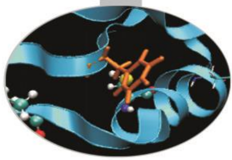
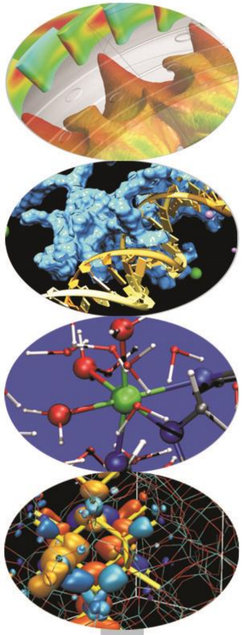
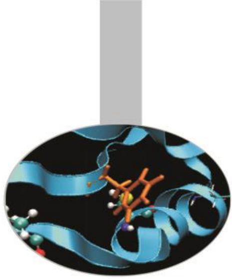


Profiling



Introduction



A serial or parallel program is normally composed by a large number of procedures.

To optimize and parallelize a complex code is fundamental to find out the parts where most of time is spent.

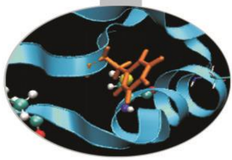
Moreover is very important to understand the graph of computation and the dependencies and correlations between the different sections of the code.

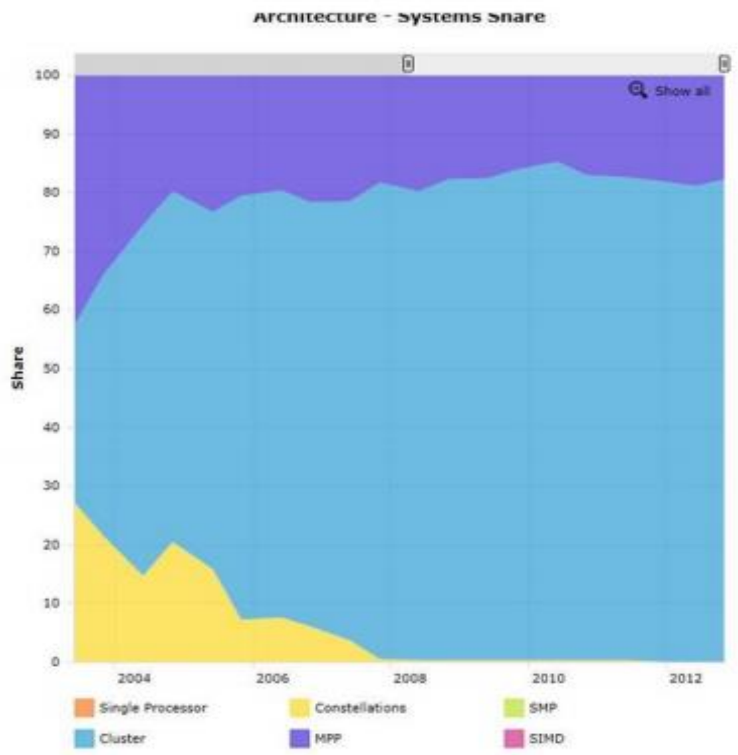
For a good scalability in **parallel programs**, it’s necessary to have a good load and communication balancing between processes.

To **discover** the **hotspots** and the **bottlenecks** of a code and find out the **best optimization and parallelization strategy** the programmer can follow two common methods:

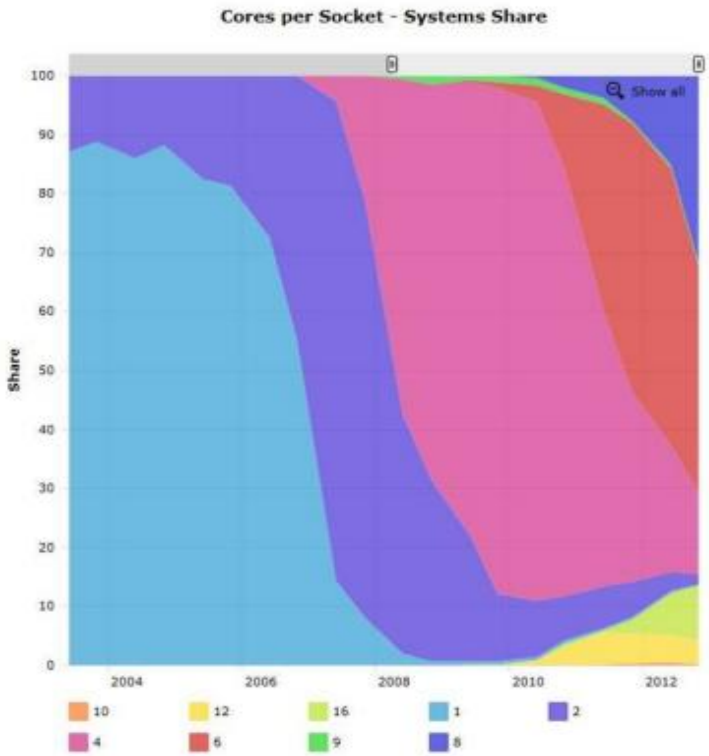
- Manual instumentation inserting timing and collecting functions (difficult)
- Automatic profiling using **profilers** (easier and very powerful)

Top 500 trend



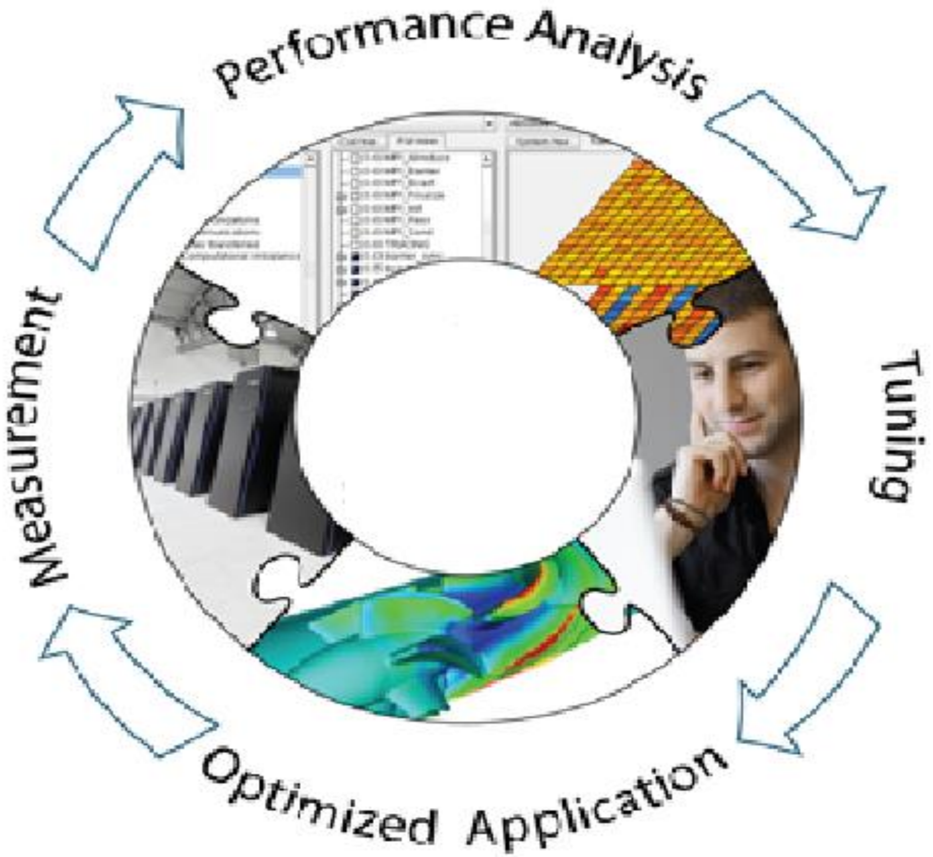


Trend delle architetture



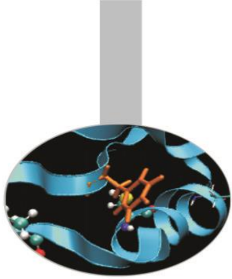
Trend dei processori

Introduction



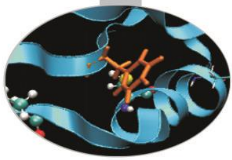
Ciclo di vita delle prestazioni

Measuring execution time



- Both C/C++ and Fortran programmers are used to instrument the code with timing and printing functions to measure and collect or visualize the time spent in critical or computationally intensive code' sections.
    - **Fortran77**
        - `etime(),dtime()`
    - **Fortran90**
        - `cputime(), system_clock(), date_and_time()`
    - **C/C++**
        - `clock()`
- In this kind of operations it must be taken into account of:
    - Intrusivity
    - Granularity
    - Relaiability
    - Overhead
- **Very difficult task for third party complex codes**

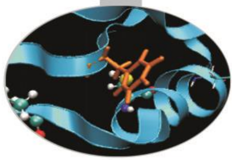
Measuring execution time



C example:

```
#include <time.h>
clock_t time1, time2;
double dub_time;
…
time1 = clock();
for (i = 0; i < nn; i++)
for (k = 0; k < nn; k++)
for (j = 0; j < nn; j ++)
c[i][j] = c[i][j] + a[i][k]*b[k][j];
time2 = clock();
dub_time = (time2 - time1)/(double) CLOCKS_PER_SEC;
printf("Time -----------------> %lf \n", dub_time);
```

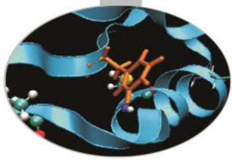
Measuring execution time



Fortran example:

```
real(my_kind), intent(out) :: t
integer :: time_array(8)
…
call date_and_time(values=time_array)
t1 =
3600.*time_array(5)+60.*time_array(6)+time_array(7)+time_array(8)/1000.
do j = 1,n
do k = 1,n
do i = 1,n
c(i,j) = c(i,j) + a(i,k)*b(k,j)
enddo
enddo
enddo
call date_and_time(values=time_array)
t2 =
3600.*time_array(5)+60.*time_array(6)+time_array(7)+time_array(8)/1000.
write(6,*) t2-t1
```

Measuring execution time



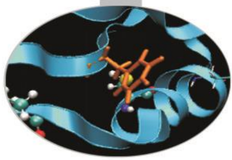
Time Command

- It is present on all Unix / Linux architectures .
- Provides the total execution time of a program and other useful information.
- It does not need the program to be compiled with special compilation options (absolutely non-intrusive).

Usage:

time <nome_eseguibile>

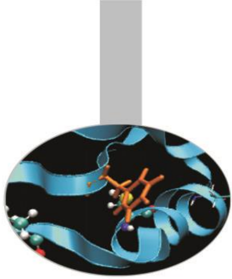
Measuring execution time



Time Command Output

- *(User time) The CPU time (in seconds) of the executable to run.*
- *(System time) The CPU time (in seconds) it takes the process system calls during the execution of program.*
- *(Elapsed time) The time (hours: minutes: seconds) actually employed ("elapsed time").*
- *The percentage of CPU used in the process.*
- *Parameters relative to the data area (overall) of the process executable (in Kbytes).*
- *Parameters related to the input / output (integers).*
- *The usage of page-faults (integers).*

Measuring execution time



Time Output Example

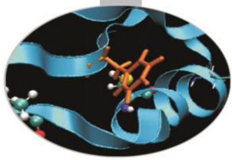
```
[lanucara@louis ~/CORSO2013]$ /usr/bin/time ./a.out<realloc.in
9.29user 6.19system 0:15.52elapsed 99%CPU (0avgtext+0avgdata 18753424maxresident)k
0inputs+0outputs (0major+78809minor)pagefaults 0swaps
```

- The "user" time is comparable with the "sys" time
- The percentage of CPU usage is nearly 100%
- There is no I / O
- There are almost no "page-faults"
- The data area (maximum) during the execution is about 18Gbytes

System code for this time is equal to User time.

This may be index of many page-faults or of an improper use of memory, and in the specific case, of many calls to the system. The program "allocate" and "deallocate" a lot of matrices: highly not recommended.

Measuring execution time



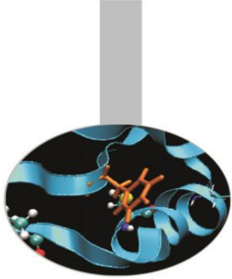
Time Output Example

By changing the structure of the program (eliminating allocations and deallocations during the execution of the program) :

```
[lanucara@louis ~/CORSO2013]$ /usr/bin/time ./a.out<realloc.in
2.28user 0.38system 0:02.67elapsed 99%CPU (0avgtext+0avgdata 9378352maxresident)k
0inputs+0outputs (0major+3153minor)pagefaults 0swaps
```

- Now correctly System time << User time .
- Time is a tool that provides useful and non-intrusive information about our code
- It is difficult, if not impossible, to extract something interesting to simulations "grand-challenge".

Profilers



- There are many versions of commercial profilers, developed by manufacturers of compilers and specialized software house. In addition there are **free profilers**, as those resulting from the GNU, TAU or Scalasca project.

Tau Performance System
- University of Oregon

Intel® VTune™ Amplifier

Scalasca
-Research Centre Juelich

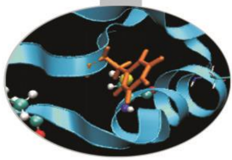
PGPROF

OPT

GNU gprof

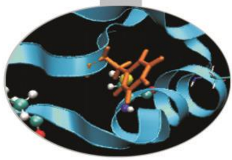
PerfSuite
– National Center for Supercomputing Applications

Profilers



- Profilers allow the programmer to obtain very useful information on the various parts of a code with basically two levels of profiling:
- **Subroutine/Function level**
  - Timing at routine/funcion level, graph of computation flow
  - less intrusive
  - Near realistic execution time
- **Construct/instruction/statement level**
  - capability to profile each instrumented statement
  - more intrusive
  - very accurate timing information
  - longer profiling execution time

GNU Profiler



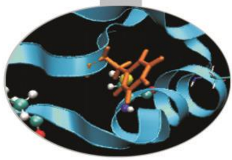
- The GNU profiler “gprof” is an open-source tool that allows profiling of serial and parallel codes.
- GNU profiler how to:
  - Recompile source code using compiler profiling flag:

```
gcc -pg source code

g++ -pg source code

gfortran -pg source code
```

  - Run the executable to allow the generation of the files containing profiling information:
    - At the end of the execution in the working directory will be generated a specific file generally named “*gmon.out*” containing all the analytic information for the profiler
  - Results analysis

```
gprof executable gmon.out
```

GNU Profiler



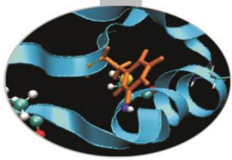
The GNU profiler “gprof” is based on the concept of "Sampling" as well as on the concept of "Instrumentation".

- The technique of "Sampling" is used by gprof to gather information relating to the "timing" of our application during its execution.
- The gprof is based on a Time Based Sampling: at intervals of time you set query to the "program counter" to locate in what point in the code the execution has arrived. The advantage is that Sampling is less intrusive

"Instrumentation" means a code to add actual instructions in the program (ie so intrusive), to gather the required information.

- It may be more invasive and therefore affect the performance of our executable.
- Regards to gprof, this technique is guided by compiler and this should ensure a good degree of efficiency. It is used by gprof for all that concerns the "function calls" in our code.

GNU Profiler

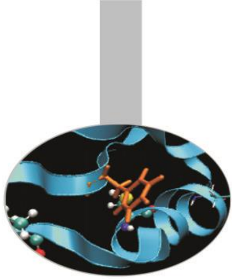


Code is automatically instrumented by the compiler when using the `-pg` flag, during the execution:

- the **number of calls** and the **execution time** of each subroutine is collected
- a call graph containing **dependences between subroutines** is implemented
- a binary file containing above information is generated (**gmon.out**)

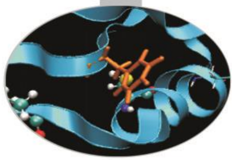
The profiler, using data contained in the file *gmon.out,* is able to give precise information about:

1. the **number of calls** of each routine
2. the **execution time** of a routine
3. the **execution time** of a routine and all the child routines called by that routine
4. a **call graph profile** containing **timing information and relations** between subroutines



Gnu Profiler

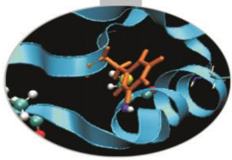
```
double add3(double x){
        return x+3;
}

double mysum(double *a, int n){
double sum=0.0;
for(int i=0;i<n;i++)
        sum+=a[i]+add3(a[i]);
return sum;
}
double init(double *a,int n){
double res;
for (int i=0;i<n;i++) a[i]=double(i);
res=mysum(a,n);
return res;
}
```



Example

```
int main(){
double res,mysum;
int n=1000;
double a[n];

for (int i=0;i<n;i++){
        res=init(a,n);
}
printf("Result %f\n",res);
return 0;
}
```

Profiler output

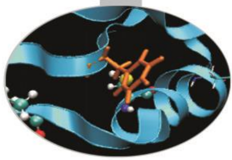


- The profiler **gprof** produces two kinds of statistical output: “**flat profile**” and “**call graph profile**”.

- According to previous example **flat profile** gives the following information:

```
Flat profile:

Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls  us/call  us/call  name
 48.60      0.41     0.41    10000    41.31    81.61  init(double*, int)
 27.26      0.64     0.23    10000    23.17    40.30  mysum(double*, int)
 20.15      0.82     0.17 100000000     0.00     0.00  add3(double)
  3.56      0.85     0.03                             frame_dummy
```

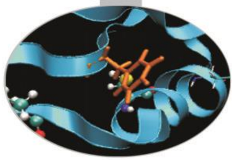
Flat profile



The meaning of the columns displayed in the **flat profile** is:

- **% time**: percentage of the total execution time your program spent in this function
- **cumulative seconds**: cumulative total number of seconds the computer spent executing this functions, plus the time spent in all the functions above this one in this table
- **self seconds**: number of seconds accounted for by this function alone.
- **calls**: total number of times the function was called
- **self us/calls**: represents the average number of microseconds spent in this function per call
- **total us/call**: represents the average number of microseconds spent in this function and its descendants per call if this function is profiled, else blank
- **name**: name of the function

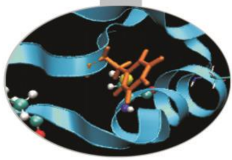
Call Graph



- **Call Graph Profile**: gives more detailed timing and calling sequence information through a dependency call graph.

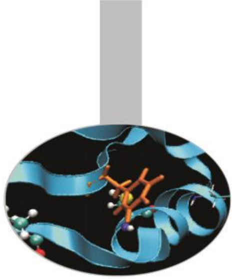
```
Call graph (explanation follows)

index % time    self  children    called      name
                                                  <spontaneous>
[1]     96.4    0.00    0.82                  main [1]
                0.41    0.40   10000/10000        init(double*, int) [2]
-----------------------------------------------
                0.41    0.40   10000/10000        main [1]
[2]     96.4    0.41    0.40   10000          init(double*, int) [2]
                0.23    0.17   10000/10000        mysum(double*, int) [3]
```

Call Graph



```
-----------------------------------------------
                0.23    0.17   10000/10000       init(double*, int)
[2]
[3]     47.6    0.23    0.17   10000           mysum(double*, int) [3]
                0.17    0.00 100000000/100000000     add3(double) [4]
-----------------------------------------------
                0.17    0.00 100000000/100000000     mysum(double*,
int) [3]
[4]     20.2    0.17    0.00 100000000           add3(double) [4]
-----------------------------------------------
                                                   <spontaneous>
[5]      3.6    0.03    0.00                   frame_dummy [5]
-----------------------------------------------
```

Line level profiling



If necessary it’s possible to profile single lines or blocks of code with the GNU profiler used together with the “*gcov*” tool to see:

– lines that are most frequently accessed

– computationally critical statements or regions

Line level profiling with gcov requires the following steps

– compile with `-fprofile-arcs -ftest-coverage`
  At the end of compilation files `*.gcno` will be produced

– Run the executable. The execution will produce `*.gcda` files

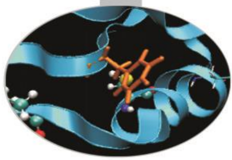
– Run `gcov:  gcov [options] sourcefiles`

– At the end of running in the working directory will be present a specific file with extension `*.gcov` which contains all the analytic information for the profiler

NOTES:

- `gcov` is compatible only with code compiled with GNU compilers
- use low level optimization flags.

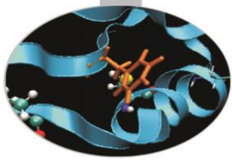
Example



C example

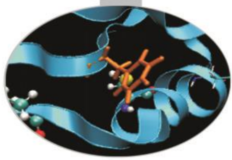
```
#include <stdlib.h>
#include <stdio.h>
 int prime (int num);
 int main()
 {
        int i,cnt=0;
    for (i=2; i <= 1000000; i++)
                if (prime(i)) {
        cnt++;
                if (cnt%9 == 0) {
                        printf("%5d\n",i);
                        cnt = 0;
                }
                else
                printf("%5d ", i);
                }
```

Example



```
putchar('\n');
        if (i<2)
    printf("OK\n");
        return 0;
 }

int prime (int num) {
 int i;
 for (i=2; i < num; i++)
        if (num %i == 0) return 0;
 return 1;
 }
```

Example



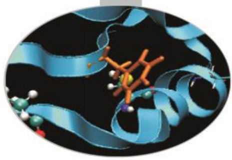
Routine level profiling produces the following information:

```
Each sample counts as 0.01 seconds.
  %   cumulative   self              self     total
 time   seconds   seconds    calls  us/call  us/call  name
100.99    109.74   109.74   999999   109.74   109.74  prime(int)
```

Granularity: each sample hit covers 2 byte(s) for 0.01% of 109.74 seconds

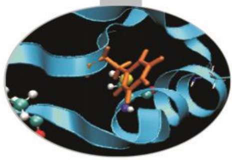
```
index % time    self  children    called     name
                                                 <spontaneous>
[1]    100.0    0.00  109.74                 main [1]
              109.74    0.00  999999/999999      prime(int) [2]
-----------------------------------------------
              109.74    0.00  999999/999999      main [1]
[2]    100.0  109.74    0.00  999999         prime(int) [2]
```

Example

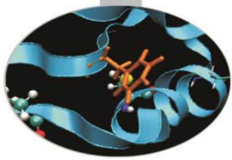


```
          -:     1:#include <stdlib.h>
      -:    2:#include <stdio.h>
      -:    3:
      -:    4:int prime (int num);
      -:    5:
      1:    6:int main()
      -:    7: {
      -:    8:        int i;
      1:    9:        int cnt = 0;
1000000:   10:        for (i=2; i <= 1000000; i++)
 999999:   11:                if (prime(i)) {
  78498:   12:                cnt++;
  78498:   13:                if (cnt%9 == 0) {
   8722:   14:                        printf("%5d\n",i);
   8722:   15:                        cnt = 0;
      -:   16:                }
      -:   17:                else
  69776:   18:                printf("%5d ", i);
```

Example



```
           -:   19:                   }
       1:   20:         putchar('\n');
       1:   21:         if (i<2)
   #####:   22:                 printf("OK\n");
       1:   23:         return 0;
       -:   24: }
       -:   25:
  999999:   26:int prime (int num) {
       -:   27: /* check to see if the number is a prime? */
       -:   28: int i;
 37567404990:   29: for (i=2; i < num; i++)
 37567326492:   30:         if (num %i == 0) return 0;
   78498:   31: return 1;
       -:   32: }
```



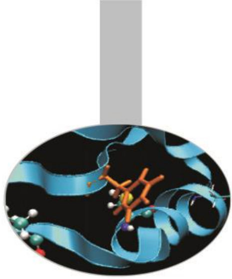
Example

Line level profiling shows that most of time is spent in the `for` loop and in the `if` construct contained in the `prime` function.

