Lecture 27 — Memory Profiling

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~~Memory Profiling~~ Return to Asgard

Thus far we have focused on CPU profiling.

Memory profiling is also a thing; specifically on heap profiling.

“Still Reachable”, things that remained allocated and we still had pointers to them, but were not properly deallocated?

~~Memory Profiling~~ Return to Asgard

If we don't look after those things, we're just using more and more memory over time.

That likely means more paging and the potential for running out of heap space altogether.

Again, the memory isn't really lost, because we could free it.

So, our tool for this comes from the Valgrind tool suite.

Shieldmaiden to Thor

Using Massif

So what does Massif do?

It will tell you about how much heap memory your program is using, and also how the situation got to be that way.

So let's start with the example program from the documentation.

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 the `-g` option 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?

Your program executed slowly, as is the case with any of the Valgrind toolset.

You don't get summary data on the console like we did with Valgrind or helgrind or cachegrind.

Weird. What we got instead was the file `massif.out.25187` (matches the PID of whatever we ran).

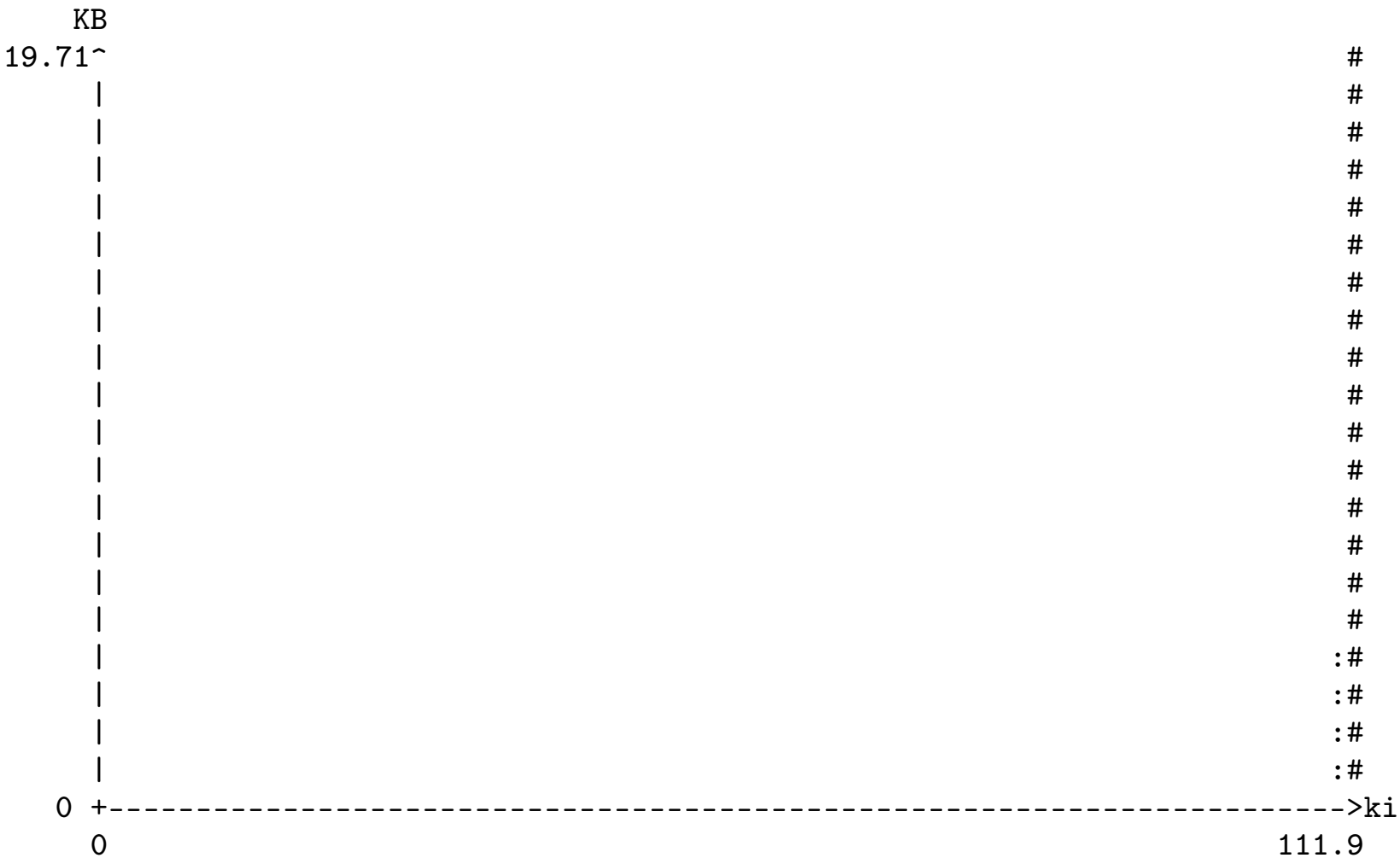
Post-Processing

This file, which you can open up in your favourite text editor is not especially human readable, but it's not incomprehensible like the output from cachegrind.

There is an associated tool for summarizing and interpreting this data in a much nicer way: `ms_print`.

Which has nothing whatsoever to do with Microsoft. Promise.

