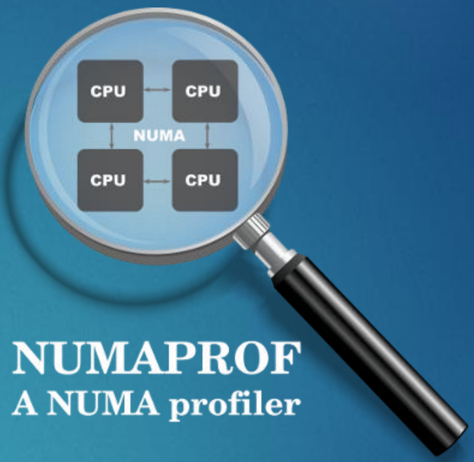


MALT & **NUMAPROF**, Memory Profiling for HPC Applications

SÉBASTIEN VALAT – FOSDEM 2019 – TRACK HPC

Origin of the tools

- **PhD.** on **memory management** for **HPC** (at CEA/UVSQ)
- **MALT**, post-doc at Versailles :

Exascale
computing research

- **NUMAPROF**, side project post-doc work at :

CERN

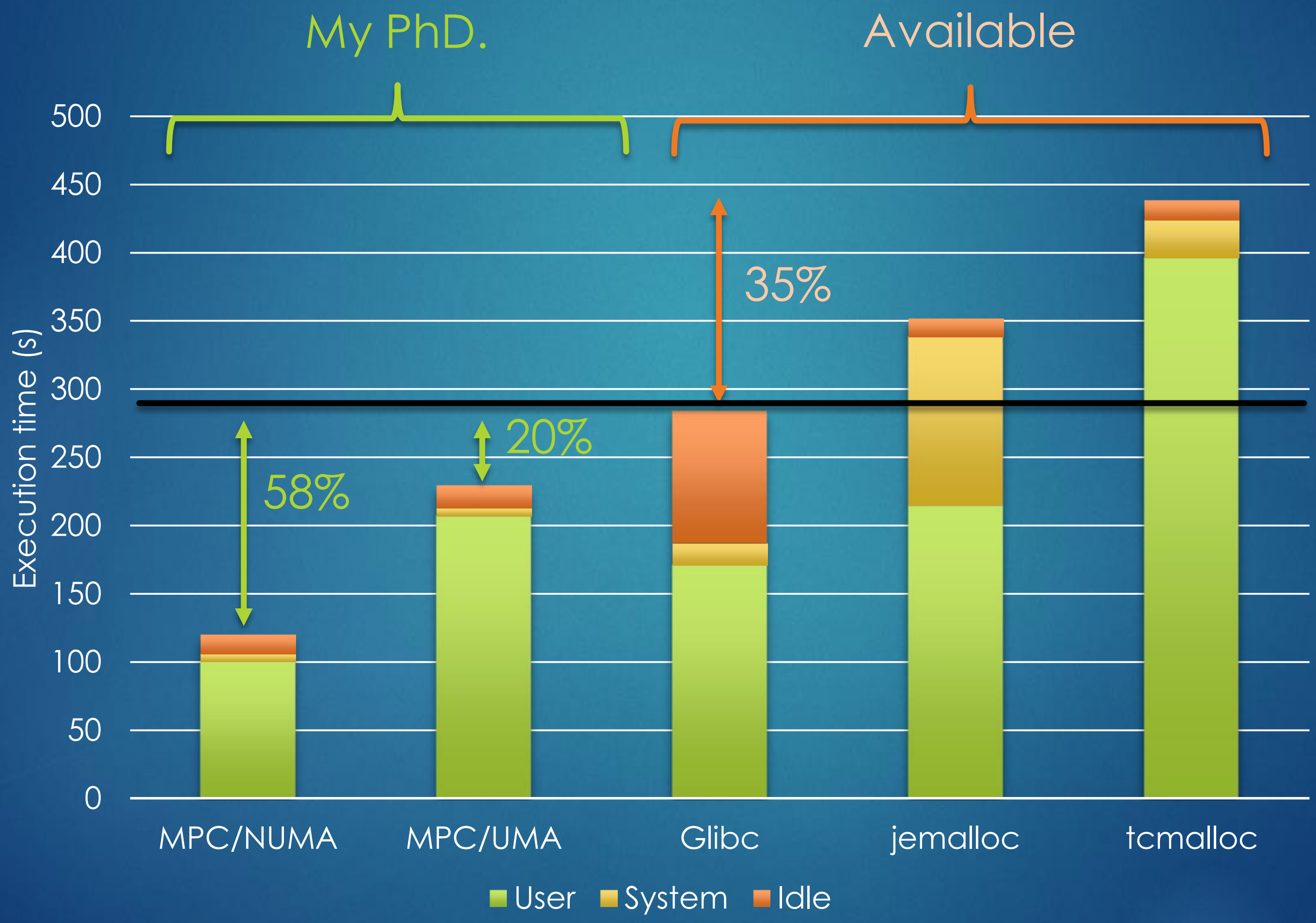
Motivation

- Lot of **issues** today :
  - **Huge** memory **space** to **manage** (~TB of memory)
  - **Lot more** distinct **allocations** (75 M in 5 minutes)
  - **Multi-threading** : 256 threads
  - **Hidden** into large (**huge**) C/C++/Fortran **codes** (**~1M** lines).
- Access:
  - **NUMA** (Non Uniform Memory Access)
  - **Memory wall** !