That portion of code can be written in a more efficient way.

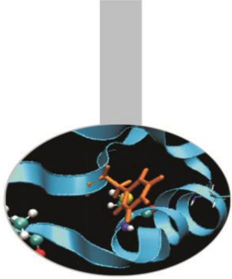
```
 int prime (int num) {
 /* check to see if the number is a prime? */
    int i;
    for (i=2; i <= faster(num); i++)
    if (num %i == 0)
        return 0;
    return 1;
 }

 int faster (int num)
 {
    return (int) sqrt( (float) num);
}
```

Example



```
     1:      7:int main(){
       -:     8: int i;
       1:     9: int colcnt = 0;
 1000000:    10: for (i=2; i <= 1000000; i++)
  999999:    11: if (prime(i)) {
   78498:    12: colcnt++;
   78498:    13: if (colcnt%9 == 0) {
    8722:    14: printf("%5d\n",i);
    8722:    15: colcnt = 0;
       -:    16: }
       -:    17: else
   69776:    18: printf("%5d ", i);
       -:    19: }
```

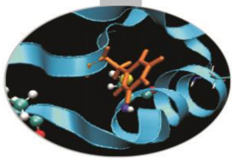
Example



```
       1:   20: putchar('\n');
        1:    21: return 0;
        -:    22: }
        -:    23:
   999999:    24: int prime (int num) {
        -:    25: int i;
 67818902:    26: for (i=2; i <= faster(num); i++)
 67740404:    27: if (num %i == 0)
   921501:    28:          return 0;
    78498:    29: return 1;
        -:    30: }
        -:    31:
 67818902:    32: int faster (int num)
        -:    33: {
 67818902:    34: return (int) sqrt( (float) num);
        -:    35: }
```

Results
0.96 sec Vs 109.67 sec
10^7 operations VS
10^10 operations

gprof execution time impact



- Routine level and above all line level profiling can cause a certain overhead in execution time:
- Travelling Salesman Problem (TSP):

```
g++ -pg -o tsp_prof tsp.cc

g++ -o tsp_no_prof tsp.cc
```

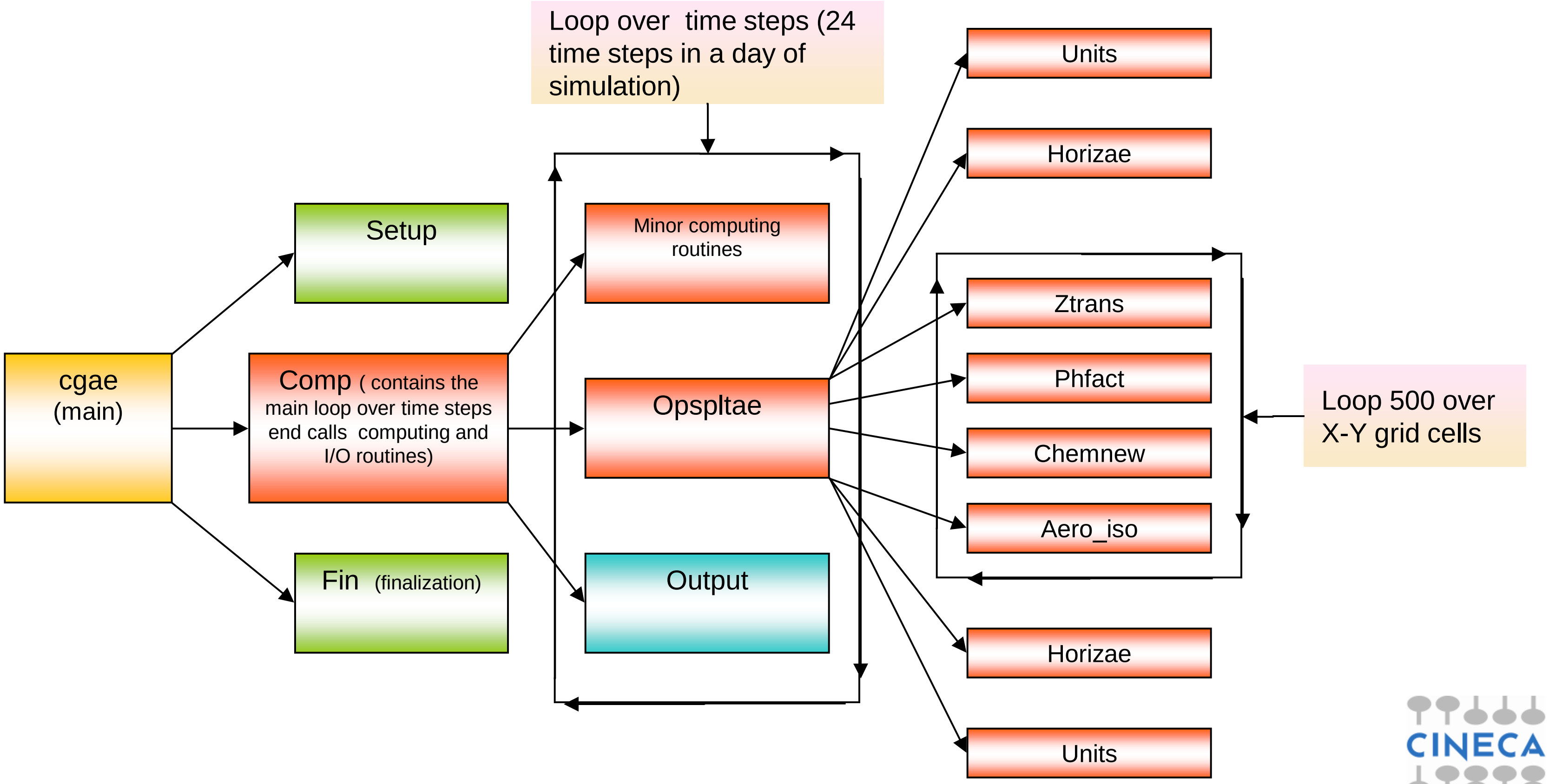
- Execution time

```
time ./TSP.noprof

10.260u 0.000s 0:10.26 100.0%



time ./TSP.prof

15.480u 0.020s 0:15.87 97.6%
```

Be careful when you have to choose input dataset and configuration for profiling

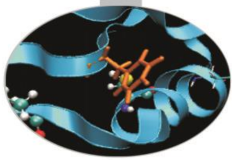
Real case Air Pollution Model

- Model structure and call graph
- Fluid dynamics equations are solved over a 3D grid

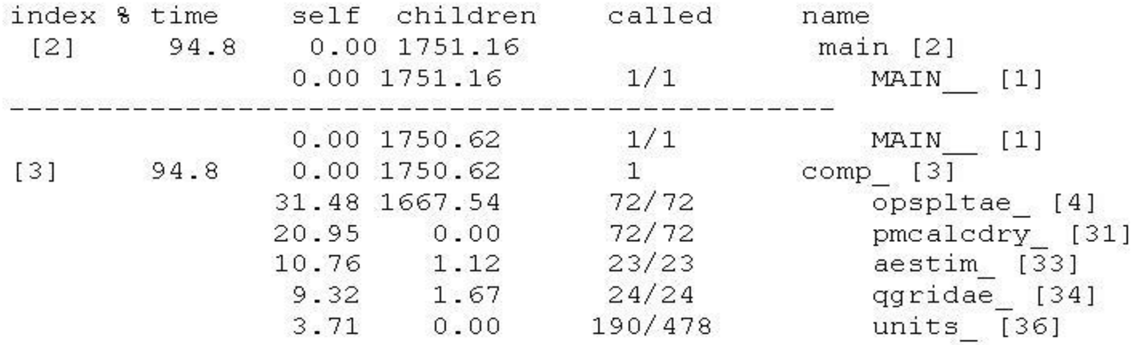


Loop over time steps (24 time steps in a day of simulation)
cgae (main)
Setup
Comp (contains the main loop over time steps end calls computing and I/O routines)
Fin (finalization)
Minor computing routines
Opspltae
Output
Units
Horizae
Ztrans
Phfact
Chemnew
Aero_iso
Horizae
Units
Loop 500 over X-Y grid cells

Real case air pollution model

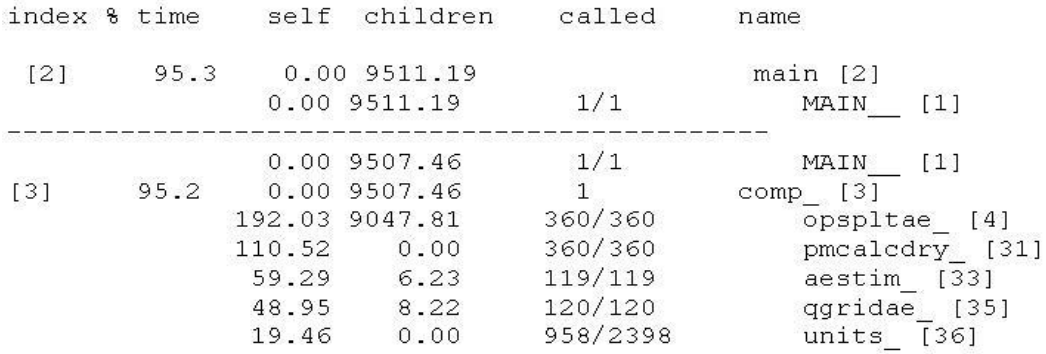


- Profiling with GNU profiler (call graph)



```
index % time    self  children    called      name
 [2]     94.8    0.00 1751.16                  main [2]
                 0.00 1751.16      1/1            MAIN__ [1]
-----------------------------------------------
                 0.00 1750.62      1/1            MAIN__ [1]
[3]     94.8     0.00 1750.62      1          comp_ [3]
                31.48 1667.54     72/72           opspltae_ [4]
                20.95    0.00     72/72           pmcalcdry_ [31]
                10.76    1.12     23/23           aestim_ [33]
                 9.32    1.67     24/24           qgridae_ [34]
                 3.71    0.00    190/478          units_ [36]
```

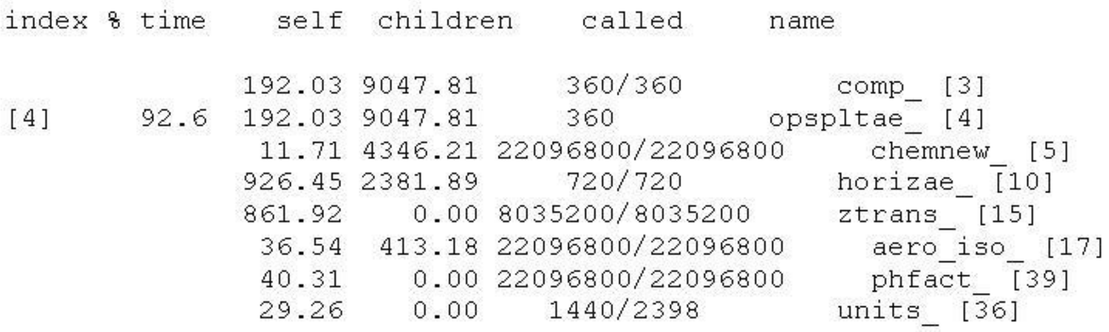
- **1 day of simulation**. Only the computationally intensive routines of the model are shown



```
index % time    self  children    called      name

 [2]     95.3    0.00 9511.19                  main [2]
                 0.00 9511.19      1/1            MAIN__ [1]
-----------------------------------------------
                 0.00 9507.46      1/1            MAIN__ [1]
[3]     95.2     0.00 9507.46      1          comp_ [3]
               192.03 9047.81    360/360          opspltae_ [4]
               110.52    0.00    360/360          pmcalcdry_ [31]
                59.29    6.23    119/119          aestim_ [33]
                48.95    8.22    120/120          qgridae_ [35]
                19.46    0.00    958/2398         units_ [36]
```

- **5 days of simulation**. Only the computationally intensive routines of the model are shown

Real case air pollution model parallelization strategy



```
index % time    self  children    called       name

                192.03 9047.81      360/360          comp_ [3]
[4]      92.6   192.03 9047.81      360          opspltae_ [4]
                 11.71 4346.21 22096800/22096800      chemnew_ [5]
                926.45 2381.89      720/720         horizae_ [10]
                861.92    0.00 8035200/8035200     ztrans_ [15]
                 36.54  413.18 22096800/22096800      aero_iso_ [17]
                 40.31    0.00 22096800/22096800      phfact_ [39]
                 29.26    0.00    1440/2398         units_ [36]
```

Dependency call graph of "`opspltae`" routine

- `Opspltae` is called every time step by "`comp`" and calls `chemnew`, `horizae`, `ztrans`, `aero_iso`, `phfact` and `units` routines. In these routines is spent 92,6% of simulation time.
- The rest of time is spent for initialization, finalization and I/O operations which are not parallelizable or which parallelization doesn't make sense for.
- Ideal speedup obtainable according to profiler output:

$$S(N) = \frac{1}{(1-P)+\frac{P}{N}} \Rightarrow S(N) = 14$$

Real Case Air Pollution Model

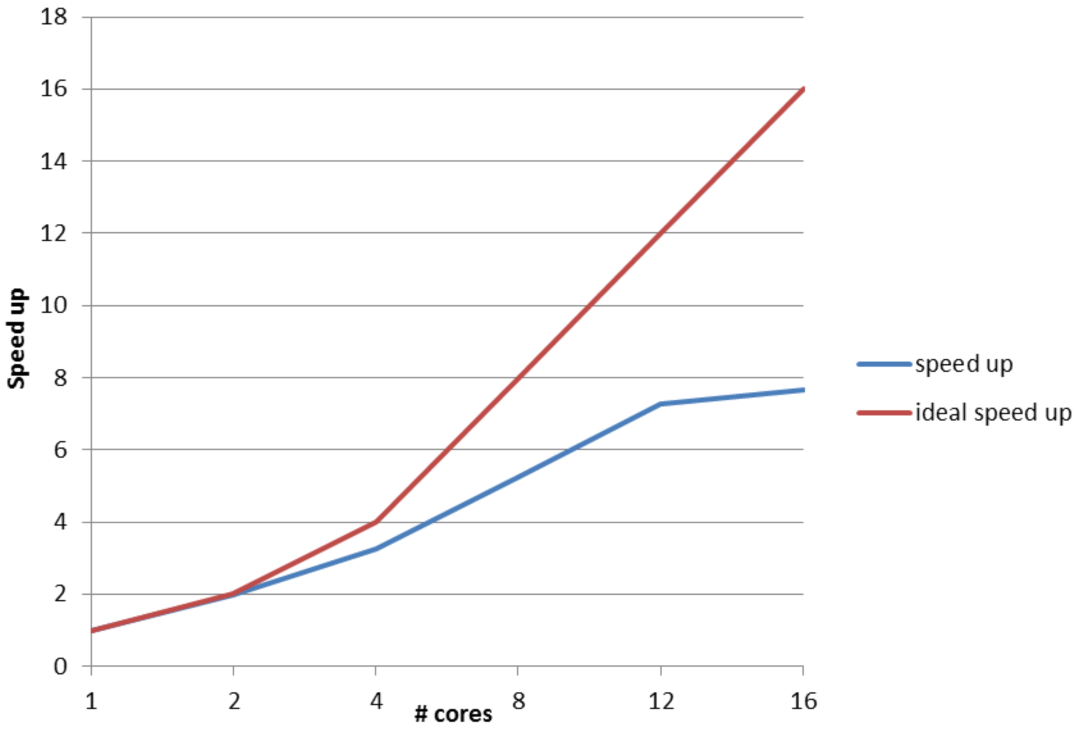
Amdahl law

Theoretical speedup

$$S(N) = \frac{1}{(1-P) + \frac{P}{N}}.$$

P=0.93 ➔ S(N)=14

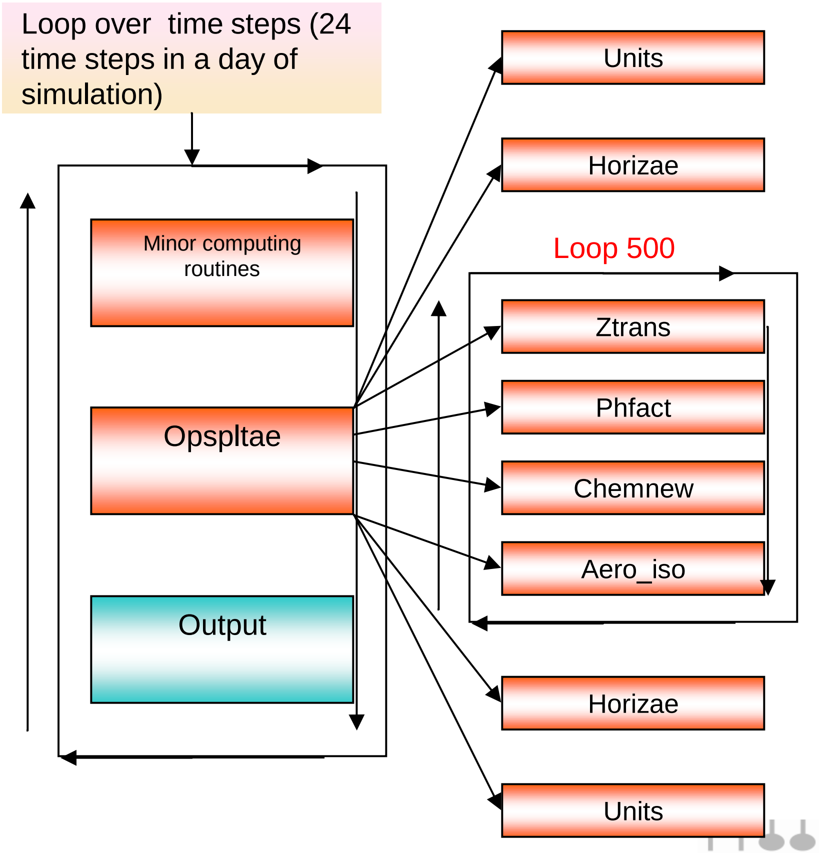
Real speedup = 7.6 ☹



Let’s check communication and load balancing !!

Real case air pollution model parallelization strategy

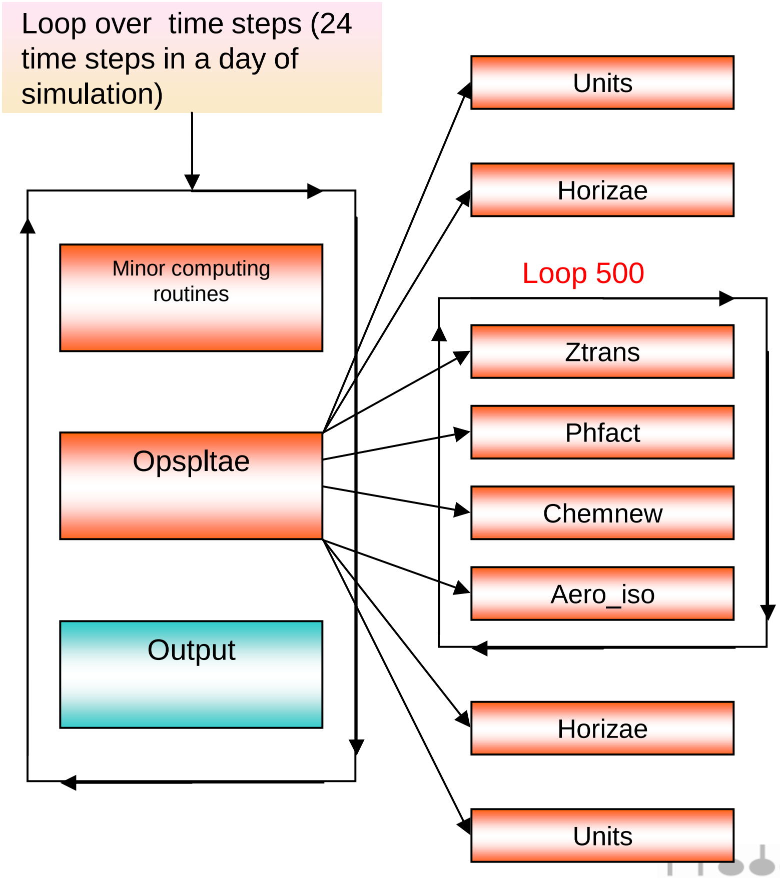
- Opspltae:
  - The most computationally intensive part of this routine is Loop 500 which contains calls to ztrans, phfact, chemnew,aero_iso routines which work on a single X,Y point of the 3D grid with no communication, so can be called in parallel by each MPI process.
  - The operations in Loop 500 are independent along X,Y direction → domain can be decomposed along X or Y.
  - At the end of the loop 500 communication is required because some matrices must be gathered by master process and broadcasted to other MPI processes.



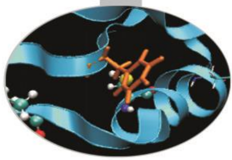
Real case air pollution model parallelization strategy

- `Horizae:`
  - This routine is responsible for the transport along X,Y directions. It’s called in `opspltae` before and after `Loop 500.` It receives in input the entire 3D grid and integrates respectively in the X and Y dimension.
  - During integration in the X dimension domain is decomposed in the Y direction and vice versa.
  - Between the two integration phases communication of some matrices is required and at the end of the routine the master must receive all the partial contributes by others MPI processes.
- Results
  - Real speedup : 7.6 ☹

Why?



