Performance Profiling of Parallel Codes

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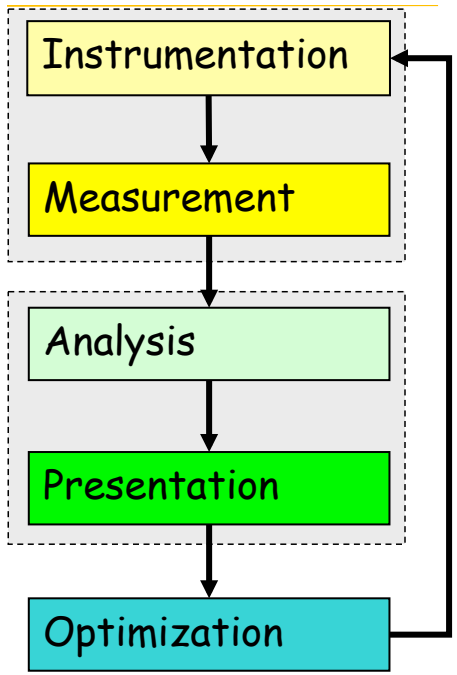
Performance Science and Engineering

A sophisticated and well developed field.

1. Performance profiling and benchmarking.
2. Performance modeling.
3. Performance tuning.



Outline and Goals

- Basics of performance evaluation.
- Tools for performance evaluation of parallel codes.
- Working with TAU.
  - Basic options for generating profiles.
  - Analyzing the performance profiles.
  - Advanced options and integration with PAPI.
  - Tracing.
- Performance evaluation on accelerators.

Building a Parallel Profiling Tool

- Language independence.
- Avoid excessive instrumentation.
- Binary analysis capability.
- Collection of multiple metrics.
- Hierarchical analysis.
- Hierarchical aggregation.
- Scalable.

Various Profiling Tools

- **`gprof`**
- HPCToolkit
- TAU
- PAPI
- Nvidia Visual Profiler
- Intel Vtune

TAU: Tuning and Analysis Utilities

- **`http://tau.uoregon.edu`**
- Developed at University of Oregon.
- Open Source.
- Comprehensive performance profiling and tracing.
- Integrated tool with instrumentation, measurement and visualization.
- Supports most HPC systems.
- Simple to integrate into applications.

DISCLAIMER: Some figures have been taken from Sameer Shende's slides.

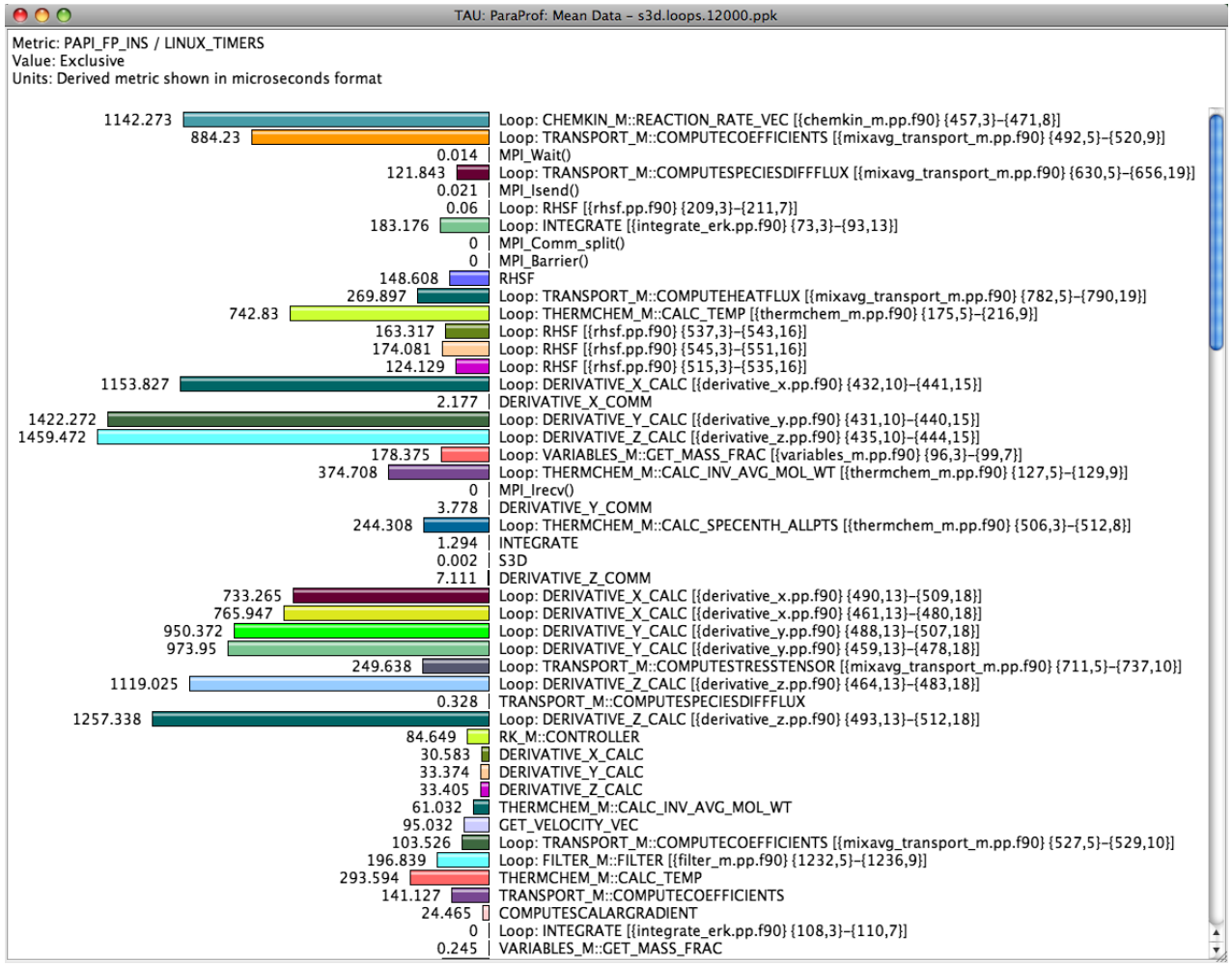
TAU: Using it right away ...

```
$ mpirun -np 4 tauex ./app
```