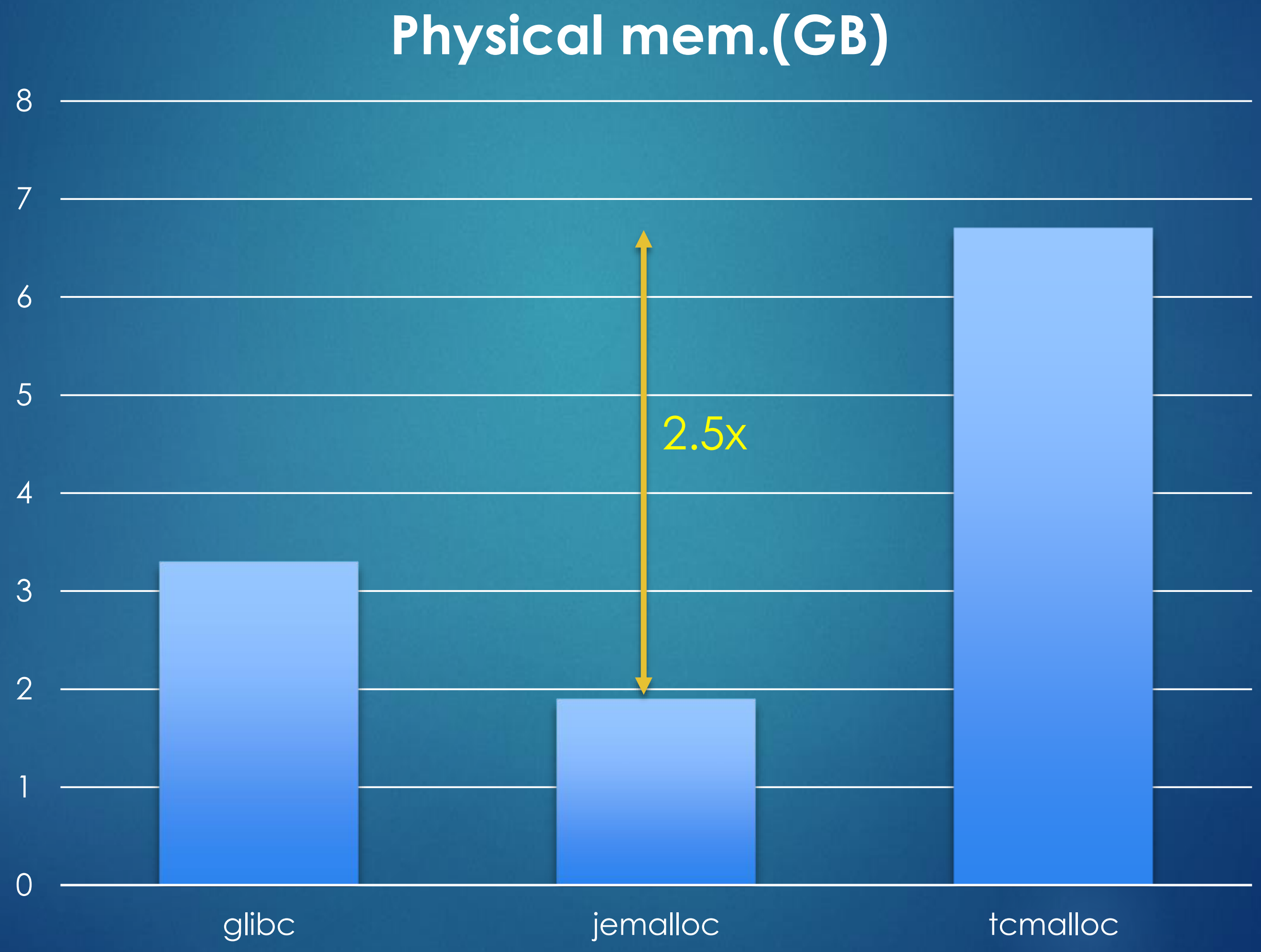
Key today

You need to **well understand memory behavior** of your *(HPC)* application !

Eg: **>1M lines** C++ simulation. On **128** cores / **16** NUMA CPUs



