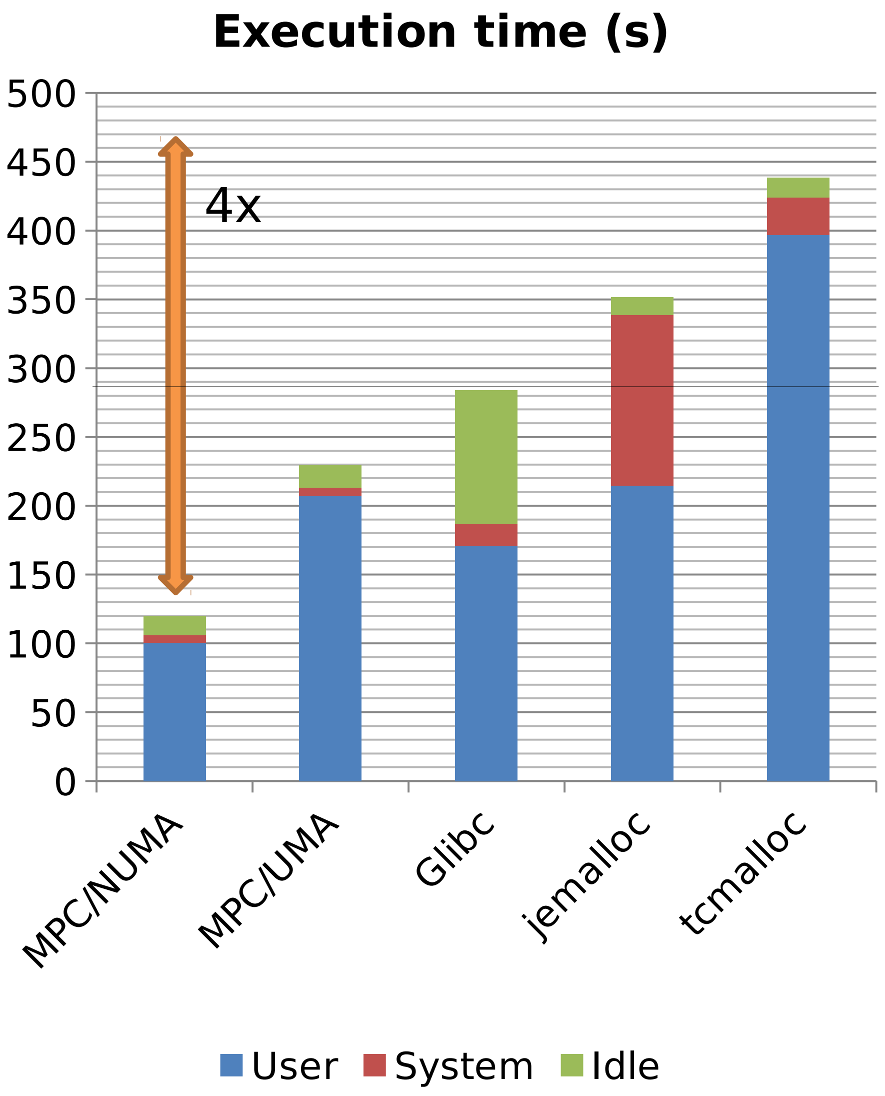
MALT : MALloc Tracker

A memory profiling tool

Possibly huge impact

- **Memory management** can have **huge impact** on performance

- **Extreme case** on a **1.5 million** C++ lines **HPC simulation** app. on a **16 processors** server



Questions

- We have **good profiling tool** for **timings** (eg. Valgrind or *vtune*)
- But for what **memory profiling**?
- Memory can be an issue :
  - **Availability** of the resource
  - **Performance**
- Three main questions :
  - How to reduce **memory footprint** ?
  - How to improve overhead of **memory management** ?
  - How to improve **memory usage** ?

Some issue examples

- I wanted to point :
  - **Where** memory is allocated.
  - **Properties** of allocated chunks.
  - **Bad** allocation **patterns** for performance.

```
__thread Int gblVar[SIZE];
int * func(int size)
{
	child_func_with_allocs();
	void * ptr = new char[size];
	double* ret = new double[size*size*size];
	for (auto it : iter_Items)
	{
		double* buffer = new double[size];
		//short and quick do stuff
		delete [] buffer;
	}
	return ret;
}
```

Global variables and TLS

Indirect allocations

Leak

Might lead to swap for large size

C++11 auto induced allocs

Short life allocations

What I want to provide

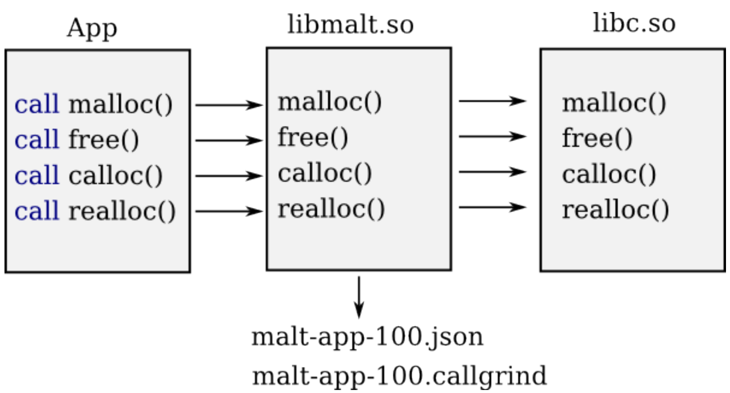
- Same **approach** than **valgrind/kcachgind**

- **Mapped** allocations on **sources lines** and **call stacks**

- **Using a web-based GUI**
  - I started with kcachgrind
  - But wanted more flexibility and time charts

How it works

- Use **LD_PRELOAD** to intercept **malloc/free/...** as Google heap profiler



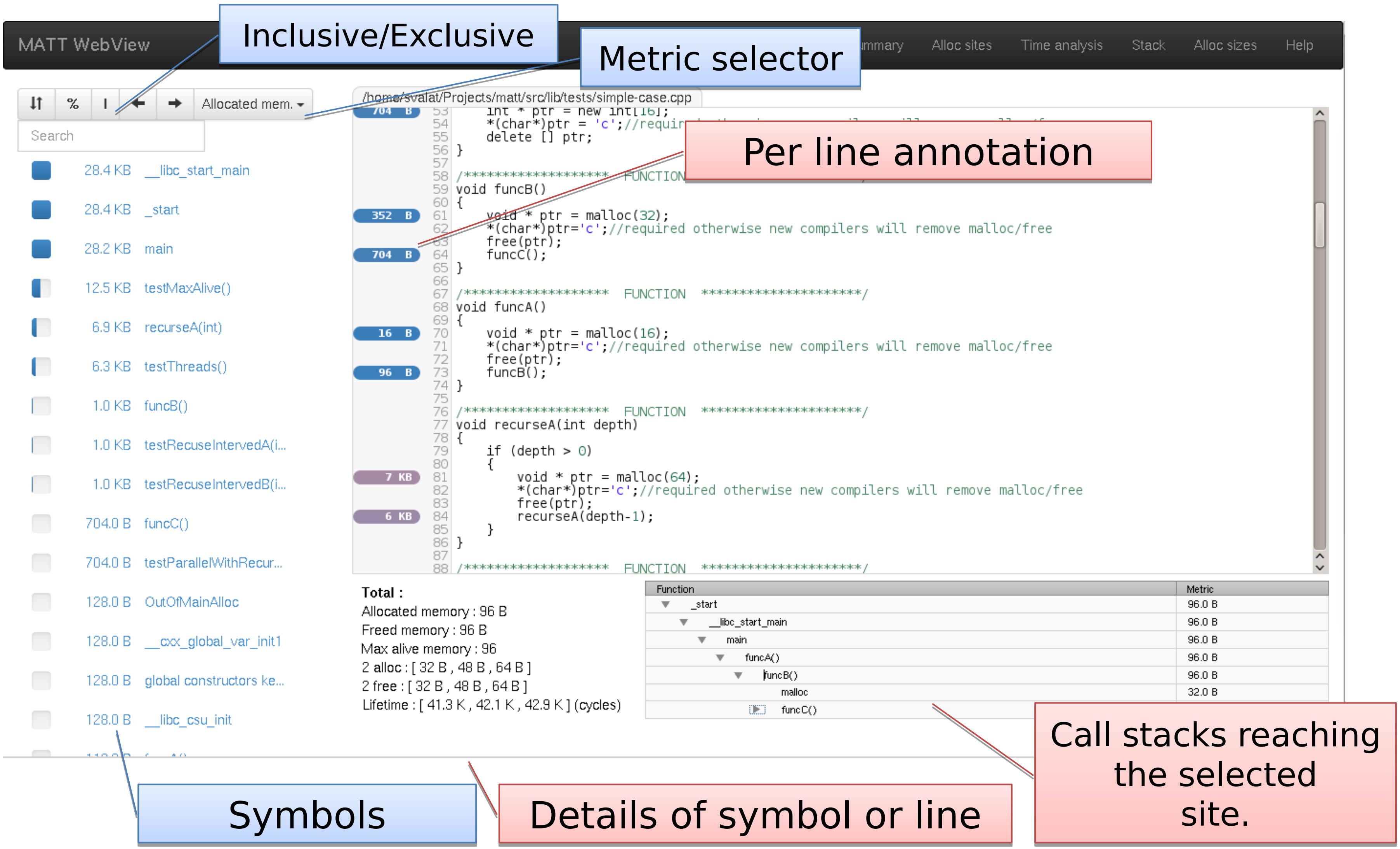
- **Map** allocations on **call stacks**