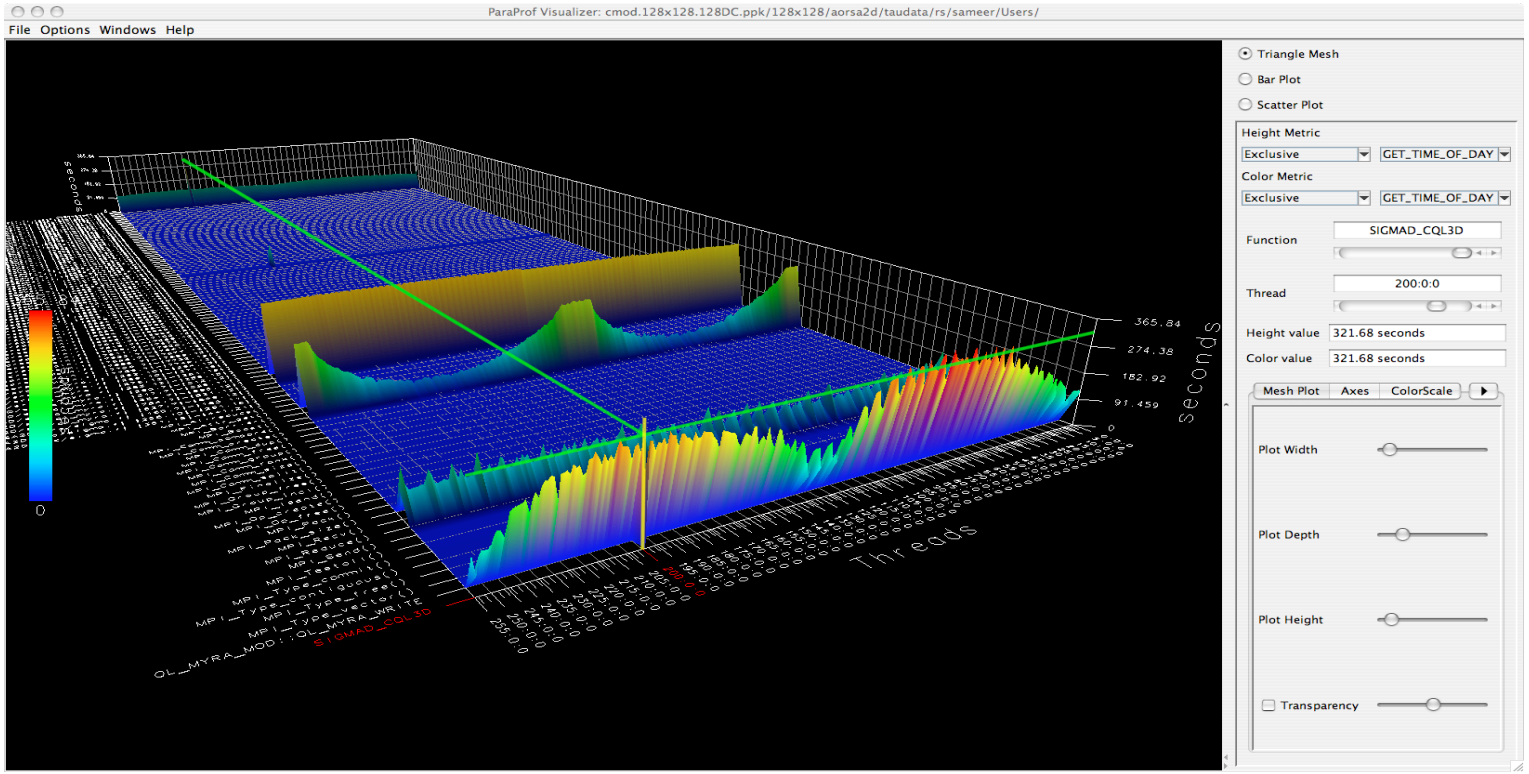
- This generates a basic profile of the application.
- Easy to identify bottleneck routines.