Parallel codes profiling with gprof



GNU profiler can be used to profile **parallel codes** but result analysis is not straightforward .

To profile parallel codes the user must follow these steps:

- Set the environment variable GMON_OUT_PREFIX

```
export GMON_OUT_PREFIX=“profile_data_file”
```

- Compile with “–p” flag:

```
mpic++/mpicc/mpif70/mpif90 –p filenames
```

- Run the executable:

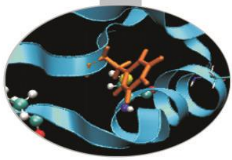
```
mpirun –np number executable
```

At the end of simulation in the working directory will be present as many profile_data_file.pid files as MPI or OpenMP processes were used.

Each profiling file must be analyzed and than results have to be matched together:

```
gprof ./executable profile_data_file.pid
```

TAU Tuning and Analysis Utilities

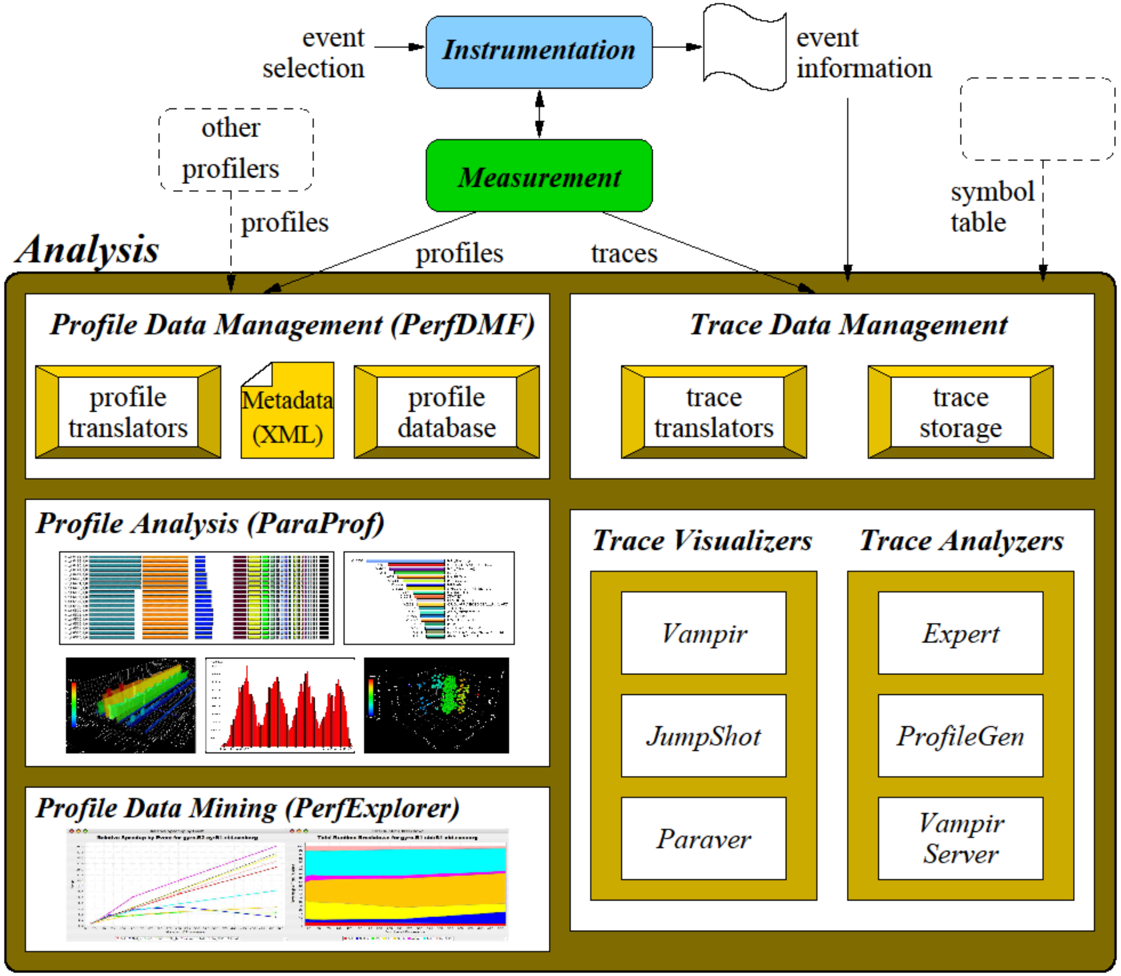


- TAU Performance System® is a portable profiling and tracing toolkit for performance analysis of serial and parallel programs written in Fortran, C, C++, Java, and Python.

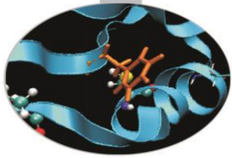
  www.cs.uoregon.edu/research/tau

- 12+ years of project in which are currently involved:
  - University of Oregon Performance Research Lab
  - LANL Advanced Computing Laboratory
  - Research Centre Julich at ZAM, Germany
- TAU (Tuning and Analysis Utilities) is capable of gathering performance information through instrumentation of functions, methods, basic blocks and statements of serial and shared or distributed memory parallel codes
- It’s portable on all architectures
- Provides powerful and user friendly graphic tools for result analysis

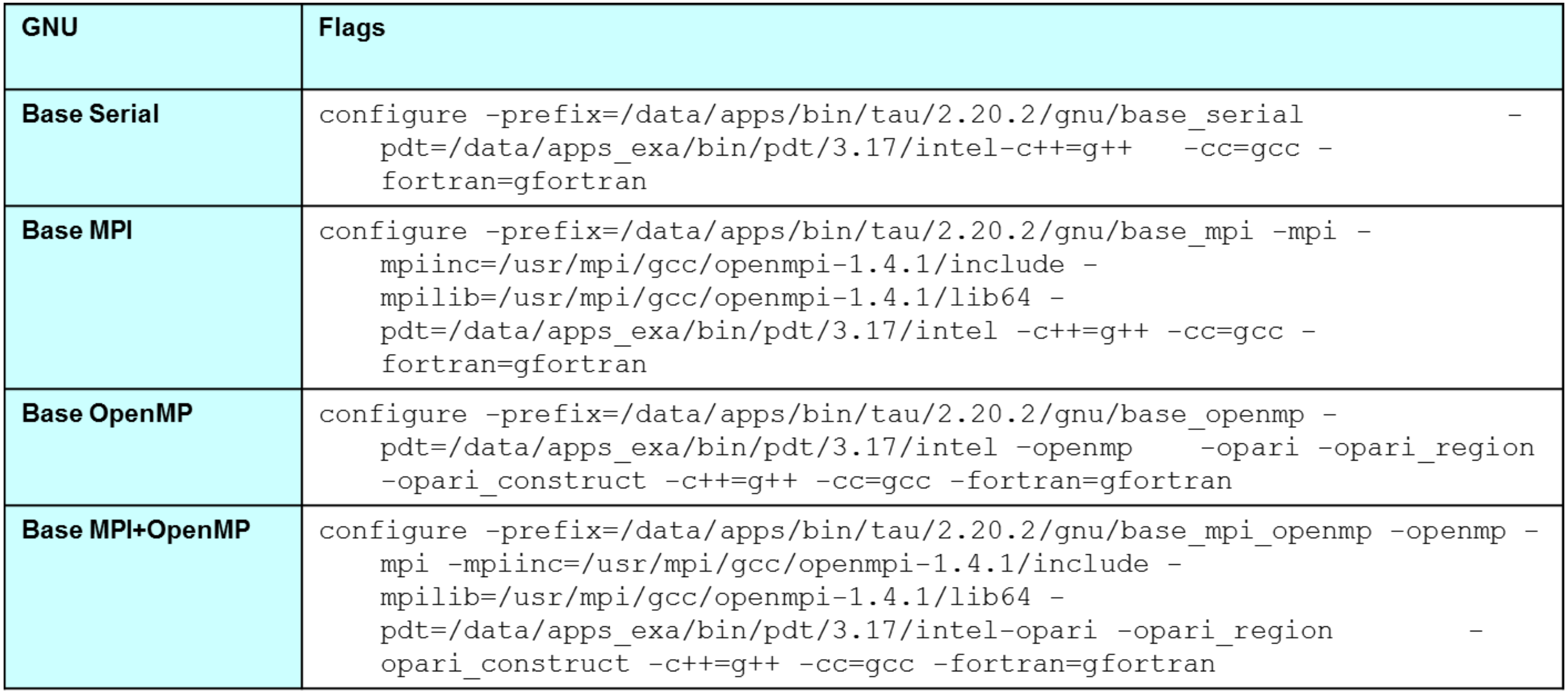
TAU: architecture



TAU Installation and configuration



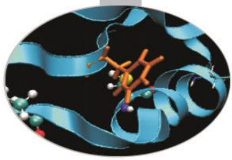
During the installation phase TAU requires different configurations flags depending on the kind of code to be analyzed.



GNU	Flags
Base Serial	`configure -prefix=/data/apps/bin/tau/2.20.2/gnu/base_serial -pdt=/data/apps_exa/bin/pdt/3.17/intel-c++=g++ -cc=gcc -fortran=gfortran`
Base MPI	`configure -prefix=/data/apps/bin/tau/2.20.2/gnu/base_mpi -mpi -mpiinc=/usr/mpi/gcc/openmpi-1.4.1/include -mpilib=/usr/mpi/gcc/openmpi-1.4.1/lib64 -pdt=/data/apps_exa/bin/pdt/3.17/intel -c++=g++ -cc=gcc -fortran=gfortran`
Base OpenMP	`configure -prefix=/data/apps/bin/tau/2.20.2/gnu/base_openmp -pdt=/data/apps_exa/bin/pdt/3.17/intel -openmp -opari -opari_region -opari_construct -c++=g++ -cc=gcc -fortran=gfortran`
Base MPI+OpenMP	`configure -prefix=/data/apps/bin/tau/2.20.2/gnu/base_mpi_openmp -openmp -mpi -mpiinc=/usr/mpi/gcc/openmpi-1.4.1/include -mpilib=/usr/mpi/gcc/openmpi-1.4.1/lib64 -pdt=/data/apps_exa/bin/pdt/3.17/intel-opari -opari_region -opari_construct -c++=g++ -cc=gcc -fortran=gfortran`

- After configuration TAU can be easily installed with:
  - make
  - make install

TAU: introduction



- TAU provides three different methods to track the performance of your application.
- The simplest way is to use TAU with dynamic instrumentation based on pre-charged libraries

Dynamic instrumentation

- **Doesn’t** requires to recompile the executable
- Instrumentation is achieved at **run-time** through library pre-loading
- Dynamic instrumentation include tracking MPI, io, memory, cuda, opencl library calls. MPI instrumentation is included by default, the others are enabled by command-line options to tau_exec.
  - Serial code

```
%> tau_exec -io ./a.out
```

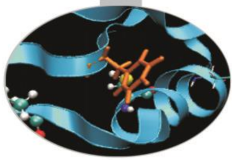
  - Parallel MPI code

```
%> mpirun -np 4 tau_exec -io ./a.out
```

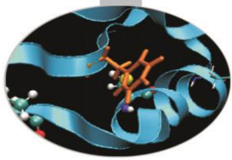
  - Parallel MPI + OpenMP code

```
%> mpirun -x OMP_NUM_THREADS=2 -np 4 tau_exec -io
./a.out
```

TAU: Compiler based instrumentation



- For more detailed profiles, TAU provides two means to compile your application with TAU: through your compiler or through source transformation using PDT.
- **It's necessary** to recompile the application, **static instrumentation** at compile time
- TAU provides these scripts to instrument and compile Fortran, C,and C++ programs respectively:
  - `tau_f90.sh`
  - `tau_cc.sh`
  - `tau_cxx.sh`
- Compiler based instrumentation needs the following steps:
  - `Environment configuration`
  - `Code recompiling`
  - `Execution`
  - `Result analysis`



TAU: Compiler based instrumentation

1. Environment configuration:

```
%>export TAU_MAKEFILE=[path to tau]/[arch]/lib/[makefile]
%>export TAU_OPTIONS=‘-optCompInst –optRevert’
```

Optional:

```
%>export PROFILEDIR = [path to directory with result]
```

2. Code recompiling:

```
%>tau_cc.sh source_code.c
```

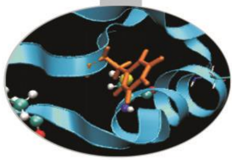
3. To enable callpath creation:

```
%>export TAU_CALLPATH=1
%>export TAU_CALLPATH_DEPTH=30
```

1. To enable MPI message statistics

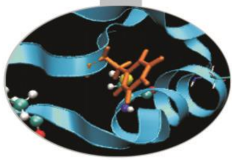
```
%>export TAU_TRACK_MESSAGE=1
```

TAU environment variables



Environment Variable	Default	Description
TAU_PROFILE	0	Set to 1 to have TAU profile your code
TAU_CALLPATH	0	When set to 1 TAU will generate call-path data. Use with TAU_CALLPATH_DEPTH.
TAU_TRACK_MEMORY_LEAKS	0	Set to 1 for tracking of memory leaks (to be used with tau_exec –memory)
TAU_TRACK_HEAP or TAU_TRACK_HEADROOM	0	Setting to 1 turns on tracking heap memory/headroom at routine entry & exit using context events (e.g., Heap at Entry: main=>foo=>bar)
TAU_CALLPATH_DEPTH	2	Callapath depth. 0 No callapath. 1 flat profile
TAU_SYNCHRONIZE_CLOCKS	1	When set TAU will correct for any time discrepancies between nodes because of their CPU clock lag.
TAU_COMM_MATRIX	0	If set to 1 generate MPI communication matrix data.
TAU_THROTTLE	1	If set to 1 enables the runtime throttling of events that are lightweight
TAU_THROTTLE_NUMCALLS	100000	Set the maximum number of calls that will be profiled for any function when TAU_THROTTLE is enabled
TAU_THROTTLE_PERCALL	10	Set the minimum inclusive time (in milliseconds) a function has to have to be instrumented when TAU_THROTTLE is enabled.

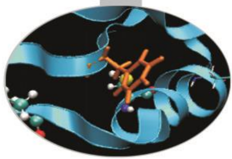
TAU_OPTIONS



- Optional parameters for TAU_OPTIONS: [tau_compiler.sh –help]

-optVerbose	Vebose debugging
-optCompInst	Compiler based instrumentation
-optNoCompInst	No Compiler based instrumentation
-optDetectMemoryLeaks	Debug memory allocations/de-allocations
-optPreProcess	Fortran preprocessing before code instrumentation

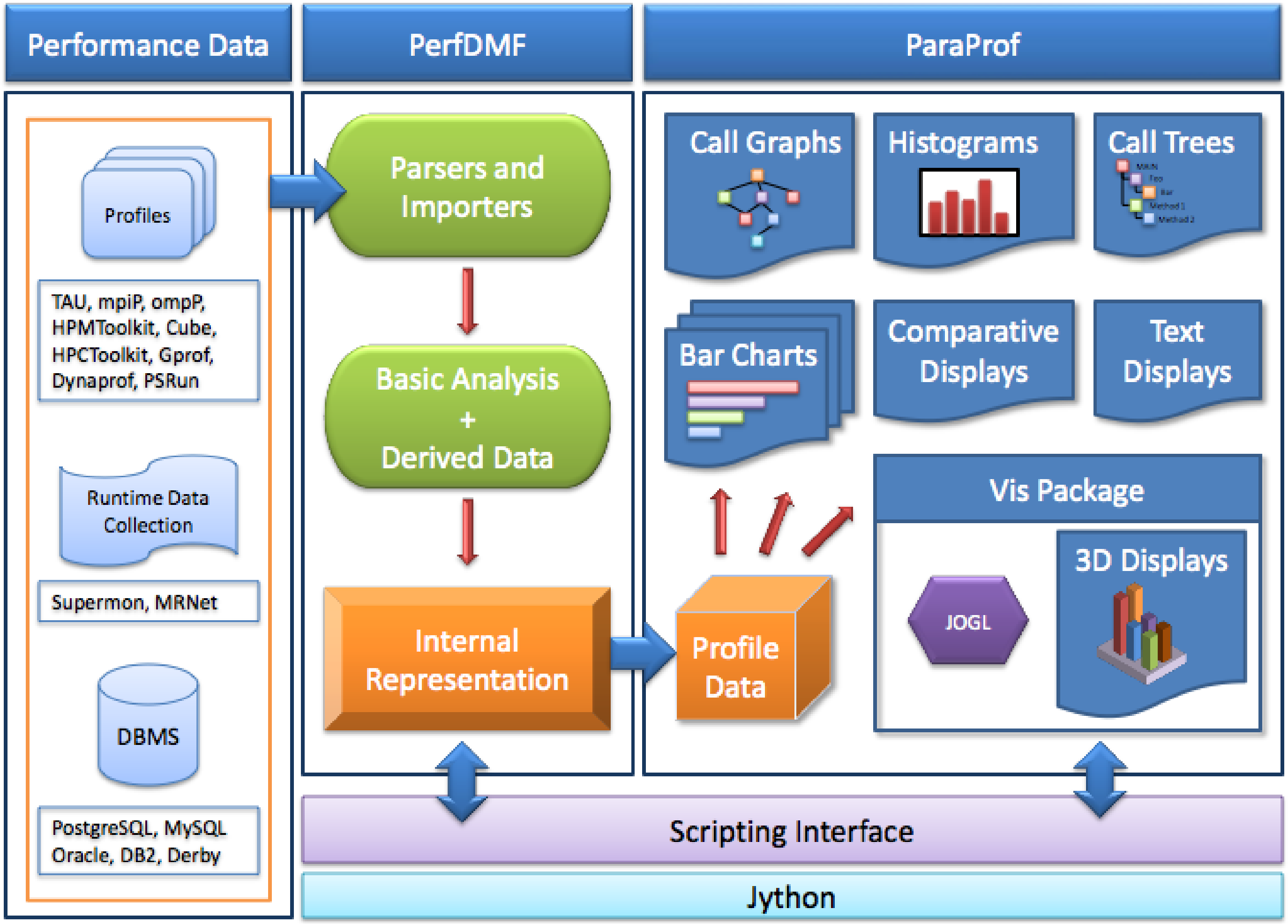
Result analysis



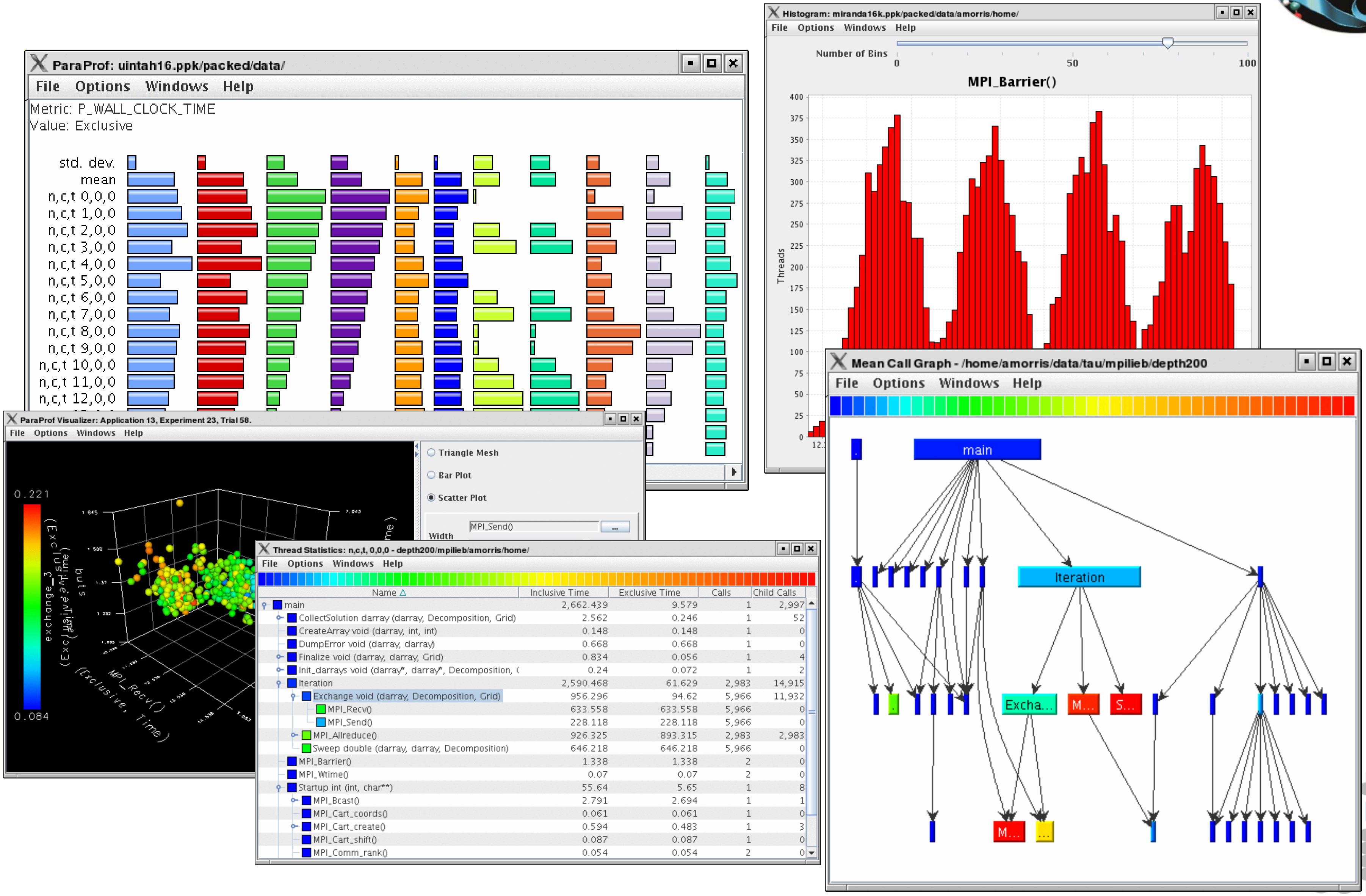
- At the end of a run, a code instrumented with TAU produces a series of files “`profile.x.x.x`” containing the profiling information.
- TAU provides two tools for profiling analysis :
  - `pprof` command line, useful for a quick view summary of TAU performance
  - `Paraprof` with a sophisticated GUI allows very detailed and powerful analysis
- **Usage:** `pprof [-c|-b|-m|-t|-e|-i|-v] [-r] [-s] [-n num] [-f filename] [-p] [-l] [-d] [node numbers]`

```
 -a : Show all location information available
-c : Sort according to number of Calls
-b : Sort according to number of suBroutines called by a function
-m : Sort according to Milliseconds (exclusive time total)
-t : Sort according to Total milliseconds (inclusive time total)  (default)
-e : Sort according to Exclusive time per call (msec/call)
-i : Sort according to Inclusive time per call (total msec/call)
-v : Sort according to Standard Deviation (excl usec)
-r : Reverse sorting order
-s : print only Summary profile information
-n <num> : print only first <num> number of functions
-f filename : specify full path and Filename without node ids
-p : suPpress conversion to hh:mm:ss:mmm format
-l : List all functions and exit
-d : Dump output format (for tau_reduce) [node numbers] : prints only info about all contexts/threads of given
   node numbers
```