- **Build & consolidate summary** metrics

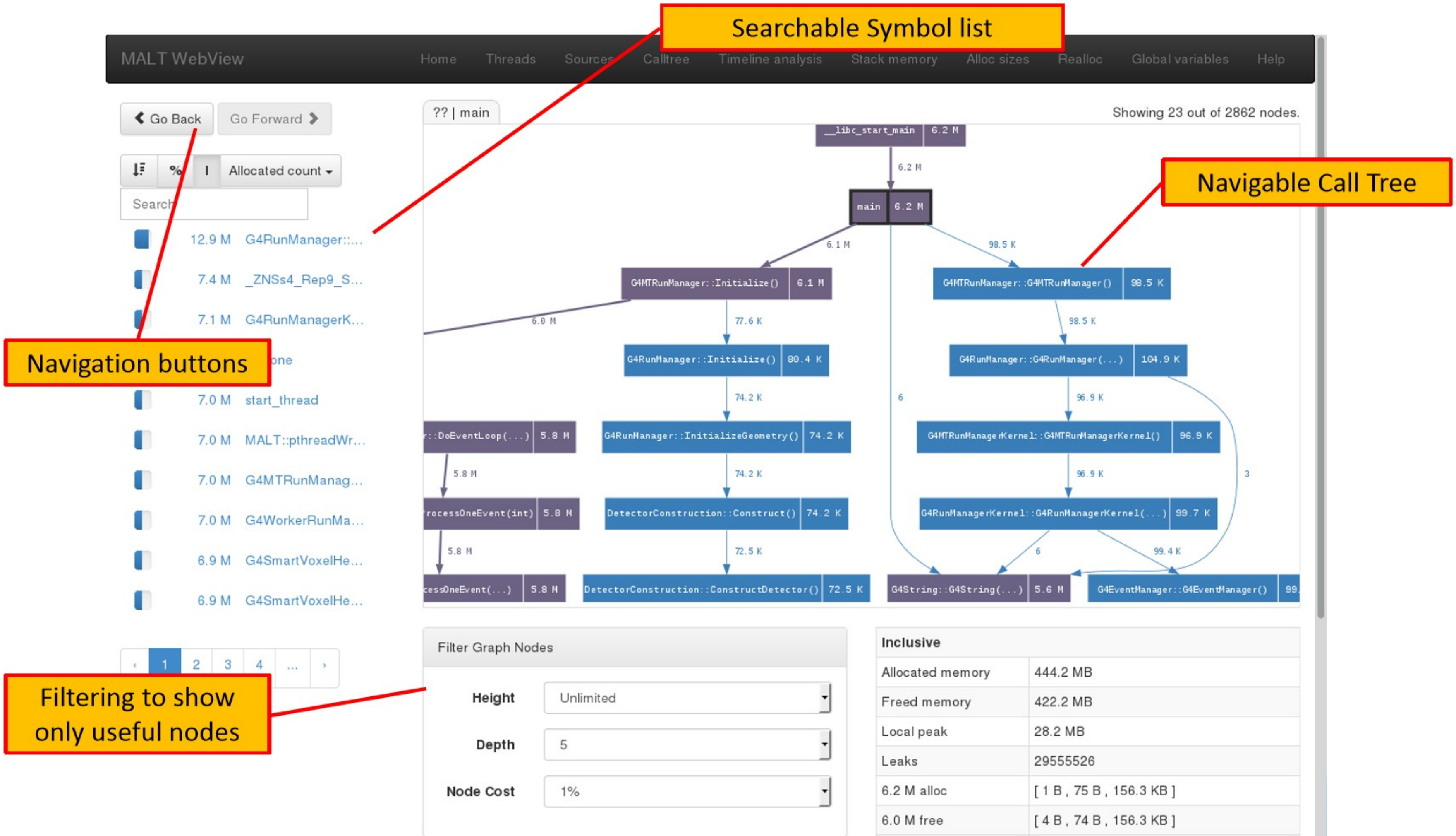
- Generate **JSON** output file

Source annotations

Web technology (**NodeJS**, **D3JS**, **Jquery**, **AngularS**)