TAU: Visualizing Performance Data

- Paraprof (packaged with TAU.)



TAU: Visualizing Performance Data



TAU: System Workings

1. Instrumentation
   - Source code instrumentation
   - External library wrapping
   - Re-generate application binary
2. Measurement
   - Direct instrumentation: Interval events
   - Indirect instrumentation: Sampling
3. Analysis
   - Visualization and analysis in paraprof and perexplorer
   - Visualization in external tools, like Vampir and Jumpshot

TAU: Instrumentation Options

- Source code instrumentation
  - Automatic instrumentation with static source code analysis.
  - Manual instrumentation.
- Library level instrumentation
  - Wrapping external libraries.
- Binary code instrumentation
  - Runtime instrumentation.

TAU: Instrumentation Options

- Instrumentation levels:
  - Source code.
  - Object code.
  - Library code.
  - Executable code.
  - Runtime system.
  - Operating system.
- Different levels provide different information.

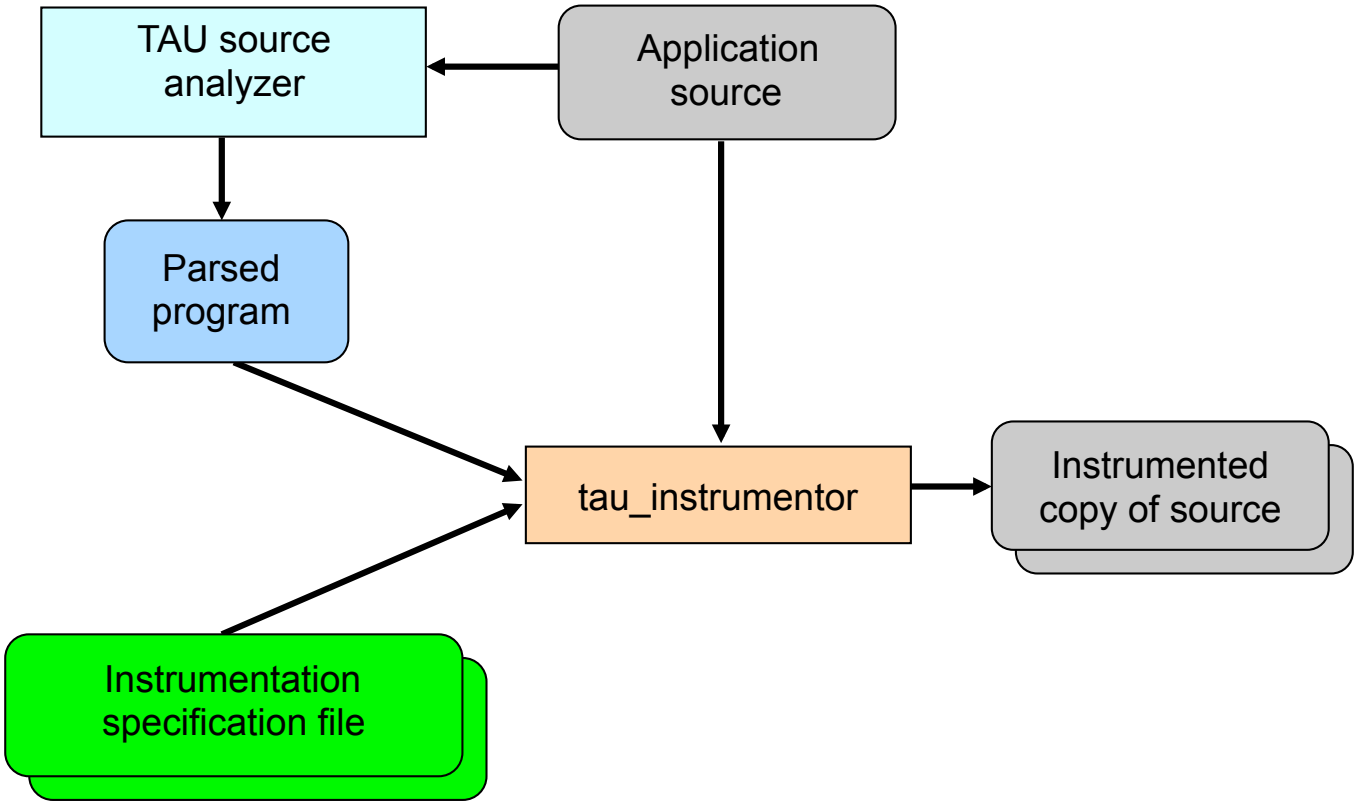
TAU: Instrumentation Techniques

- Static: instrument code prior to execution.
- Dynamic: instrument executable code at runtime.
- Manual and automatic.

TAU: Events

- **Interval events**. Have begin and end events.
  E.g. exclusive and inclusive duration
- **Atomic events**. Capture state with data values.
  E.g. cache miss reading from hardware counter

TAU: Automatic Source Instrumentation



- Compile time options with **`TAU_OPTIONS`**.
- Runtime environment variables, e.g. **`TAU_TRACE`**, **`TAU_METRICS`**.

