Debugging Malloc Lab

15-213: Introduction to Computer Systems
Recitation 12: Monday, Nov. 11th, 2013

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Section A

News

- Shell Lab:
  - Grades will be released todayish.
  - If you saw them this weekend, that was a mistake, and the grade you saw was probably not the final grade.
  - We can add, honest.

- Malloc Lab:
  - Due Thursday.

- Proxy Lab:
  - Goes out the same day, due Dec. 3.
  - Last lab of the semester! ☺ / ☹

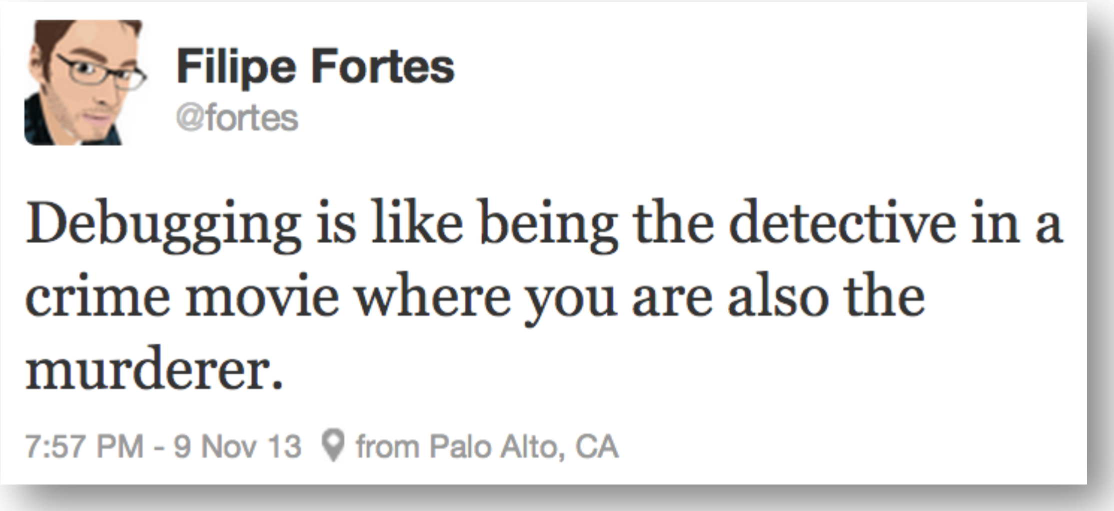
My Thoughts on Grading Shell Lab

- Y’all are losing a *lot* of points on things that are *really easy* to fix.
  - Consistent indentation, ≤ 80 characters per line.
  - Program header comments: easiest 2 points ever?

```
tsh is a simplistic shell. It provides a command line and allows the user to input very
basic Unix commands, which it runs by forking & execing.
Acceptable inputs:
*  basic Unix commands, including path, e.g. /bin/ls –l or /bin/echo "Hello world".
     *  typing % at the end of the command runs it as a background job.
     *  supports redirection (< or >) but not pipes (|).
*  built-in commands:
     *  jobs: lists all currently running or stopped processes.
     *  fg x: moves job x to the foreground.
     *  bg x: moves job x to the background.
     *  quit: exits the shell.
*  Ctrl-C and Ctrl-Z are appropriately passed to the foreground job and its children.
```

  - Error-checking system calls.
    - e.g., what if you try to open`(filename)` but don’t have read permissions on that file, or the filename is too long, or you’re out of file descriptors, or or or…?