Result analysis: paraprof



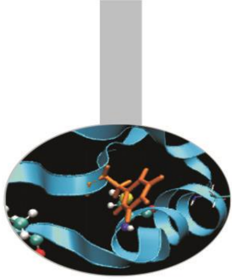
Paraprof


ParaProf: uintah16.ppk/packed/data/
File Options Windows Help
std. dev.
mean
n,c,t 0,0,0
n,c,t 1,0,0
n,c,t 2,0,0
n,c,t 3,0,0
n,c,t 4,0,0
n,c,t 5,0,0
n,c,t 6,0,0
n,c,t 7,0,0
n,c,t 8,0,0
n,c,t 9,0,0
n,c,t 10,0,0
n,c,t 11,0,0
n,c,t 12,0,0
Histogram: miranda16k.ppk/packed/data/amorris/home/
File Options Windows Help
Number of Bins
0
50
100
MPI_Barrier()
Threads
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
ParaProf Visualizer: Application 13, Experiment 23, Trial 58.
File Options Windows Help
0.221
0.084
exchange_3 (Exclusive Time)
MPI_Recv() (Exclusive, Time)
○ Triangle Mesh
○ Bar Plot
● Scatter Plot
Width
MPI_Send()
...
Mean Call Graph - /home/amorris/data/tau/mpilieb/depth200
File Options Windows Help
main
Iteration
Excha...
M...
S...
M...
...
Thread Statistics: n,c,t, 0,0,0 - depth200/mpilieb/amorris/home/
File Options Windows Help

Metric: P_WALL_CLOCK_TIME
Value: Exclusive

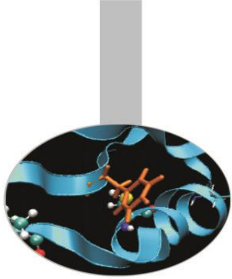
Name △	Inclusive Time	Exclusive Time	Calls	Child Calls
main	2,662.439	9.579	1	2,997
CollectSolution darray (darray, Decomposition, Grid)	2.562	0.246	1	52
CreateArray void (darray, int, int)	0.148	0.148	1	0
DumpError void (darray, darray)	0.668	0.668	1	0
Finalize void (darray, darray, Grid)	0.834	0.056	1	4
Init_darrays void (darray*, darray*, Decomposition, (	0.24	0.072	1	2
Iteration	2,590.468	61.629	2,983	14,915
Exchange void (darray, Decomposition, Grid)	956.296	94.62	5,966	11,932
MPI_Recv()	633.558	633.558	5,966	0
MPI_Send()	228.118	228.118	5,966	0
MPI_Allreduce()	926.325	893.315	2,983	2,983
Sweep double (darray, darray, Decomposition)	646.218	646.218	5,966	0
MPI_Barrier()	1.338	1.338	2	0
MPI_Wtime()	0.07	0.07	2	0
Startup int (int, char**)	55.64	5.65	1	8
MPI_Bcast()	2.791	2.694	1	1
MPI_Cart_coords()	0.061	0.061	1	0
MPI_Cart_create()	0.594	0.483	1	3
MPI_Cart_shift()	0.087	0.087	1	0
MPI_Comm_rank()	0.054	0.054	2	0

Example



```
#include<stdio.h>
double add3(double x){
        return x+3;}
double mysum(double *a, int n){
    double sum=0.0;
    for(int i=0;i<n;i++)
           sum+=a[i]+add3(a[i]);
    return sum;
}
double init(double *a,int n){
        double res;
        for (int i=0;i<n;i++) a[i]=double(i);
         res=mysum(a,n);
         return res;
}
int main(){
double res,mysum;
int n=30000;
double a[n];
for (int i=0;i<n;i++){
           res=init(a,n);
}
printf("Result %f\n",res);
return 0;}
```

Pprof



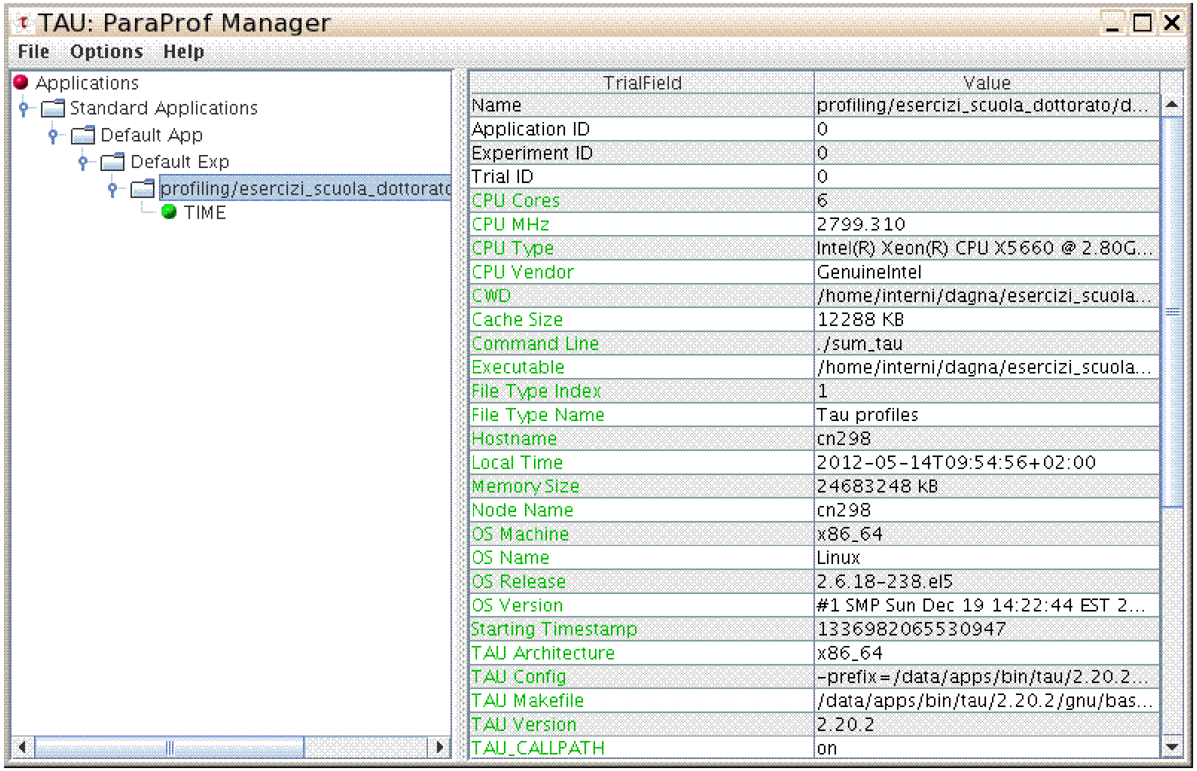
`pprof` **output:**

```
%> pprof
```

```
Reading Profile files in profile.*

NODE 0;CONTEXT 0;THREAD 0:
-------------------------------------------------------------------------------
%Time    Exclusive    Inclusive       #Call      #Subrs  Inclusive Name
              msec   total msec                          usec/call
-------------------------------------------------------------------------------
100.0            3     3:20.342           1           1  200342511 .TAU application
100.0            4     3:20.338           1       30000  200338851 main
100.0        2,344     3:20.334       30000       30000       6678 init
 98.8     1:40.824     3:17.989       30000       9E+08       6600 mysum
 48.5     1:37.164     1:37.164       9E+08           0          0 add3
```

Paraprof Manager Window

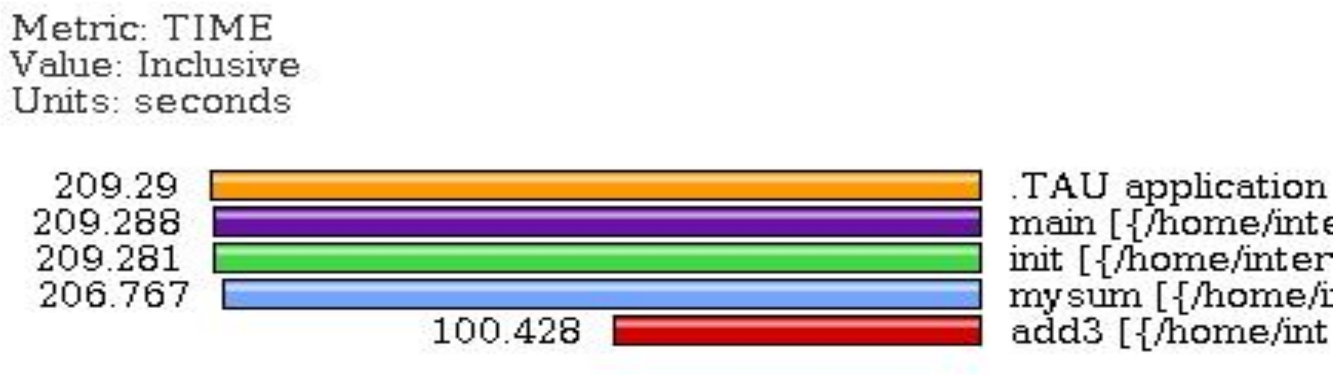
`paraprof` **output:**

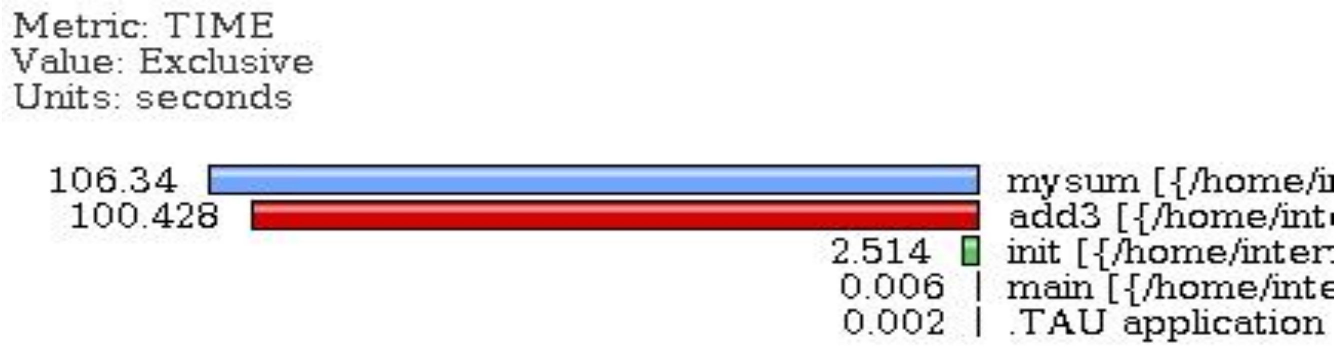


TrialField	Value
Name	profiling/esercizi_scuola_dottorato/d...
Application ID	0
Experiment ID	0
Trial ID	0
CPU Cores	6
CPU MHz	2799.310
CPU Type	Intel(R) Xeon(R) CPU X5660 @ 2.80G...
CPU Vendor	GenuineIntel
CWD	/home/interni/dagna/esercizi_scuola...
Cache Size	12288 KB
Command Line	./sum_tau
Executable	/home/interni/dagna/esercizi_scuola...
File Type Index	1
File Type Name	Tau profiles
Hostname	cn298
Local Time	2012-05-14T09:54:56+02:00
Memory Size	24683248 KB
Node Name	cn298
OS Machine	x86_64
OS Name	Linux
OS Release	2.6.18-238.el5
OS Version	#1 SMP Sun Dec 19 14:22:44 EST 2...
Starting Timestamp	1336982065530947
TAU Architecture	x86_64
TAU Config	-prefix=/data/apps/bin/tau/2.20.2...
TAU Makefile	/data/apps/bin/tau/2.20.2/gnu/bas...
TAU Version	2.20.2
TAU_CALLPATH	on

This window is used to manage profile data. The user can upload/download profile data, edit meta-data,launch visual displays, export data, derive new metrics, etc.

Thread bar chart





This display graphs each function on a particular thread for comparison. The metric, units, and sort order can be changed from the **Options** menu.

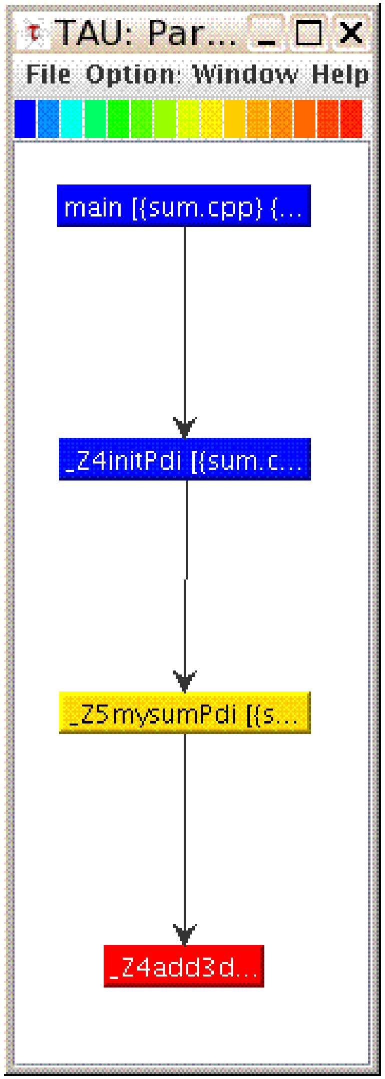
Call Graph

- This display shows callpath data in a graph using two metrics, one determines the width, the other the color.

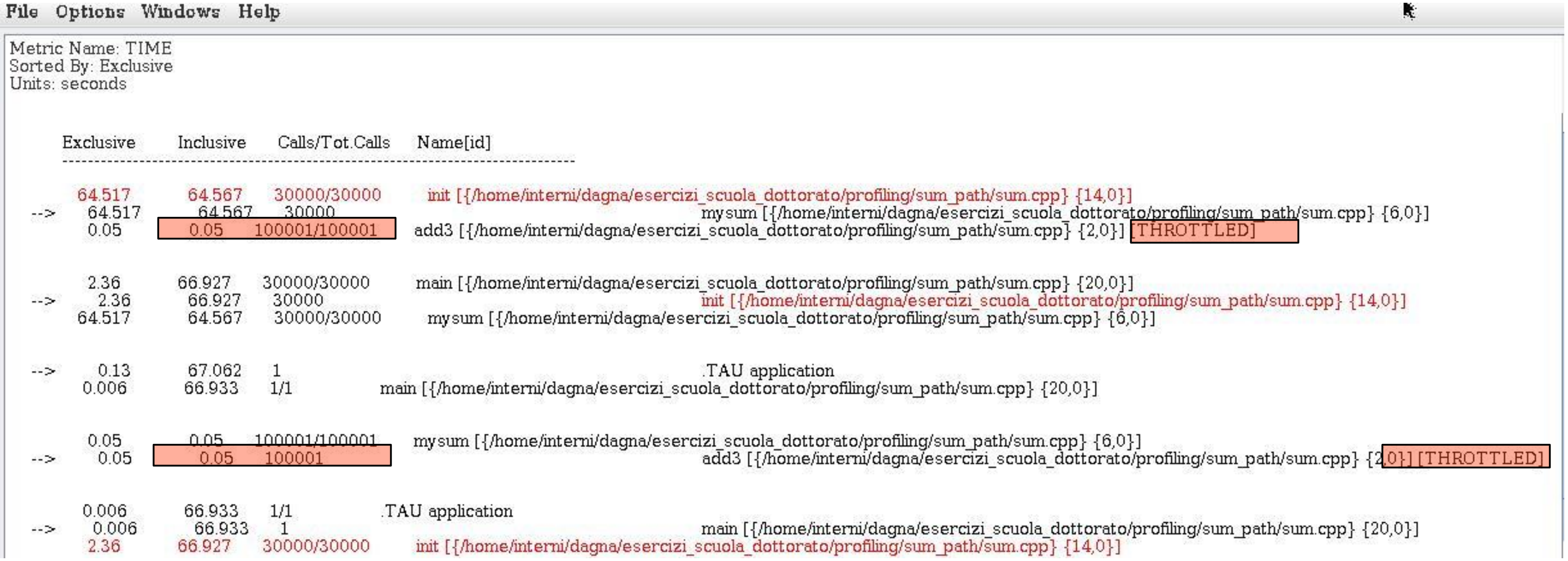
- The full name of the function as well as the two values (color and width) are displayed in a tooltip when hovering over a box.

- By clicking on a box, the actual ancestors and descendants for that function and their paths (arrows) will be highlighted with blue.

- This allows you to see which functions are called by which other functions since the interplay of multiple paths may obscure it.



Thread Call Path Relations Window



```
Metric Name: TIME
Sorted By: Exclusive
Units: seconds

     Exclusive     Inclusive    Calls/Tot.Calls    Name[id]
     --------------------------------------------------------------------

       64.517       64.567     30000/30000      init [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {14,0}]
-->     64.517       64.567     30000                              mysum [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {6,0}]
        0.05         0.05     100001/100001    add3 [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {2,0}] [THROTTLED]

        2.36       66.927     30000/30000      main [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {20,0}]
-->      2.36       66.927     30000                              init [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {14,0}]
       64.517       64.567     30000/30000      mysum [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {6,0}]

-->      0.13       67.062     1                                  .TAU application
        0.006       66.933     1/1            main [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {20,0}]

        0.05         0.05     100001/100001    mysum [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {6,0}]
-->      0.05         0.05     100001                             add3 [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {2,0}] [THROTTLED]

        0.006       66.933     1/1            .TAU application
-->      0.006       66.933     1                                  main [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {20,0}]
        2.36        66.927     30000/30000      init [{/home/interni/dagna/esercizi_scuola_dottorato/profiling/sum_path/sum.cpp} {14,0}]
```

For example “mysum” is called from “init” 30000 times for a total of 64.5 seconds and calls “add3” function.

TAU automatically throttles short running functions in an effort to reduce the amount of overhead associated with profiles of such functions, default throttle limit is:

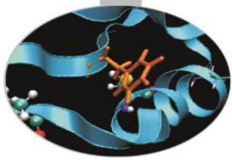
`numcalls> 100000 && usecs/call < 10`

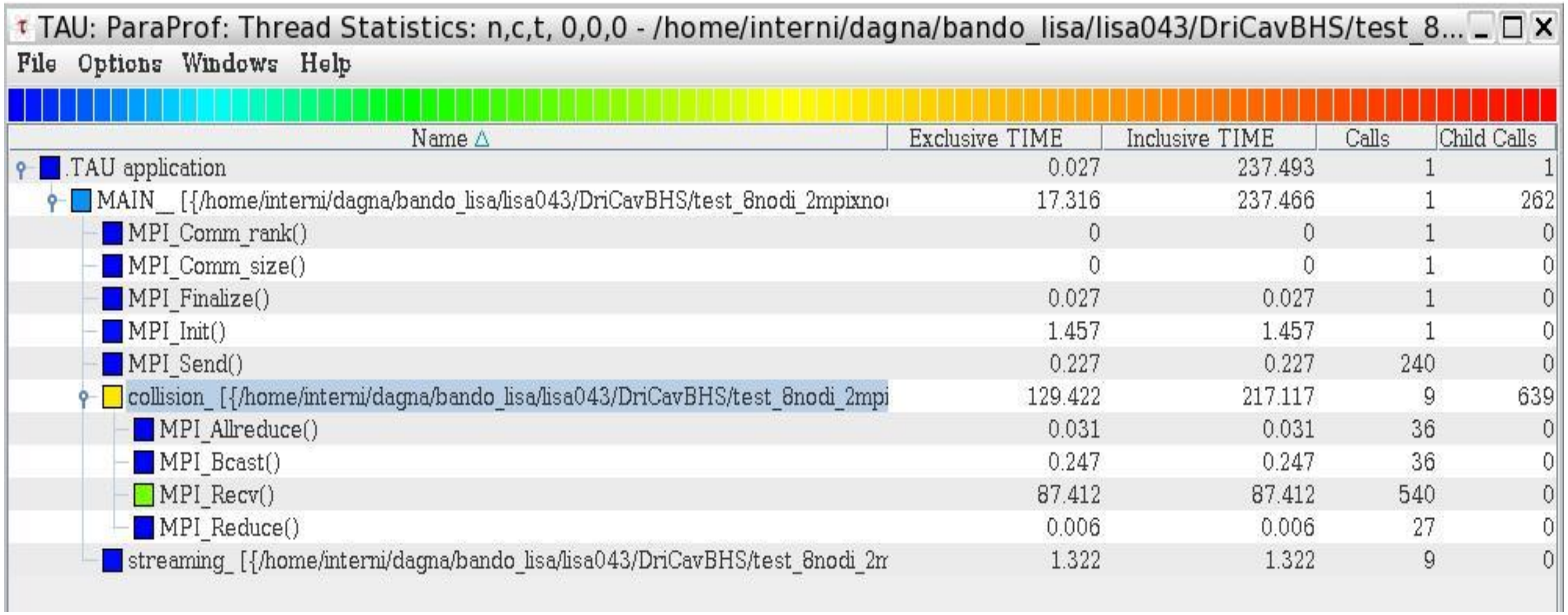
To change default settings TAU gives the following environment variables:

`TAU_THROTTLE_NUMCALLS, TAU_THROTTLE_PERCALL`

To disable TAU throttle : `export TAU_THROTTLE=0`

Thread Statistics Table





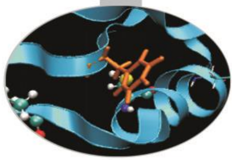
TAU: ParaProf: Thread Statistics: n,c,t, 0,0,0 - /home/interni/dagna/bando_lisa/lisa043/DriCavBHS/test_8...

