Lecture 27 — Memory Profiling

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January 3, 2019

~~Memory Profiling~~ Return to Asgard

So far: CPU profiling.

Memory profiling is also a thing;
specifically heap profiling.

“Still Reachable”: not freed & still have pointers,
but should have been freed?

~~Memory Profiling~~ Return to Asgard

As with queueing theory:

$$\text{allocs} > \text{frees} \implies \text{usage} \to \infty$$

At least more paging, maybe total out-of-memory.

But! Memory isn't really lost: we could free it.

Our tool for this comes from the Valgrind tool suite.

Shieldmaiden to Thor

What does Massif do?

- How much heap memory is your program using?
- How did this happen?

Next up: example from Massif docs.

Example Allocation Program

```
#include <stdlib.h>

void g ( void ) {
    malloc( 4000 );
}

void f ( void ) {
    malloc( 2000 );
    g();
}

int main ( void ) {
    int i;
    int* a[10];

    for ( i = 0; i < 10; i++ ) {
        a[i] = malloc( 1000 );
    }
    f();
    g();

    for ( i = 0; i < 10; i++ ) {
        free( a[i] );
    }
    return 0;
}
```

Send in Sif

After we compile (remember -g for debug symbols), run the command:

```
jz@Loki:~/ece459$ valgrind --tool=massif ./massif
==25187== Massif, a heap profiler
==25187== Copyright (C) 2003-2013, and GNU GPL'd, by Nicholas Nethercote
==25187== Using Valgrind-3.10.1 and LibVEX; rerun with -h for copyright info
==25187== Command: ./massif
==25187==
==25187==
```

That Was Useful!!!

What happened?

1. The program ran slowly (because Valgrind!)
2. No summary data on the console
   (like memcheck or helgrind or cachegrind.)

Weird. What we got instead was the file `massif.out.[PID]`.

Post-Processing

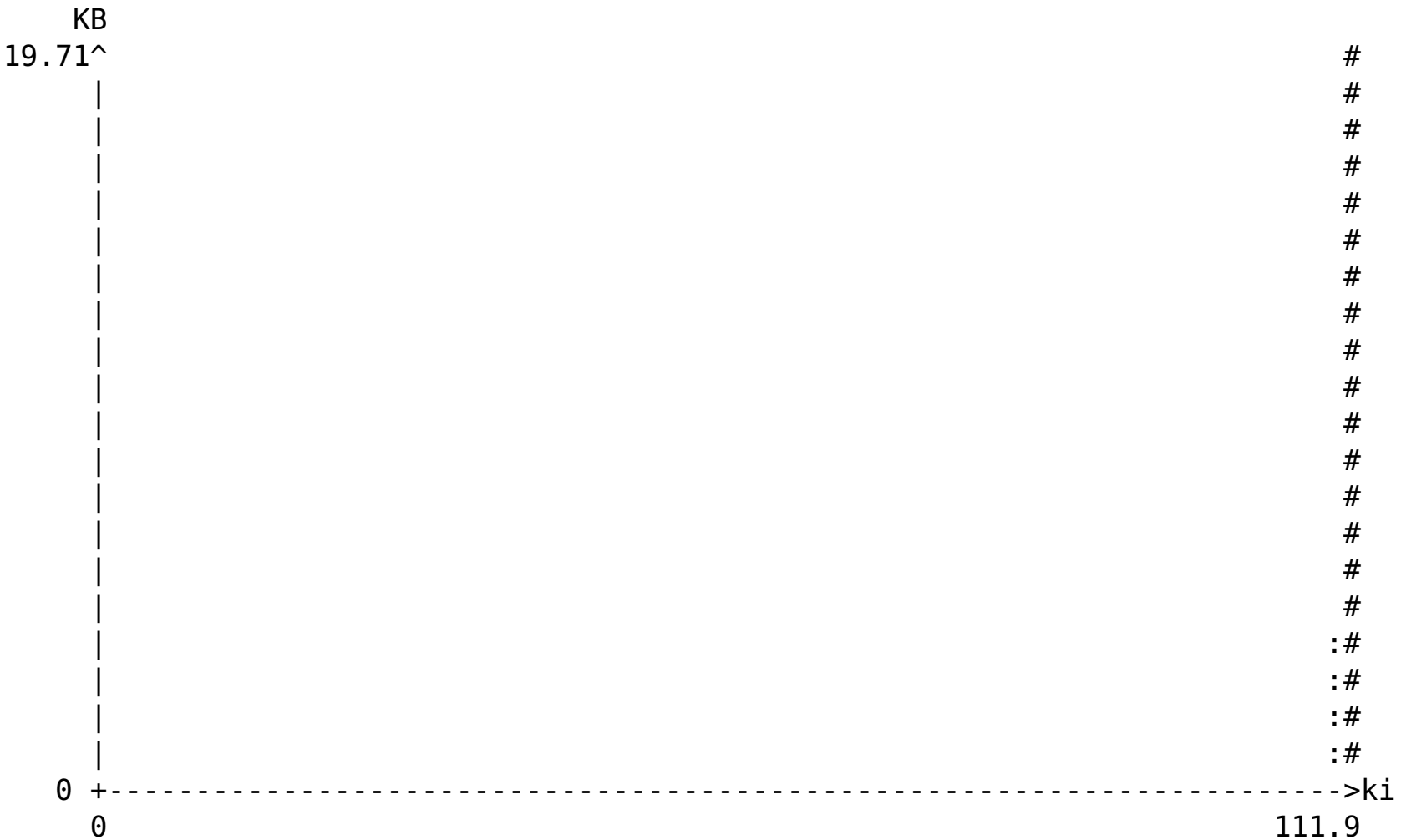
`massif.out.[PID]`:

plain text, sort of readable.

Better: `ms_print`.

Which has nothing whatsoever to do with Microsoft. Promise.

Post-Processed Output



User Friendly, But Not Useful

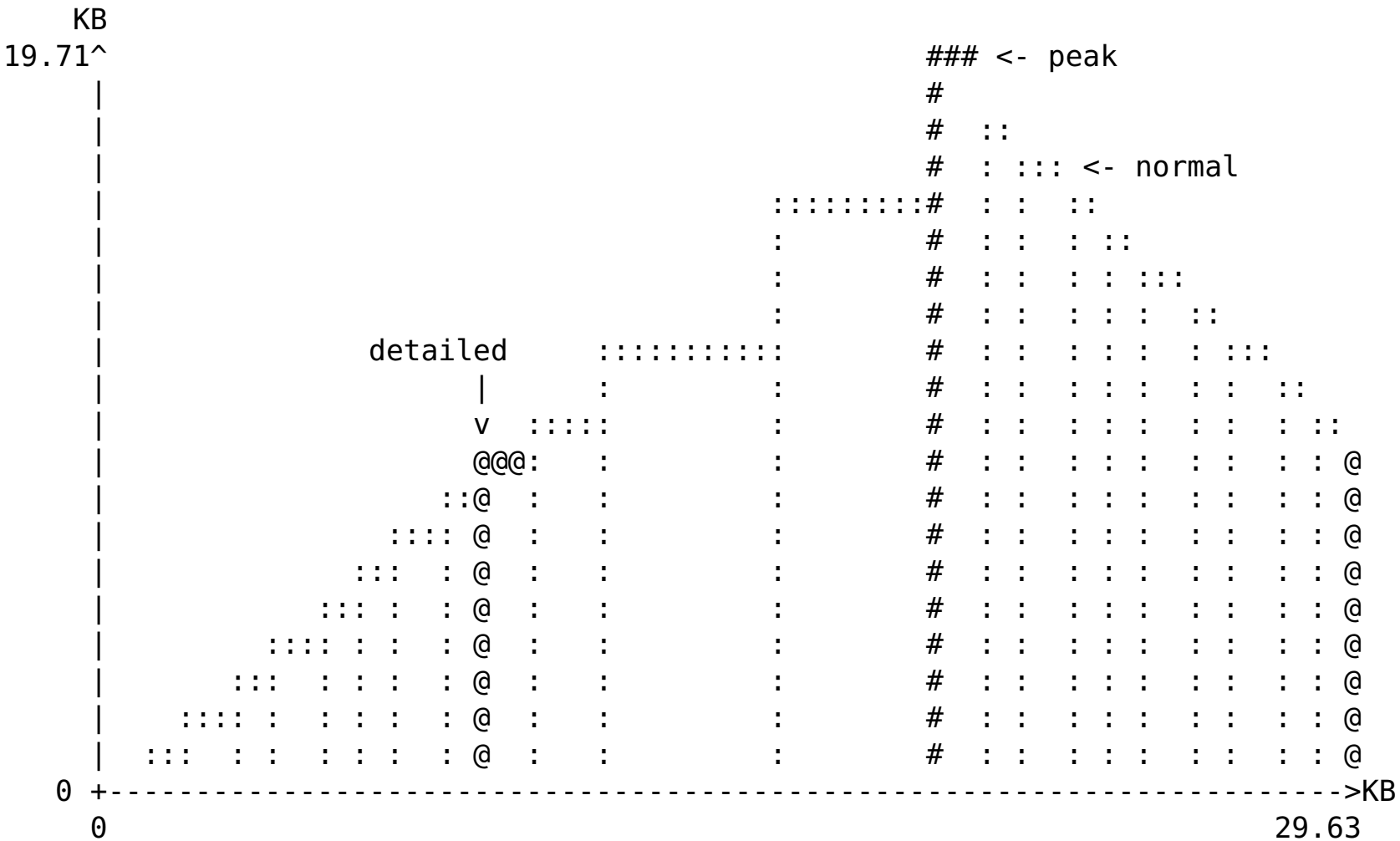
For a long time, nothing happens,
then…kaboom!

Why? We gave it a trivial program.

We should tell Massif to care more
about bytes than CPU cycles,
with `--time-unit=B`.

Let's try that.

ASCII Art (telnet towel.blinkenlights.nl)



OK! Massif took 25 snapshots.

- whenever there are appropriate allocation and deallocation statements, up to a configurable maximum.

Long running program:
will toss some old data if necessary.

Normal Snapshots

n	time(B)	total(B)	useful-heap(B)	extra-heap(B)	stacks(B)
0	0	0	0	0	0
1	1,016	1,016	1,000	16	0
2	2,032	2,032	2,000	32	0
3	3,048	3,048	3,000	48	0
4	4,064	4,064	4,000	64	0
5	5,080	5,080	5,000	80	0
6	6,096	6,096	6,000	96	0
7	7,112	7,112	7,000	112	0
8	8,128	8,128	8,000	128	0

time(B) column = time measured in allocations (our choice of time unit on cmdline).

extra-heap(B) = internal fragmentation.

(Why are stacks all shown as 0?)

Detailed Snapshots

```
--------------------------------------------------------------------------------
  n        time(B)         total(B)   useful-heap(B) extra-heap(B)    stacks(B)
--------------------------------------------------------------------------------
  9          9,144            9,144            9,000           144            0
98.43% (9,000B) (heap allocation functions) malloc/new/new[], --alloc-fns, etc.
->98.43% (9,000B) 0x4005BB: main (massif.c:17)
```

Now: where did heap allocations take place?

So far, all the allocations took place on line 17, which was `a[i] = malloc( 1000 );` inside that for loop.

