Debugging and Profiling with Arm Forge

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Argonne NATIONAL LABORATORY

Agenda

- Introduction to Arm Forge
- Basic Arm DDT Example
- Memory Debugging Arm DDT Example
- Offline Mode DDT Example
- Basic Arm MAP Profiling Example
- Using Arm MAP to Improve Performance
- Questions
- Hands on Examples

Arm in HPC Tools

arm Allinea Studio

For Arm

Arm Forge

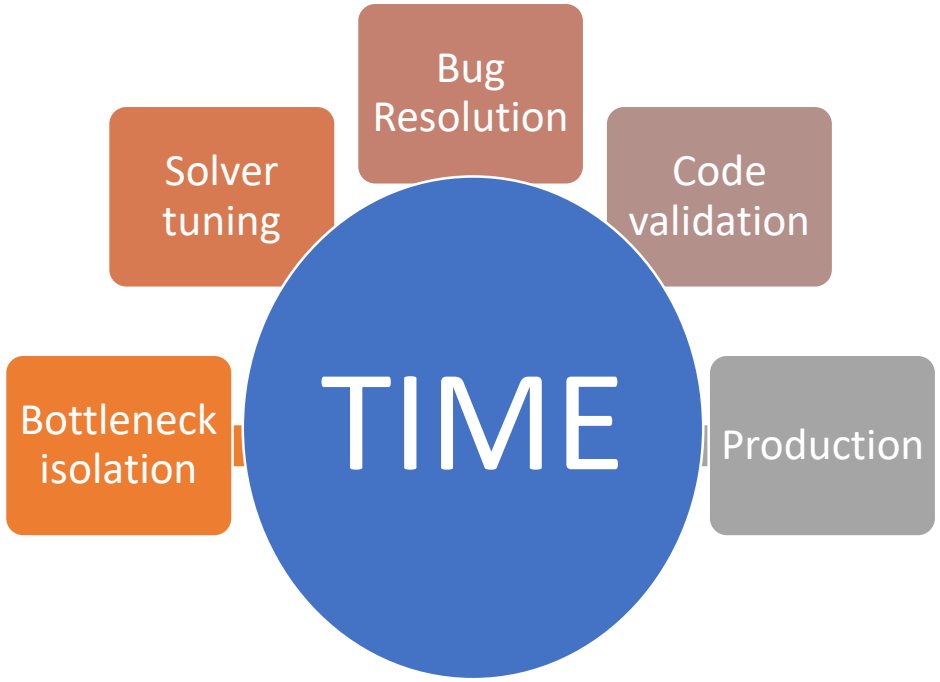
Arm MAP

Arm DDT

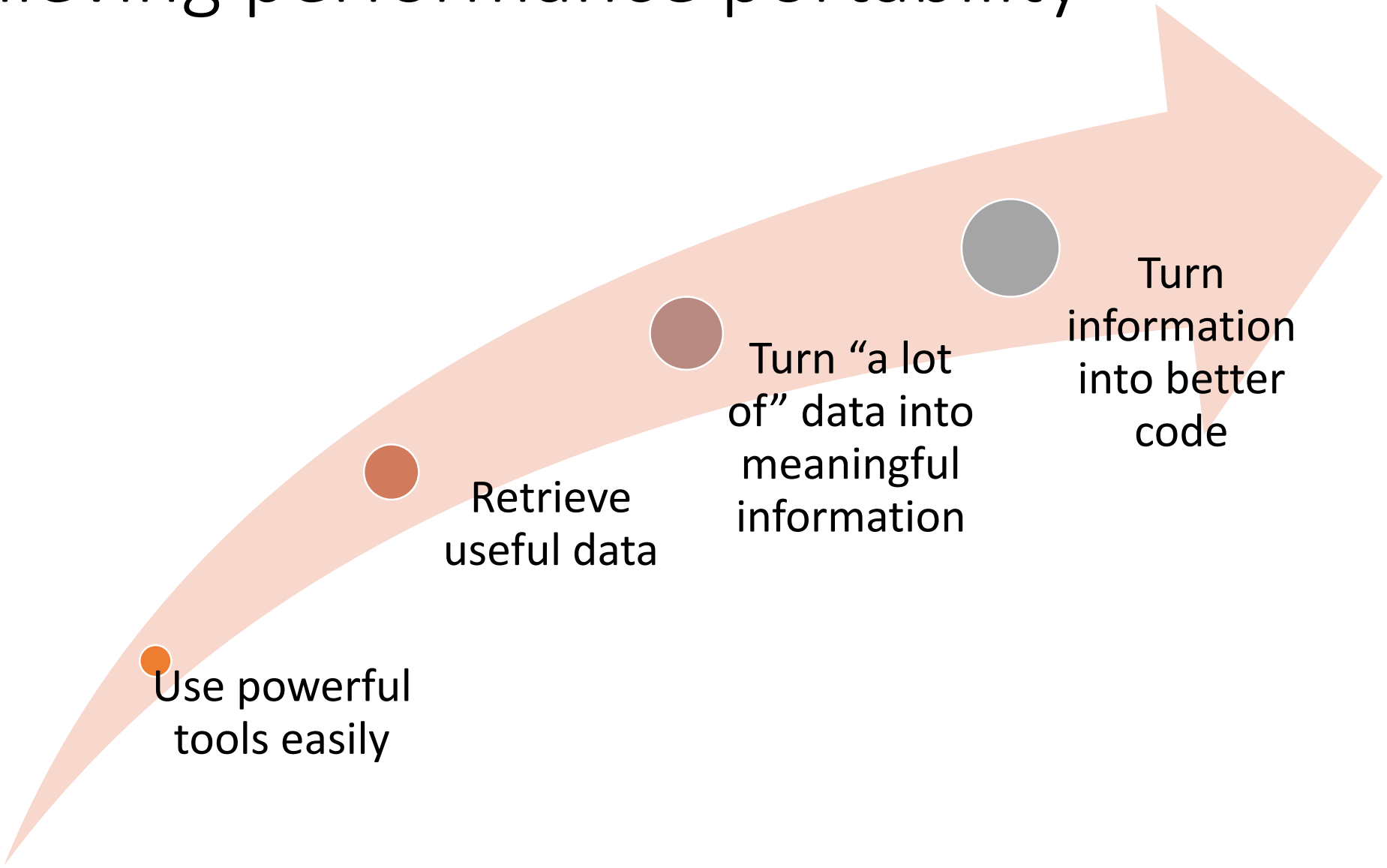
Arm Performance Reports

For Cross-platform

We do tools for a single reason: help people save their time.



Achieving performance portability



Using powerful tools more easily

Remote Client

- Fast and easy alternative to X-Forwarding and VNC

Reverse Connect

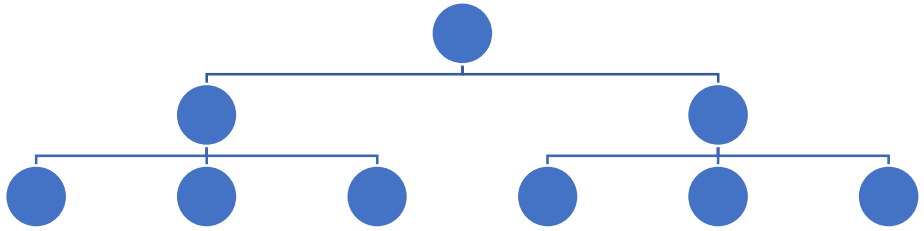
- Simplifies integration with job submission scripts

Continuous Integration

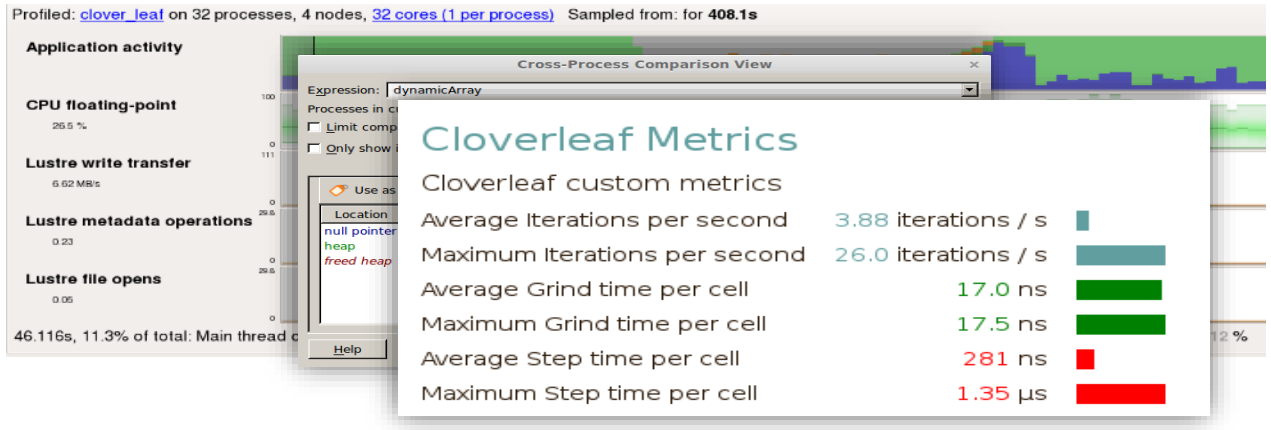
- Automation of debugging & profiling for professional workflows