TAU: Using

- Source code instrumentation:

```
$ export TAU_MAKEFILE=/path/to/tau/lib/Makefile.tau-mpi-pdt
$ export TAU_OPTIONS='-optVerbose'
$ taucxx app.cpp
$ mpirun -np 4 ./app
```

- Analyze generated performance data:

```
$ paraprof
```
or,
```
$ pprof
```

TAU: Makefiles

```
$ ls -l /path/to/tau/lib/Makefile.*
Makefile.tau-mpi-pdt
Makefile.tau-mpi-pdt-openmp
Makefile.tau-mpi-pdt-pthread
Makefile.tau-papi-mpi-pdt
...
```

TAU: Selective Instrumentation

```
$ cat select.tau
BEGIN_INSTRUMENT_SECTION
loops routine="#"
END_INSTRUMENT_SECTION
BEGIN_EXCLUDE_LIST
foo
bar
END_EXCLUDE_LIST
$ export TAU_OPTIONS='-optTauSelectFile=select.tau
-optVerbose'
```

TAU: Hardware Counters with PAPI

- **`http://icl.cs.utk.edu/papi`**

- Developed at University of Tennessee, Knoxville.
- Provides interface to hardware counters found in most processors.
- Information such as cache behaviors, branching, memory patterns, stalls, floating point efficiency, number of instructions, etc.

PAPI: Available Counters

```
$ papi_avail
...
Name         Code    Avail Deriv Description (Note)
PAPI_L1_DCM  0x80000000  No    No   Level 1 data cache misses
PAPI_L1_ICM  0x80000001  Yes   No   Level 1 instruction cache misses
PAPI_L2_DCM  0x80000002  Yes   Yes  Level 2 data cache misses
...
```

PAPI: Choosing Counters

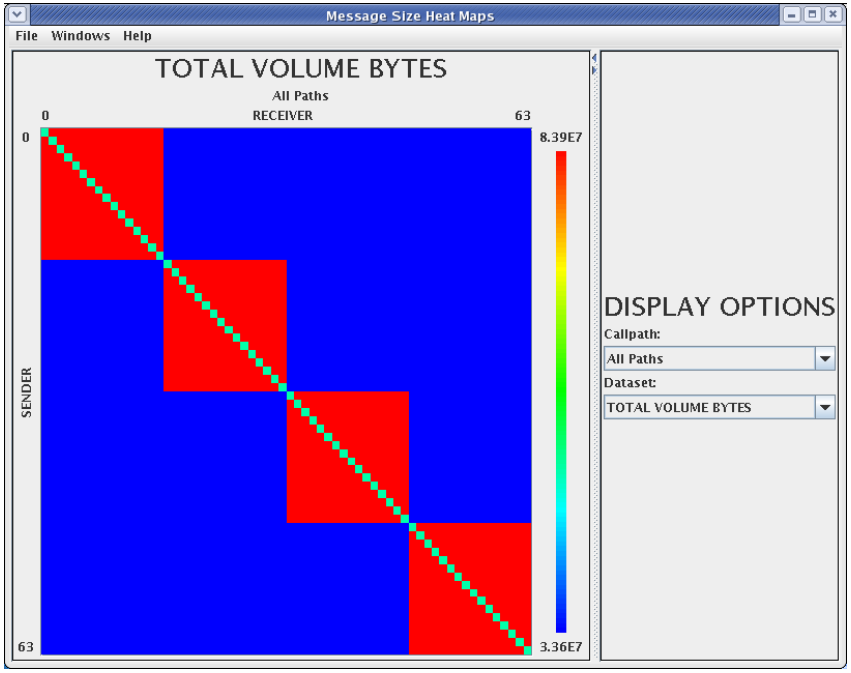
```
$ papi_event_chooser PAPI_FP_OPS
Event Chooser:  Available events which can be added with given events.
...
Name         Code    Deriv Description (Note)
PAPI_L1_ICM  0x80000001  No   Level 1 instruction cache misses
PAPI_L2_DCM  0x80000002  Yes  Level 2 data cache misses
PAPI_L2_ICM  0x80000003  No   Level 2 instruction cache misses
...
```

TAU: Profiling with PAPI

```
$ export TAU_MAKEFILE=/path/to/tau/lib/Makefile.tau-papi-mpi-pdt
$ export TAU_METRICS=TIME:PAPI_FP_INS:PAPI_L1_DCM
$ mpiexec -np 4 ./app
$ paraprof
```