Same about **memory consumption** on 12 cores



Tool 1 : **MALT**

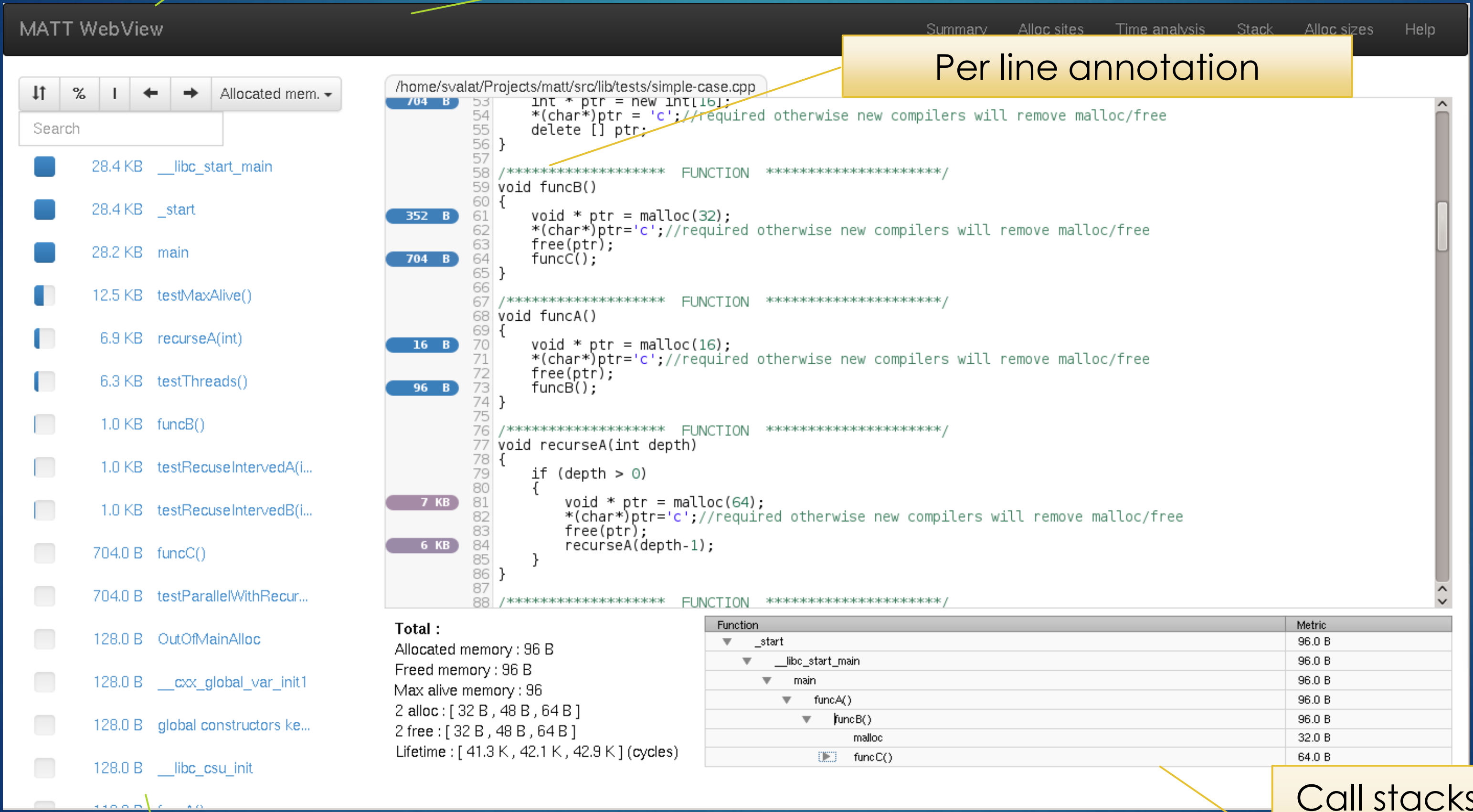
- **Memory management** can have **huge impact**
- Tool to **track mallocs**
- Report **properties** onto **annotated sources**