Name △	Exclusive TIME	Inclusive TIME	Calls	Child Calls
🟦 .TAU application	0.027	237.493	1	1
🟦 MAIN__[{/home/interni/dagna/bando_lisa/lisa043/DriCavBHS/test_8nodi_2mpixno	17.316	237.466	1	262
🟦 MPI_Comm_rank()	0	0	1	0
🟦 MPI_Comm_size()	0	0	1	0
🟦 MPI_Finalize()	0.027	0.027	1	0
🟦 MPI_Init()	1.457	1.457	1	0
🟦 MPI_Send()	0.227	0.227	240	0
🟨 collision_[{/home/interni/dagna/bando_lisa/lisa043/DriCavBHS/test_8nodi_2mpi	129.422	217.117	9	639
🟦 MPI_Allreduce()	0.031	0.031	36	0
🟦 MPI_Bcast()	0.247	0.247	36	0
🟩 MPI_Recv()	87.412	87.412	540	0
🟦 MPI_Reduce()	0.006	0.006	27	0
🟦 streaming_[{/home/interni/dagna/bando_lisa/lisa043/DriCavBHS/test_8nodi_2m	1.322	1.322	9	0

This display shows the callpath data in a table. Each callpath can be traced from root to leaf by opening each node in the tree view.

A colorscale immediately draws attention to "hot spots" areas that contain highest values.

Tau profiler: parallel codes



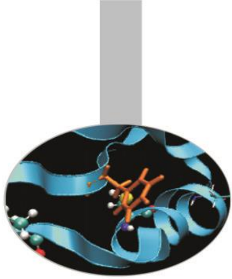
TAU provides a lot of tools to analyze OpenMP, MPI or OpenMP + MPI parallel codes.

Profiling the application the user can obtain a lot of useful information which can help to identify the causes of an unexpected low parallel efficiency.

Principal factors which can affect parallel efficiency are:

- load balancing
- communication overhead
- process synchronization
- Latency and bandwidth

Tau profiler: parallel codes



- Configure:

```
%>export TAU_MAKEFILE=[path to
   tau]/[arch]/lib/[makefile]
%>export TAU_OPTIONS=-optCompInst
```

- Compile:

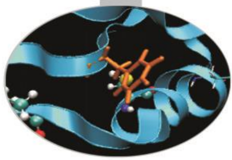
```
Tau_cc.sh –o executable source.c   (C)
Tau_cxx.sh –o executable source.cpp   (C++)
Tau_f90.sh –o executable source.f90   (Fortran)
```

- Run the application:

```
mpirun -np #procs ./executable
```

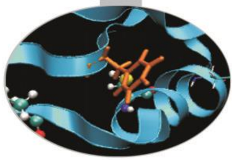
At the end of simulation, in the working directory or in the path specified with the PROFILEDIR variable, the data for the profiler will be saved in files `profile.x.x.x`

Unbalanced load



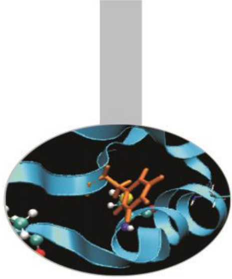
```
# include <cstdlib>
# include <iostream>
# include <iomanip>
# include <cmath>
using namespace std;
# include "mpi.h"
void compute(float * data, int start, int stop){
        for (int i=0;i<1000000;i++){
                for(int j=start;j<stop;j++){
                        data[j]=pow((double)j/(j+4),3.5);}}
}
int main ( int argc, char *argv[] )
 {
  int count;
  float data[24000];
  int dest,i,num_procs,rank,tag;
  MPI::Status status;
  float value[12000];
MPI::Init ( argc, argv );
rank = MPI::COMM_WORLD.Get_rank ( );
if ( rank == 0 )
```

Unbalanced load



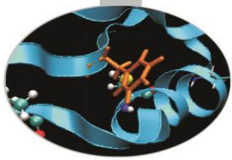
```
{
    num_procs = MPI::COMM_WORLD.Get_size ( );

    cout << "  The number of processes available is " << num_procs <<
"\n";
  }
if ( rank == 0 )
  {
    tag = 55;
    MPI::COMM_WORLD.Recv ( value,12000, MPI::FLOAT, MPI::ANY_SOURCE,
tag,
      status );

    cout << "P:" << rank << " Got data from process " <<
      status.Get_source() << "\n";
    count = status.Get_count ( MPI::FLOAT );
    cout << "P:" << rank << " Got " << count << " elements.\n";
    compute(value,0,12000);
  }
```

Unbalanced load



```
else if ( rank == 1 )
  {
    cout << "\n";
    cout << "P:" << rank << " - setting up data to send to process 0.\n";
    for ( i = 0; i <24000; i++ )
    {
      data[i] = i;
    }
    dest = 0;
    tag = 55;
    MPI::COMM_WORLD.Send ( data, 12000, MPI::FLOAT, dest, tag );
    compute(data,12000,24000);
  }else{
    cout << "\n";
    cout << "P:" << rank << " - MPI has no work for me!\n";
  }
  MPI::Finalize ( );
  if ( rank == 0 )
  {
    cout << "  Normal end of execution.\n";
  }
  return 0;
}
```

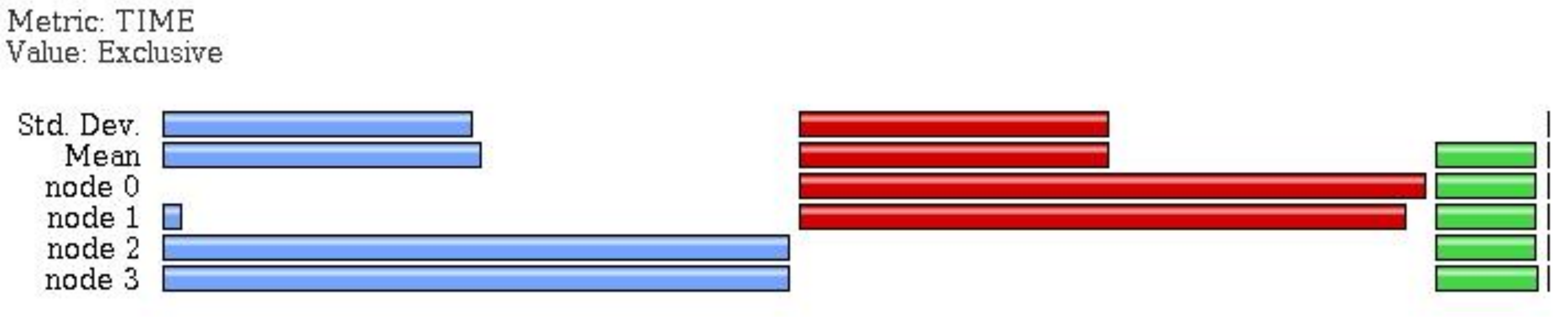
Unbalanced load



Output:

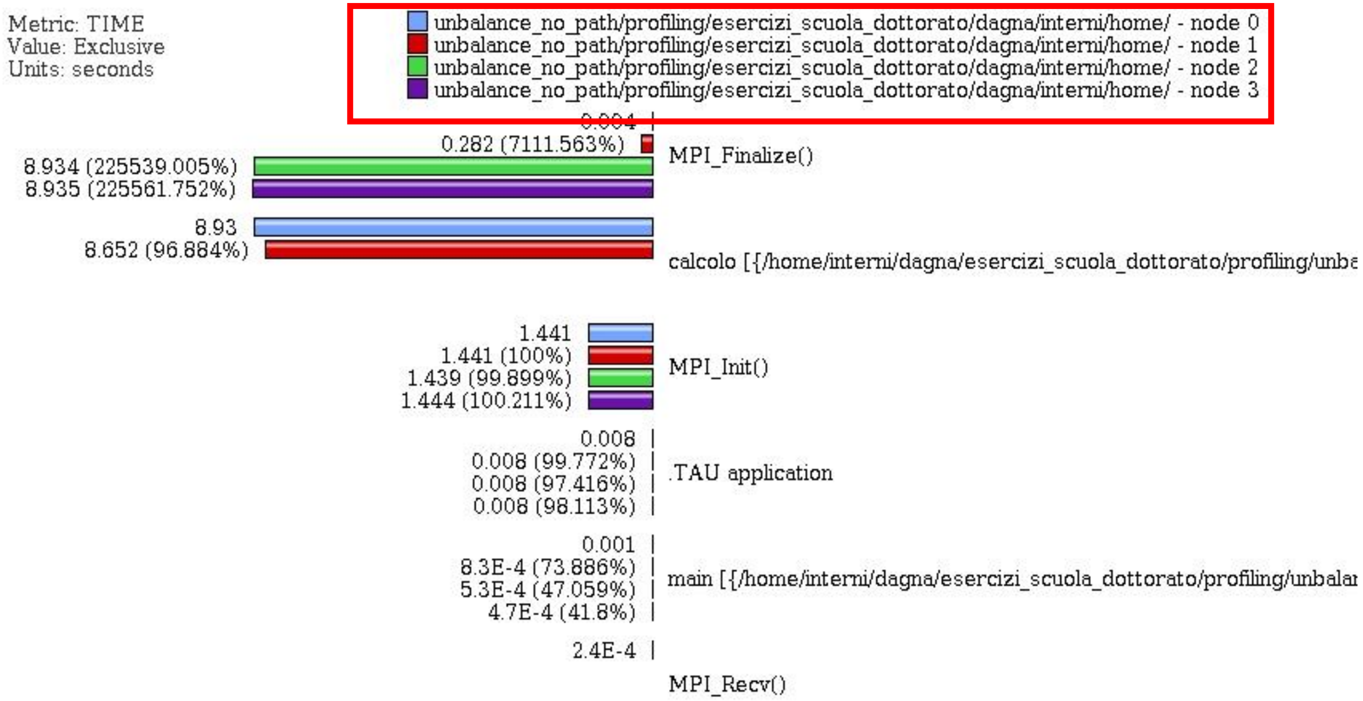
```
The number of processes available is 4
P:0 Got data from process 1
P:0 Got 12000 elements.

P:1 - setting up data to send to process 0.

P:3 - MPI has no work for me!

P:2 - MPI has no work for me!
Normal end of execution.
```

Unstacked bars



- Very useful to compare individual functions across threads in a global display

Comparison window

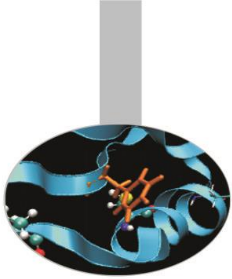


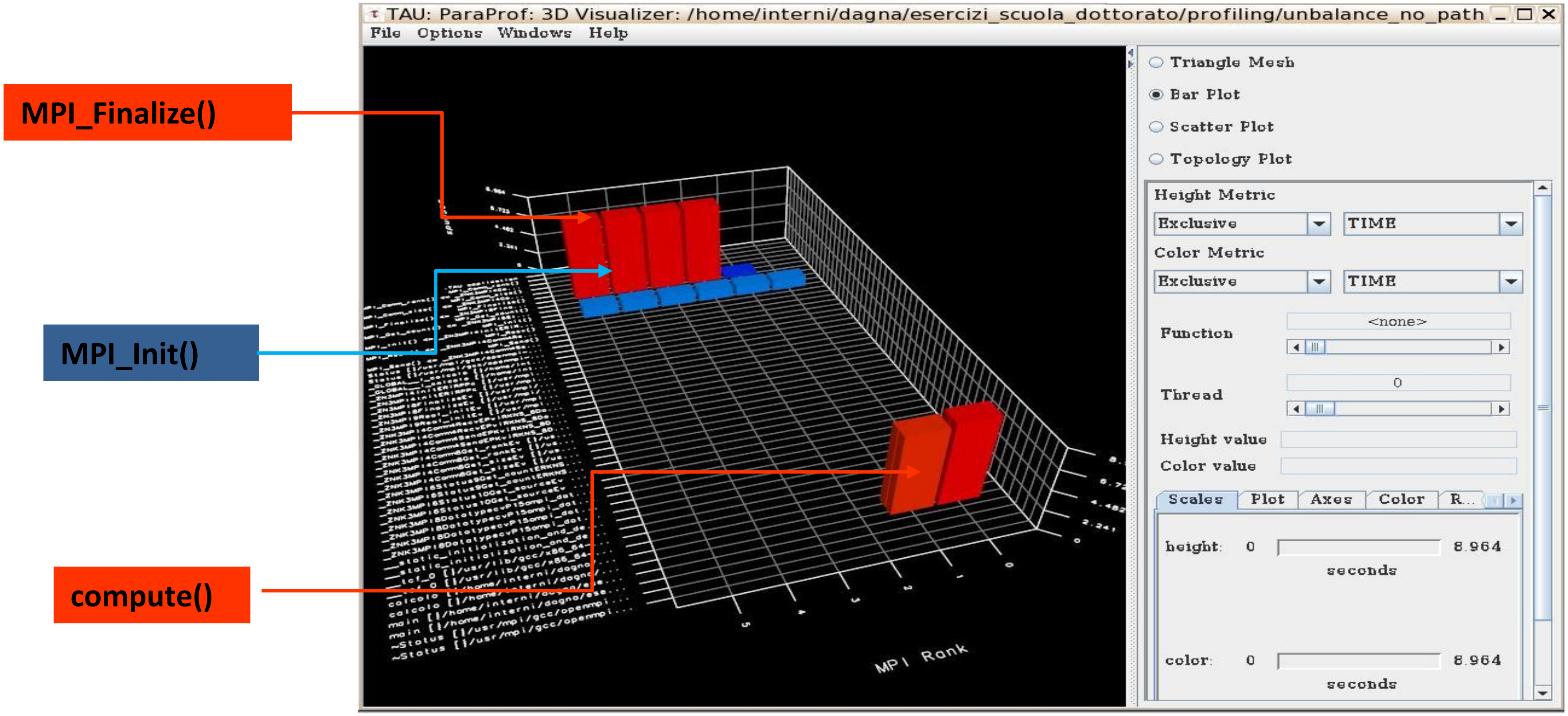
Metric: TIME
Value: Exclusive
Units: seconds

🟦 unbalance_no_path/profiling/esercizi_scuola_dottorato/dagna/interni/home/ - node 0
🟥 unbalance_no_path/profiling/esercizi_scuola_dottorato/dagna/interni/home/ - node 1
🟩 unbalance_no_path/profiling/esercizi_scuola_dottorato/dagna/interni/home/ - node 2
🟪 unbalance_no_path/profiling/esercizi_scuola_dottorato/dagna/interni/home/ - node 3

- Very useful to compare the behavior of process and threads in all the functions or regions of the code to find load unbalances.

3D Visualizer





MPI_Finalize()

MPI_Init()

compute()

TAU: ParaProf: 3D Visualizer: /home/interni/dagna/esercizi_scuola_dottorato/profiling/unbalance_no_path

○ Triangle Mesh
● Bar Plot
○ Scatter Plot
○ Topology Plot

Height Metric: Exclusive, TIME

Color Metric: Exclusive, TIME

Function: <none>

Thread: 0

Height value:

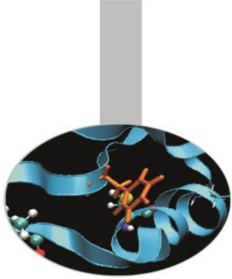
Color value:

height: 0 8.964 seconds

color: 0 8.964 seconds

- This visualization method shows two metrics for all functions, all threads. The height represents one chosen metric, and the color, another. These are selected from the drop-down boxes on the right.
- To pinpoint a specific value in the plot, move the *Function* and *Thread* sliders to cycle through the available functions/threads.

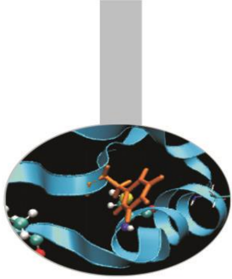
Balanced load



Balancing the load:

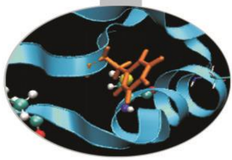
```
int main ( int argc, char *argv[] )
{
MPI::Init ( argc, argv );
rank = MPI::COMM_WORLD.Get_rank ( );
float data[24000];
  if ( rank == 0 )
  {
    num_procs = MPI::COMM_WORLD.Get_size ( );
    cout << "  The number of processes available is " << num_procs << "\n";
  }
  int subd = 24000/num_procs
  if ( rank!= 0)
  {
    tag = 55;
    MPI::COMM_WORLD.Recv ( data,subd, MPI::FLOAT, MPI::ANY_SOURCE, tag, status );
    cout << "P:" << rank << " Got data from process " <<
      status.Get_source() << "\n";
    count = status.Get_count ( MPI::FLOAT );
    cout << "P:" << rank << " Got " << count << " elements.\n";
    compute(data,rank*subd,rank*subd+subd);
    printf("Done\n");
  }
```

Balanced load



```
else if ( rank == 0 )
  {
    cout << "\n";
    cout << "P:" << rank << " - setting up data to send to processes.\n";
    for ( i = 0; i <24000; i++ )
    {
      data[i] = i;
    }
    tag = 55;
    printf("Done\n");
    for(int el=1;el<num_procs;el++){
        MPI::COMM_WORLD.Send ( &data[subd*el], subd, MPI::FLOAT, el, tag );
        }
    compute(data,0,subd);
  }
  MPI::Finalize ( );
  if ( rank == 0 )
  {
    cout << "  Normal end of execution.\n";
  }
  return 0;
}
```

Balanced load



- Output:

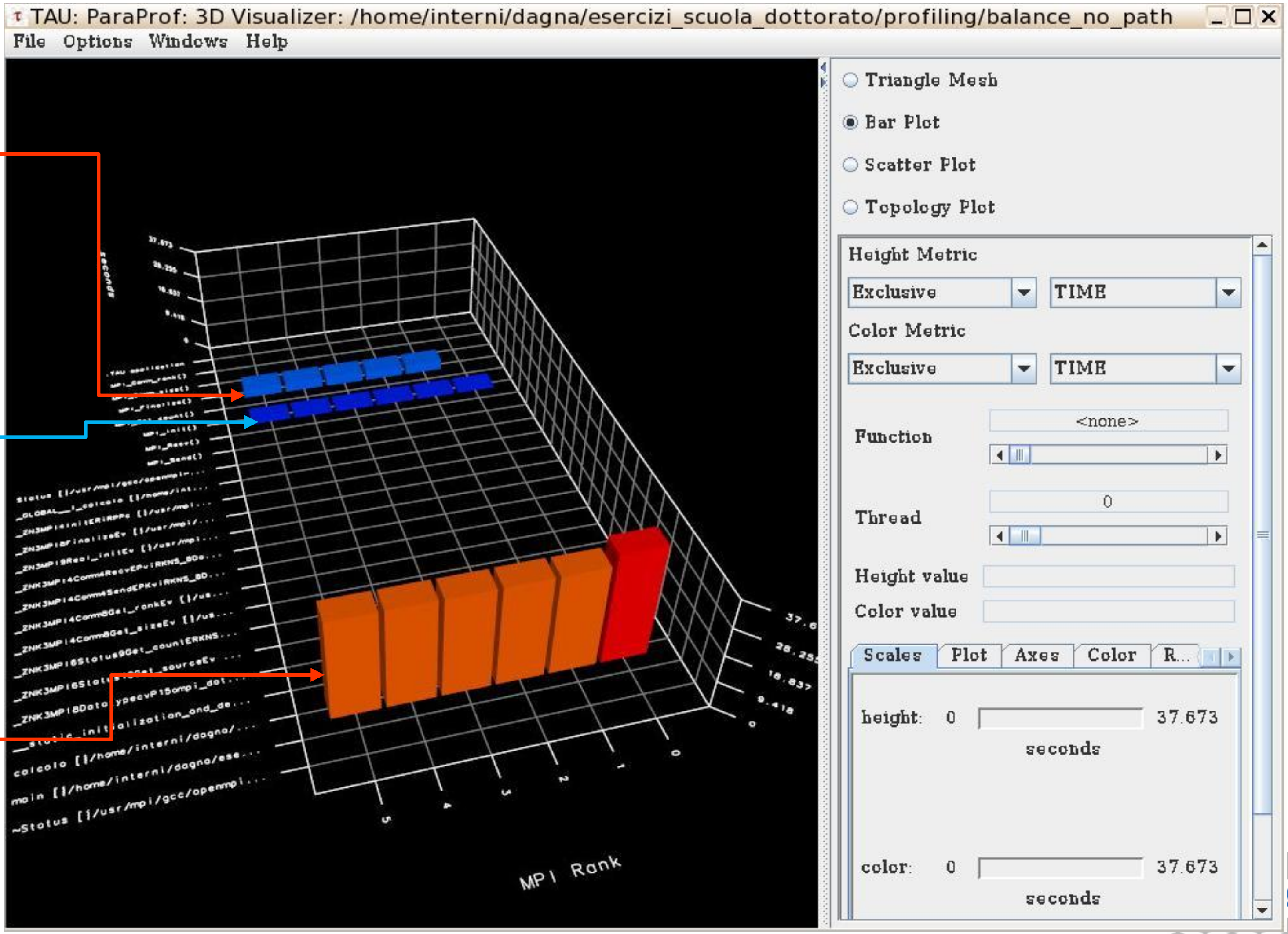
```
 The number of processes available is 6
P:0 - setting up data to send to processes.
Done
P:5 Got data from process 0
P:5 Got 4000 elements.
P:1 Got data from process 0
P:1 Got 4000 elements.
P:2 Got data from process 0
P:2 Got 4000 elements.
P:3 Got data from process 0
P:3 Got 4000 elements.
P:4 Got data from process 0
P:4 Got 4000 elements.
Done
Done
Done
Done
Done
Normal end of execution.
```

Balanced load

MPI_Finalize()

MPI_Init()

compute()



TAU: ParaProf: 3D Visualizer: /home/interni/dagna/esercizi_scuola_dottorato/profiling/balance_no_path

○ Triangle Mesh

● Bar Plot

○ Scatter Plot

○ Topology Plot

Height Metric: Exclusive, TIME

Color Metric: Exclusive, TIME

Function: <none>

Thread: 0

Height value:

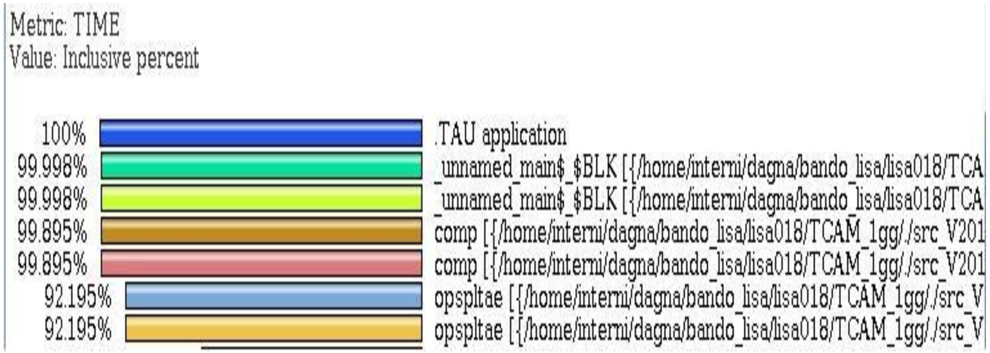
Color value:

height: 0 – 37.673 seconds

color: 0 – 37.673 seconds

File
Options
Windows
Help
Scales
Plot
Axes
Color
R...
seconds
37.673
28.255
18.837
9.418
0
.TAU application
MPI_Comm_rank()
MPI_Comm_size()
MPI_Finalize()
MPI_Get_count()
MPI_Init()
MPI_Recv()
MPI_Send()
Status [{/usr/mpi/gcc/openmpi-...
_GLOBAL__I_calcolo [{/home/int...
_ZN3MPI4InitERiRPPc [{/usr/mpi...
_ZN3MPI8FinalizeEv [{/usr/mpi/...
_ZN3MPI9Real_initEv [{/usr/mpi...
_ZNK3MPI4Comm4RecvEPviRKNS_8Da...
_ZNK3MPI4Comm4SendEPKviRKNS_8D...
_ZNK3MPI4Comm8Get_rankEv [{/us...
_ZNK3MPI4Comm8Get_sizeEv [{/us...
_ZNK3MPI6Status9Get_countERKNS...
_ZNK3MPI6Status10Get_sourceEv ...
_ZNK3MPI8DatatypecvP15ompi_dat...
__static_initialization_and_de...
calcolo [{/home/interni/dagna/...
main [{/home/interni/dagna/ese...
~Status [{/usr/mpi/gcc/openmpi...
37.6
28.25
18.837
9.418
0
0
1
2
3
4
5
MPI Rank

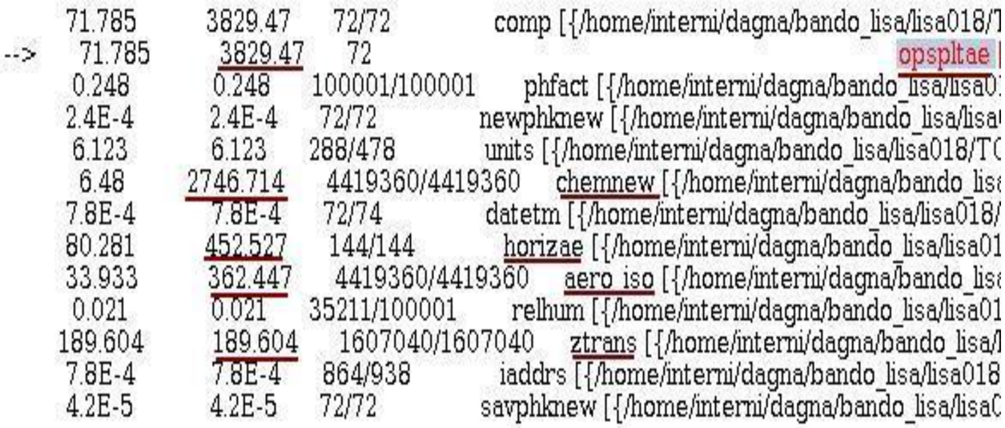
Real Case Air Pollution Model



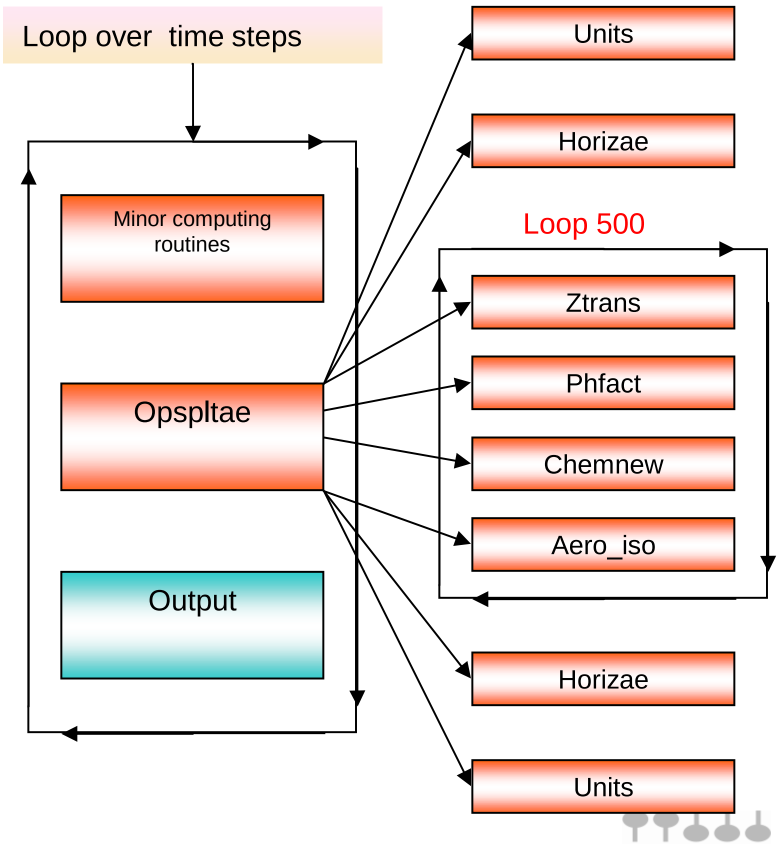
```
Metric: TIME
Value: Inclusive percent

 100%     TAU application
 99.998%  _unnamed_main$_$BLK [{/home/interni/dagna/bando_lisa/lisa018/TCA
 99.998%  _unnamed_main$_$BLK [{/home/interni/dagna/bando_lisa/lisa018/TCA
 99.895%  comp [{/home/interni/dagna/bando_lisa/lisa018/TCAM_1gg/./src_V201
 99.895%  comp [{/home/interni/dagna/bando_lisa/lisa018/TCAM_1gg/./src_V201
 92.195%  opspltae [{/home/interni/dagna/bando_lisa/lisa018/TCAM_1gg/./src_V
 92.195%  opspltae [{/home/interni/dagna/bando_lisa/lisa018/TCAM_1gg/./src_V
```

Metric: TIME
Sorted By: Exclusive
Units: seconds

Exclusive Inclusive Calls/Tot.Calls



```
     71.785     3829.47    72/72                comp [{/home/interni/dagna/bando_lisa/lisa018/T
-->   71.785     3829.47    72                                                        opspltae [
      0.248     0.248     100001/100001       phfact [{/home/interni/dagna/bando_lisa/lisa0
     2.4E-4     2.4E-4     72/72              newphknew [{/home/interni/dagna/bando_lisa/lisa
      6.123     6.123     288/478             units [{/home/interni/dagna/bando_lisa/lisa018/TC
       6.48    2746.714    4419360/4419360     chemnew [{/home/interni/dagna/bando_lisa
     7.8E-4     7.8E-4     72/74              datetm [{/home/interni/dagna/bando_lisa/lisa018/
     80.281     452.527    144/144             horizae [{/home/interni/dagna/bando_lisa/lisa01
     33.933     362.447    4419360/4419360     aero_iso [{/home/interni/dagna/bando_lisa
      0.021     0.021     35211/100001        relhum [{/home/interni/dagna/bando_lisa/lisa01
    189.604     189.604    1607040/1607040     ztrans [{/home/interni/dagna/bando_lisa/l
     7.8E-4     7.8E-4     864/938             iaddrs [{/home/interni/dagna/bando_lisa/lisa018
     4.2E-5     4.2E-5     72/72              savphknew [{/home/interni/dagna/bando_lisa/lisa0
```



Real Case Air Pollution Model

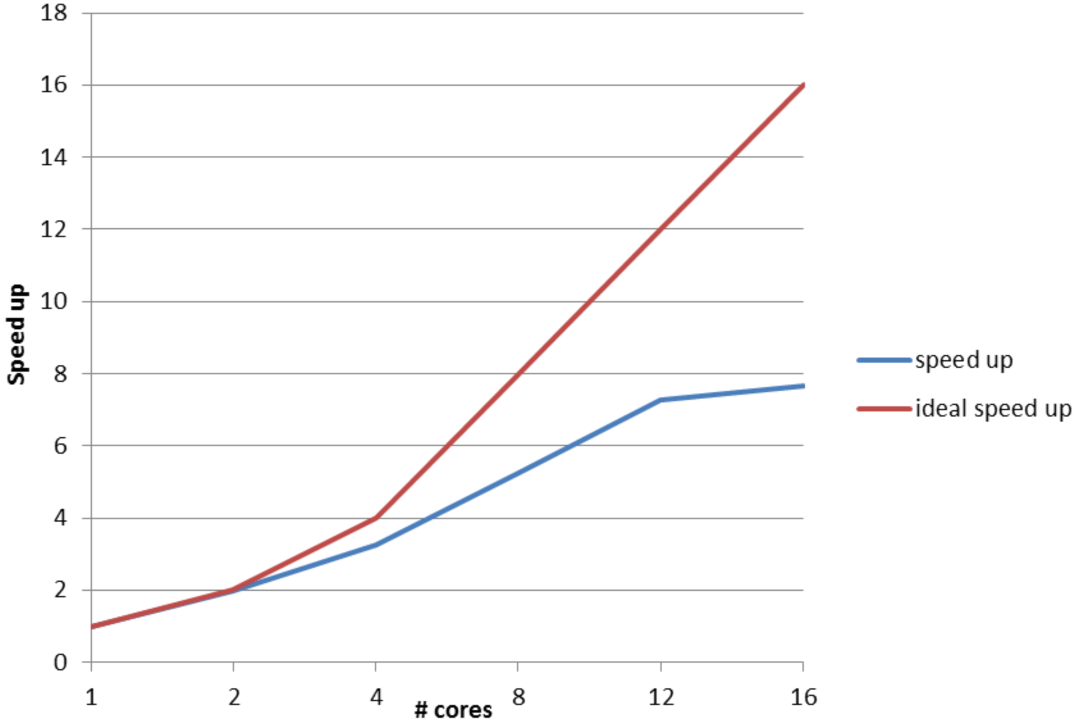
Amdahl law

Theoretical speedup

$$S(N) = \frac{1}{(1-P) + \frac{P}{N}}.$$

P=0.93 ➔ S(N)=14

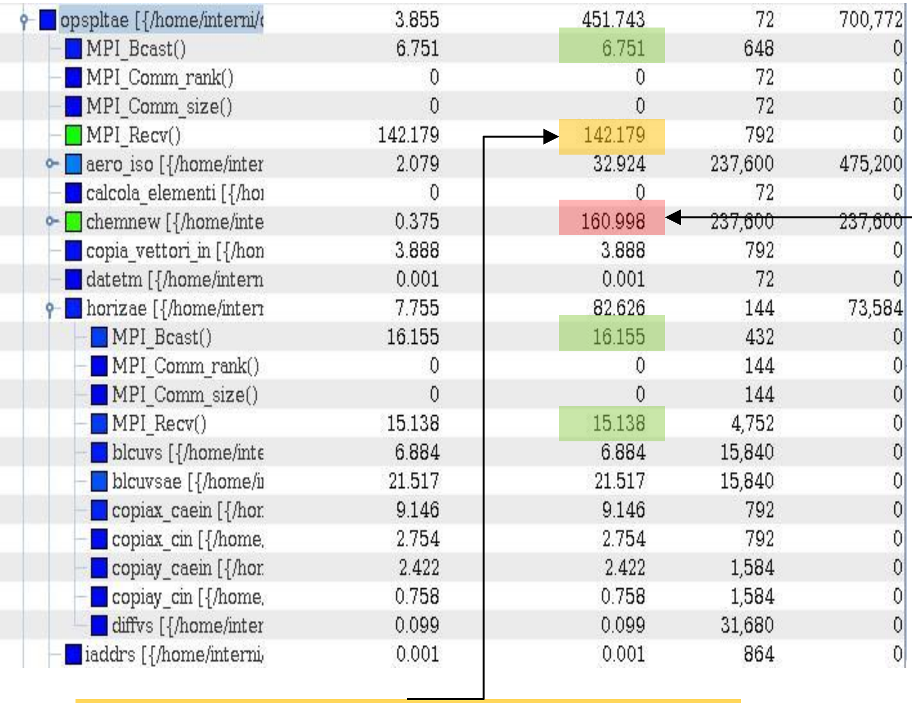
Real speedup = 7.6 ☹



Let’s check communication and load balancing !!

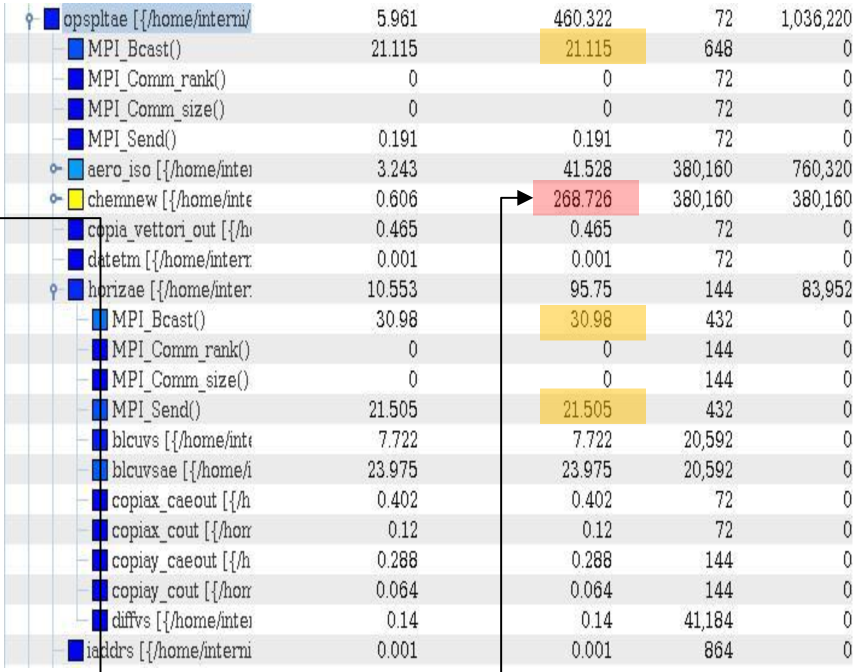
Real Case Air Pollution Model

Master process



opspltae [{/home/interni/	3.855	451.743	72	700,772
MPI_Bcast()	6.751	6.751	648	0
MPI_Comm_rank()	0	0	72	0
MPI_Comm_size()	0	0	72	0
MPI_Recv()	142.179	142.179	792	0
aero_iso [{/home/inter	2.079	32.924	237,600	475,200
calcola_elementi [{/hoi	0	0	72	0
chemnew [{/home/inte	0.375	160.998	237,600	237,600
copia_vettori_in [{/hon	3.888	3.888	792	0
datetm [{/home/intern	0.001	0.001	72	0
horizae [{/home/interi	7.755	82.626	144	73,584
MPI_Bcast()	16.155	16.155	432	0
MPI_Comm_rank()	0	0	144	0
MPI_Comm_size()	0	0	144	0
MPI_Recv()	15.138	15.138	4,752	0
blcuvs [{/home/inte	6.884	6.884	15,840	0
blcuvsae [{/home/ii	21.517	21.517	15,840	0
copiax_caein [{/hor	9.146	9.146	792	0
copiax_cin [{/home,	2.754	2.754	792	0
copiay_caein [{/hor	2.422	2.422	1,584	0
copiay_cin [{/home,	0.758	0.758	1,584	0
diffvs [{/home/inter	0.099	0.099	31,680	0
iaddrs [{/home/interni,	0.001	0.001	864	0

Slave processes



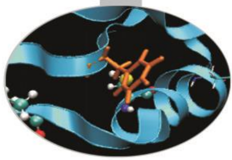
opspltae [{/home/interni/	5.961	460.322	72	1,036,220
MPI_Bcast()	21.115	21.115	648	0
MPI_Comm_rank()	0	0	72	0
MPI_Comm_size()	0	0	72	0
MPI_Send()	0.191	0.191	72	0
aero_iso [{/home/intei	3.243	41.528	380,160	760,320
chemnew [{/home/inte	0.606	268.726	380,160	380,160
copia_vettori_out [{/h	0.465	0.465	72	0
datetm [{/home/interr	0.001	0.001	72	0
horizae [{/home/inter	10.553	95.75	144	83,952
MPI_Bcast()	30.98	30.98	432	0
MPI_Comm_rank()	0	0	144	0
MPI_Comm_size()	0	0	144	0
MPI_Send()	21.505	21.505	432	0
blcuvs [{/home/inte	7.722	7.722	20,592	0
blcuvsae [{/home/i	23.975	23.975	20,592	0
copiax_caeout [{/h	0.402	0.402	72	0
copiax_cout [{/hon	0.12	0.12	72	0
copiay_caeout [{/h	0.288	0.288	144	0
copiay_cout [{/hon	0.064	0.064	144	0
diffvs [{/home/intei	0.14	0.14	41,184	0
iaddrs [{/home/interni	0.001	0.001	864	0

Communication issues

Load balancing issues

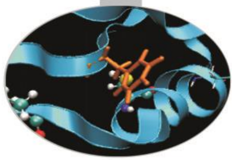
The imbalance of computational load causes an overhead in the MPI directives due to long synchronization times dramatically reducing the scalability

TAU Instrumentation API



- Using the specific API with TAU it’s possible to obtain a very detailed profiling of your code.
- Code instrumentation based on the API can be done authomatically or manually. With manual code instrumentation the programmer can establish exactly **which sections** are to be profiled and **how**.
- TAU API is available for C++, C and Fortran77/90/95 codes and is portable among different platforms and compilers.
- To use the API at the beginning of each source to be profiled must be present the line: #include<TAU.h>
- Most important API capabilities:
  - **Routines profiling**
  - **Blocks or lines profiling**
  - **Heap-memory tracing**

TAU Instrumentation API



- Configuration and Initialization:
  - At the beginning of each instrumented source file, include the header "TAU.h"

```
TAU_PROFILE_INIT(argc, argv);
TAU_PROFILE_SET_NODE(myNode);
```

- Class funcitions and methods (C++ only):

```
TAU_PROFILE(name, type, group);
```

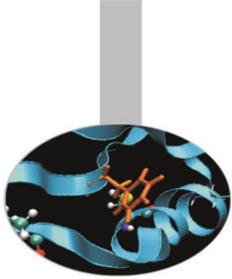
- User-defined timing

```
TAU_PROFILE_TIMER(timer, name, type, group);
TAU_PROFILE_START(timer);
TAU_PROFILE_STOP(timer);
```

- Heap-memory tracing:

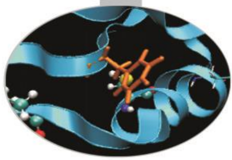
```
TAU_TRACK_MEMORY();
TAU_SET_INTERRUPT_INTERVAL(seconds);
```

C++ example

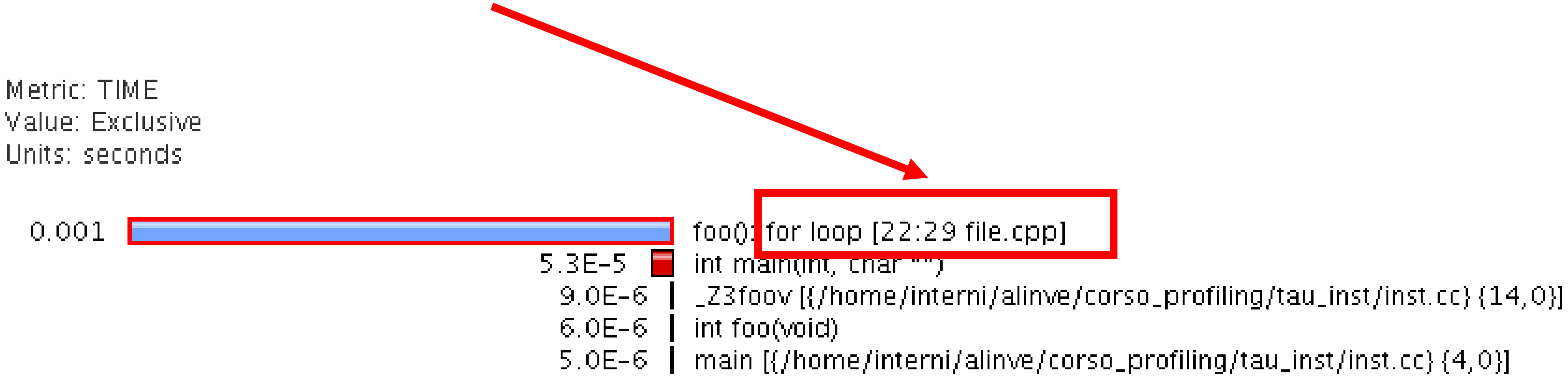


```
#include <TAU.h>
int foo();
int main(int argc, char **argv)
{
TAU_PROFILE("int main(int, char **)","", TAU_DEFAULT);
TAU_PROFILE_INIT(argc, argv);
TAU_PROFILE_SET_NODE(0); /* just for serial programs */
int cond=foo();
return 0;
}
int foo()
{
int N=100000;
double a[N];
int cond=0;
TAU_PROFILE("int foo(void)","", TAU_DEFAULT); // routine level profiling foo()
TAU_PROFILE_TIMER(t,"foo(): for loop", "[22:29 file.cpp]", TAU_USER);
TAU_PROFILE_START(t);
for(int i = 0; i < N ; i++){
a[i]=i/2;
if (i%2 ==0) cond=0;
      else cond=1;
}
TAU_PROFILE_STOP(t);
if (cond==1) return 25;
else return 15;}
```

Example

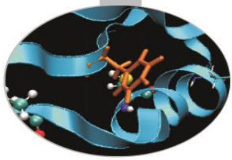


With manual instrumentation using the API we can see detailed statistic information on a specific block of code



```
Metric: TIME
Value: Exclusive
Units: seconds

0.001                                   foo(): for loop [22:29 file.cpp]
                               5.3E-5   int main(int, char **)
                                9.0E-6  _Z3foov [{/home/interni/alinve/corso_profiling/tau_inst/inst.cc} {14,0}]
                                6.0E-6  int foo(void)
                                5.0E-6  main [{/home/interni/alinve/corso_profiling/tau_inst/inst.cc} {4,0}]
```

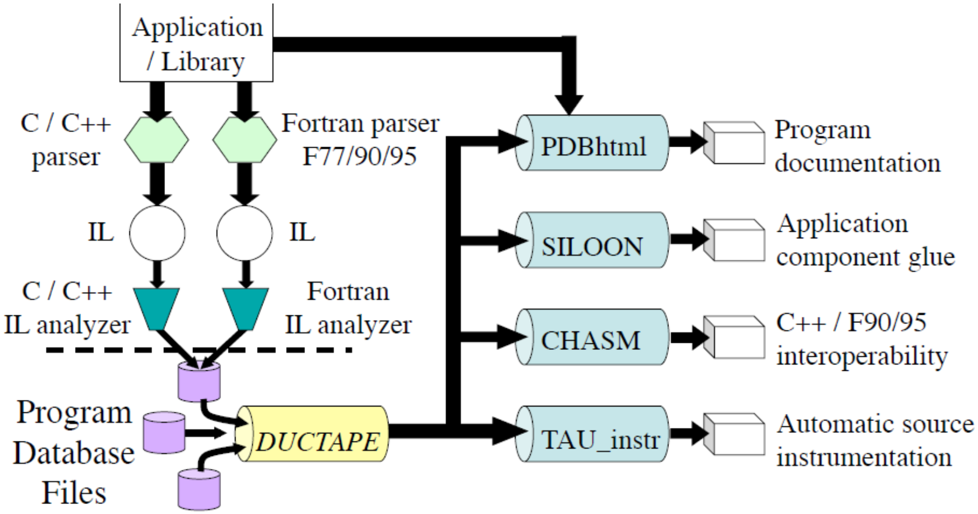
Fortran example



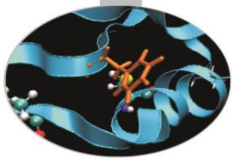
```
PROGRAM SUM_OF_CUBES
integer profiler(2)
save profiler
INTEGER :: H, T, U
call TAU_PROFILE_INIT()
call TAU_PROFILE_TIMER(profiler, 'PROGRAM SUM_OF_CUBES')
call TAU_PROFILE_START(profiler)
call TAU_PROFILE_SET_NODE(0)
! This program prints all 3-digit numbers that
! equal the sum of the cubes of their digits.
DO H = 1, 9
DO T = 0, 9
DO U = 0, 9
IF (100*H + 10*T + U == H**3 + T**3 + U**3) THEN
PRINT "(3I1)", H, T, U
ENDIF
END DO
END DO
END DO
call TAU_PROFILE_STOP(profiler)
END PROGRAM SUM_OF_CUBES
```

TAU source instrumentation with PDT

- Sometimes, for complex routines manual source instrumentation can become a long and error prone task.
- With TAU instrumentation can be inserted in the source code using an automatic instrumentor tool based on the Program Database Toolkit (PDT).



