CL" clear auxiliary setting icon to clear away all the optional selections and get back to looking at the aggregated results again.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Load Balance (min,max,ave) Report:

○ Functions ● Statements ○ Linked Objects

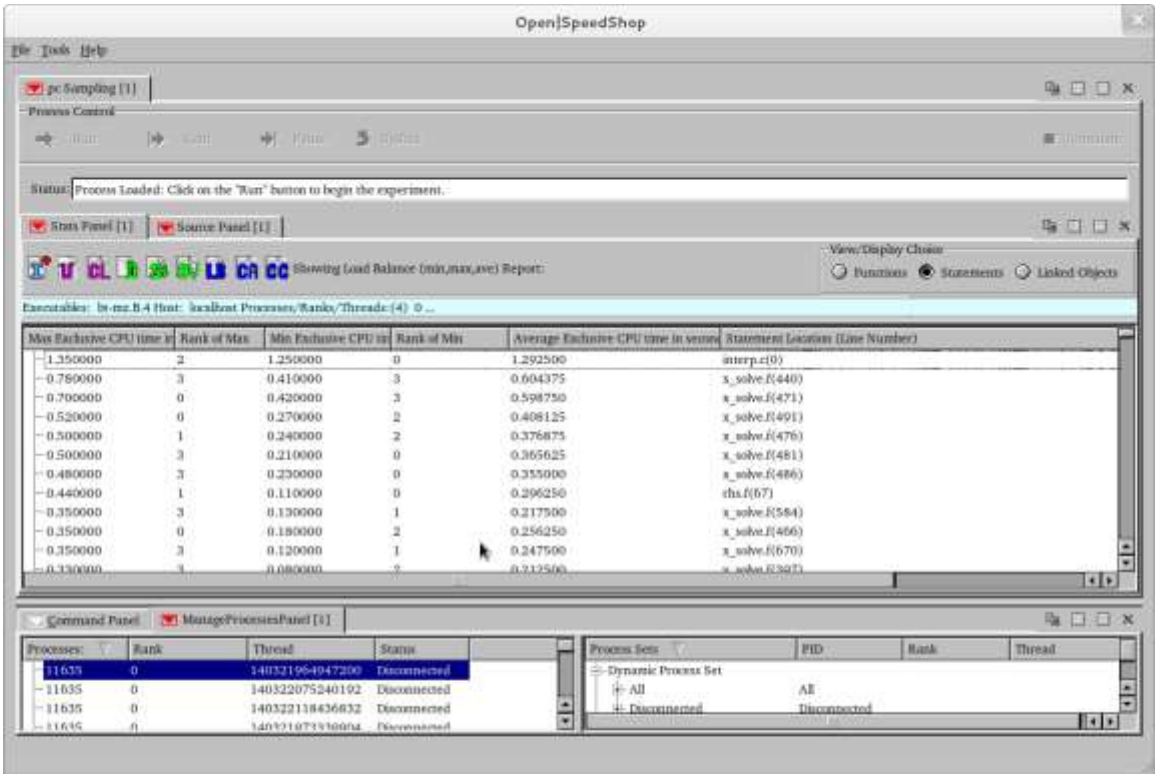
CLEAR: Clear all auxiliary "sticky" view settings, such as, specific function setting, time segment settings, per event display settings, specific ranks, threads, or processes that were focused from the Manage Process Panel, etc..