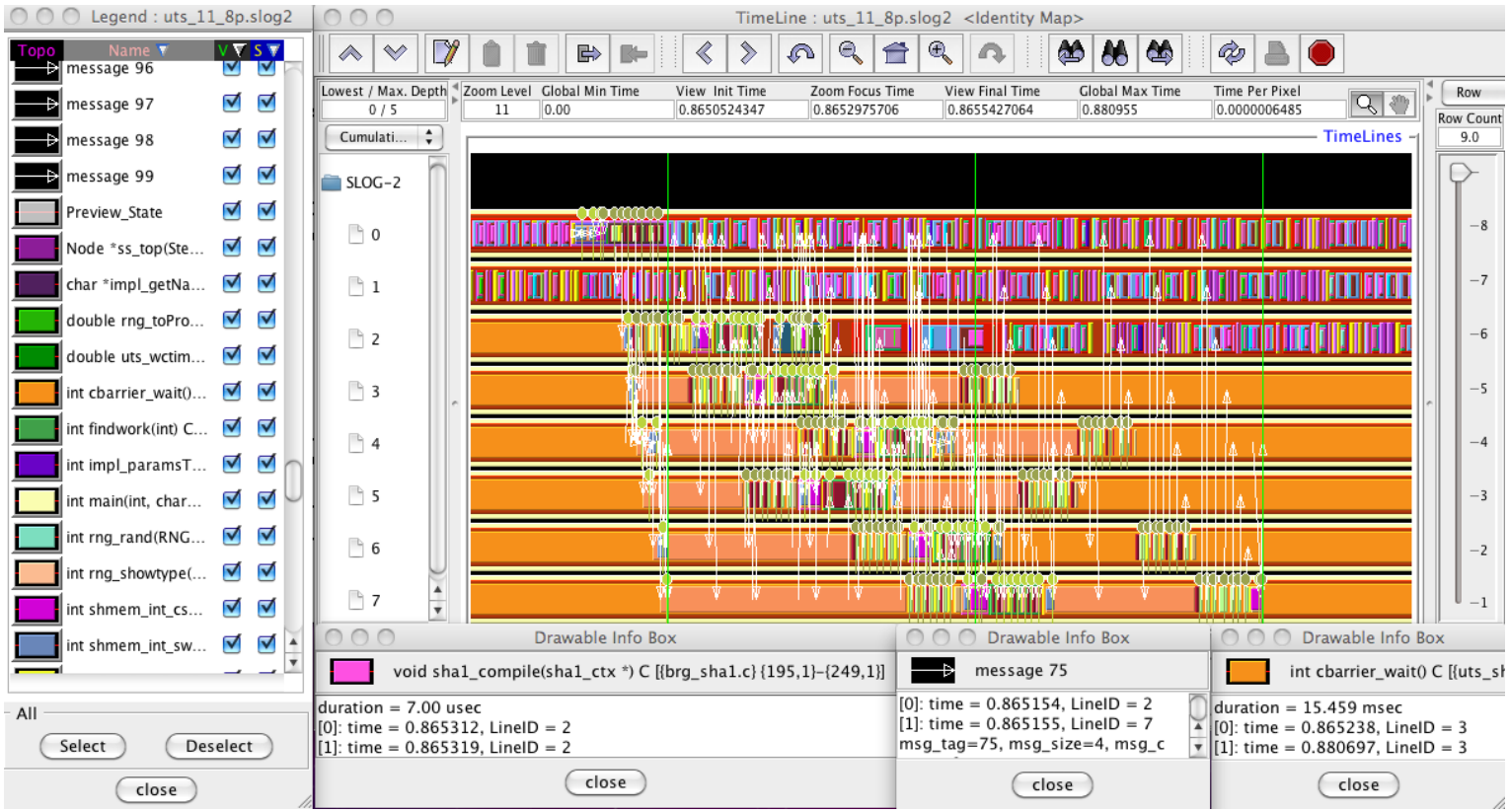
TAU: Profiling MPI Communication

```
$ export TAU_COMM_MATRIX=1
$ mpiexec -np 4 ./app
$ paraprof
```