- Same **idea** than **valgrind/kcachegrind**
  - Annotated sources
  - Annotated call graphs
  - **+ Non additive metrics** (for inclusive costs, eg. lifetime)
  - **+ Time charts**
  - **+ Properties distribution (sizes….)**

Web based GUI

Inclusive/Exclusive

Metric selector



Per line annotation

28.4 KB	__libc_start_main
28.4 KB	_start
28.2 KB	main
12.5 KB	testMaxAlive()
6.9 KB	recurseA(int)
6.3 KB	testThreads()
1.0 KB	funcB()
1.0 KB	testRecuseIntervedA(i...
1.0 KB	testRecuseIntervedB(i...
704.0 B	funcC()
704.0 B	testParallelWithRecur...
128.0 B	OutOfMainAlloc
128.0 B	__cxx_global_var_init1
128.0 B	global constructors ke...
128.0 B	__libc_csu_init

/home/svalat/Projects/matt/src/lib/tests/simple-case.cpp

```
 704  B      int * ptr = new int[16];
             *(char*)ptr = 'c';//required otherwise new compilers will remove malloc/free
             delete [] ptr;
           }

           /*******************  FUNCTION  *********************/
           void funcB()
           {
 352  B        void * ptr = malloc(32);
               *(char*)ptr='c';//required otherwise new compilers will remove malloc/free
               free(ptr);
 704  B        funcC();
           }

           /*******************  FUNCTION  *********************/
           void funcA()
           {
  16  B        void * ptr = malloc(16);
               *(char*)ptr='c';//required otherwise new compilers will remove malloc/free
               free(ptr);
  96  B        funcB();
           }

           /*******************  FUNCTION  *********************/
           void recurseA(int depth)
           {
               if (depth > 0)
               {
 7 KB              void * ptr = malloc(64);
                   *(char*)ptr='c';//required otherwise new compilers will remove malloc/free
                   free(ptr);
 6 KB              recurseA(depth-1);
               }
           }

           /*******************  FUNCTION  *********************/
```

Total :
Allocated memory : 96 B
Freed memory : 96 B
Max alive memory : 96
2 alloc : [32 B , 48 B , 64 B]
2 free : [32 B , 48 B , 64 B]
Lifetime : [41.3 K , 42.1 K , 42.9 K] (cycles)