Post-Processed Output



User Friendly, But Not Useful

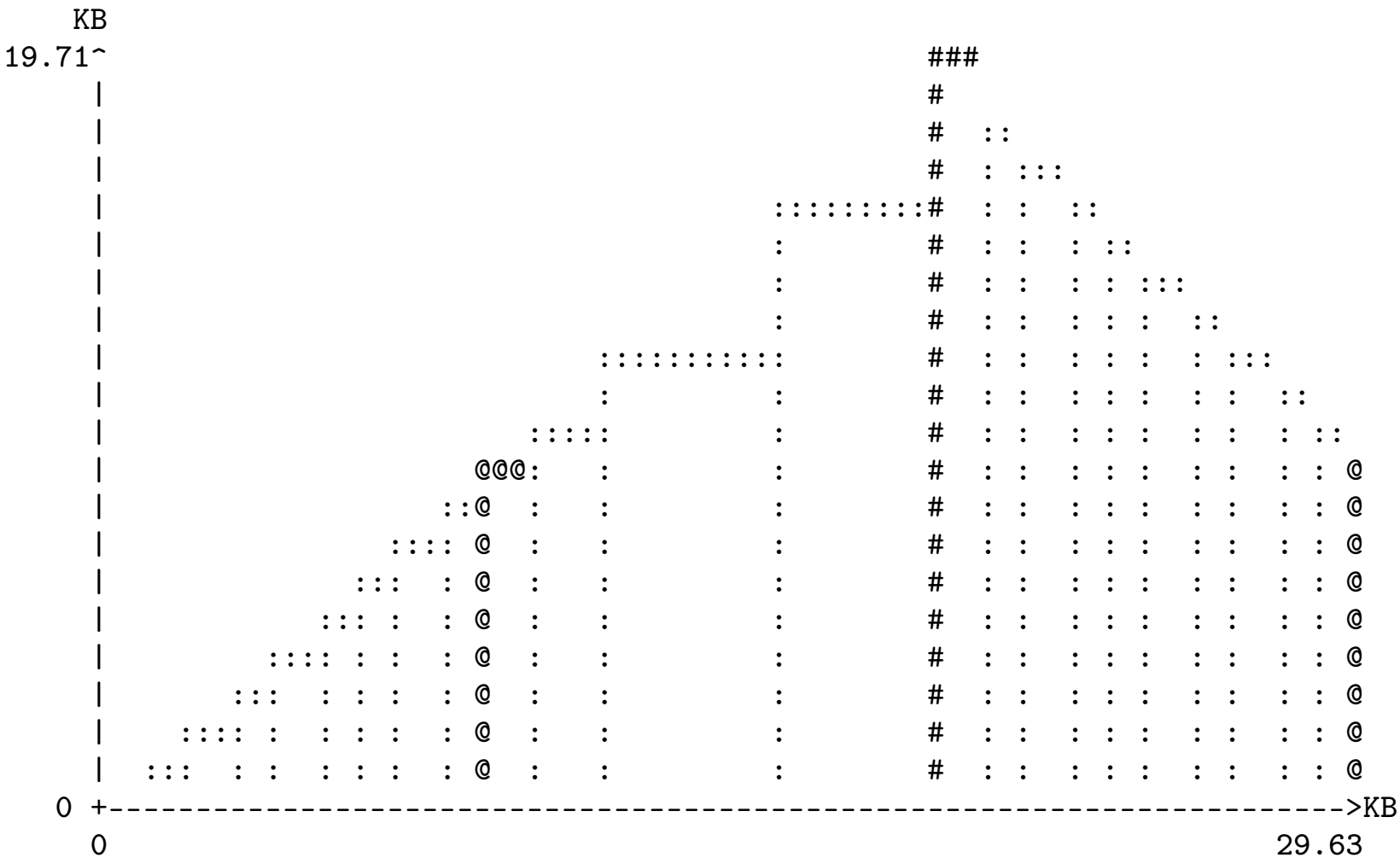
For a long time, nothing happens, then... kaboom!

Problem: we gave in a trivial program.

So for a relatively short program we should tell Massif to care more about the bytes than the CPU cycles, with the `-time-unit=B` option.

Let's try that.

ASCII Art (`telnet towel.blinkenlights.nl`)



Analyze the Art

Now we're getting somewhere. We can see that 25 snapshots were taken.

It will take snapshots whenever there are appropriate allocation and deallocation statements, up to a configurable maximum.

For a long running program, it will toss some old data if necessary.

Let's look in the documentation to see what the symbols mean.

Decode the Symbols

- Normal: :
- Detailed: @
- Peak: #

Peaks can be slightly inaccurate as they are recorded only at deallocation (and to speed up operations in general).

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

The time(B) column corresponds to time measured in allocations thanks to our choice of the time unit at the command line.

The extra-heap(B) represents 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)
```

So the additional information we got here is a reflection of where our heap allocations took place.

Thus far, all the allocations took place on line 17 of the program, 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 has found all the allocations in this program and distilled them down 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 valgrind 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%)
```

Trust, but Verify

In fact, if I ask valgrind what it thinks of this program, it says:

```
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 First

So probably a good idea to run valgrind 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?

It should be pretty easy to act upon this information. Start with the peak snapshot (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 really decreasing – memory is filling up somehow with some junk?

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

Other Massif-ly Useful Things

- Look into stack allocation (`-stacks=yes`) option.
- Look at the children of a process (anything split off with `fork`) if desired.
- Check low level stuff: if we're doing something other than `malloc`, `calloc`, `new`, etc. and doing low level stuff like `mmap` or `brk` that is usually missed, but we can do profiling at page level (`-pages-as-heap=yes`).

Live Demos

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

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