Generating useful and meaningful information

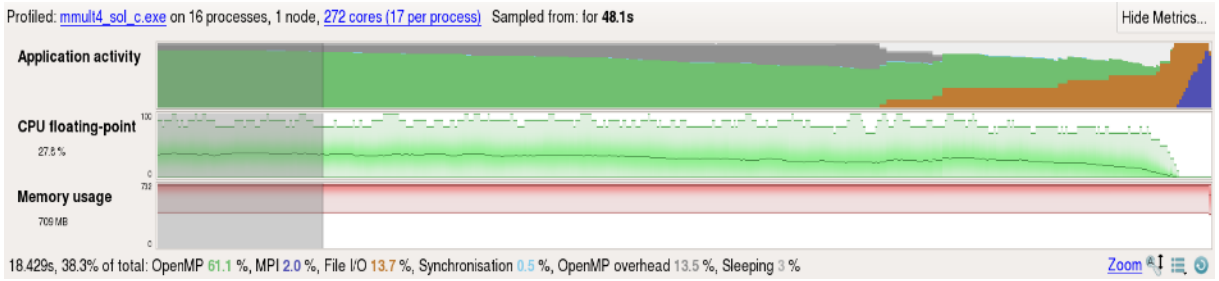
Scalable & Portable



Data collection

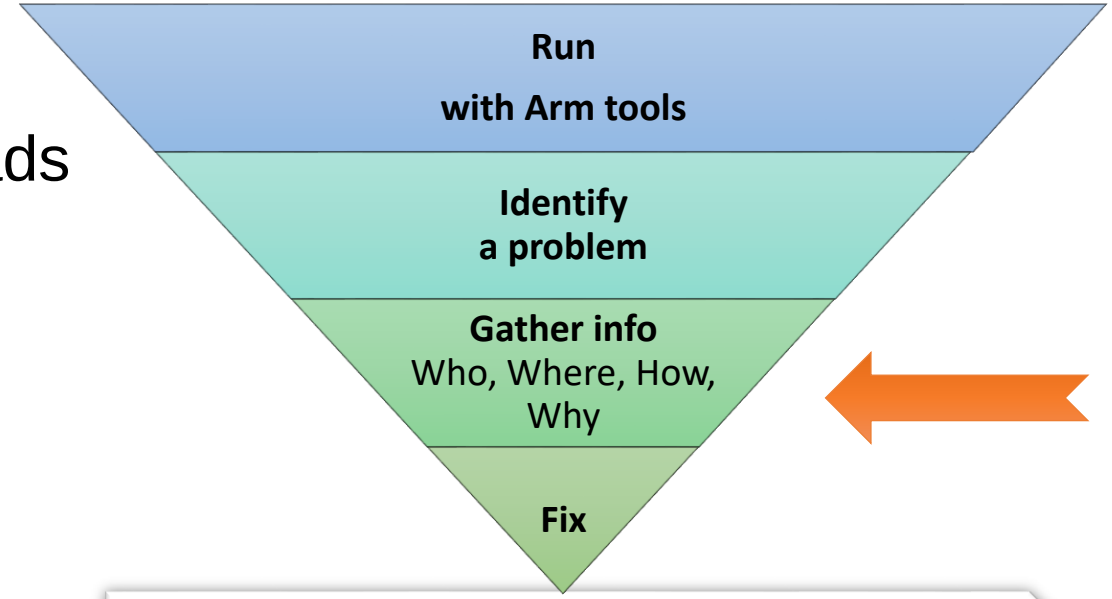


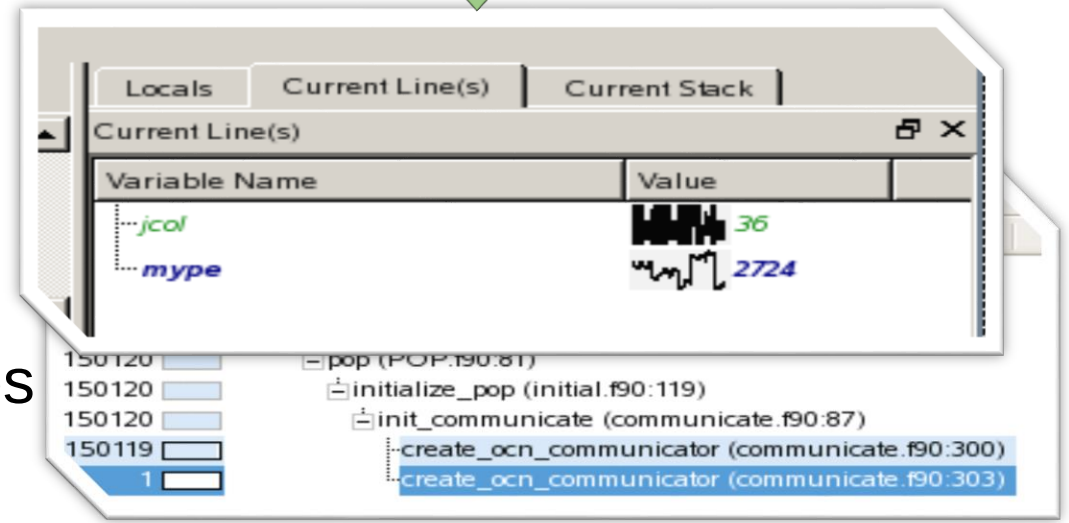
Data processing



Arm DDT – The Debugger

- Who had a rogue behavior ?
  - Merges stacks from processes and threads
- Where did it happen?
  - leaps to source
- How did it happen?
  - Diagnostic messages
  - Some faults evident instantly from source
- Why did it happen?
  - Unique “Smart Highlighting”
  - Sparklines comparing data across processes





Preparing Code for Use with DDT

- As with any debugger, code must be compiled with the debug flag typically **`-g`**
- It is recommended to turn off optimization flags i.e. **`–O0`**
- Leaving optimizations turned on can cause the compiler to *optimize out* some variables and even functions making it more difficult to debug

Basic Arm DDT Example

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Memory Debugging Arm DDT Example

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Offline Mode DDT Examples

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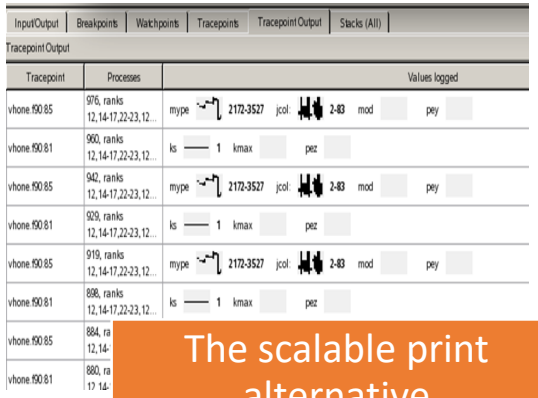
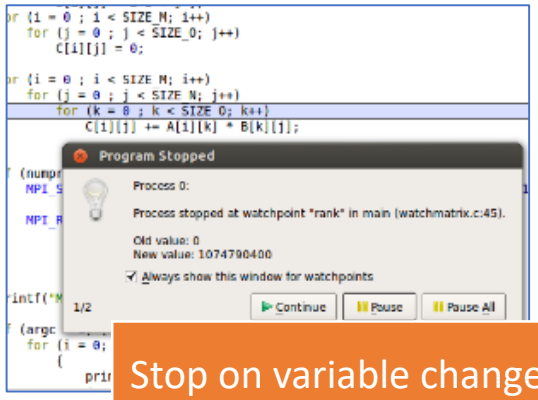
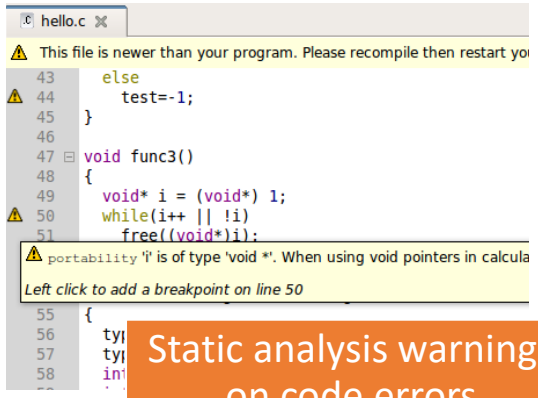
Five great things to try with Arm DDT