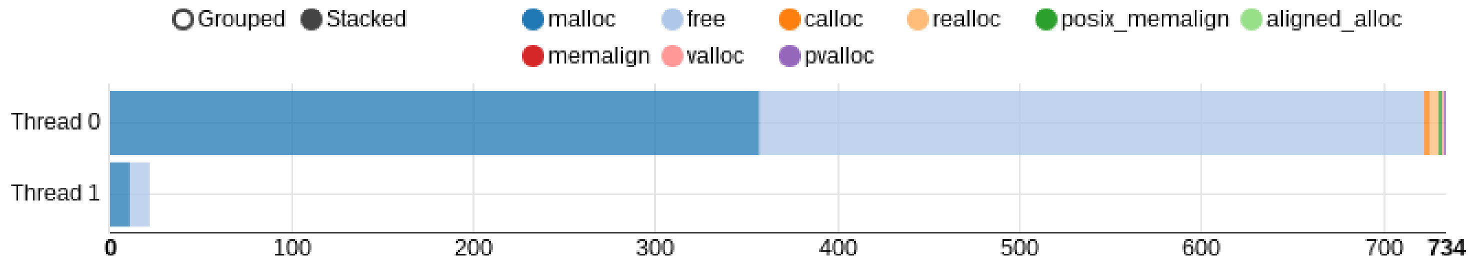


Call tree view

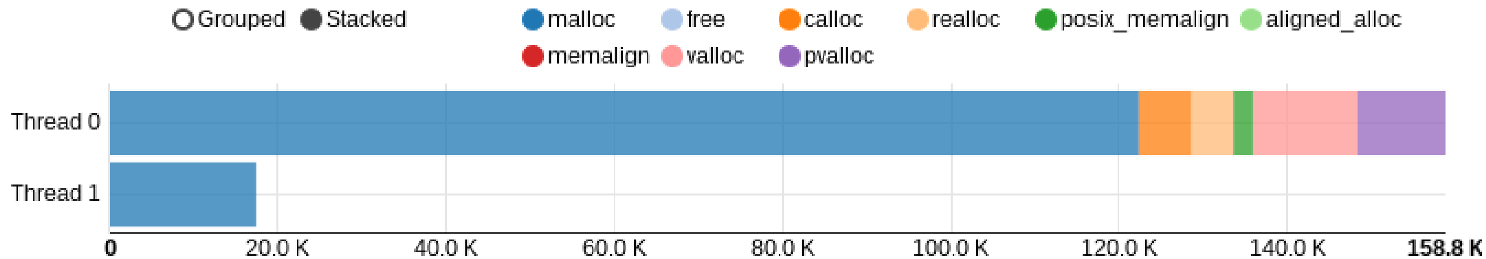


Per thread statistics

Call per thread



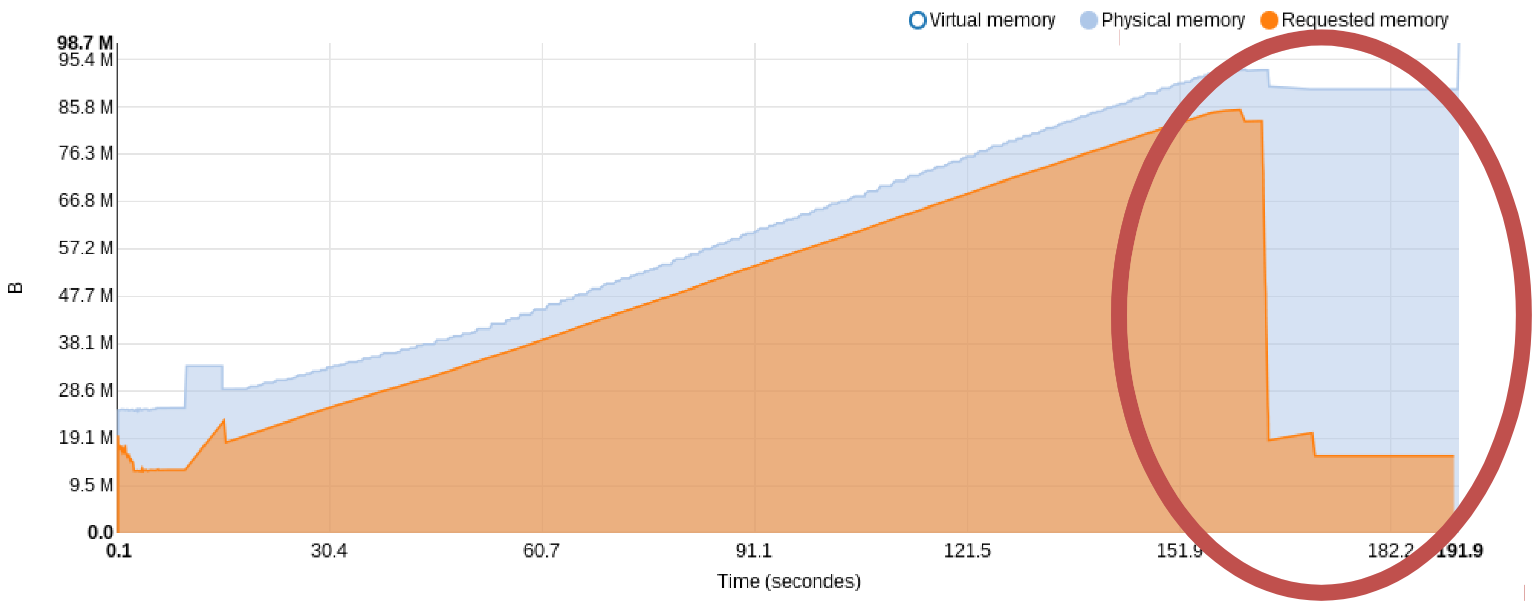
Time per thread



Fragmentation issue

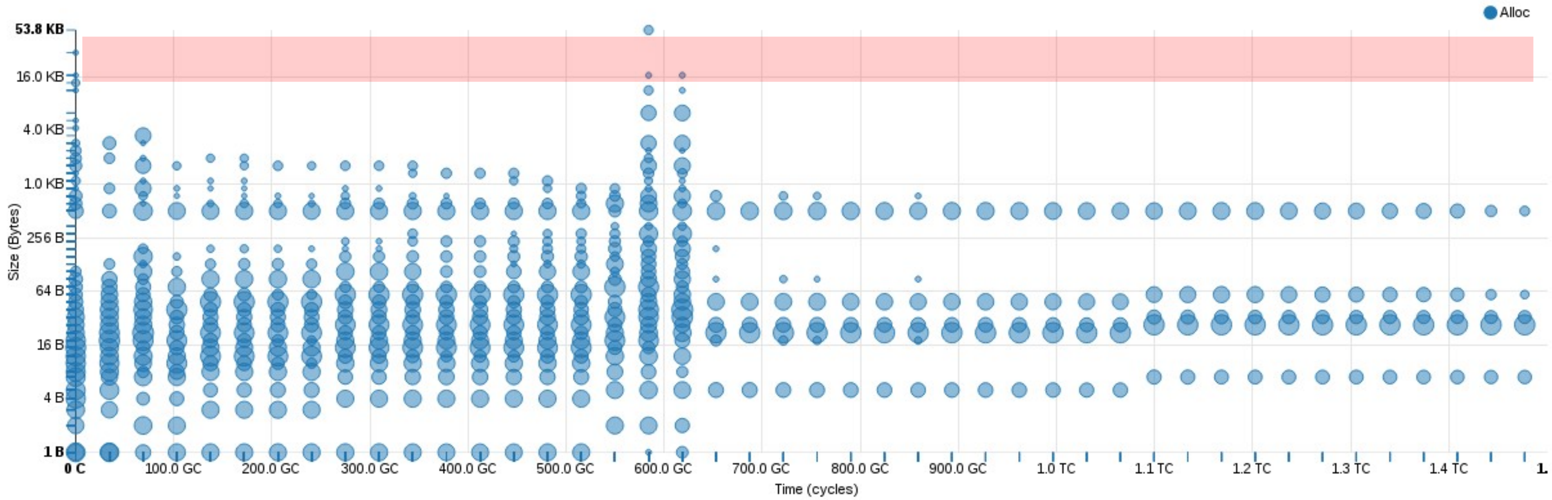
- Memory consumption over time
  - Physical
  - Virtual
  - Requested (malloced)

Memory allocated over time

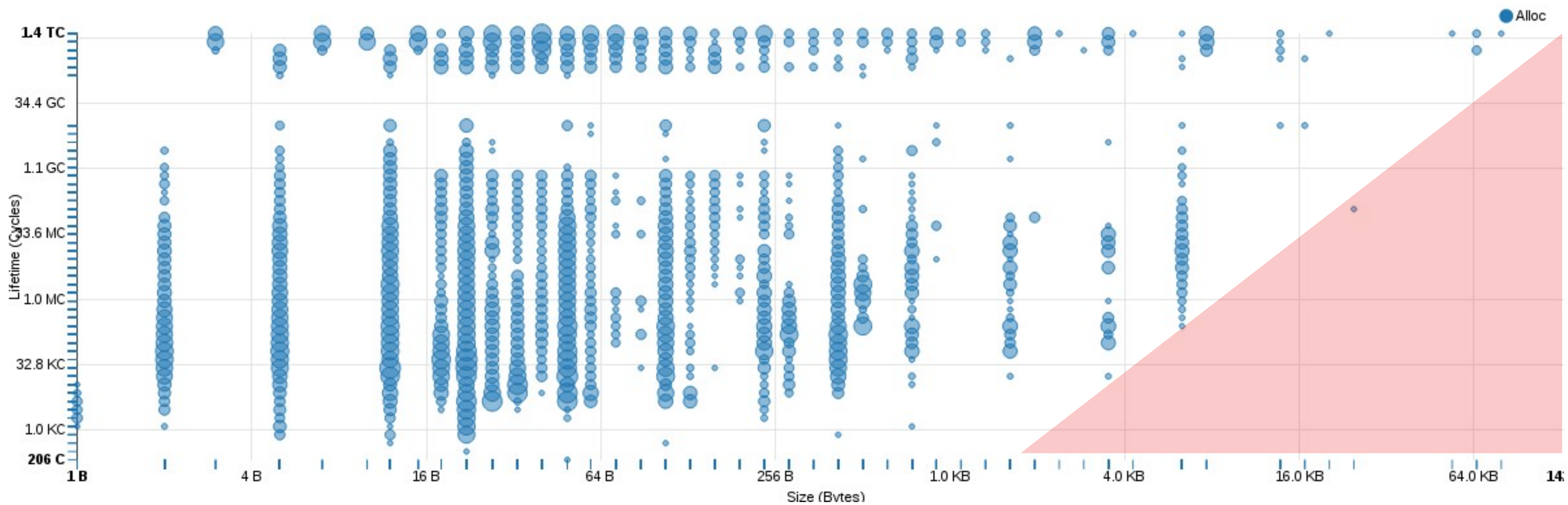


Dynamics

Size over time

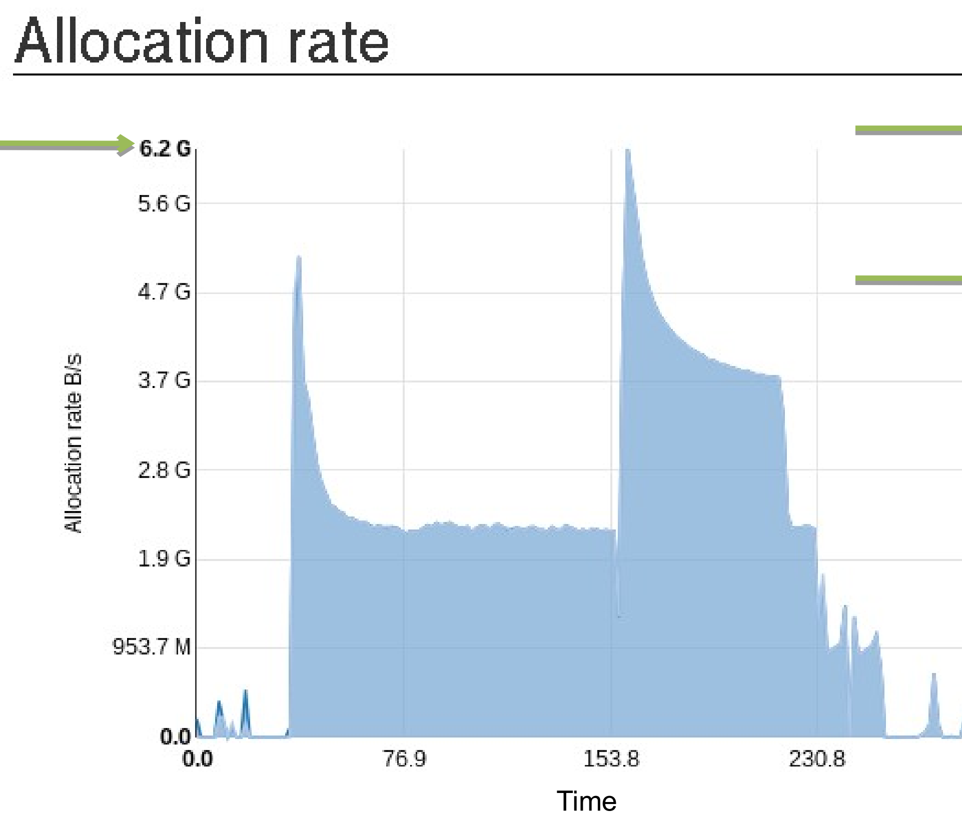


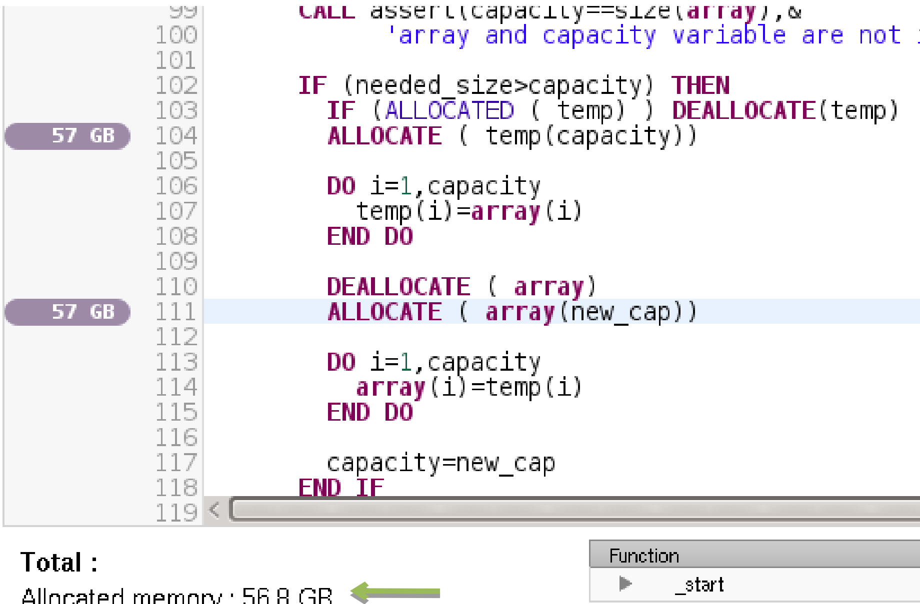
Lifetime over size



Example on AVBP init phase

- Issue with **reallocation** on init
- Detected with **allocation rate** & **cumulated allocatated mem.**





Total :
Allocated memory : 56.8 GB
Max alive memory : 135.7 M
3.5 K alloc : [16.0 KB , 16.3 MB , 33.7 MB]
Lifetime : [107.8 K , 26.7 M , 476.7 M] (cycles)
Own :
Allocated memory : 56.8 GB
Max alive memory : 135.7 M
3.5 K alloc : [16.0 KB , 16.3 MB , 33.7 MB]
Lifetime : [107.8 K , 26.7 M , 476.7 M] (cycles)