TAU: Tracing

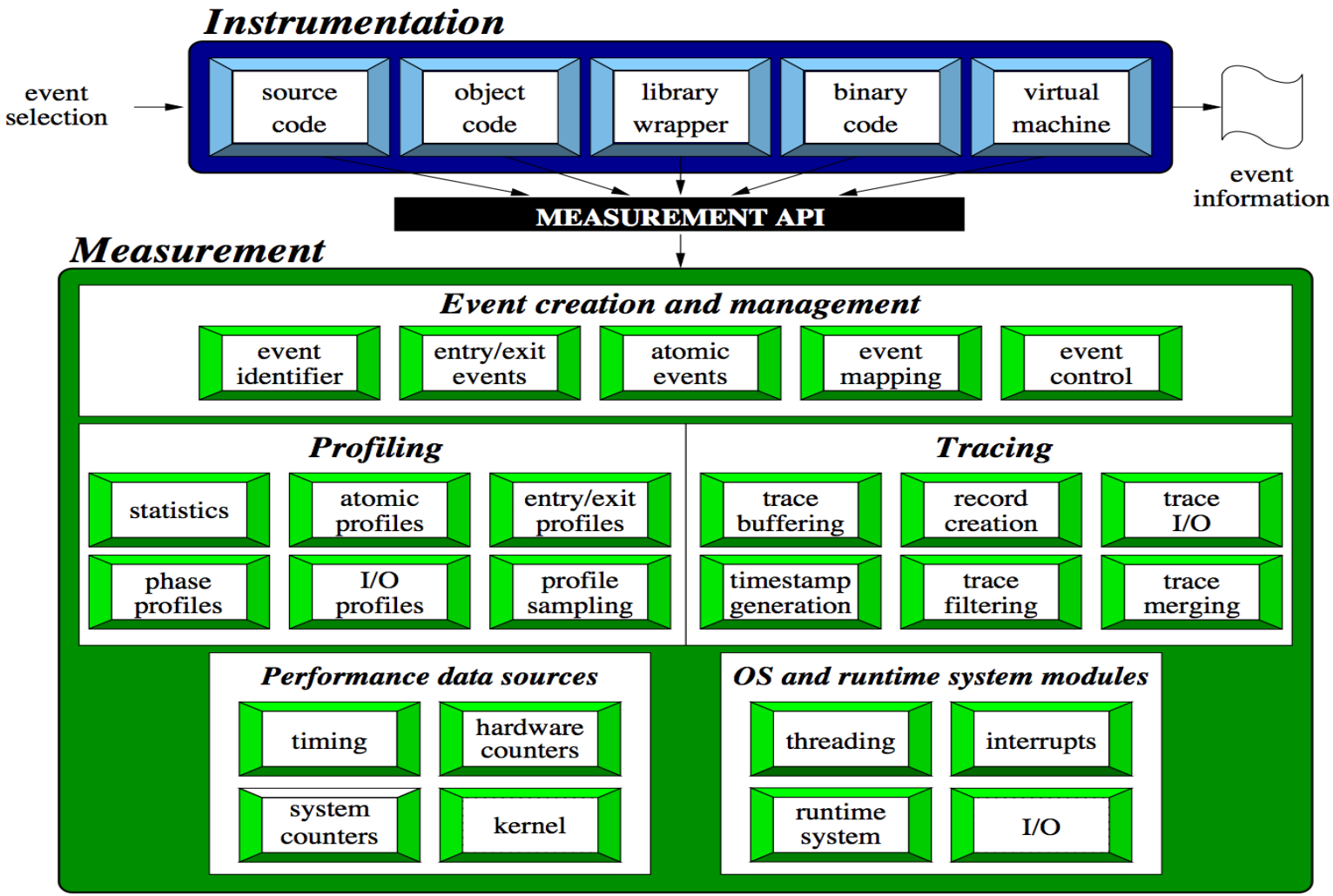
```
$ export TAU_TRACE=1
$ mpiexec -np 4 ./app
$ tau_treemerge.pl
$ tau2slog2 tau.trc tau.edf -o app.slog2
$ jumpshot
```



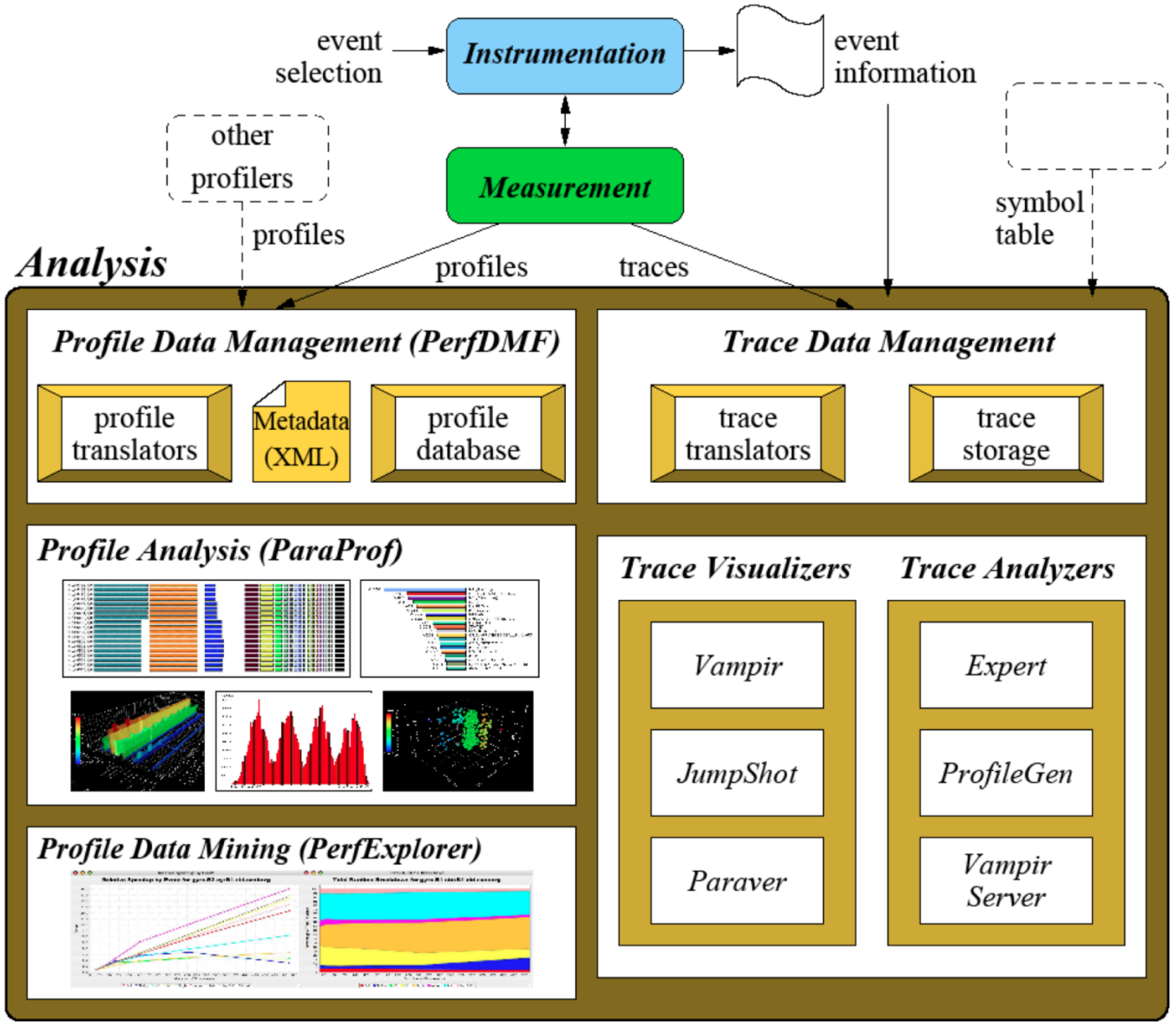
TAU: Manual Instrumentation

```
#include <tau.h>

int foo(int x) {
TAU_START("foo");
/* do something */
TAU_STOP("foo");
}

int main(int argc, char **argv) {
TAU_INIT(&argc, &argv);
TAU_START("main");
TAU_PROFILE_SET_NODE(rank);
...
TAU_STOP("main");
}
```