TAU source instrumentation with PDT



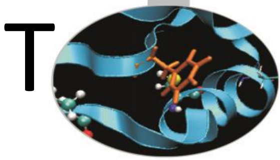
TAU and PDT howto:

- Parse the source code to produce the .pdb file:
    - cxxparse file.cpp C++
    - cparse   file.c C
    - f95parse file.f90 Fortran

- Instrument the program:
    - tau_instrumentor file.pdb file.cpp -o file.inst.cpp -f select.tau

- Complile:
    - tau_compiler.sh file.inst.cpp -o file.exe

TAU source instrumentation with PDT



- The ”-f” flag associated to the command “tau_instrumentator” allows you to customize the instrumentation of a program by using a selective instrumentation file. This instrumentation file is used to manually control which parts of the application are profiled and how they are profiled.
- Selective instrumentation file can contain the following sections:

1. Routines exclusion/inclusion list:

```
BEGIN_EXCLUDE_LIST / END_EXCLUDE_LIST
BEGIN_INCLUDE_LIST / END_INCLUDE_LIST
```

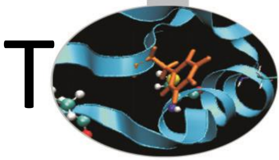
1. Files exclusion/inclusion list:

```
BEGIN_FILE_EXCLUDE_LIST / END_FILE_EXCLUDE_LIST
BEGIN_FILE_INCLUDE_LIST / END_FILE_INCLUDE_LIST
```

1. More detailed instrumentation specifics:

```
BEGIN_INSTRUMENT_SECTION / END_INSTRUMENT_SECTION
```

TAU source instrumentation with PDT



In a `BEGIN_INSTRUMENT_SECTION/END_INSTRUMENT_SECTION` block it’s possible to specify the profiling of:

- Cycles

```
loops file=“filename.cpp" routine=“routinename"
```

- Memory

```
memory file=“filename.f90" routine=“routinename"
```

- I/O with dimension of read/write data

```
io file="foo.f90" routine=“routinename"
```

- Static and dynamic timers

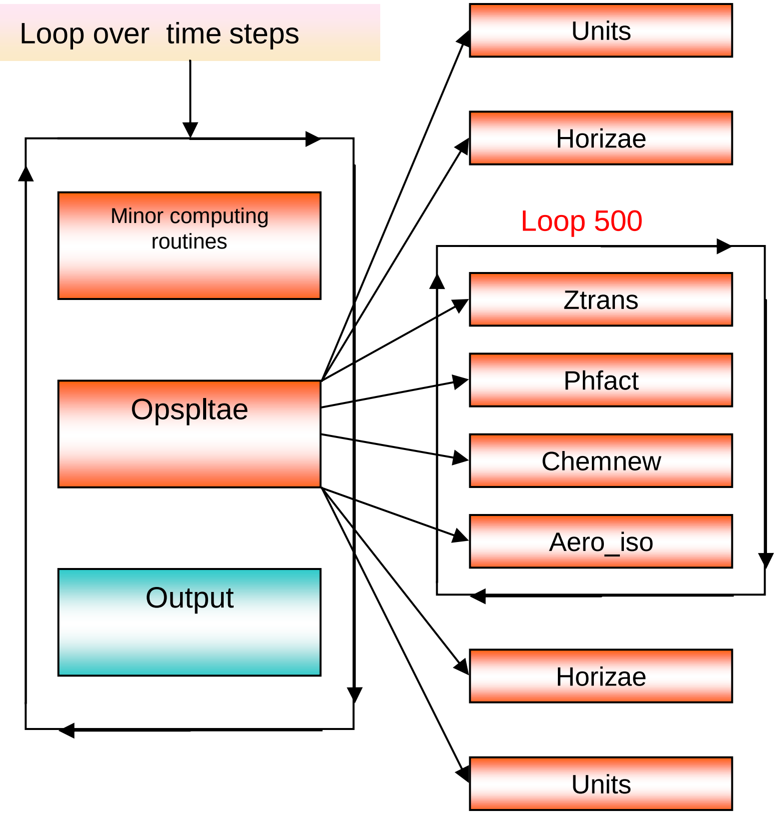
```
static/dynamic timer name=“name" file=“filename.c"
   line=17 to line=23
```

TAU with PDT Real Case Air Pollution Model

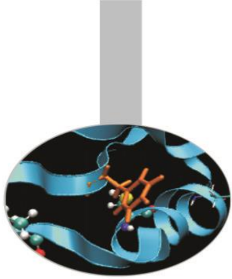
Custom profiling

Instrumentation file : instrument_rules.txt

```
----------------------------------------------------------
BEGIN_FILE_INCLUDE_LIST
opspltae.f
chemnew.f
horizae.f
ztrans.f
END_FILE_INCLUDE_LIST



BEGIN_INSTRUMENT_SECTION

loops file="opspltae.f" routine="OPSPLTAE"
loops file="chemnew.f" routine="CHEMNEW"
loops file="horizae.f" routine="HORIZAE"
loops file="ztrans.f" routine="ZTRANS"
io file="wrout1.f" routine="WROUT1"
dynamic timer name="dyn_timer" file="opspltae.f" line=183 to line=189
END_INSTRUMENT_SECTION
----------------------------------------------------------
```



TAU with PDT Real Case Air Pollution Model



Routine `opspltae`: Loop 500, TAU automatic instrumentation

```
call TAU_PROFILE_TIMER(profiler, 'OPSPLTAE [{opspltae.f} {2,18}]')
call TAU_PROFILE_START(profiler)
call TAU_PROFILE_TIMER(t_131, ' Loop: OPSPLTAE [{opspltae.f} {131,7}-{143,12}]')
call TAU_PROFILE_TIMER(t_195, ' Loop: OPSPLTAE [{opspltae.f} {195,10}-{203,17}]')
call TAU_PROFILE_TIMER(t_247, ' Loop: OPSPLTAE [{opspltae.f} {247,7}-{592,14}]')
call TAU_PROFILE_TIMER(t_597, ' Loop: OPSPLTAE [{opspltae.f} {597,10}-{605,17}]')
call TAU_PROFILE_TIMER(t_639, ' Loop: OPSPLTAE [{opspltae.f} {639,10}-{647,17}]')
```

TAU TIMER Initialization

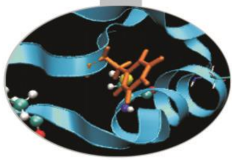
```
iugrid= iaddrs('UGRID   ',1,1,1,1,1)
          ...........
 call TAU_PROFILE_START(t_247)
```

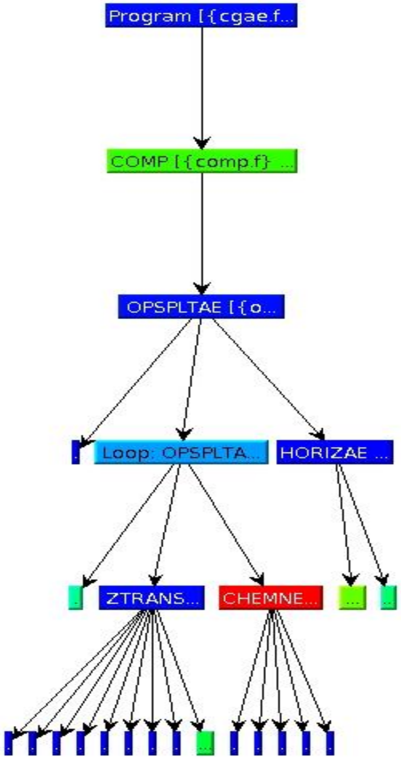
TAU Loop 500 instrumentation

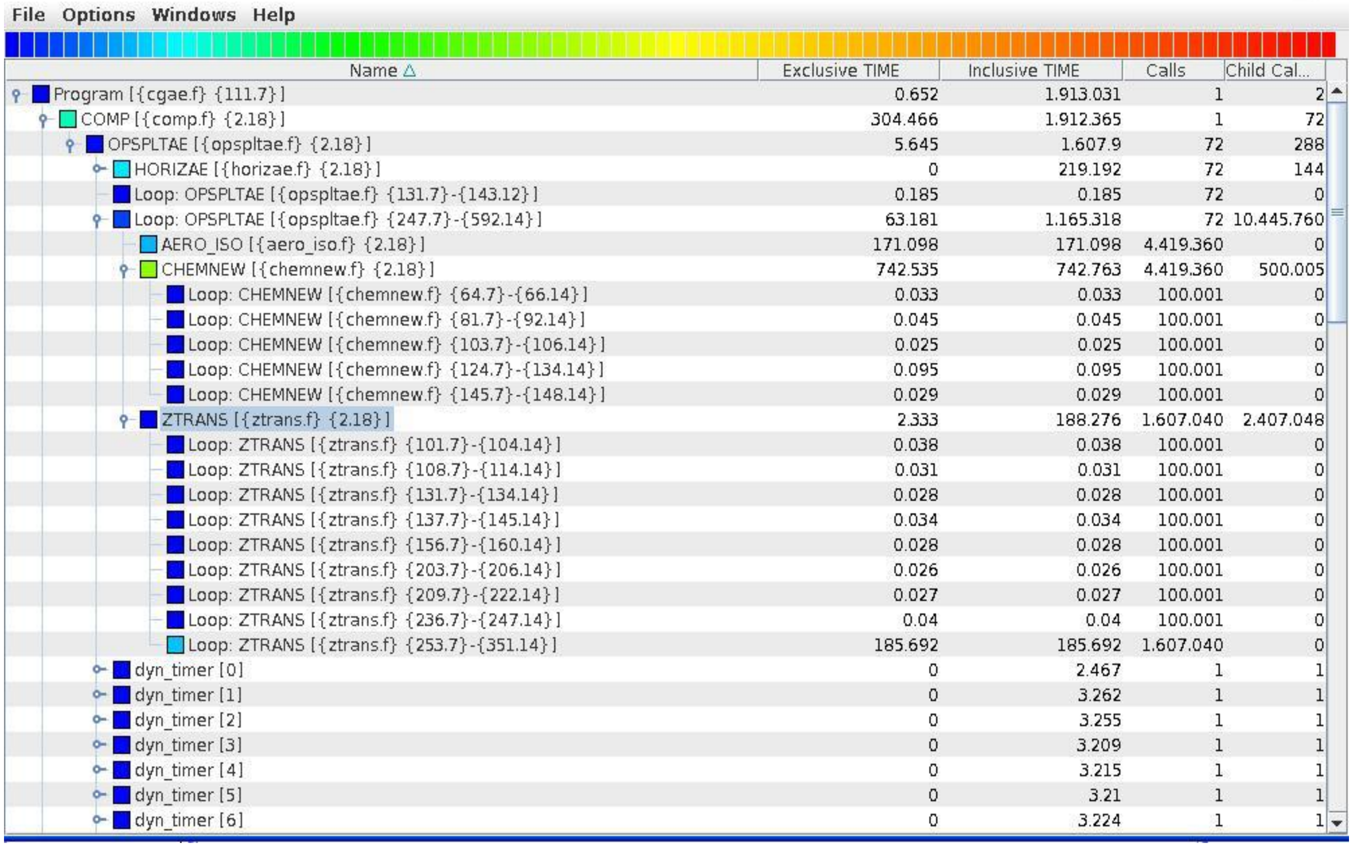
```
   do 500 i=2,nxm1
      do 500 j=2,nym1
      ...................
      ...................
  500   continue
call TAU_PROFILE_STOP(t_247)
```

TAU Loop 500 end instrumentation

TAU with PDT Real Case Air Pollution Model







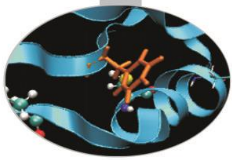
Name △	Exclusive TIME	Inclusive TIME	Calls	Child Cal...
Program [{cgae.f} {111.7}]	0.652	1.913.031	1	2
COMP [{comp.f} {2.18}]	304.466	1.912.365	1	72
OPSPLTAE [{opspltae.f} {2.18}]	5.645	1.607.9	72	288
HORIZAE [{horizae.f} {2.18}]	0	219.192	72	144
Loop: OPSPLTAE [{opspltae.f} {131.7}-{143.12}]	0.185	0.185	72	0
Loop: OPSPLTAE [{opspltae.f} {247.7}-{592.14}]	63.181	1.165.318	72	10.445.760
AERO_ISO [{aero_iso.f} {2.18}]	171.098	171.098	4.419.360	0
CHEMNEW [{chemnew.f} {2.18}]	742.535	742.763	4.419.360	500.005
Loop: CHEMNEW [{chemnew.f} {64.7}-{66.14}]	0.033	0.033	100.001	0
Loop: CHEMNEW [{chemnew.f} {81.7}-{92.14}]	0.045	0.045	100.001	0
Loop: CHEMNEW [{chemnew.f} {103.7}-{106.14}]	0.025	0.025	100.001	0
Loop: CHEMNEW [{chemnew.f} {124.7}-{134.14}]	0.095	0.095	100.001	0
Loop: CHEMNEW [{chemnew.f} {145.7}-{148.14}]	0.029	0.029	100.001	0
ZTRANS [{ztrans.f} {2.18}]	2.333	188.276	1.607.040	2.407.048
Loop: ZTRANS [{ztrans.f} {101.7}-{104.14}]	0.038	0.038	100.001	0
Loop: ZTRANS [{ztrans.f} {108.7}-{114.14}]	0.031	0.031	100.001	0
Loop: ZTRANS [{ztrans.f} {131.7}-{134.14}]	0.028	0.028	100.001	0
Loop: ZTRANS [{ztrans.f} {137.7}-{145.14}]	0.034	0.034	100.001	0
Loop: ZTRANS [{ztrans.f} {156.7}-{160.14}]	0.028	0.028	100.001	0
Loop: ZTRANS [{ztrans.f} {203.7}-{206.14}]	0.026	0.026	100.001	0
Loop: ZTRANS [{ztrans.f} {209.7}-{222.14}]	0.027	0.027	100.001	0
Loop: ZTRANS [{ztrans.f} {236.7}-{247.14}]	0.04	0.04	100.001	0
Loop: ZTRANS [{ztrans.f} {253.7}-{351.14}]	185.692	185.692	1.607.040	0
dyn_timer [0]	0	2.467	1	1
dyn_timer [1]	0	3.262	1	1
dyn_timer [2]	0	3.255	1	1
dyn_timer [3]	0	3.209	1	1
dyn_timer [4]	0	3.215	1	1
dyn_timer [5]	0	3.21	1	1
dyn_timer [6]	0	3.224	1	1

Profiling time with default routine level compiler based instrumentation : 4192 sec

Profiling time with PDT and selective instrumentation : **1913 sec**

Execution time without profiling overhead: **1875 sec**

TAU: Memory Profiling C/C++



TAU can evaluate the following memory events:

- how much heap memory is currently used
- how much a program can grow (or how much headroom it has) before it runs out of free memory on the heap
- Memory leaks (C/C++)

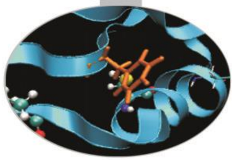
TAU gives two main functions to evaluate memory:

- TAU_TRACK_MEMORY()
- TAU_TRACK_MEMORY_HERE()

Esempio:

```
#include<TAU.h>

int main(int argc, char **argv) {

    TAU_TRACK_MEMORY();

sleep(12);

double *x = new double[1024];

sleep(12); return 0; }
```

TAU: Memory Profiling C/C++

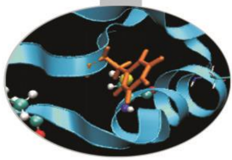


```
NODE 0;CONTEXT 0;THREAD 0:
---------------------------------------------------------------------------------------
%Time    Exclusive    Inclusive       #Call      #Subrs  Inclusive Name
              msec   total msec                          usec/call
---------------------------------------------------------------------------------------
100.0       20,002       20,002           1           0   20002086 int main(int, char **)
---------------------------------------------------------------------------------------

USER EVENTS Profile :NODE 0, CONTEXT 0, THREAD 0
---------------------------------------------------------------------------------------
NumSamples   MaxValue   MinValue  MeanValue  Std. Dev.  Event Name
---------------------------------------------------------------------------------------
         2      31.92       23.8      27.86      4.062  Memory Utilization (heap, in KB)
---------------------------------------------------------------------------------------
```

In the same way for the functions:

```
TAU_TRACK_MEMORY_HEADROOM()
TAU_TRACK_MEMORY_HEADROOM_HERE()
```

TAU: Memory Profiling Fortran



To profile memory usage in Fortran 90 use TAU's ability to selectively instrument a program. The option `-optTauSelectFile=<file>` for tau_compilier.sh let you specify a selective instrumentation file which defines regions of the source code to instrument.

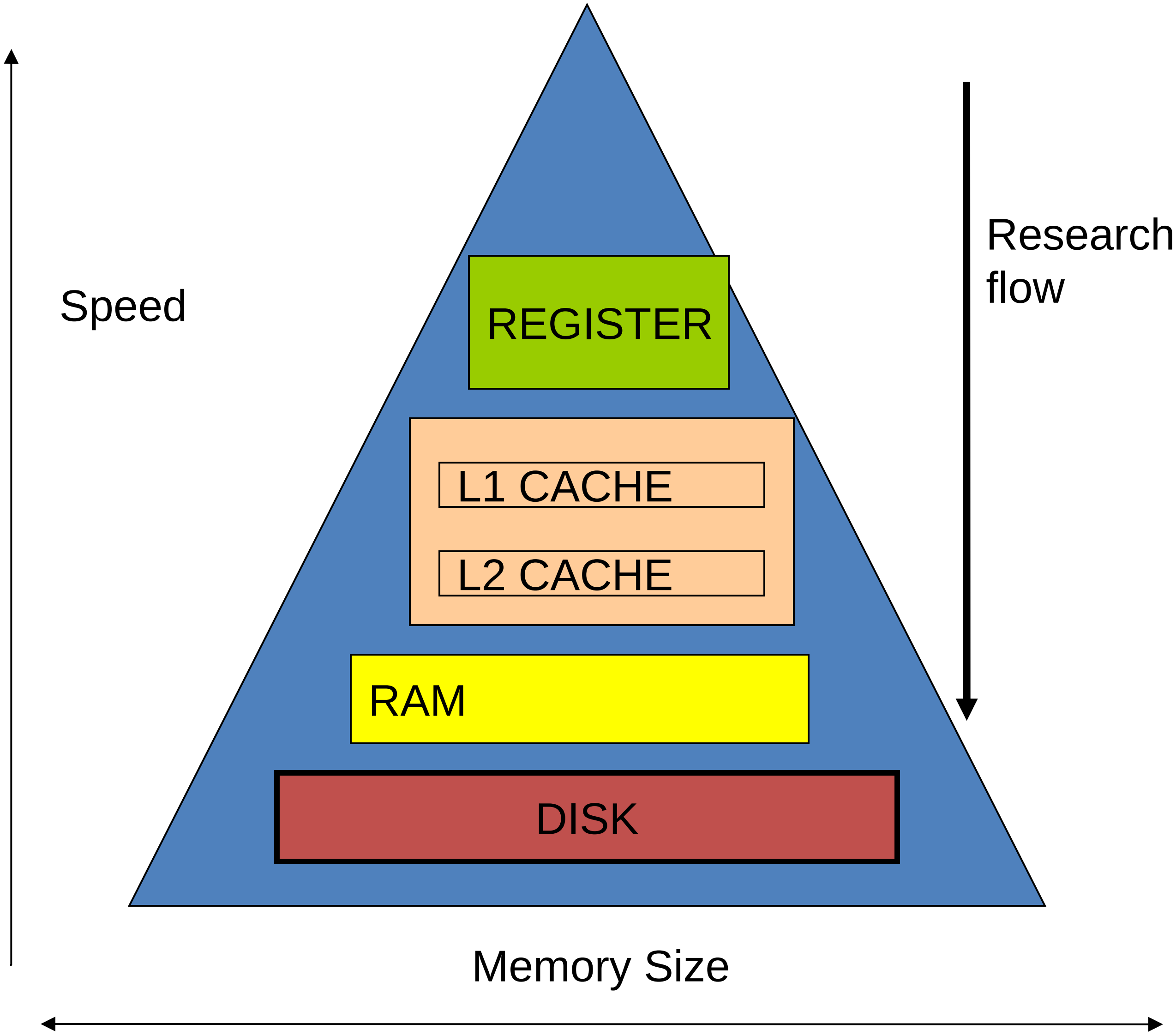
To begin memory profiling, state which file/routines to profile by typing:

```
BEGIN_INSTRUMENT_SECTION
memory file=“source.f90” routine=“routine_name”
END_INSTRUMENT_SECTION
```

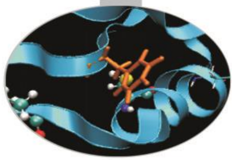
Memory Profile in Fortran gives you these three metrics:

- Total size of memory for each malloc and free in the source code
- The callpath for each occurrence of malloc or free
- A list of all variable that were not deallocated in the source code.