Usage

- Optionally recompile with debug flags :

```
gcc -g ...
```

- Run

```
malt [--config=file.ini] YOUR_PRGM [OPTIONS]
```

- Use the web view && http://localhost:8080:

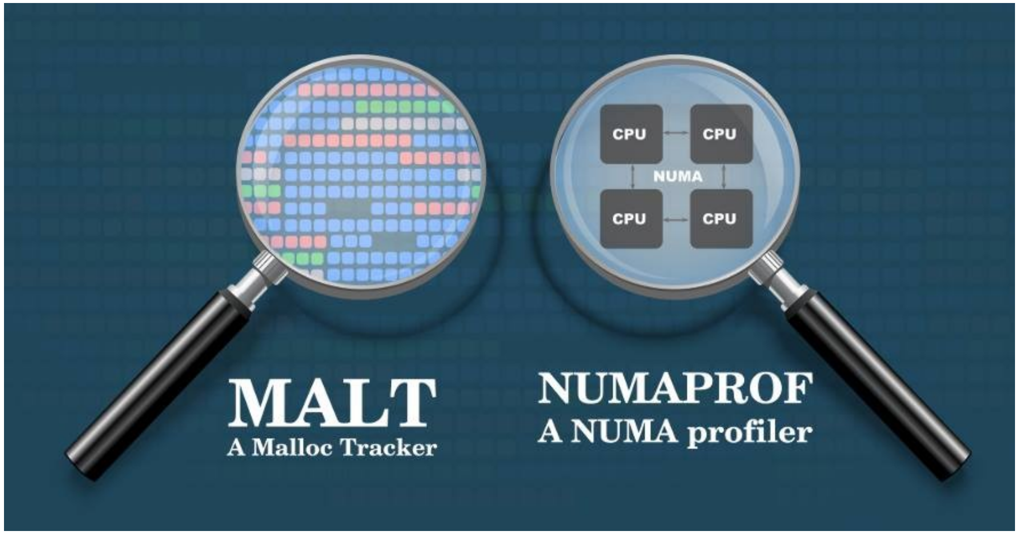
```
malt-webview -i malt-{YOUR_PRGM}-{PID}.json
```

- In case there is a QT wrapper embedding NodeJS + Webkit

```
malt-qt -i malt-{YOUR_PRGM}-{PID}.json
```

Status

- **Open sourced** since one year on https://github.com/memtt
- Co-hosted with a **similar tool :**
  NUMAPROF for **Non Uniform Memory Access** profiling.



- My **research** on memory management for **HPC** : http://svalat.github.io/

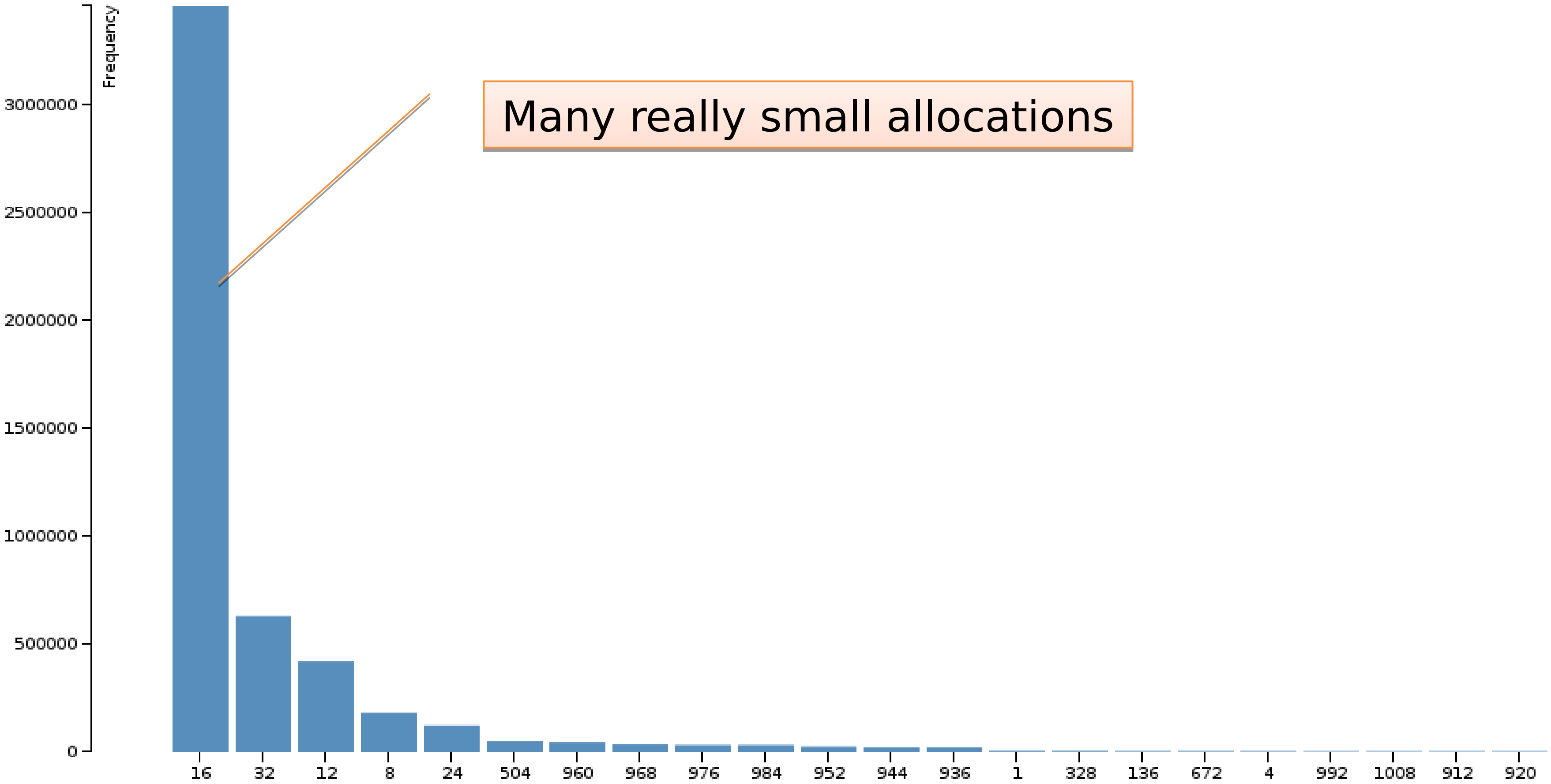
Thank you.

QUESTIONS ?

BACKUP

Chunk size distribution

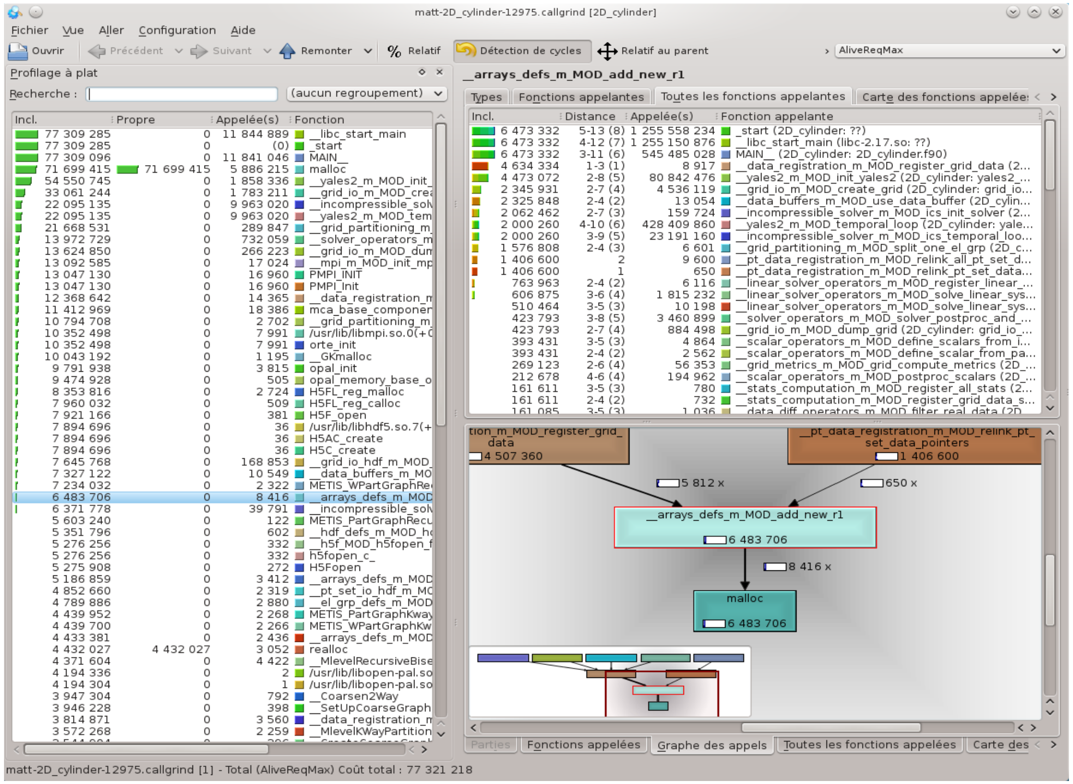
Example from YALES2 with gfortran issue



Output, first idea, kcachegrind

Callgrind compatibiltiy

- Can use kcachgrind
- Might be usefull for some users, cannot provide all metrics.



What is missing to kcachegrind

- **Started** with **kcacegrind** GUI…. But …
- Display **human readable** units
  - You prefer **15728640** or **15 MB** ?
  - I want to **compare to what I expect**.
- Cannot handle **non sum cumulative metrics**
  - **Inclusive** costs **only rely** on **+ operator**
  - Some mem. metrics **requires max/min** (eg. lifetime)
- No way to express **time charts**
- No way to express **parameter distributions** (eg. sizes).