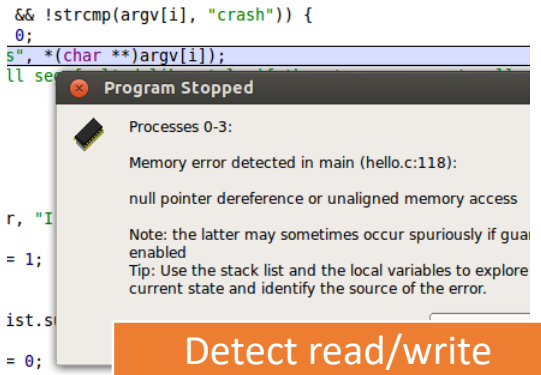
The scalable print alternative



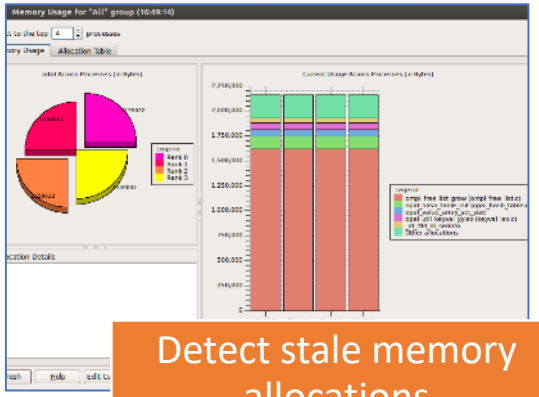
Stop on variable change



Static analysis warnings on code errors

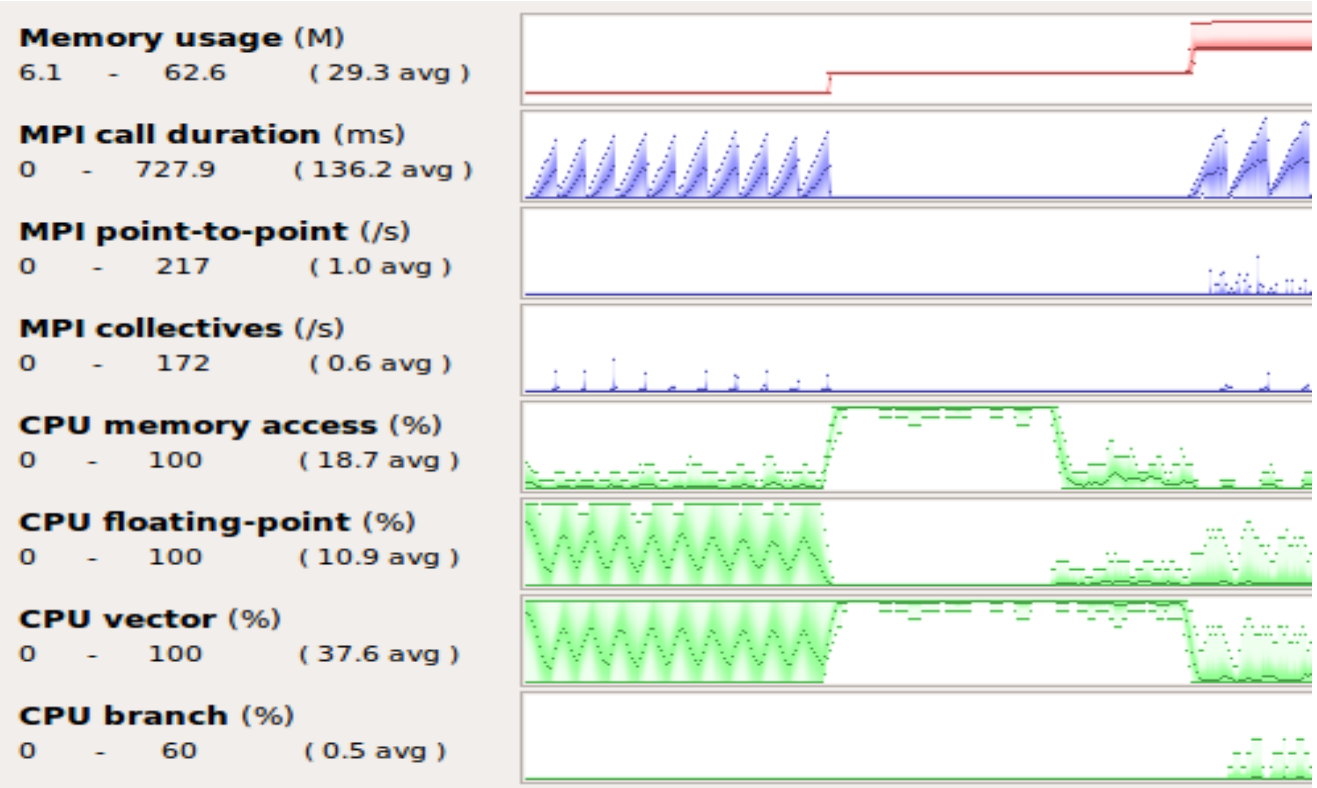


Detect read/write beyond array bounds



Detect stale memory allocations

Glean Deep Insight from our Source-Level Profiler



Track memory usage across the entire application over time

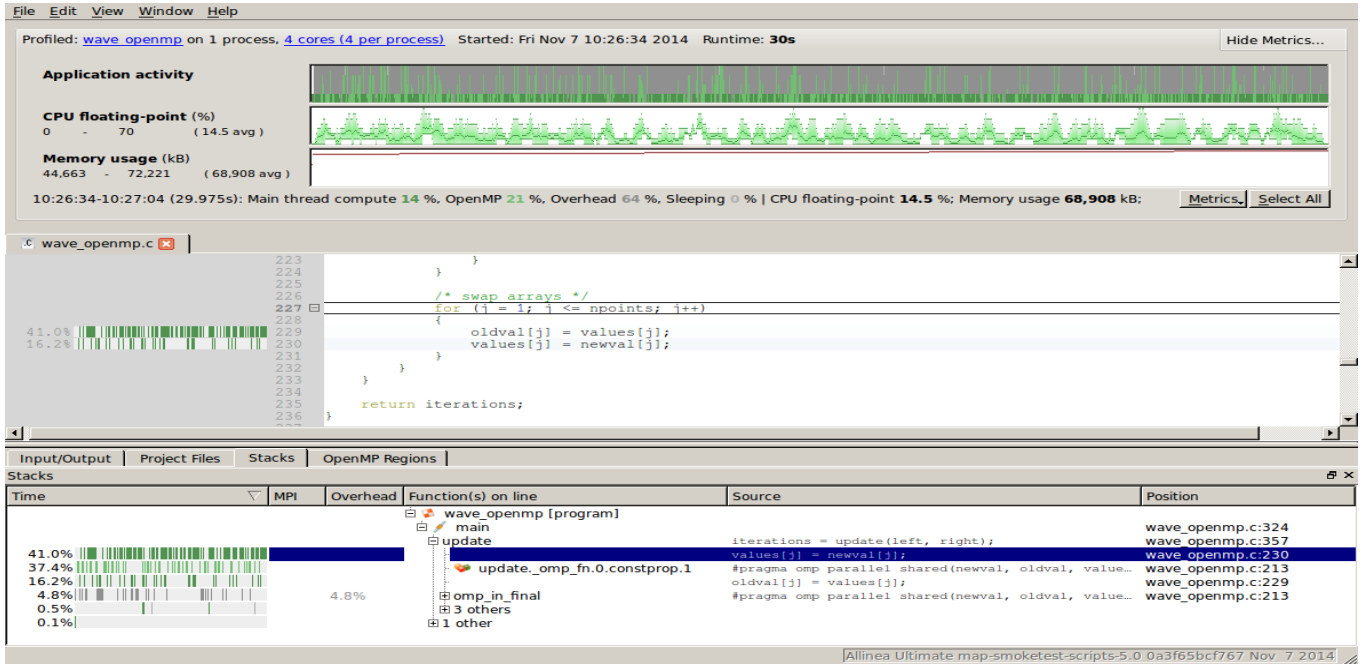
Spot MPI and OpenMP imbalance and overhead