Memory Hierarchy



Hit and Miss



- **Hit:** the processor immediately reads or writes the data in the cache line
- **Miss:** the cache allocates a new entry, and copies in data from main memory.

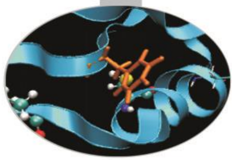
Hit rate: percentage of memory accesses which are satisfied by cache

Miss rate: 1 - hit rate

Hit time: Time to access cache

Miss Time: Time to replace a block in cache and deliver data

Performance Optimization



- Optimization of cache access can be helpful to improve code performance

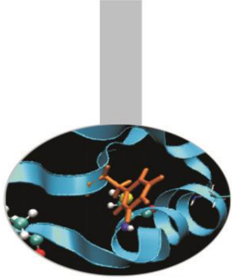
- Optimization can be done at different stage:

  - During compililation in order to reduce the instruction missing and the data missing

  - Writing code in order to reduce spatial and time locality

Cache access can be analized through hardware counters and through profiling tools.

PAPI



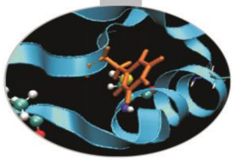
- Performance Api Programming Interface

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

- PAPI is a set of API that can be used to access to the hardware counter information

- PAPI can be used with serial and parallel code

- PAPI can be used in two different way:
  1. Low Level Interface
  2. High Level Interface



PAPI:High Level

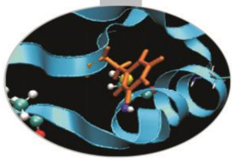
- Simple to use
- High level API
- 8 functions for C/C++ and Fortran.

```
PAPI_start_counters    PAPI_stop_counters
 PAPI_read_counters PAPI_accum_counters
  PAPI_num_counters       PAPI_ipc
       PAPI_flips     PAPI_flops
```

Example:

```
#include "papi.h”
#define NUM_EVENTS 2
long_long values[NUM_EVENTS];

unsigned int Events[NUM_EVENTS]={PAPI_TOT_INS,PAPI_TOT_CYC};

PAPI_start_counters((int*)Events,NUM_EVENTS);

do_work();

 retval = PAPI_stop_counters(values,NUM_EVENTS);
```

PAPI Low Level

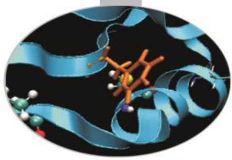


- Low level interface
- Increase granularity of information
- Hard to use

PAPI can be used integrated in many high level instruments:

- TAU (U Oregon) **http://www.cs.uoregon.edu/research/tau/**
- HPCToolkit (Rice Univ) **http://hipersoft.cs.rice.edu/hpctoolkit/**
- KOJAK (UTK, FZ Juelich) **http://icl.cs.utk.edu/kojak/**
- PerfSuite (NCSA) **http://perfsuite.ncsa.uiuc.edu/**

TAU & PAPI



- Before compiling configure TAU with the flag

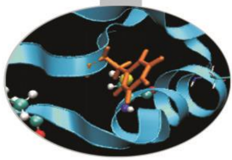
```
-papi=directory_to_papi
```

- Verify events supported by your OS:

```
papi_avail
```

```
PAPI Version             : 4.1.2.1
Vendor string and code   : GenuineIntel (1)
Model string and code    : Intel(R) Xeon(R) CPU           E7520  @ 1.87GHz (46)
CPU Revision             : 6.000000
CPUID Info               : Family: 6  Model: 46  Stepping: 6
CPU Megahertz            : 1064.000000
CPU Clock Megahertz      : 1064
Hdw Threads per core     : 2
Cores per Socket         : 4
NUMA Nodes               : 8
CPU's per Node           : 8
Total CPU's              : 64
Number Hardware Counters : 7
Max Multiplex Counters   : 512
```

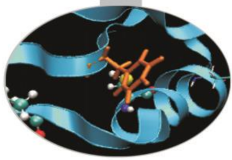
TAU & PAPI



- Checks metrics compatibility:

```
                           papi_event_chooser metrica1 metrica2 metricaN
 ./papi_event_chooser PAPI_FP_OPS PAPI_L1_DCM
Event Chooser: Available events which can be added with given events.
--------------------------------------------------------------------------------
PAPI Version             : 4.1.2.1
Vendor string and code   : GenuineIntel (1)
Model string and code    : Intel(R) Xeon(R) CPU           E7520  @ 1.87GHz (46)
CPU Revision             : 6.000000
CPUID Info               : Family: 6  Model: 46  Stepping: 6
CPU Megahertz            : 1064.000000
CPU Clock Megahertz      : 1064
Hdw Threads per core     : 2
Cores per Socket         : 4
NUMA Nodes               : 8
CPU's per Node           : 8
Total CPU's              : 64
Number Hardware Counters : 7
Max Multiplex Counters   : 512
--------------------------------------------------------------------------------


Usage: papi_event_chooser NATIVE|PRESET evt1 evt2 ...
```

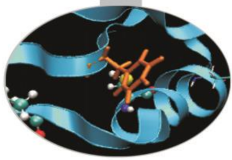
TAU & PAPI



```
./papi_event_chooser PAPI_FP_OPS GET_TIME_OF_DAY
Event Chooser: Available events which can be added with given events.
--------------------------------------------------------------------------------
PAPI Version             : 4.1.2.1
Vendor string and code   : GenuineIntel (1)
Model string and code    : Intel(R) Xeon(R) CPU           E7520  @ 1.87GHz (46)
CPU Revision             : 6.000000
CPUID Info               : Family: 6  Model: 46  Stepping: 6
CPU Megahertz            : 1064.000000
CPU Clock Megahertz      : 1064
Hdw Threads per core     : 2
Cores per Socket         : 4
NUMA Nodes               : 8
CPU's per Node           : 8
Total CPU's              : 64
Number Hardware Counters : 7
Max Multiplex Counters   : 512
--------------------------------------------------------------------------------
 Event GET_TIME_OF_DAY can't be counted with others
```

NOTE: In order to use TAU with different harware counter it is necessary to configure it with the option –MULTIPLECOUNTERS

TAU & PAPI



- Set `TAU_MAKEFILE` environment variable:

```
    export TAU_MAKEFILE $TAU/Makefile.tau-
multiplecounters-mpi-papi-pdt
```

- Set TAU_OPTIONS:

```
export TAU_OPTIONS='-optCompInst -optRevert‘
```

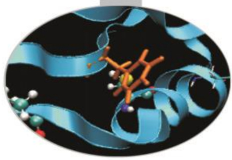
- Compile with TAU wrapper

```
tau_cc.sh example.cc –o my_exe
```

- Select hardware counter neededs:

```
export TAU_METRICS=GET_TIME_OF_DAY:PAPI_FP_INS:PAPI_L1_DCM
```

TAU & PAPI



- Run the program as usual

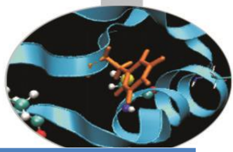
```
./my_exe
```

- At the end of run a folder for each selected hardware counter will be created in the working directory

- `MULTI__GET_TIME_OF_DAY`
- `MULTI__PAPI_FP_OPS`
- `MULTI__PAPI_L1_DCM`

- To analize results you can simply use `paraprof` gui.

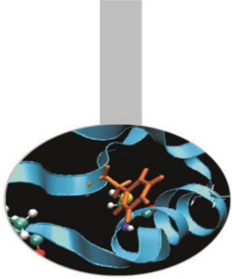
PAPI EVENTS



Counter/Event Name	Meaning
PAPI_L1_DCM	Level 1 data cache misses
PAPI_L1_ICM	Level 1 instruction cache misses
PAPI_L2_DCM	Level 2 data cache misses
PAPI_L2_ICM	Level 2 instruction cache misses
PAPI_L2_TCM	Level 2 cache misses
PAPI_L3_TCM	Level 3 cache misses
PAPI_FPU_IDL	Cycles floating point units are idle
PAPI_TLB_DM	Data translation lookaside buffer misses
PAPI_TLB_IM	Instruction translation lookaside buffer misses
PAPI_STL_ICY	Cycles with no instruction issue
PAPI_HW_INT	Hardware interrupts
PAPI_BR_TKN	Conditional branch instructions taken
PAPI_BR_MSP	Conditional branch instructions mispredicted
PAPI_TOT_INS	Instructions completed
PAPI_FP_INS	Floating point instructions
PAPI_BR_INS	Branch instructions

Counter/Event Name	Meaning
PAPI_VEC_INS	Vector/SIMD instructions
PAPI_RES_STL	Cycles stalled on any resource
PAPI_TOT_CYC	Total cycles
PAPI_L1_DCA	Level 1 data cache accesses
PAPI_L2_DCA	Level 2 data cache accesses
PAPI_L2_ICH	Level 2 instruction cache hits
PAPI_L1_ICA	Level 1 instruction cache accesses
PAPI_L2_ICA	Level 2 instruction cache accesses
PAPI_L1_ICR	Level 1 instruction cache reads
PAPI_L2_TCA	Level 2 total cache accesses
PAPI_L3_TCR	Level 3 total cache reads
PAPI_FML_INS	Floating point multiply instructions
PAPI_FAD_INS	Floating point add instructions (Also includes subtract instructions)
PAPI_FDV_INS	Floating point divide instructions (Counts both divide and square root instructions)
PAPI_FSQ_INS	Floating point square root instructions (Counts both divide and square root instructions)
PAPI_FP_OPS	Floating point operations

Example



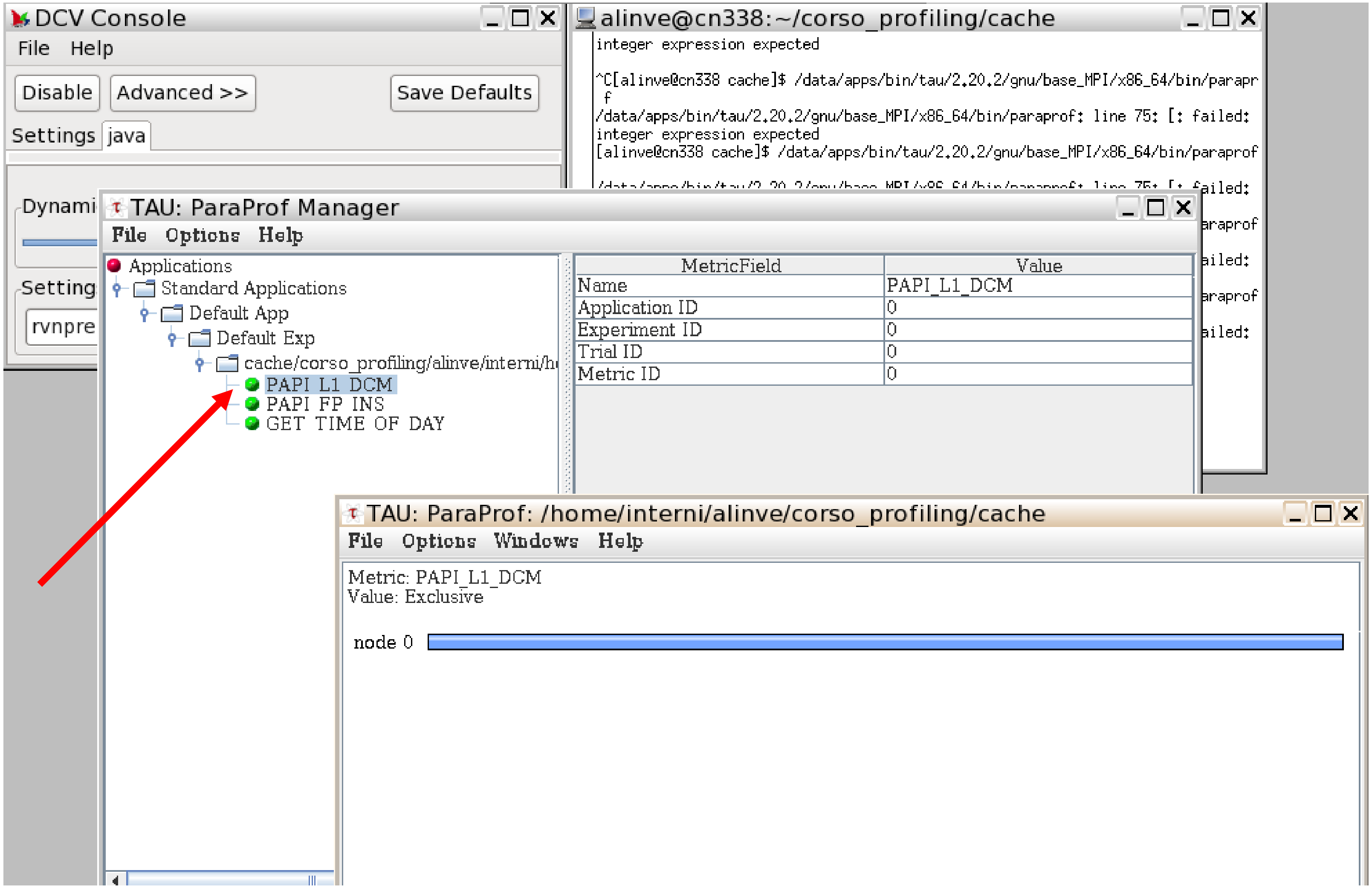
```
#include <stdio.h>
#include <math.h>
#include <stdlib.h>
#include <time.h>
#define nn (2048)
double a[nn][nn], b[nn][nn], c[nn][nn]; /** matrici**/
int main()
{
int k, i, j, ii, jj;
float time1, time2, dub_time,somma;
/* initialize matrix */
time1 = clock();
for (j = 0; j < nn; j++)
{
for (i = 0; i < nn; i++)
{
     a[j][i] = ((double)rand())/((double)RAND_MAX);
     b[j][i] = ((double)rand())/((double)RAND_MAX);
     c[j][i] = 0.0L;
}
}
time2 = clock();
dub_time = (time2 - time1)/(double) CLOCKS_PER_SEC;
printf("Tempo impiegato per inizializzare \n");
printf("Tempo -----------------> %f \n", dub_time);
time1 = clock();
for (i = 0; i < nn; i++)
for (k = 0; k < nn; k++)
     for (j = 0; j < nn; j ++)
          c[i][j] = c[i][j] + a[i][k]*b[k][j];
time2 = clock();
dub_time = (time2 - time1)/(double) CLOCKS_PER_SEC;
printf("==============================\n");}
```

I Option

II Option

```
for (j = 0; j< nn; j++)
     for (k = 0; k < nn; k++)
        for (i = 0; i < nn; i ++)
         c[i][j] = c[i][j] + a[i][k]*b[k][j];
```

Example



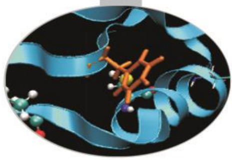
```
integer expression expected

^C[alinve@cn338 cache]$ /data/apps/bin/tau/2.20.2/gnu/base_MPI/x86_64/bin/parapr
 f
/data/apps/bin/tau/2.20.2/gnu/base_MPI/x86_64/bin/paraprof: line 75: [: failed:
integer expression expected
[alinve@cn338 cache]$ /data/apps/bin/tau/2.20.2/gnu/base_MPI/x86_64/bin/paraprof

/data/apps/bin/tau/2.20.2/gnu/base_MPI/x86_64/bin/paraprof: line 75: [: failed:
araprof
ailed:
araprof
ailed:
```

MetricField	Value
Name	PAPI_L1_DCM
Application ID	0
Experiment ID	0
Trial ID	0
Metric ID	0

Metric: PAPI_L1_DCM
Value: Exclusive

node 0

Example

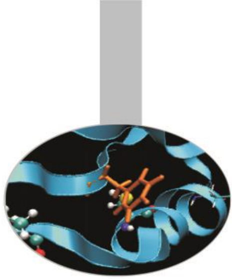


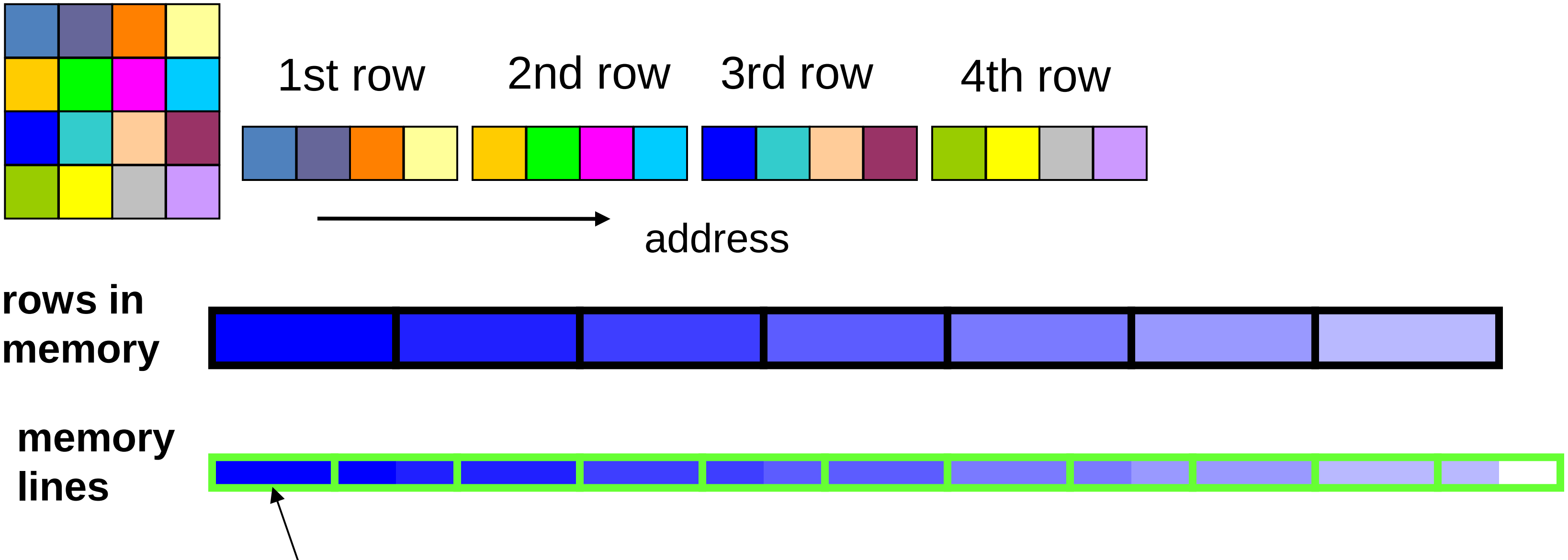
Tempi (s)		
Dimension	Opzione 1	Opzione 2
512	1.9	3.46
1024	10.42	19.45
2048	77.23	182.91

L1 Cache Missing		
Dimension	Opzione 1	Opzione 2
512	1.6938 E7	2.7585 E8
1024	1.3531 E8	2.2164 E9
2048	1.1339 E9	1.826 E10

MFlops		
Dimension	Opzione 1	Opzione 2
512	141.28	77.58
1024	206.09	110.41
2048	222.42	93.92

Example





1st row

2nd row

3rd row

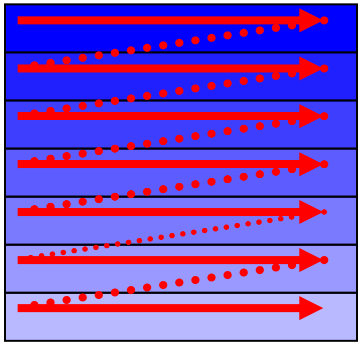
4th row

address

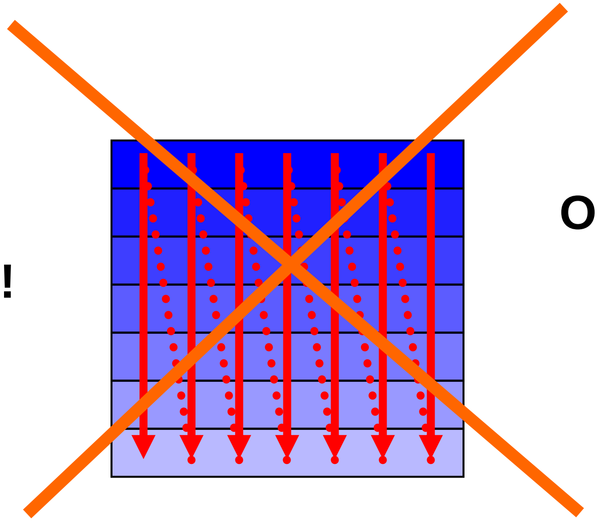
rows in memory

memory lines

memory/cache line



Opzione 1
Buona Località!



Opzione 2