Ideas of improvement

- Add NUMA statistics
- Provide virtual/physical ratio
- Estimate page fault costs
- Exploit traces in GUI for deeper analysis
  - Alive allocations at a certain time
  - Fragmentation analysis
  - Time charts from call sites
  - Usage over threads for call sites

Global summary

EXECUTION TIME	PHYSICAL MEMORY PEAK	ALLOCATION COUNT	AVAILABLE PHYSICAL MEMORY
00:00:00.25	2.3 MB	379	4.1 Gb

Run description

Executable :	simple-case-finstr-linked
Commande :	`./simple-case-finstr-linked`
Tool :	matt-0.0.0
Host :	localhost
Date :	2014-11-26 22:40
Execution time :	00:00:00.25
Ticks frequency :	1.8 GHz

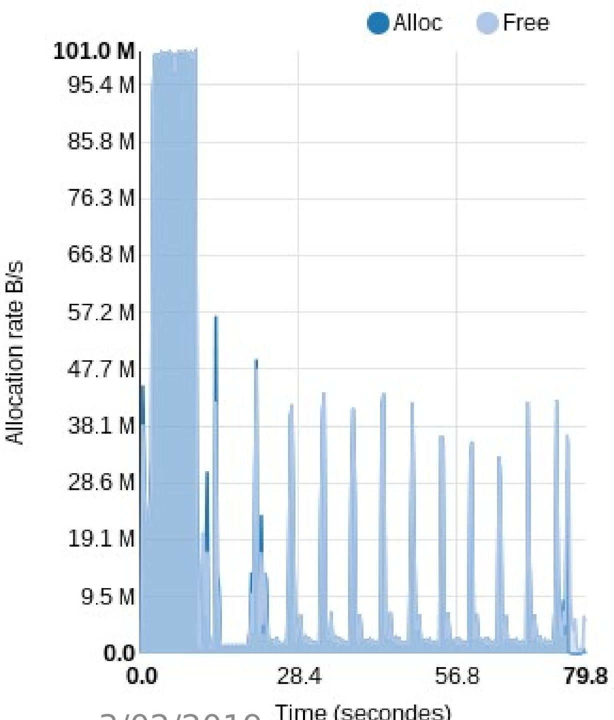
Global statistics

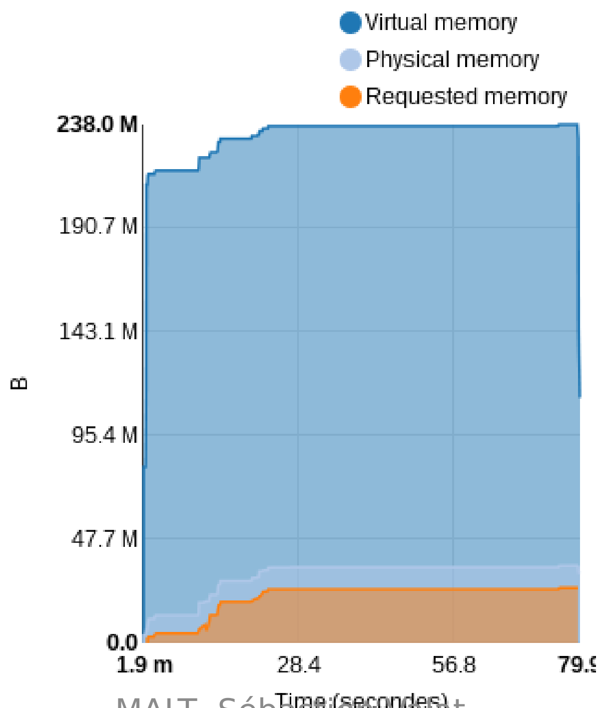
Show all details Show help

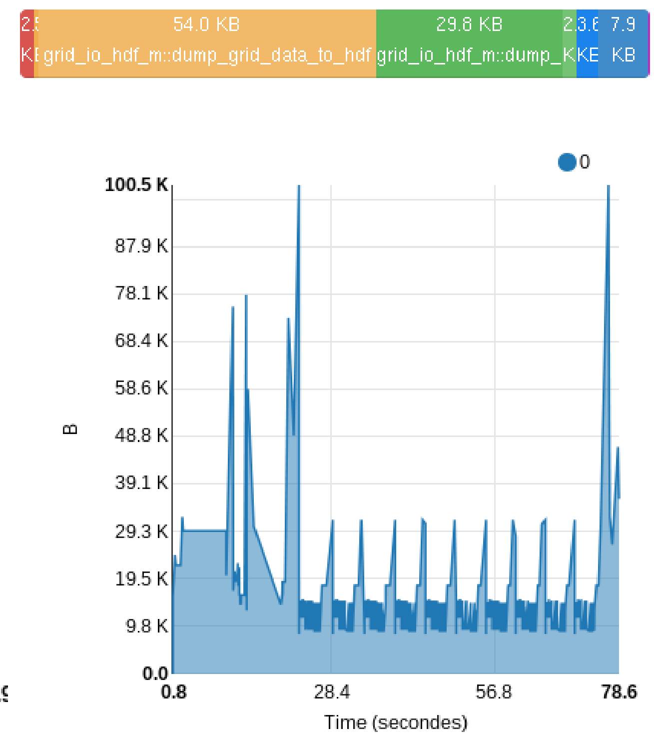
Physical memory peak	2.3 MB
Virtual memory peak	103.7 MB

Temporal metrics

- **Profile over time** :
  - Allocation **rate**
  - **Physical / Virtual / Requested** memory
  - **Stack size** for each **thread** (require function instrumentation)
- **Example on YALES2 with gfortran** :



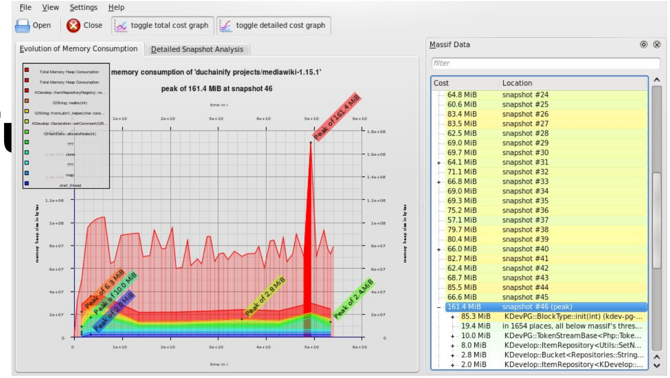




EXISTING TOOLS

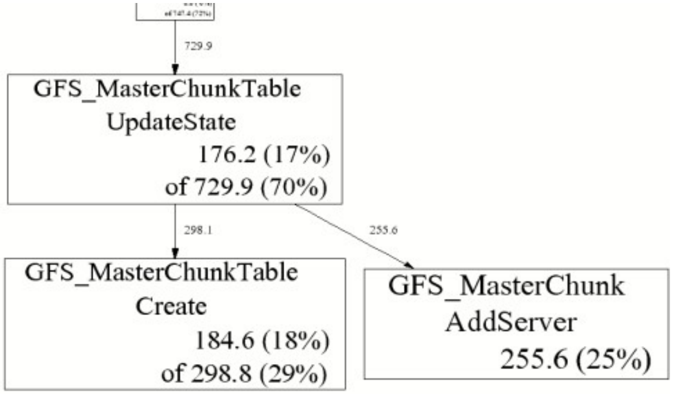
Existing tools

- Valgrind (massif)
  - Memory **over time** (snapshots) & **fu**
  - Memory per function **at peak**
  - Has a simple GUI



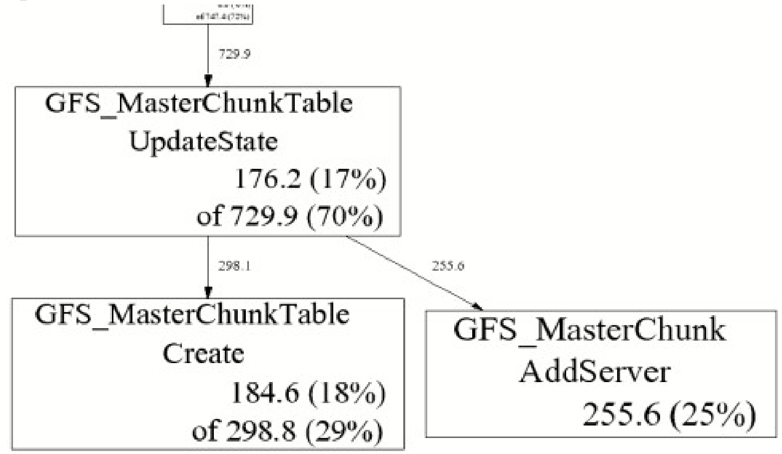
- Valgrind (memchek)
  - **Leaks**
  - No real GUI

- Google heap profiler (tcmalloc)
  - Memory **over time** (snapshots)
  - Faster then valgrind
  - No GUI