Agenda: Debugging Malloc Lab



Filipe Fortes
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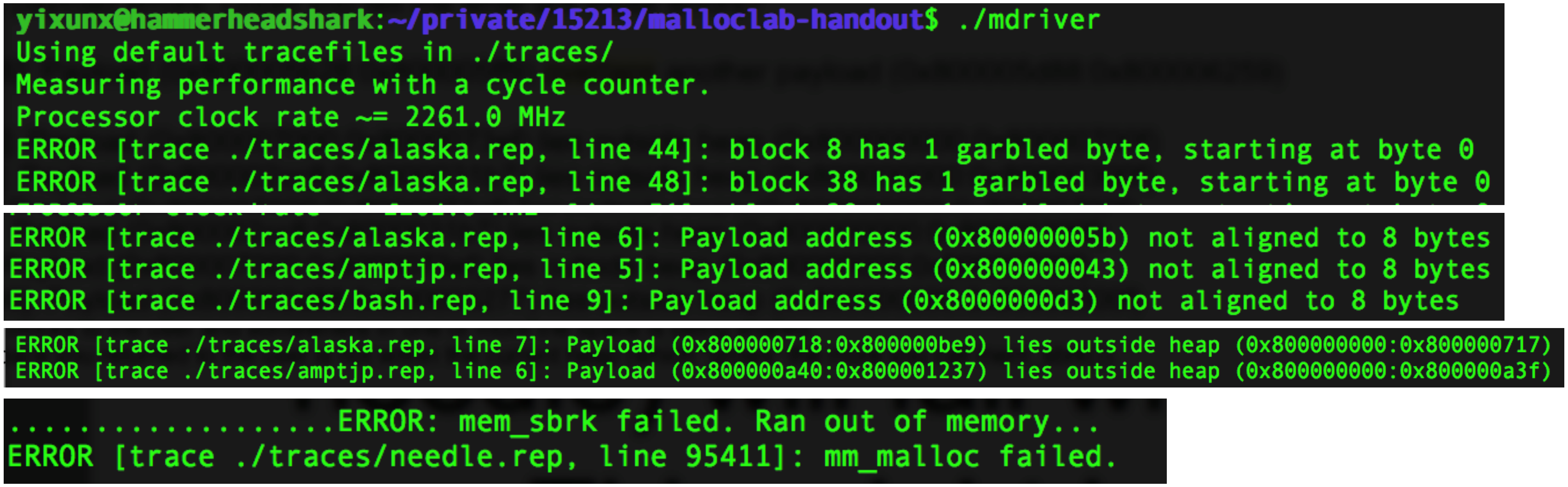
Debugging is like being the detective in a crime movie where you are also the murderer.

7:57 PM - 9 Nov 13 from Palo Alto, CA

1. **Errors you might get & what might cause them**
2. Your best friend, the heap checker
3. Other useful tools
4. Beyond debugging: error prevention; version control
5. Optimization: good coding; gprof

Errors

- Some errors are identified by the driver



```
yixunx@hammerheadshark:~/private/15213/malloclab-handout$ ./mdriver
Using default tracefiles in ./traces/
Measuring performance with a cycle counter.
Processor clock rate ~= 2261.0 MHz
ERROR [trace ./traces/alaska.rep, line 44]: block 8 has 1 garbled byte, starting at byte 0
ERROR [trace ./traces/alaska.rep, line 48]: block 38 has 1 garbled byte, starting at byte 0
```

```
ERROR [trace ./traces/alaska.rep, line 6]: Payload address (0x80000005b) not aligned to 8 bytes
ERROR [trace ./traces/amptjp.rep, line 5]: Payload address (0x800000043) not aligned to 8 bytes
ERROR [trace ./traces/bash.rep, line 9]: Payload address (0x8000000d3) not aligned to 8 bytes
```