Max Exclusi			ThrId of Min	Average Exclusive CPU	Statement Location (Line Number)
1.250000	140322118436832	1.250000	140322118436832	1.250000	interp.c(0)
0.770000	140322075240192	0.550000	140322118436832	0.632500	x_solve.f(440)
0.700000	140322118436832	0.540000	140321964947200	0.655000	x_solve.f(471)
0.520000	140322075240192	0.280000	140321964947200	0.447500	x_solve.f(491)
0.480000	140322075240192	0.320000	140321973339904	0.392500	x_solve.f(476)
0.450000	140321973339904	0.230000	140322118436832	0.332500	x_solve.f(486)
0.430000	140322118436832	0.210000	140321964947200	0.337500	x_solve.f(481)
0.400000	140322075240192	0.110000	140321964947200	0.310000	rhs.f(67)
0.350000	140322118436832	0.200000	140321964947200	0.287500	x_solve.f(466)
0.320000	140322118436832	0.200000	140322075240192	0.242500	x_solve.f(670)
0.290000	140322075240192	0.110000	140321964947200	0.205000	y_solve.f(397)

Processes:	Rank	Thread	Status
11635	0	140321964947200	Disconnected
11635	0	140322075240192	Disconnected
11635	0	140322118436832	Disconnected

Process Sets	PID	Rank	Thread
Dynamic Process Set			
All	All		
Disconnected	Disconnected		

After clearing the specific rank and/or thread selections, we can click the "LB" load balance icon and Open|SpeedShop will display the min, max, average values across all the ranks in the hybrid code. This helps decide if there is imbalance across the ranks of the hybrid application. We can focus on individual ranks to see the balance across the openMP threads that are in an individual rank (next example image).



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Load Balance (min,max,ave) Report:

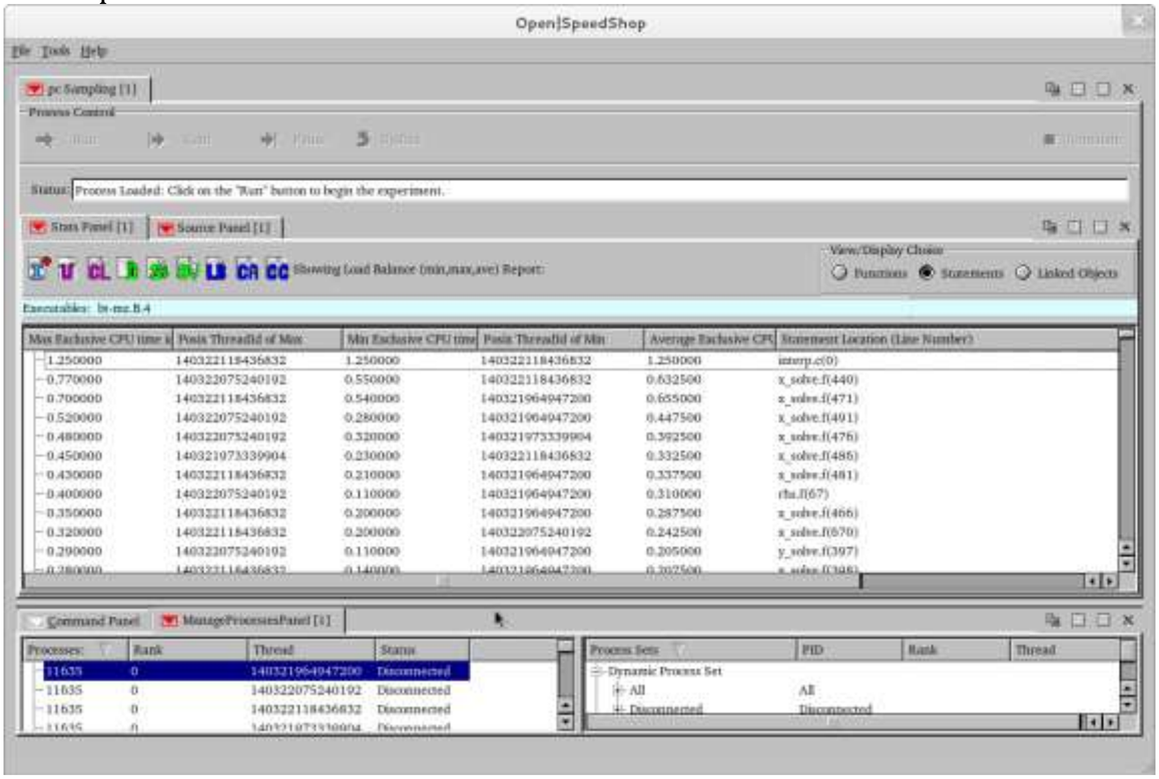
Executables: bt-mz.B.4 Host: localhost Processes/Ranks/Threads:(4) 0 ...