Optimize CPU memory and vectorization in loops

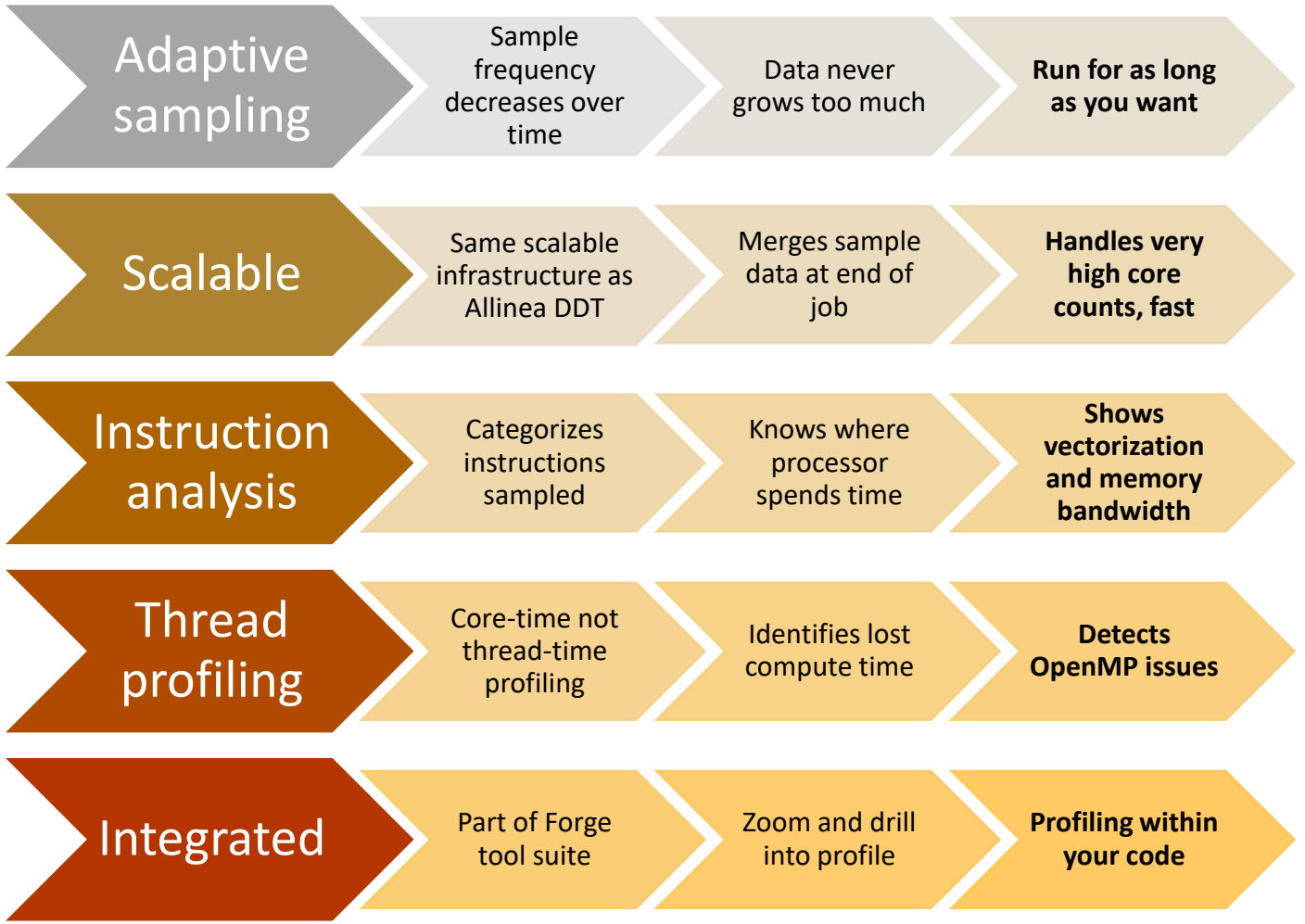
Detect and diagnose I/O bottlenecks at real scale

Allinea MAP – The Profiler

- Small data files
- <5% slowdown
- No instrumentation
- No recompilation



How Arm MAP is different



Preparing Code for Use with MAP

- To see the source code, the application should be compiled with the debug flag typically **`-g`**
- It is recommended to *always* keep optimization flags on when profiling

Basic Arm Map Profiling Example

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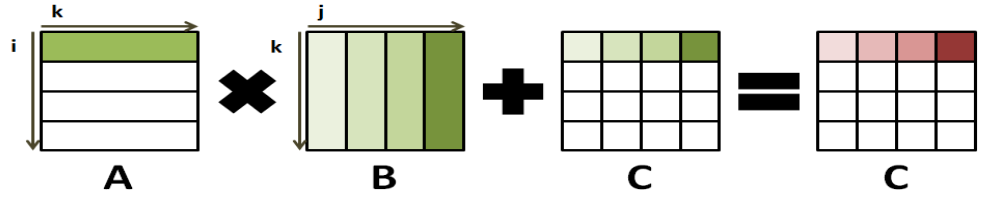
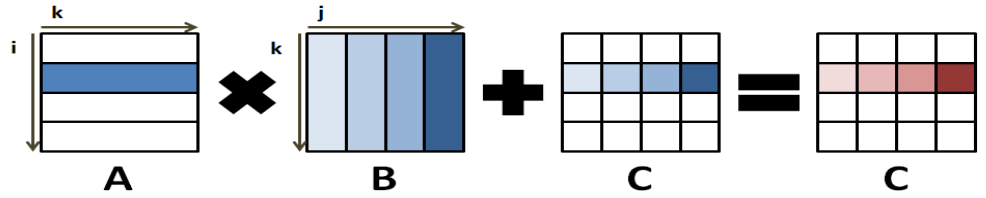
Matrix Multiplication Example

C = A x B + C

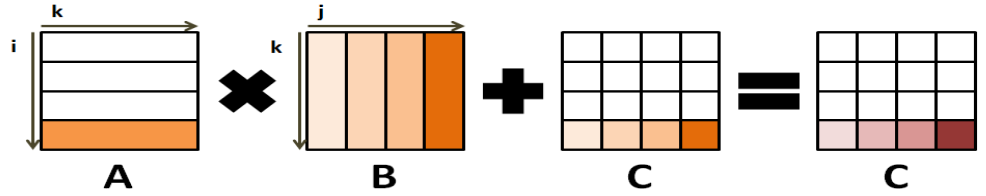
Master process



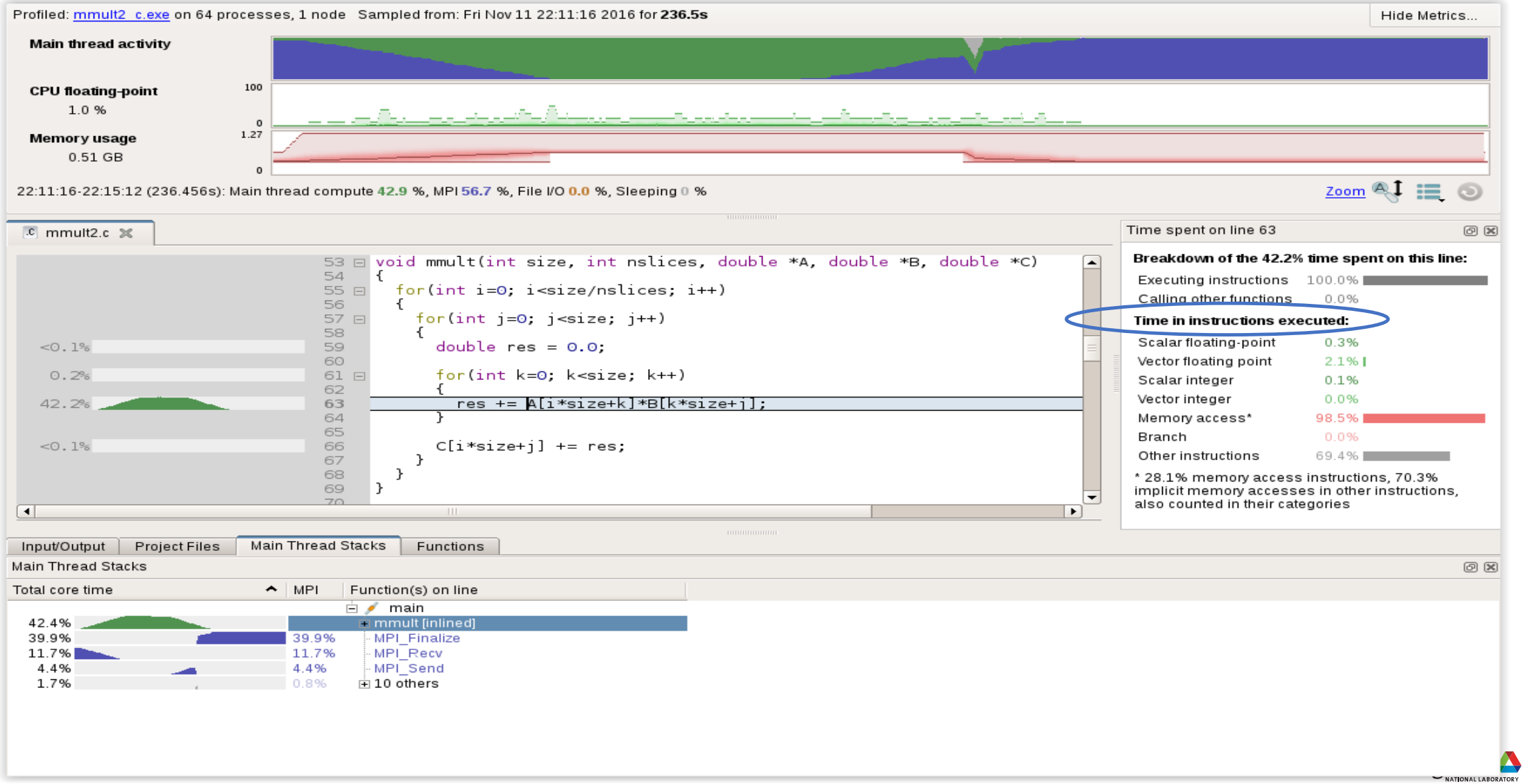
Slave process 1



Slave process n-1



Matrix Multiplication Profile



Enabling Vectorization

The compiler is unable to vectorize efficiently because of the following line in C:

```
res += A[i*size+k]*B[k*size+j];
```