Peak Snapshot (Trimmed)

```
--------------------------------------------------------------------------------
  n        time(B)         total(B)   useful-heap(B) extra-heap(B)    stacks(B)
--------------------------------------------------------------------------------
 14         20,184           20,184           20,000           184            0
99.09% (20,000B) (heap allocation functions) malloc/new/new[], --alloc-fns, etc.
->49.54% (10,000B) 0x4005BB: main (massif.c:17)
|
->39.64% (8,000B) 0x400589: g (massif.c:4)
| ->19.82% (4,000B) 0x40059E: f (massif.c:9)
| | ->19.82% (4,000B) 0x4005D7: main (massif.c:20)
| |
| ->19.82% (4,000B) 0x4005DC: main (massif.c:22)
|
->09.91% (2,000B) 0x400599: f (massif.c:8)
  ->09.91% (2,000B) 0x4005D7: main (massif.c:20)
```

Massif found all allocations and distilled them to a tree structure.

We see not just where the `malloc` call happened, but also how we got there.

“Is he dead?” “Terminated.”

Termination gives a final output of what blocks remains allocated and where they come from.

These point to memory leaks, incidentally, and Memcheck would not be amused.

```
 24         30,344           10,024           10,000            24            0
99.76% (10,000B) (heap allocation functions) malloc/new/new[], --alloc-fns, etc.
->79.81% (8,000B) 0x400589: g (massif.c:4)
| ->39.90% (4,000B) 0x40059E: f (massif.c:9)
| | ->39.90% (4,000B) 0x4005D7: main (massif.c:20)
| |
| ->39.90% (4,000B) 0x4005DC: main (massif.c:22)
|
->19.95% (2,000B) 0x400599: f (massif.c:8)
| ->19.95% (2,000B) 0x4005D7: main (massif.c:20)
|
->00.00% (0B) in 1+ places, all below ms_print’s threshold (01.00%)
```

Here's what Memcheck thinks:

```
jz@Loki:~/ece459$ valgrind ./massif
==25775== Memcheck, a memory error detector
==25775== Copyright (C) 2002-2013, and GNU GPL'd, by Julian Seward et al.
==25775== Using Valgrind-3.10.1 and LibVEX; rerun with -h for copyright info
==25775== Command: ./massif
==25775==
==25775==
==25775== HEAP SUMMARY:
==25775==     in use at exit: 10,000 bytes in 3 blocks
==25775==   total heap usage: 13 allocs, 10 frees, 20,000 bytes allocated
==25775==
==25775== LEAK SUMMARY:
==25775==    definitely lost: 10,000 bytes in 3 blocks
==25775==    indirectly lost: 0 bytes in 0 blocks
==25775==      possibly lost: 0 bytes in 0 blocks
==25775==    still reachable: 0 bytes in 0 blocks
==25775==         suppressed: 0 bytes in 0 blocks
==25775== Rerun with --leak-check=full to see details of leaked memory
==25775==
==25775== For counts of detected and suppressed errors, rerun with: -v
==25775== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 0 from 0)
```

Valgrind (Memcheck) First

Run valgrind (Memcheck) first and make it happy before we go into figuring out where heap blocks are going with Massif.

Okay, what to do with the information from Massif, anyway?

Easy!

- Start with peak (worst case scenario) and see where that takes you (if anywhere).
- You can probably identify some cases where memory is hanging around unnecessarily.

Places to Look with Massif

Memory usage climbing over a long period of time, perhaps slowly, but never decreasing—memory filling with junk?

Large spikes in the graph—why so much allocation and deallocation in a short period?

Other Massif-ly Useful Things

- stack allocation (`--stacks=yes`).
- children of a process (anything split off with `fork`) if desired.
- low level stuff: if going beyond `malloc`, `calloc`, new, etc. and using `mmap` or `brk` that is usually missed, can do profiling at page level (`--pages-as-heap=yes`).

Live Demos

As is often the case,
we have examined the tool on a trivial program.

Let’s see if we can do some
live demos of Massif at work.