Max Exclusive CPU time i	Rank of Max	Min Exclusive CPU tir	Rank of Min	Average Exclusive CPU time in secon	Statement Location (Line Number)
1.350000	2	1.250000	0	1.292500	interp.c(0)
0.780000	3	0.410000	3	0.604375	x_solve.f(440)
0.700000	0	0.420000	3	0.598750	x_solve.f(471)
0.520000	0	0.270000	2	0.408125	x_solve.f(491)
0.500000	1	0.240000	2	0.376875	x_solve.f(476)
0.500000	3	0.210000	0	0.365625	x_solve.f(481)
0.480000	3	0.230000	0	0.355000	x_solve.f(486)
0.440000	1	0.110000	0	0.296250	rhs.f(67)
0.350000	3	0.130000	1	0.217500	x_solve.f(584)
0.350000	0	0.180000	2	0.256250	x_solve.f(466)
0.350000	3	0.120000	1	0.247500	x_solve.f(670)

Processes:	Rank	Thread	Status
11635	0	140321964947200	Disconnected
11635	0	140322075240192	Disconnected
11635	0	140322118436832	Disconnected

Process Sets	PID	Rank	Thread
Dynamic Process Set			
All	All		
Disconnected	Disconnected		

Here we used the Manage Process panel "Focus on selected rank and underlying threads" menu options to view the load balance across the 4 openMP threads for the rank 0 process.



Status: Process Loaded: Click on the "Run" button to begin the experiment.

Showing Load Balance (min,max,ave) Report:

Executables: bt-mz.B.4

Max Exclusive CPU time i	Posix ThreadId of Max	Min Exclusive CPU time	Posix ThreadId of Min	Average Exclusive CPU	Statement Location (Line Number)
1.250000	140322118436832	1.250000	140322118436832	1.250000	interp.c(0)
0.770000	140322075240192	0.550000	140322118436832	0.632500	x_solve.f(440)
0.700000	140322118436832	0.540000	140321964947200	0.655000	x_solve.f(471)
0.520000	140322075240192	0.280000	140321964947200	0.447500	x_solve.f(491)
0.480000	140322075240192	0.320000	140321973339904	0.392500	x_solve.f(476)
0.450000	140321973339904	0.230000	140322118436832	0.332500	x_solve.f(486)
0.430000	140322118436832	0.210000	140321964947200	0.337500	x_solve.f(481)
0.400000	140322075240192	0.110000	140321964947200	0.310000	rhs.f(67)
0.350000	140322118436832	0.200000	140321964947200	0.287500	x_solve.f(466)
0.320000	140322118436832	0.200000	140322075240192	0.242500	x_solve.f(670)
0.290000	140322075240192	0.110000	140321964947200	0.205000	y_solve.f(397)

Processes:	Rank	Thread	Status
11635	0	140321964947200	Disconnected
11635	0	140322075240192	Disconnected
11635	0	140322118436832	Disconnected

Process Sets	PID	Rank	Thread
Dynamic Process Set			
All	All		
Disconnected	Disconnected		

Please also explore the various options offered via a panel's pull down menu. Clicking on a colored downward-facing arrow or using the Stats Panel icons can access further options. Red icons represent view options, such as updating the data or clearing the view options. The "green" icons correspond to different possible views of the performance data. The "dark blue" icons correspond to analysis options while the "light blue" icon corresponds to information about the experiment. There is context sensitive text that is shown when you hover over the icons.