and in F90:

```
res=A(i*size+k)*B(k*size+j)+res
```

rewrite mmult to have

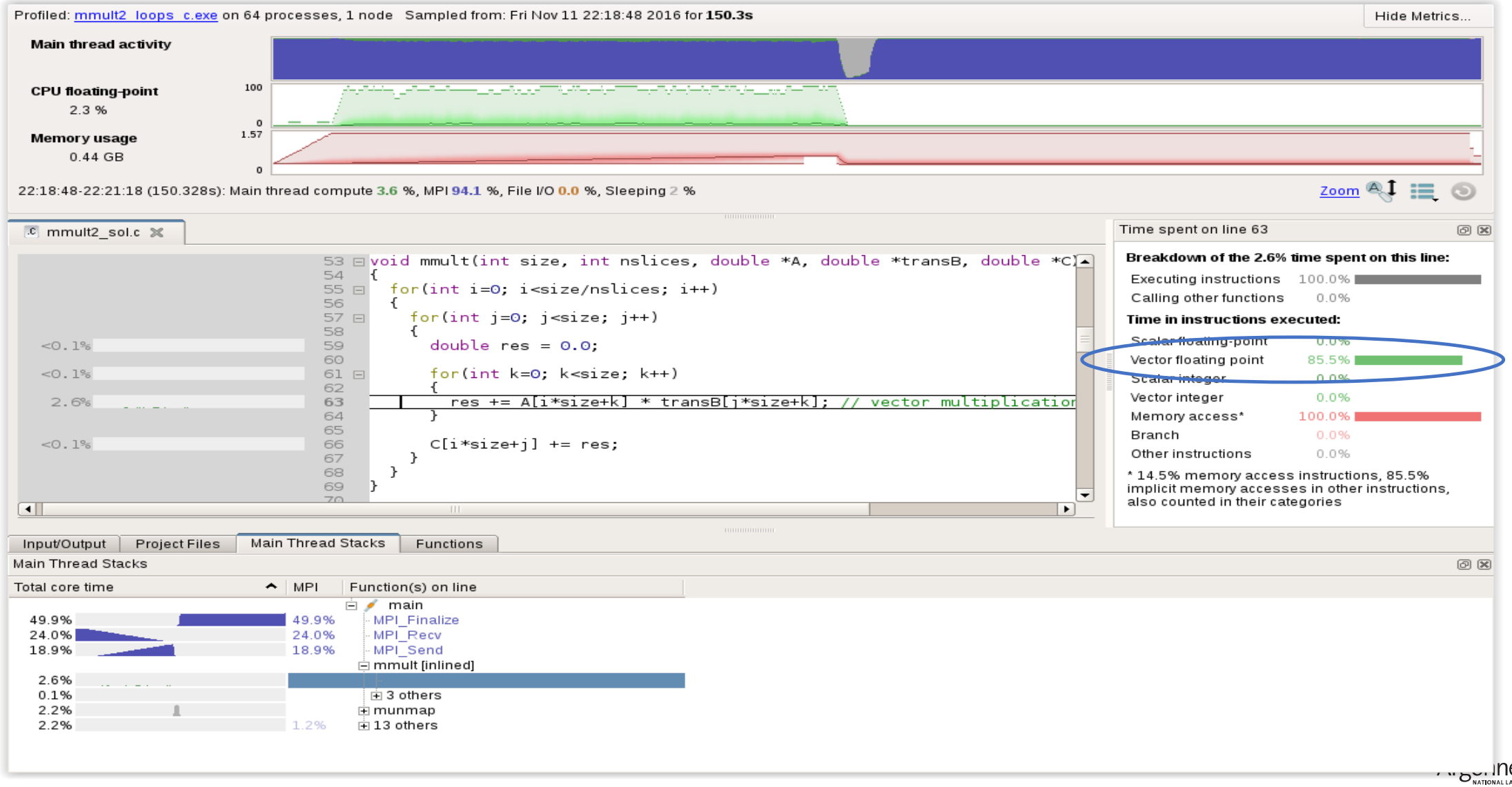
in C:

```
res += A[i*size+k]*transB[j*size+k];
```

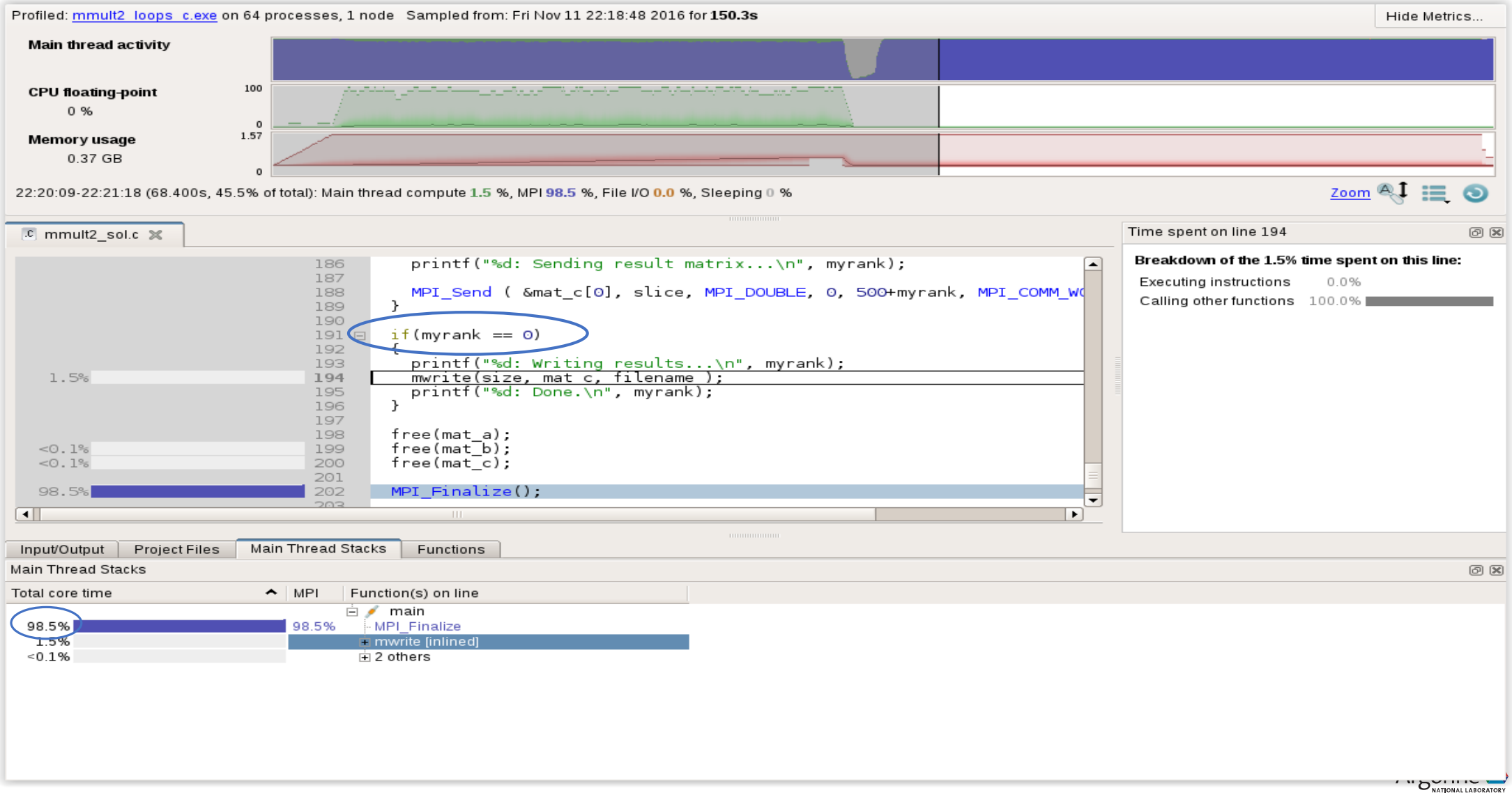
and in F90:

```
res=A(i*size+k)*transB(j*size+k)+res
```