Existing tools / Google heap profiler

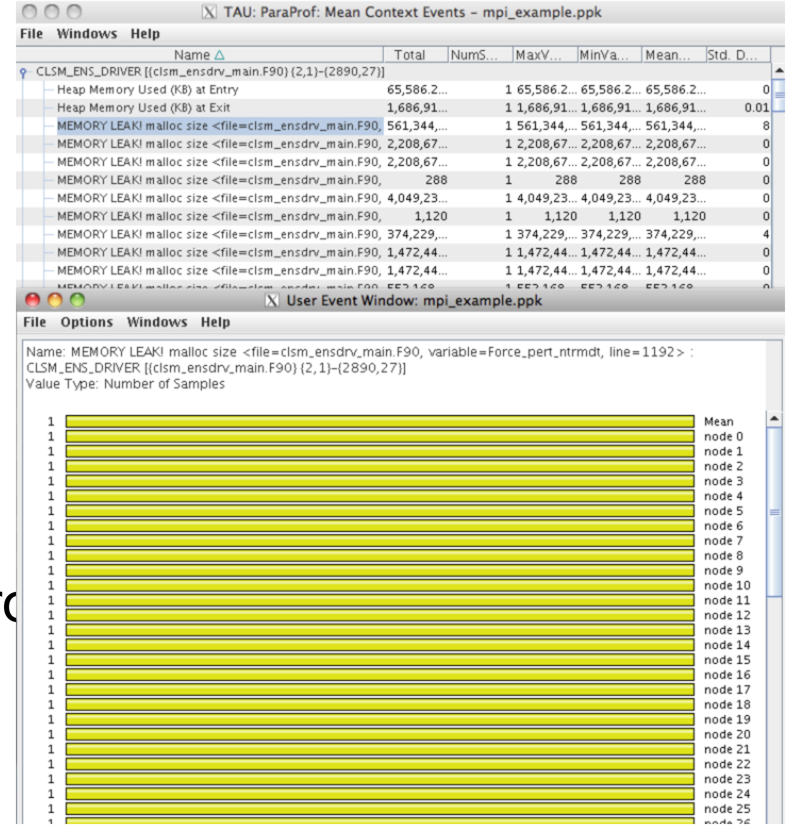
- **Google heap profiler (tcmalloc):**
  - **Small overhead.**
  - Similar metric than massif
  - Only provide snapshots of **alloca memory per stacks**.
  - Peak might not be captured.
  - Lack of a real GUI to use it.




```
% pprof gfs_master profile.0100.heap
   255.6  24.7%  24.7%    255.6  24.7% GFS_MasterChunk::AddServer
   184.6  17.8%  42.5%    298.8  28.8% GFS_MasterChunkTable::Create
   176.2  17.0%  59.5%    729.9  70.5%
GFS_MasterChunkTable::UpdateState
   169.8  16.4%  75.9%    169.8  16.4% PendingClone::PendingClone
    76.3   7.4%  83.3%     76.3   7.4%
__default_alloc_template::_S_chunk_alloc
    49.5   4.8%  88.0%     49.5   4.8% hashtable::resize
```

Existing tools

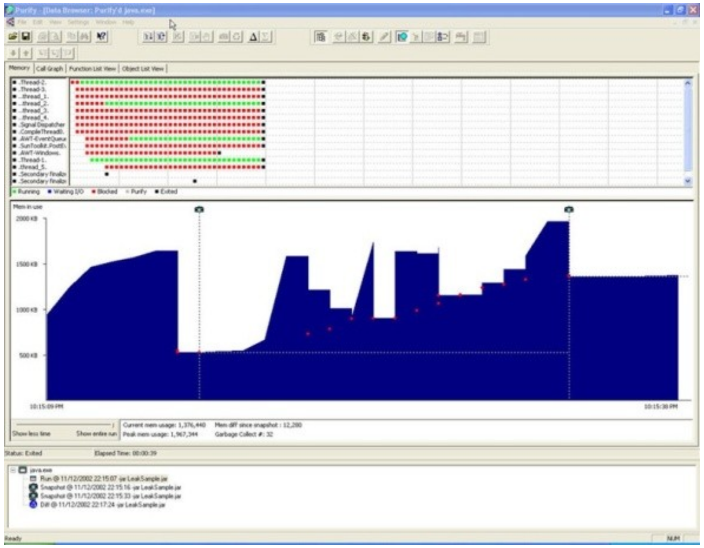
- **TAU memory profiler**
  - Provide profiles
  - Follow stacks
  - Track leaks
  - Parallel, done for HPC/MPI
  - Lack easy matching with sourc

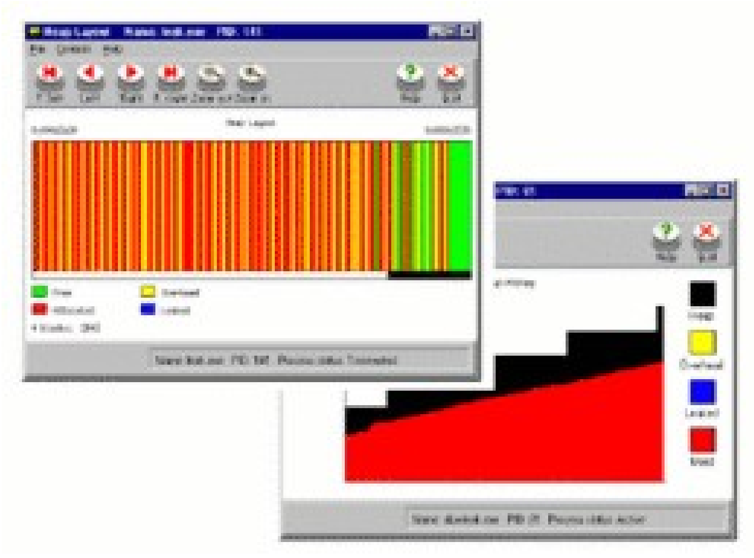


- **FOM**

Existing tools / Commercials

- **IBM Purify++ / Parasoft Insure++**
  - Commercial
  - Leak detection, access checking, memory debugging tools.
  - Use binary or source instrumentation.
  - Windows / Redhat
- **Visual Studio Ultimate Edition Memory profiler**
  - Nice but windows only and commercial





Stack tracking

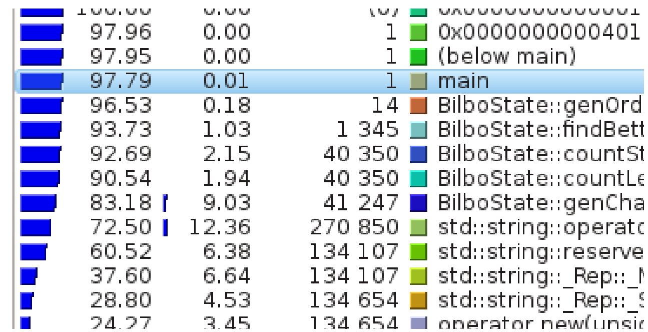
- Two approach implemented : **backtrace** and **instrumentation**

- **Backtrace** (default) :
  - Work out of the box
  - Manage all dynamic libraries
  - **Slow** for **large number of calls** (~>10M)

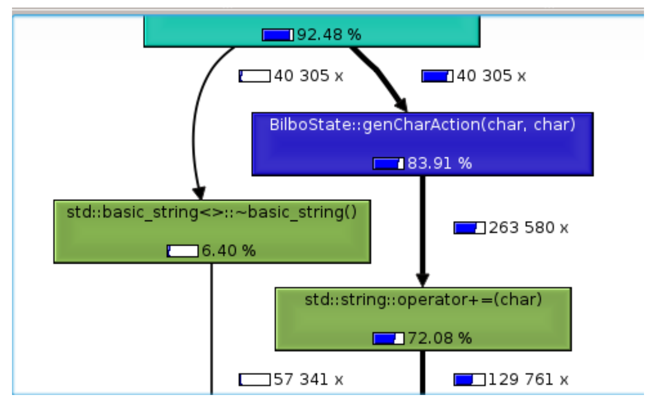
- **Instrumentation :**
  - Need source **recompilation** (available) : *-finstrument-function*
  - Or tools for **binary instrumentation** : MAQAO / Pintool (experimental)
  - Faster for really large number of calls to malloc
  - **Only** provide stacks for the **instrumented** binaries

What is good in kcachgrind

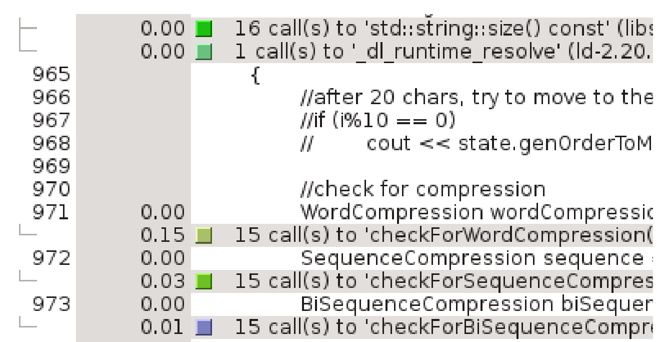
- List of **functions** with **exclusive/inclusive** costs



- Nice **call tree**



- **Annotated** sources



SOME VIEWS

Global summary

- Provide a small summary
- Provide some warnings

Show all details | Show help

Physical memory peak	66.7 MB
Virtual memory peak	158.1 MB
Requested memory peak	6.1 MB
Cumulated memory allocations	11.5 MB
Allocation count	172.2 K
Recycling ratio	1.9
Leaked memory	743.7 KB
Largest stack	0 B
Global variables	**10.0 MB** ⚠
TLS variables	48 B
Global variable count	**421.0 K** ⚠
Peak allocation rate	37.8 MB/s

Global summary : top 5 functions

- Summarize **top functions** for some metrics
- Points to check
- Examples on YALES2