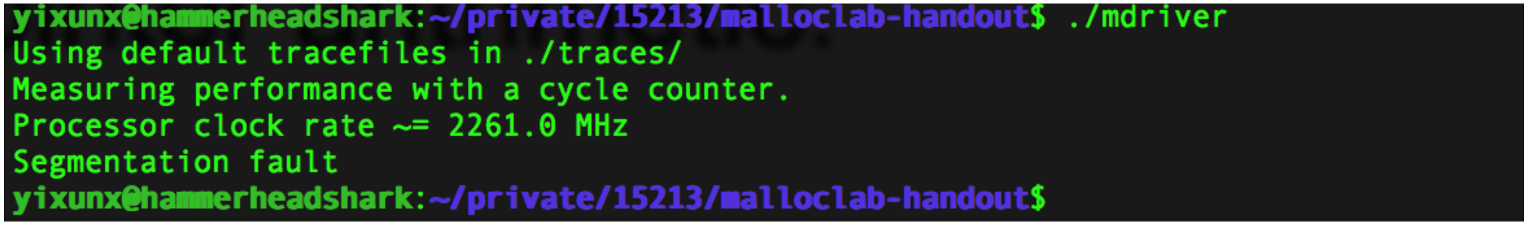
```
ERROR [trace ./traces/alaska.rep, line 7]: Payload (0x800000718:0x800000be9) lies outside heap (0x800000000:0x800000717)
ERROR [trace ./traces/amptjp.rep, line 6]: Payload (0x800000a40:0x800001237) lies outside heap (0x800000000:0x800000a3f)
```

```
...................ERROR: mem_sbrk failed. Ran out of memory...
ERROR [trace ./traces/needle.rep, line 95411]: mm_malloc failed.
```

- The error message is straightforward in most cases
  - “garbled byte” means part of the payload returned to the user has been overwritten by your allocator. (Check your pointer arithmetic!)
  - “out of memory” occurs when the memory is used very inefficiently. (Check whether you’re losing track of blocks.)

Errors

- But most of the time…



```
yixunx@hammerheadshark:~/private/15213/malloclab-handout$ ./mdriver
Using default tracefiles in ./traces/
Measuring performance with a cycle counter.
Processor clock rate ~= 2261.0 MHz
Segmentation fault
yixunx@hammerheadshark:~/private/15213/malloclab-handout$
```

- Why did you segfault? Probably either:
  - Pointer arithmetic error.
  - Violating an invariant.

Fixing a Segfault

- As always, you can use printfs and gdb to find out which line segfaulted.
  - BUUUUUUT the line that segfaults is likely not where the error is.
  - What you need to know is the moment the heap went wrong, not the moment that it became *obvious* that the heap had gone wrong.
- You could print the whole heap before/after every function that modifies it.
  - Scroll up from the point of segfault and find the earliest operation that makes the heap look wrong.
  - This will require you to manually comb through a tremendous amount of information.
- Easiest solution: USE YOUR HEAP CHECKER.

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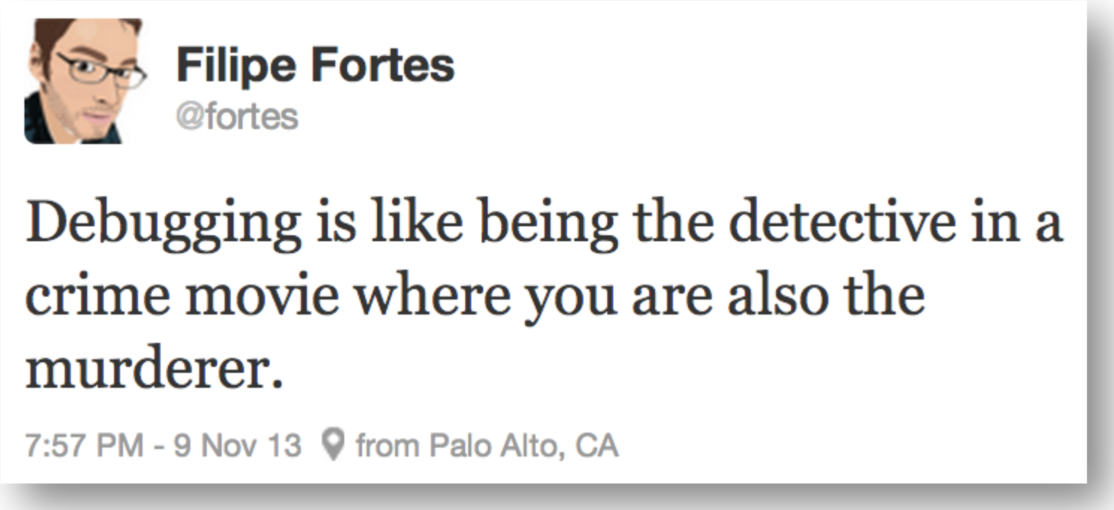