TAU: Architecture

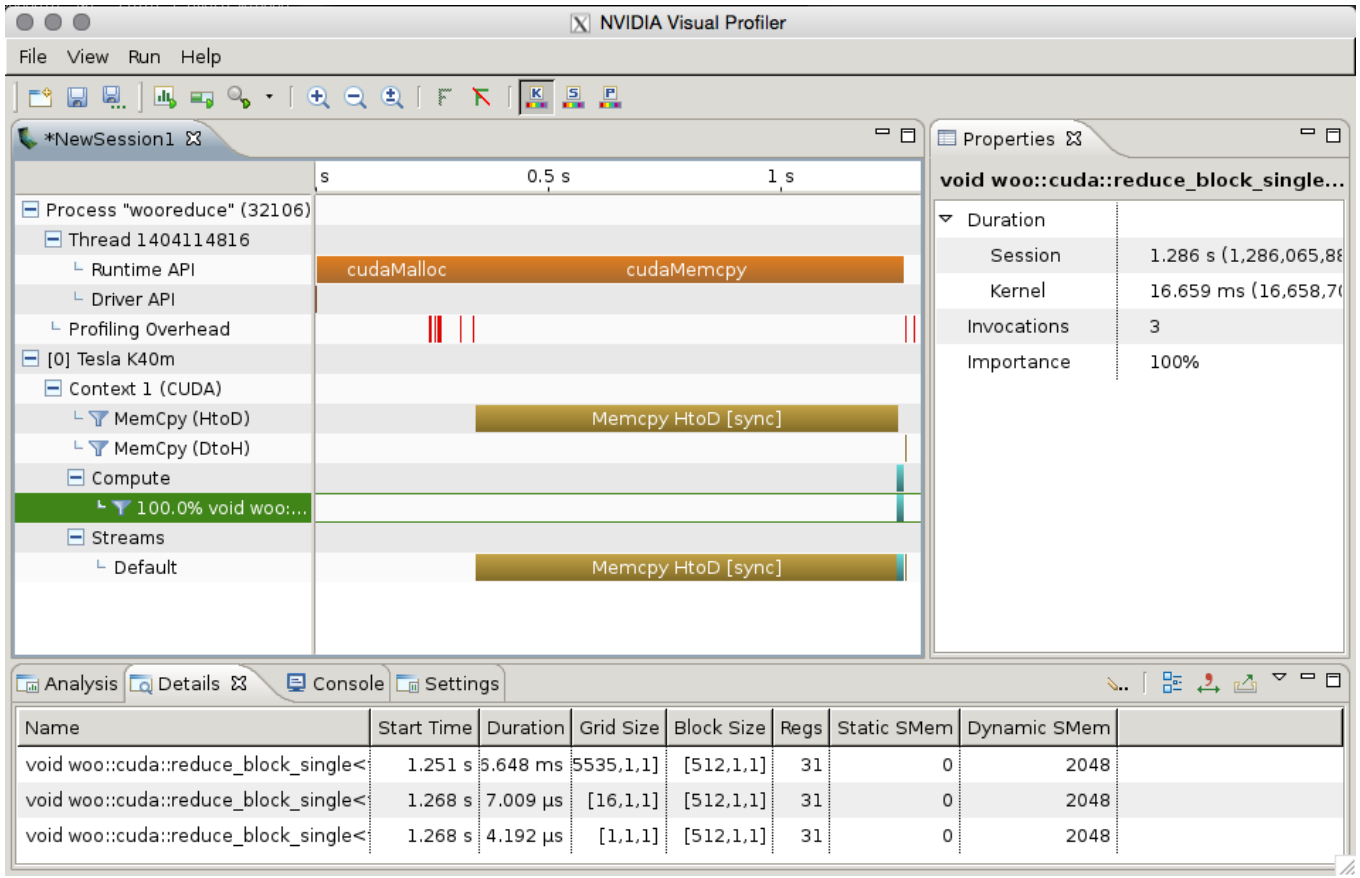


TAU: Architecture



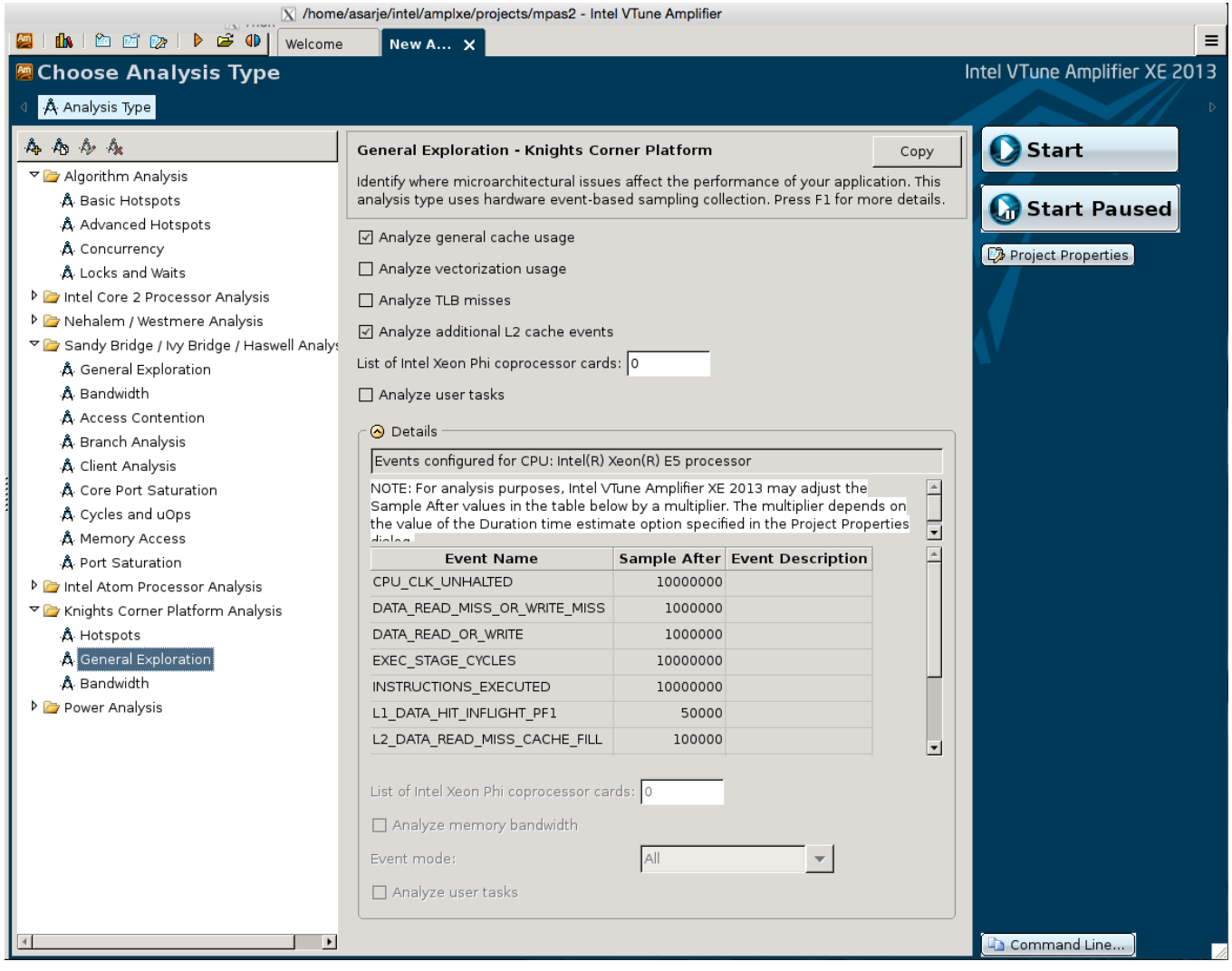
Profiling CUDA Codes

- TAU supports CUDA profiling.
- Other tools include Nvidia's **`nvprof`** and **`nvvp`**.



Profiling with Intel Xeon Phi

- Intel VTune.



Further ...

- "**Performance Tuning of Scientific Applications**", D.H. Bailey, R.F. Lucas, S.W. Williams, CRC Press 2011.
- **`http://www.cs.uoregon.edu/research/tau/docs.php`**
- **`http://icl.cs.utk.edu/papi`**
- "**Nvidia CUDA Compute Visual Profiler Guide**", version 7.0, 2015.