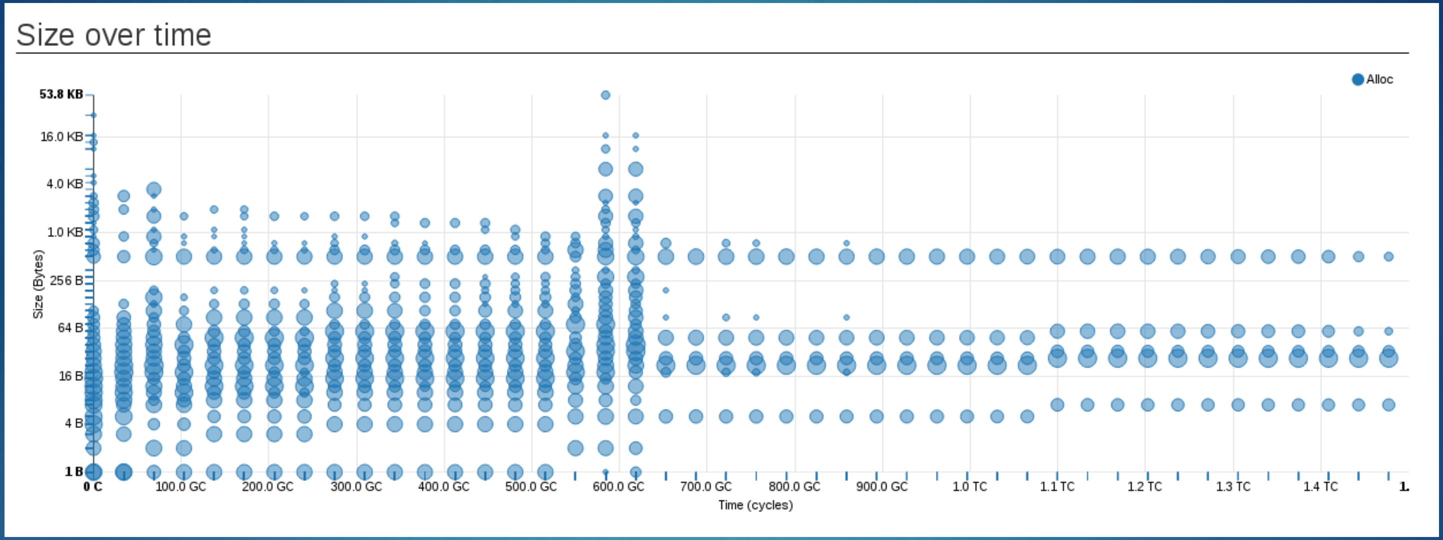
Function	Metric
▼ _start	96.0 B
▼ __libc_start_main	96.0 B
▼ main	96.0 B
▼ funcA()	96.0 B
▼ funcB()	96.0 B
malloc	32.0 B
▶ funcC()	64.0 B

Symbols

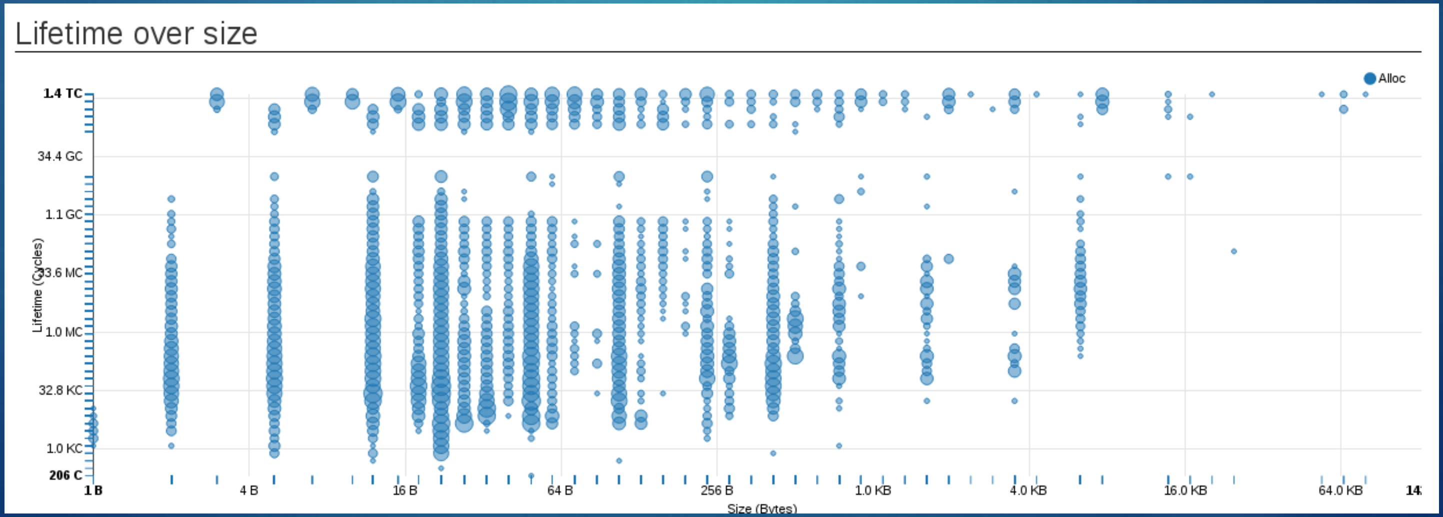
Details of symbol or line

Call stacks reaching the selected site.