Improving Data Layout and Access Pattern



Serial Bottleneck



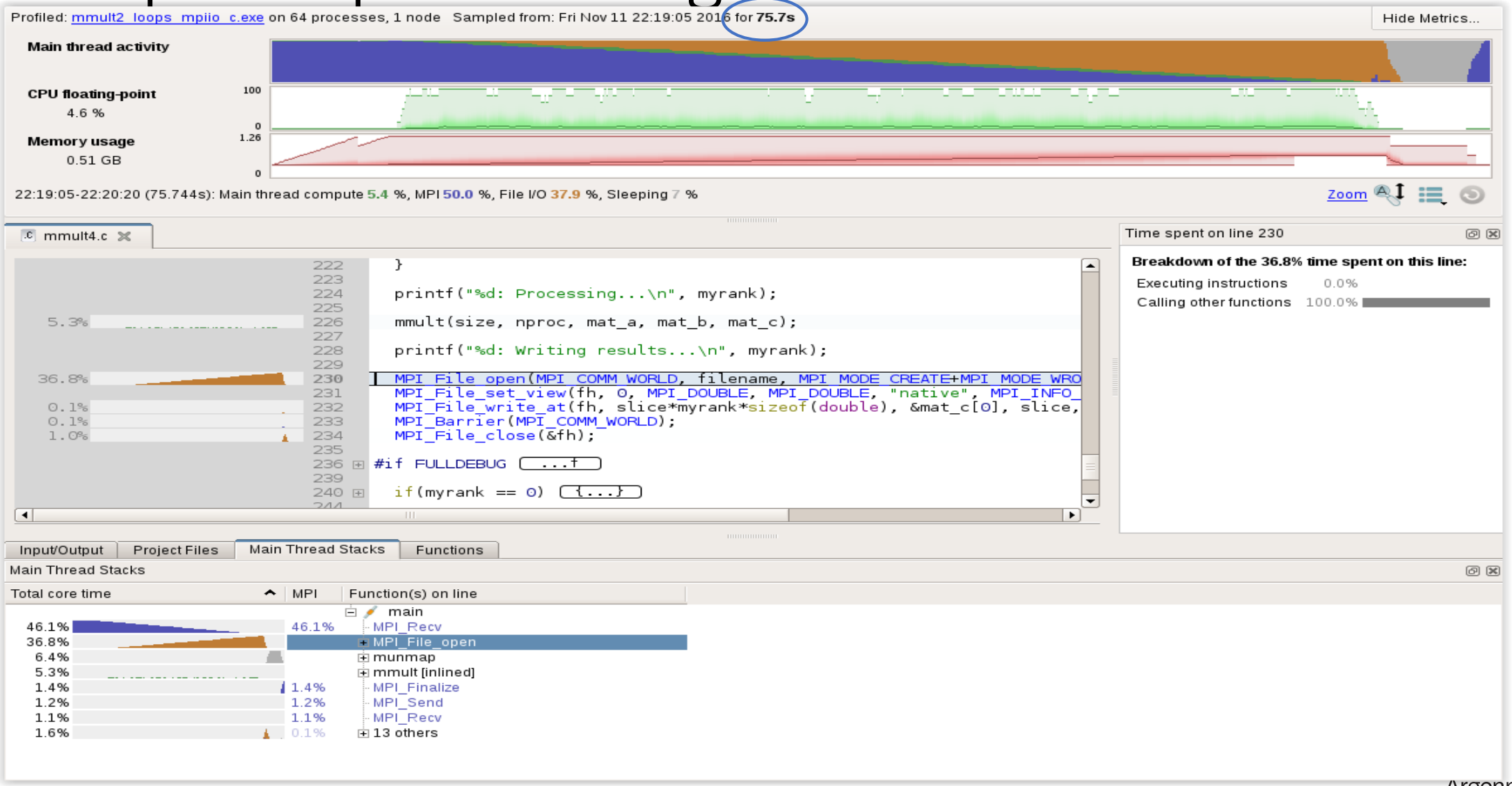
Inefficient I/O

```
if(myrank == 0)
{
  printf("%d: Receiving result matrix...\n", myrank);
  […]
}
else
{
  printf("%d: Sending result matrix...\n", myrank);
  […]
}
if(myrank == 0)
{
  printf("%d: Writing results...\n", myrank);
  mwrite(size, mat_c, filename);
}
```

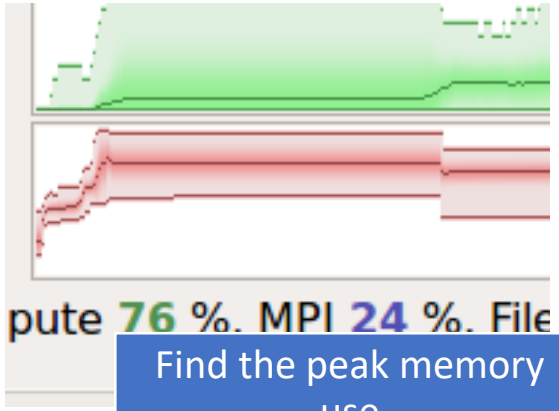
Improve Scalability of I/O Routines

- `printf("%d: Writing results...\n", myrank);`
- `MPI_File_open(MPI_COMM_WORLD, filename, MPI_MODE_CREATE+MPI_MODE_WRONLY, MPI_INFO_NULL, &fh);`
- `MPI_File_set_view(fh, 0, MPI_DOUBLE, MPI_DOUBLE, "native", MPI_INFO_NULL);`
- `MPI_File_write_at(fh, slice*myrank*sizeof(double), &mat_c[0], slice, MPI_DOUBLE, &st);`
- `MPI_Barrier(MPI_COMM_WORLD);`
- `MPI_File_close(&fh);`

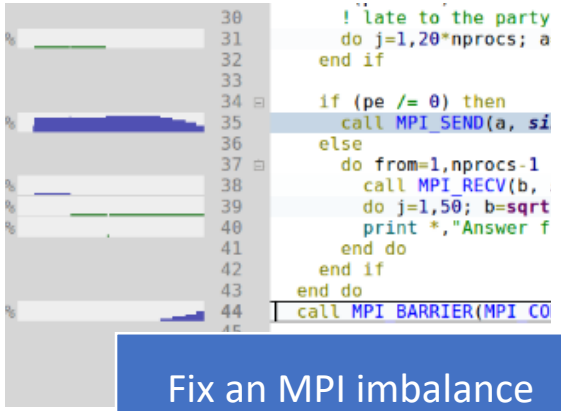
3x Speedup from Original Code



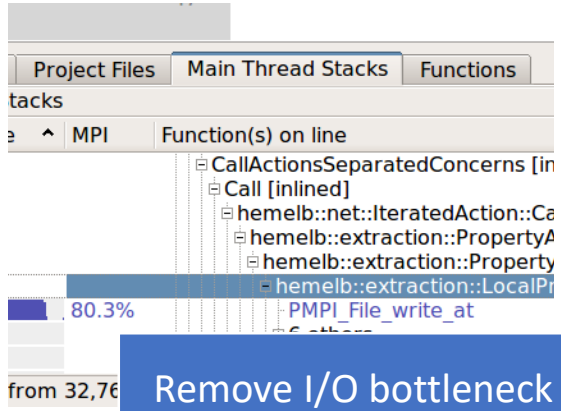
Six Great Things to Try with Arm MAP



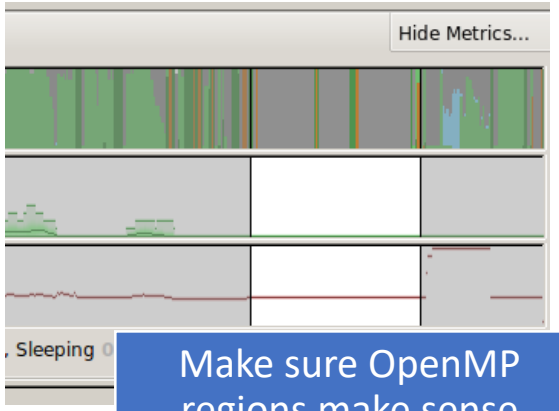
Find the peak memory use



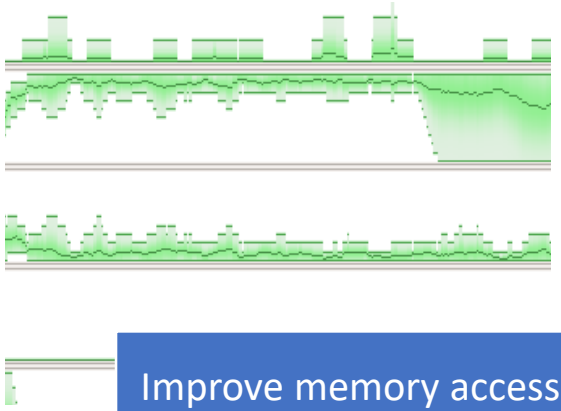
Fix an MPI imbalance



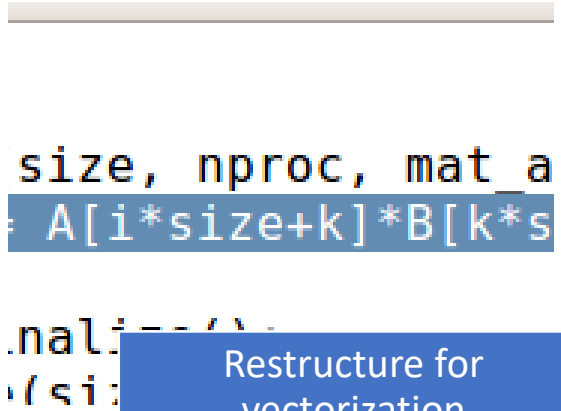
Remove I/O bottleneck



Make sure OpenMP regions make sense



Improve memory access



Restructure for vectorization

Questions?