Alloc count

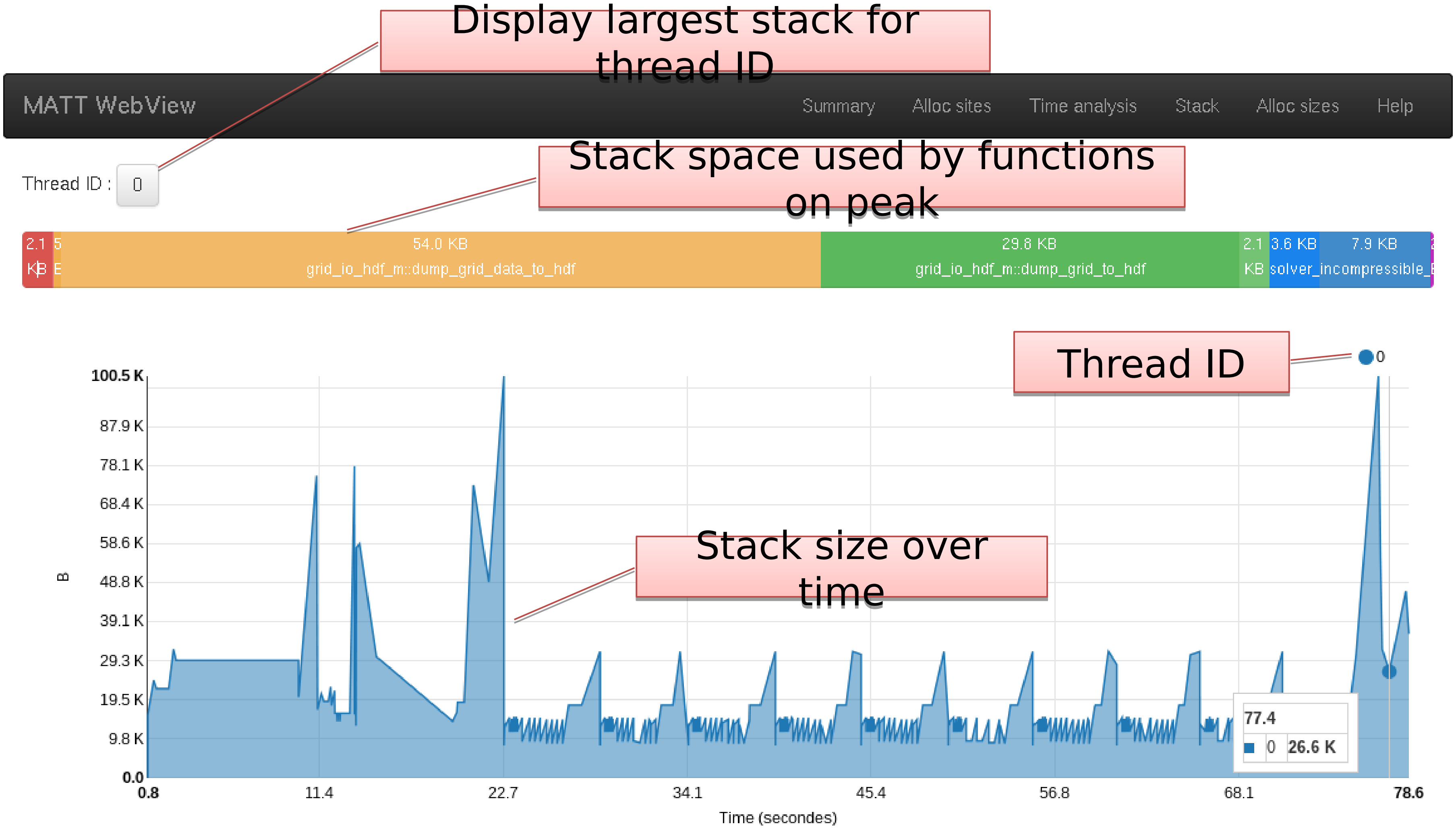
Ratio	Allocs	Function
	911.9 K	data_comm_m::copy_int_comm_to_data
	896.4 K	data_comm_m::copy_data_to_int_comm
	853.2 K	data_comm_m::update_int_comm
	484.9 K	sponge_layer_m::calc_sponge_layer_mask
	296.0 K	incompressible_numerics_m::ics_diffuse_velocity_rk_4th

Allocated memory

Ratio	Allocs	Function
	202.4 MB	linear_solver_operators_m::solve_linear_system_deflated_pcg
	26.6 MB	bnd_data_defs_m::find_bnd_data
	21.8 MB	linear_solver_operators_m::solve_el_grp_pcg
	19.0 MB	data_comm_m::copy_int_comm_to_data
	18.1 MB	data_comm_m::update_int_comm