Example of time based view



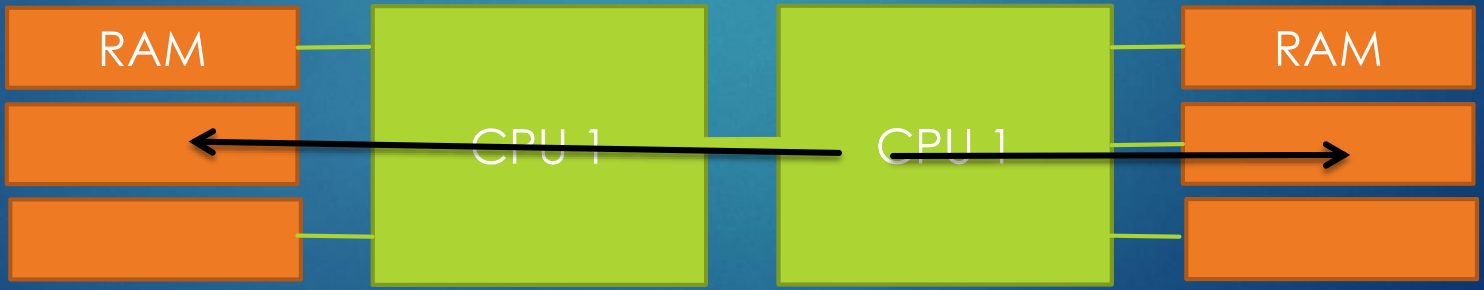
Size over time



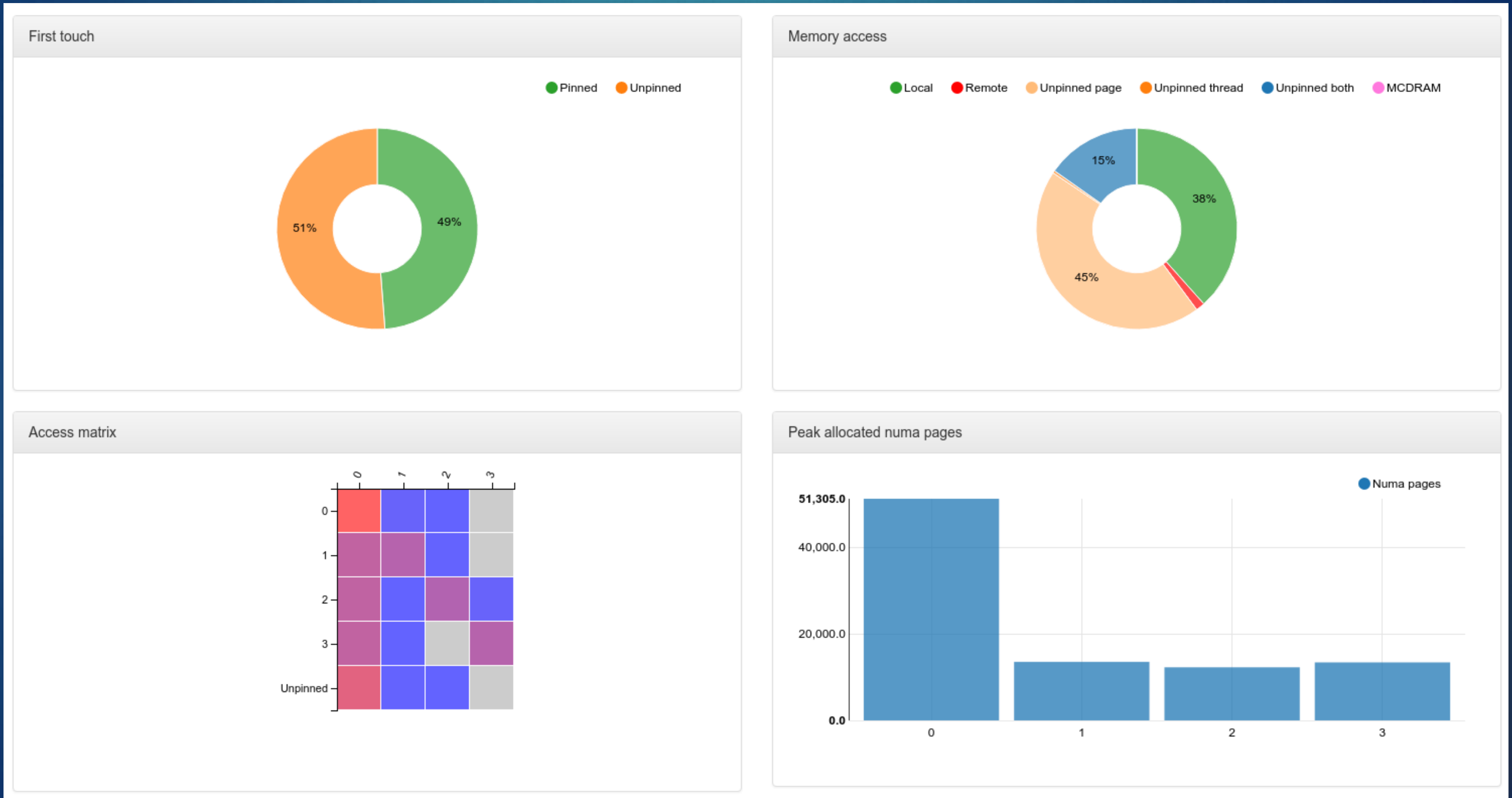
Lifetime over size

Tool 2 : **NUMAPROF**

- Based on MALT code
- But about **NUMA**
- How to **detect remote** memory **accesses**
- Unsafe & **uncontrolled memory binding**