Hands on Examples

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Arm Hands-on files

- The files for the examples that follow can be obtained on theta at the following location

- **`/projects/SDL_Workshop/arm/arm_handson.tgz`**

- This extracts 2 directories: demonstrations and arm_examples
- The demonstrations are there for you to play with and ask questions
- The examples are more like guided exercises

Launch Remote client

- Be sure to launch the remote client first
- Using a remote launch on your local machine is preferred
- Alternatively you can forward X11 when connecting to the login node of theta, and launch it there

```
module load forge/18.0.2
forge &
```

- If you accidentally close this window (easy to do), you will have to start it again

Hands-on Examples

- These examples are meant to be run on Theta in an interactive session

- **`qsub -I -q training -A SDL_Workshop -t 120 -n 1 --proccount 64`**

- Once a session has been allocated, load the Arm forge module

```
module load forge/18.0.2
```

Before Generating MAP profiles

- Static profiler libraries need to be created before MAP profiles can be generated
- Go to the arm_examples/wrapper directory
- Run

```
make-profiler-libraries --lib-type=static
```

- The Makefiles for the examples have already been modified to look for the profiler libraries in this directory

Go to exercise 1

- Exercise objectives
  - Familiarize with DDT user interface
  - Inspect values of u using multidimensional array viewer
  - Set watchpoint and tracepoint for diffnorm_global
  - Set breakpoint at line 89
- Typical run commands to use:

```
$> cd arm_examples/1_debug/
$> make
```

- Key DDT commands

```
On the login node:
$> forge &
In a submission file/interactive job:
$> ddt --connect aprun -n 4 ./jacobi.exe
```

Use Arm Forge to vectorize your codes

CPU

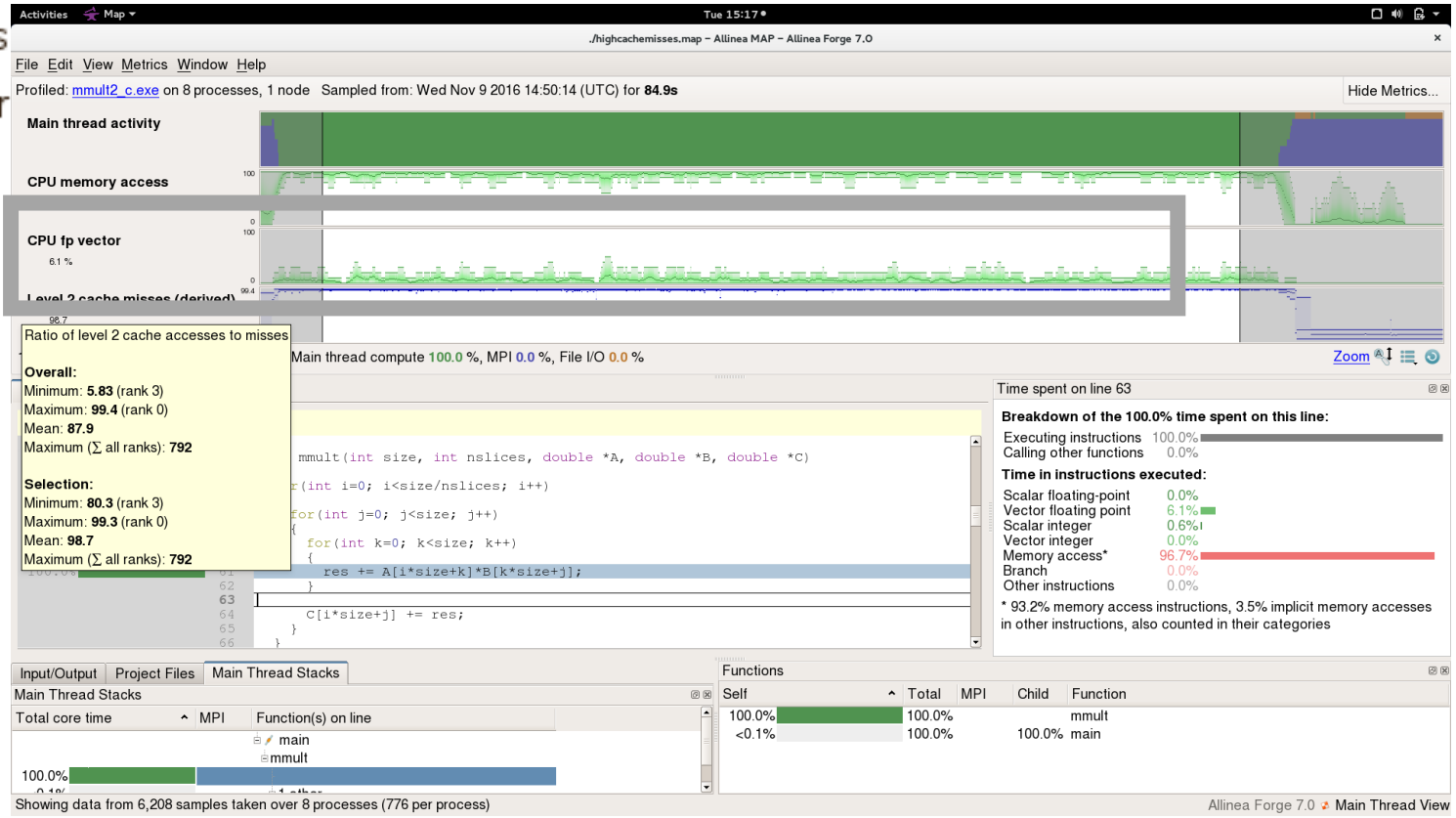
A breakdown of the 70.2% CPU time:

Scalar numeric ops 2.5%

Vector numeric ops 0.0%

Memory accesses

Waiting for acceler



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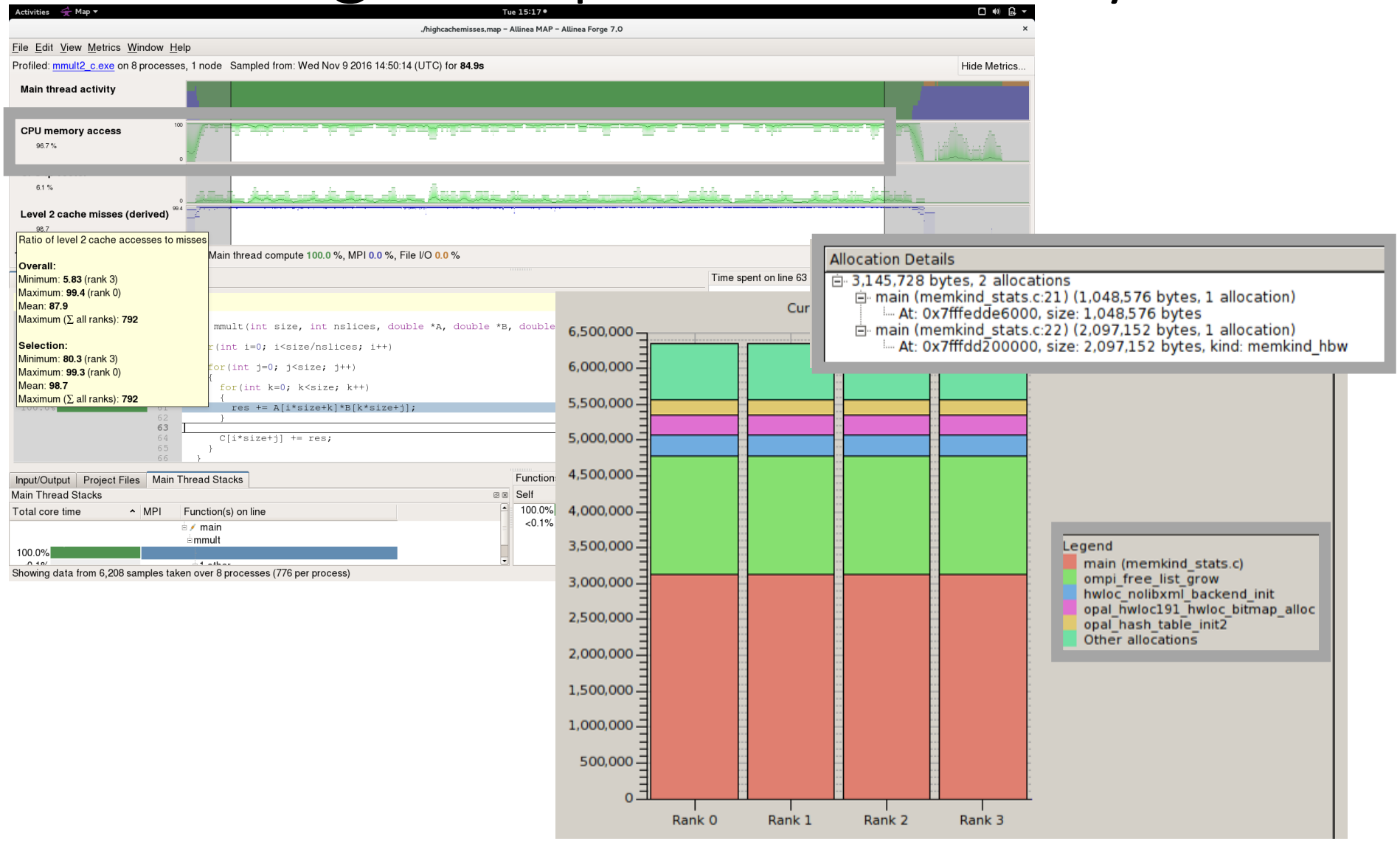
Use Arm Forge to optimize memory access