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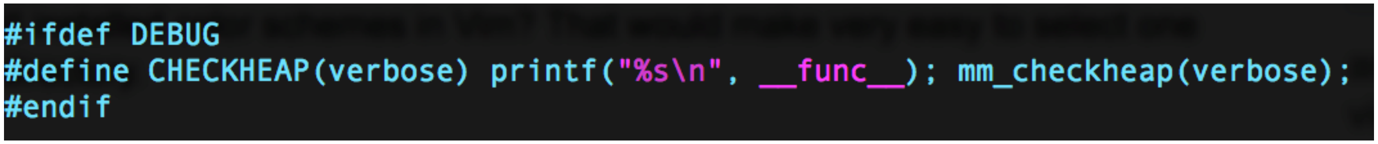
Heap Checker

- Once you’ve settled on a design, write the heap checker that checks all the invariants of the particular design.
- The checking should be detailed enough that the heap check passes **if and only if** the heap is truly well-formed.
- Call the heap checker **before and after** the major operations — whenever the heap should be well-formed.
- Define macros to enable/disable it conveniently.
  - e.g.



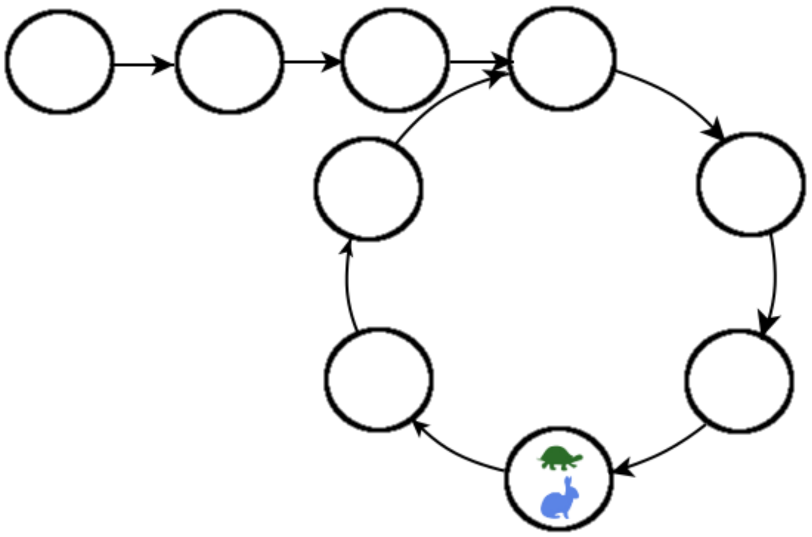
```
#ifdef DEBUG
#define CHECKHEAP(verbose) printf("%s\n", __func__); mm_checkheap(verbose);
#endif
```

Invariants (Non-Exhaustive)

- Block level:
  - Header and footer match.
  - Payload area is aligned.
- List level:
  - Next/prev pointers in consecutive free blocks are consistent.
  - Free list contains no allocated blocks.
  - All free blocks are in the free list.
  - No contiguous free blocks in memory (unless you defer coalescing).
  - There are no cycles in the list (unless you use circular lists).
  - Segregated list contains only blocks that belong to the size class.
- Heap level:
  - Prologue/Epilogue blocks are at the boundaries and have special size/alloc fields.
  - All blocks stay in between the heap boundaries.
- And your own invariants (e.g. address order)

Hare and Tortoise Algorithm

- Detects cycles in linked lists.
- Set two pointers, “hare” and “tortoise,” to the beginning of the list.
- During each iteration, move the tortoise forward one node, the hare two.
- If they ever point at the same node, the list has a cycle.
- If the tortoise reaches the end, there are no cycles.