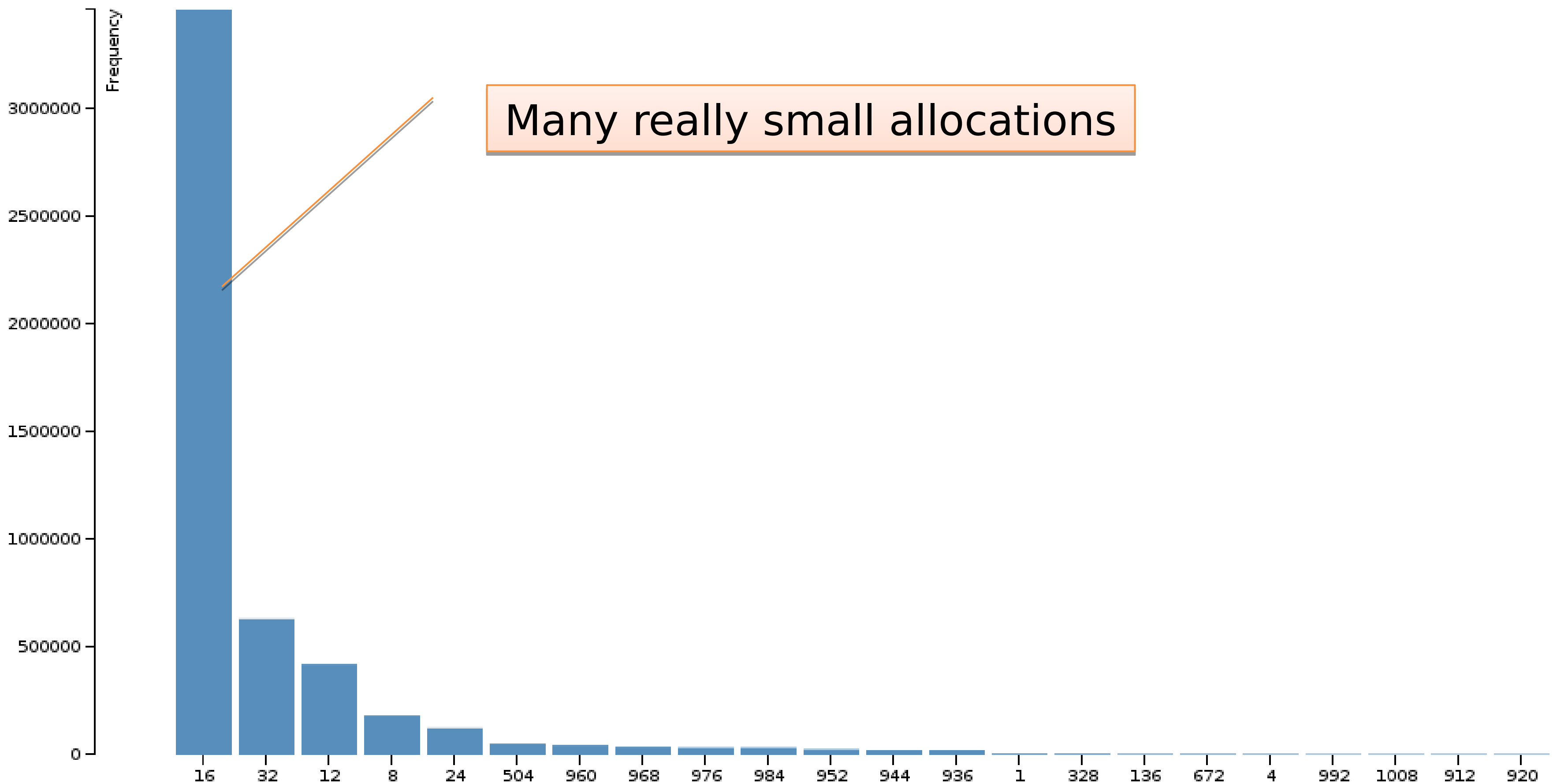
Peak memory

Tracking stack memory

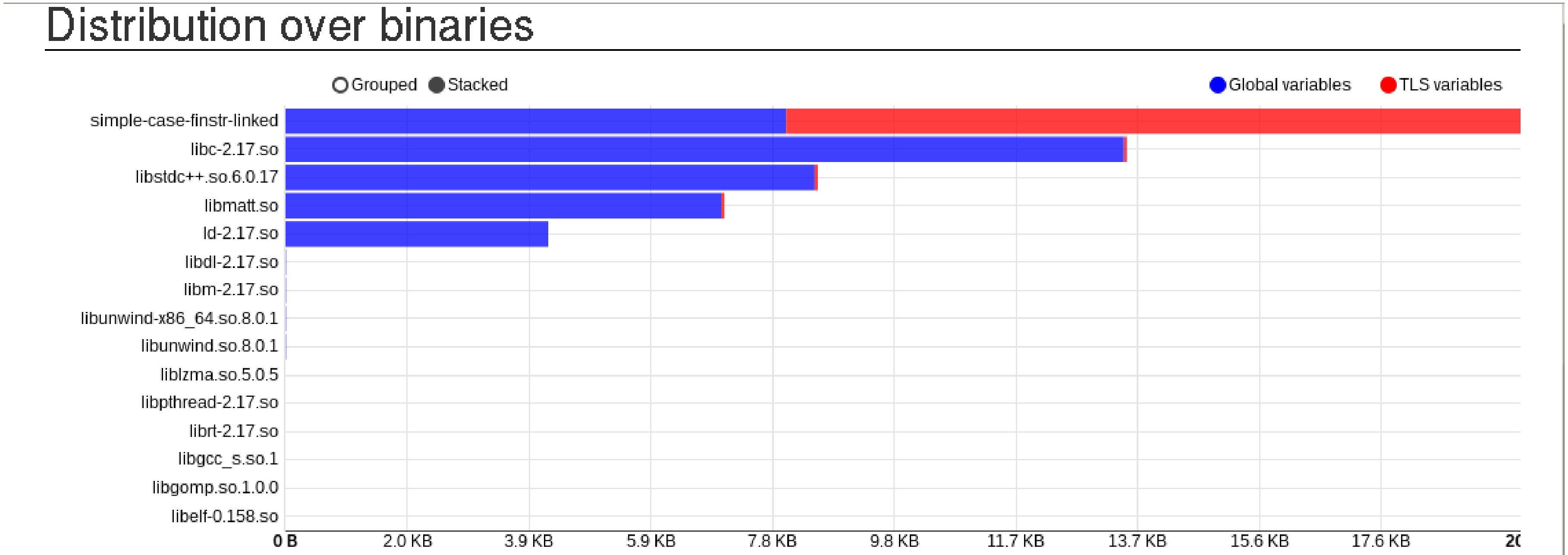


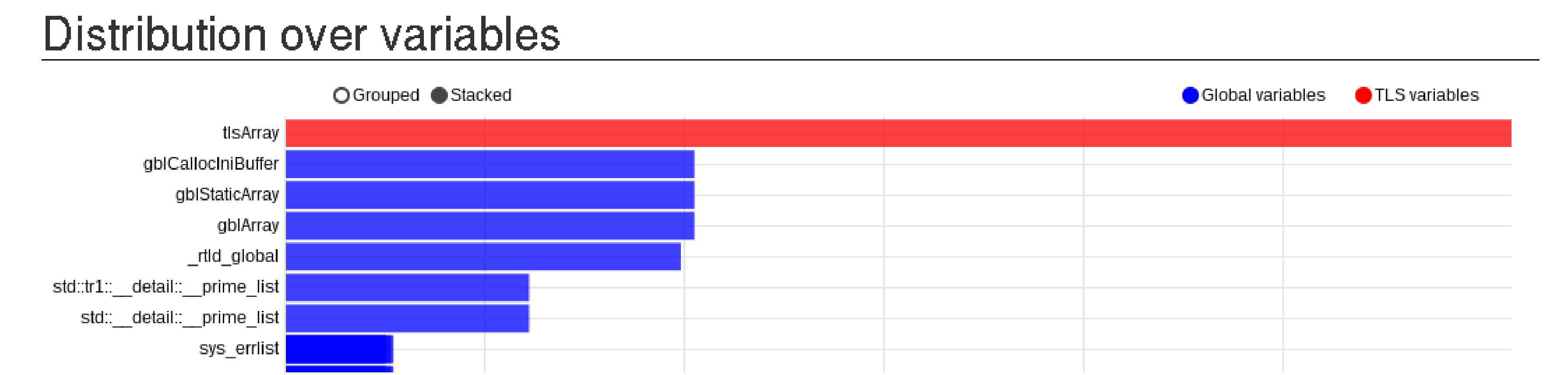
Chunk size distribution

Example from YALES2



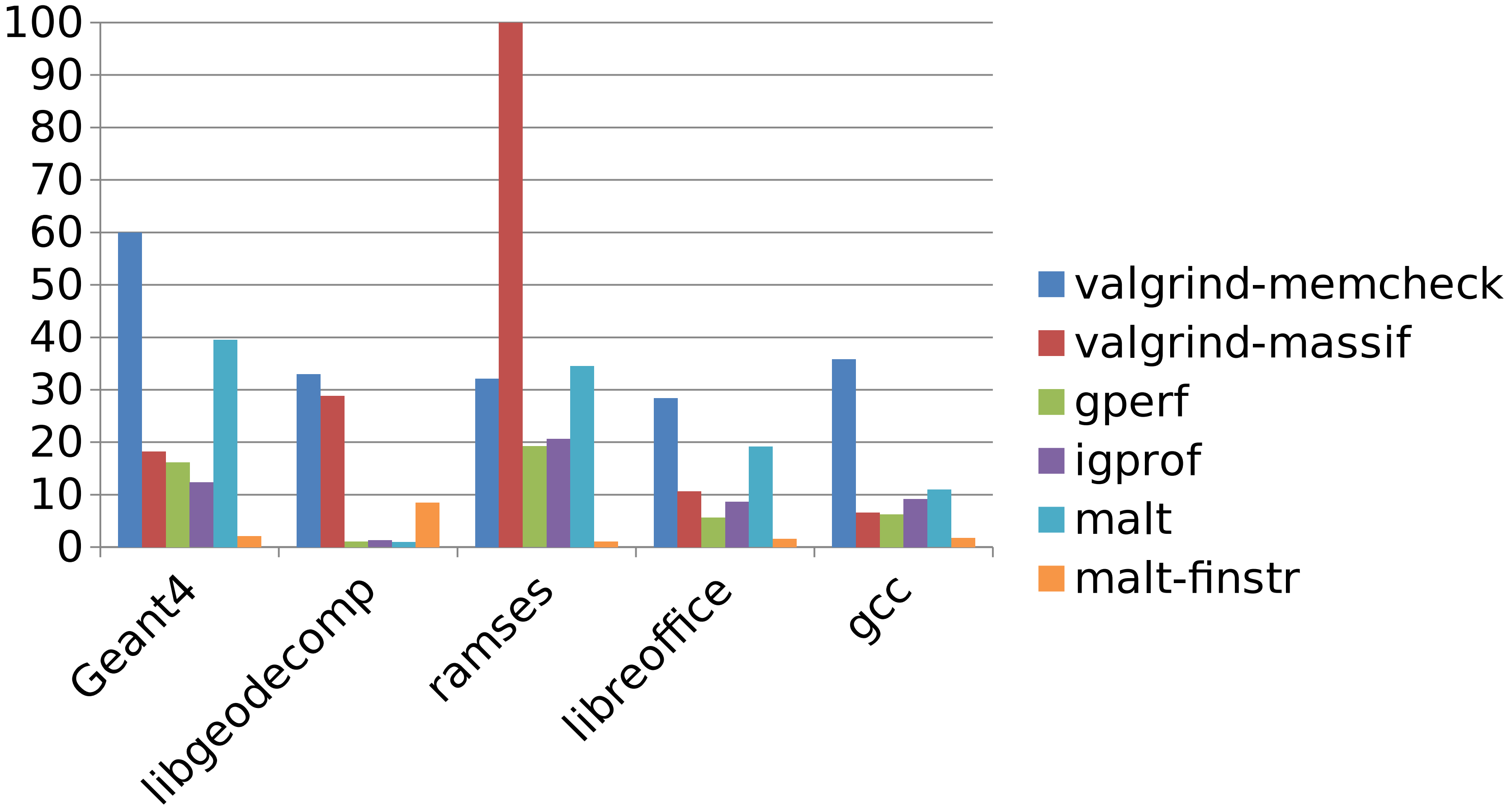
Global variables





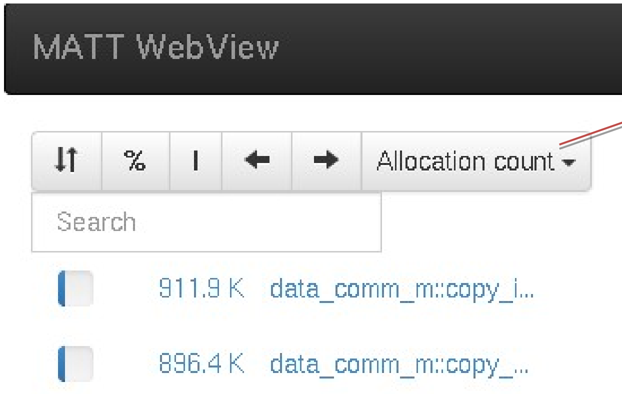
REAL CASES

Performance



Allocatable arrays on YALES2

- Issue only occur with **gfortran**, ifort uses stack arrays.



Search intensive alloc functions

Huge number of allocation for a line programmer think it doesn't do any !

608 K

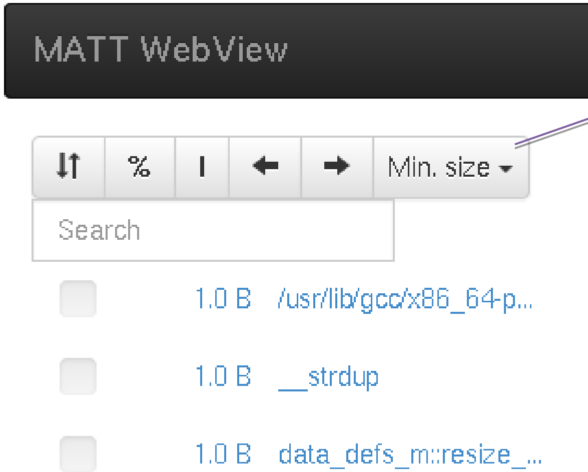
```
do i=1,nitem_el_grp
   el_grp_ind = el_grp_index2int_comm_index%val(1,i)
   int_comm_ind = el_grp_index2int_comm_index%val(2,i)
   el_grp_r2%val(1:dim1,el_grp_ind) = int_comm_r2%val(1:dim1,int_comm_ind)
end do
```

Total :
Allocated memory : 9.5 MB
Freed memory : 9.5 MB
Max alive memory : 432
608.0 K alloc : [16 B , 16 B , 16 B]
608.0 K free : [16 B , 16 B , 16 B]
Lifetime : [24.5 K , 39.9 K , 37.8 M] (cycles)
Own :
Allocated memory : 9.5 MB

And mostly really small allocations !

We can found allocs of 1B !

- Examples on YALES 2, small allocations :



Search for the minimal chunk size.

Many codes produce allocations of 1B.
OK with moderation.

```
1 B
case (DATATYPE_REAL_NODE_VECTOR,DATATYPE_REAL_ELEM_VECTOR, &
      DATATYPE_REAL_FACE_VECTOR,DATATYPE_REAL_PAIR_VECTOR)
   if (associated(data_ptr%r2_ptrs)) then
      deallocate(data_ptr%r2_ptrs)
   end if
   allocate(data_ptr%r2_ptrs(nel_grps))
   do n=1,nel_grps
      NULLIFY(data_ptr%r2_ptrs(n)%ptr)
   end do
```

Fragmentation issue

- Example of **fragmentation** detection
- Using the time chart with **physical**, **virtual** and **requested memory**
- **Solution** : **avoid interleaved** allocation of chunks with **different lifetime**.
- Looking on **source annotation** : most of them **can be**