Go to exercise 2

- Exercise objectives
  - Generate initial baseline profile
  - Ensure the matrices are stored in the MCDRAM (if applicable)
  - Fix the inefficient memory access issues
  - Further enable vectorization with Intel compiler flag **`-xMIC-AVX512`**
  - Generate profile with MAP after applying changes
- Typical run commands to use:

```
$> cd arm_examples/2_memory_accesses/
$> make
```

- Key Map commands

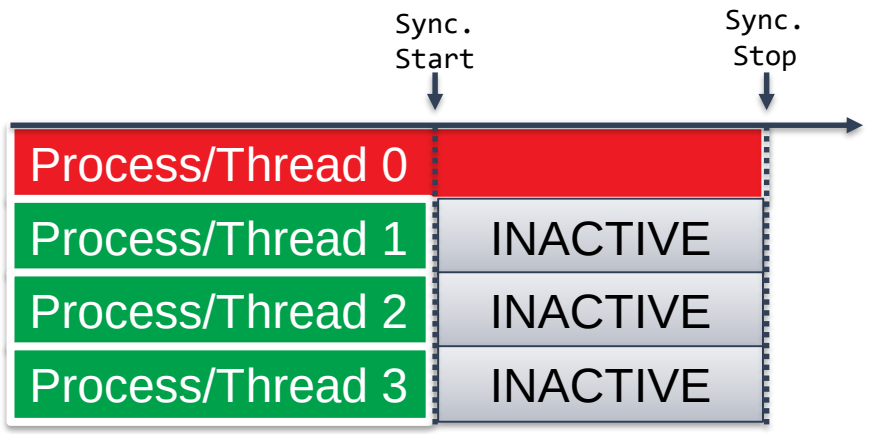
```
On the login node:
$> forge &
In a submission file/interactive job:
$> map --profile aprun -n 64 ./mmult2_c.exe
$> map --connect ./mmult2_c_*.map
```

How to identify load balancing issues?

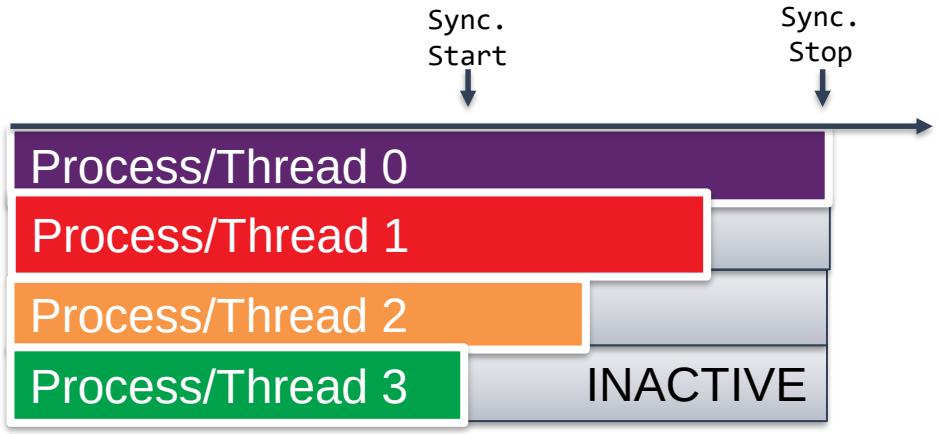
Problem: “one or some process(es) have too much work”

Clues visible in synchronization

- MPI Collective calls (MPI_Barrier, _Broadcast, etc.) with no actual data transfer
- Idle cores where threads are stuck in locks/mutexes

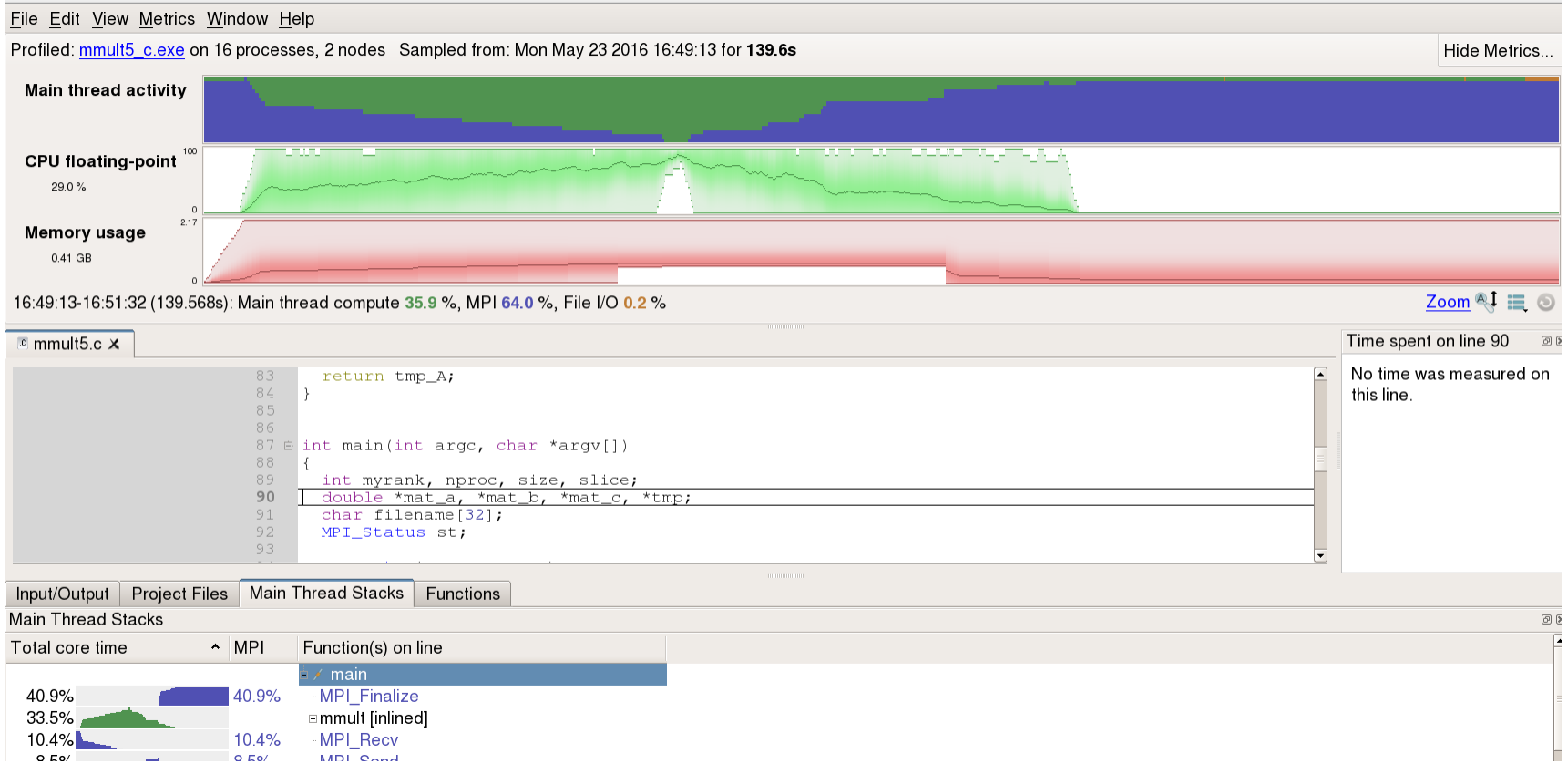



```
Total runtime: 100 sec
Total CPU time available: 400 sec
Total CPU time actually used: 250 sec
Efficiency: 62.5% of the machine time
```




```
Total runtime: 100 sec
Total CPU time available: 400 sec
Total CPU time actually used: 300 sec
Efficiency: 75% of the machine time
```

Use Arm MAP to balance your workloads



Go to exercise 3

- Exercise objectives
  - Expose workload imbalance issues in the code (preferably on 2 nodes)
  - Make suggestions to fix the problem
- Typical run commands to use:

```
$> cd arm_examples/3_imbalance/
$> make
```

- Key Map commands

```
$> map --profile aprun -n 64 ./mmult4_c.exe
$> map --connect mmult4_c_*.map
```

Go to exercise 4

Sometimes optimizations introduce bugs of their own

- Exercise objectives
  - Use ddt in offline mode to detect memory leaks
  - Examine the debug_report.txt file
  - Fix the leak
  - Generate new report
- Typical run commands to use:

```
$> cd arm_examples/4_memory_leak/
$> make
```

- Key ddt commands

```
$> ddt --offline --mem-debug --output=debug_report.txt aprun -n 4
   ./mmult6_c.exe
```

Solutions to Exercises

- Solutions to these exercises can be found in the **`.solution`** directory in each of the exercises