Some summary views



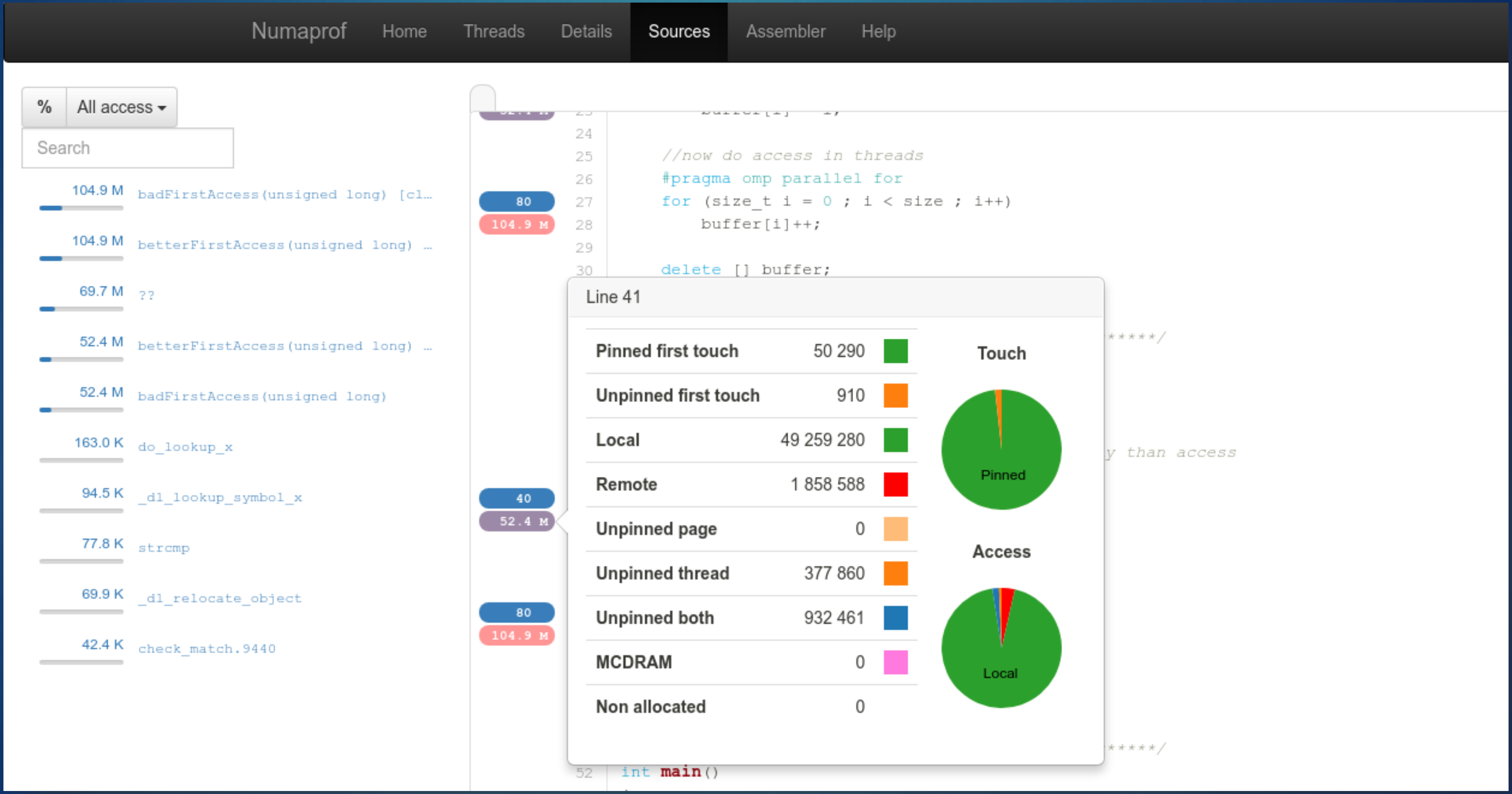
First touch

Memory access

Access matrix

Peak allocated numa pages

Still source annotation to understand code



104.9 M	badFirstAccess(unsigned long) [cl…
104.9 M	betterFirstAccess(unsigned long) …
69.7 M	??
52.4 M	betterFirstAccess(unsigned long) …
52.4 M	badFirstAccess(unsigned long)
163.0 K	do_lookup_x
94.5 K	_dl_lookup_symbol_x
77.8 K	strcmp
69.9 K	_dl_relocate_object
42.4 K	check_match.9440

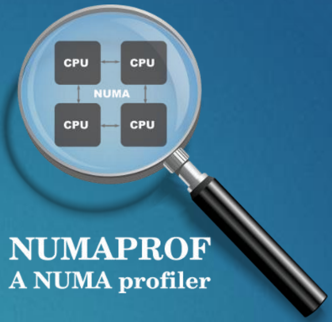
```
    //now do access in threads
    #pragma omp parallel for
    for (size_t i = 0 ; i < size ; i++)
        buffer[i]++;

    delete [] buffer;
*****/
y than access
*****/
int main()
```

Line 41

Pinned first touch	50 290	🟩
Unpinned first touch	910	🟧
Local	49 259 280	🟩
Remote	1 858 588	🟥
Unpinned page	0	🟧
Unpinned thread	377 860	🟧
Unpinned both	932 461	🟦
MCDRAM	0	🟪
Non allocated	0	

Short success

- MALT
  - **20%** CPU saving on my **CERN 32 000** C++ code.
  - Improvement on **2 commercial simulation** codes
  - Profiled **CERN LHCb 1.5 million** line C++ code
- NUMAPROF
  - **20% perf in 20 minutes** on 8000 lines simu.
  - NUMA **Linux kernel policy bug** detected.
  - CERN PhD. code **NUMA correctness**



Questions

Both tools under CeCILL-C on http://memtt.github.io

My researches : http://svalat.github.io

Example of success
MALT

- Reduce **CPU usage** of **30%** on the CERN app I was developing (mistake with C++11 `for(auto & it : lst)`)
32 000 C++ lines running on 500 servers.
- **Too large allocations** in a PhD. Student numerical simulation running on 500 cores while developing the tool.
- **Realloc pattern** in Fortran into **an industrial** R&D simulation code
- Unexpected **allocs generated** by GFortran **compiler** on another **industrial** R&D simulation **code**.
- Successfully ran on **CERN LHCb 1.5M lines** online analysis software

Example of success NUMAPROF

- **20% performance improvement** in 20 minutes on an unknown 8000 C++ lines simulation on Intel KNL
- **Linux Kernel bug** detected on NUMA management in conjunction with Transparent Huge Pages (while developing the tool).
  Was detected at same time by other way by Red-Hat…. But…..
- **Confirmation** of NUMA **correctness** on a CERN/OpenLab PhD. Student code on Intel KNL