Pictures based on those at http://blog.kyletraff.com/infinite-loops-finding-cycles-in-a-linked-list/

Other Things to Watch For

- Uninitialized pointers and/or memory.
- Make sure `mm_init()` initializes everything.
  - It is called by the driver between every trace.
  - If something is overlooked, you might be able to pass every *single* trace file, but the complete driver test will fail.

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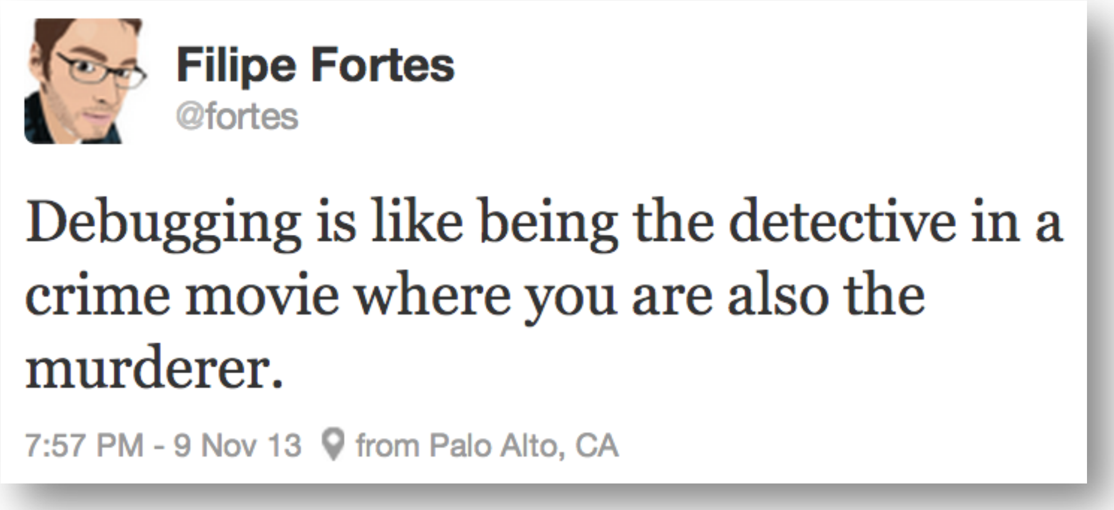

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Useful Tools: Valgrind and GDB

- Valgrind
  - The default check (memcheck) will let you know if there are any illegal memory accesses or uninitialized values.
  - A little less useful than in other labs, since you're managing your own memory.
- GDB
  - You know how to stop at a line of code using **breakpoints**.
  - You can also stop when a particular piece of memory is accessed, using **watchpoints**.
    - `watch  expr` breaks when that expression is *modified*.
    - `rwatch expr` breaks when `expr` is *read.*
    - `awatch expr` breaks when it's *read or modified*.
    - To break when the int at 0x12345678 is modified:
      `watch *((int *) 0x12345678)`

Useful Tools: Your Friendly Neighborhood TA

- It can be hard for the TAs to debug your allocator, because this is a more open-ended lab.
- Before asking for help, ask yourself some questions:
  - What part of which trace file triggers the error?
  - Around the point of the error, what sequence of events do you expect?
  - What part of the sequence already happened?
- If you can't answer them, gather more information.
  - How can you figure out which step(s) worked OK?
  - printf, breakpoints, watchpoints…
- Bring us a detailed story, not just a "plot summary."
  - YES: "Allocations of size blah corrupt my heap after coalescing the previous block at line number blah"
  - NO: "It segfaults."

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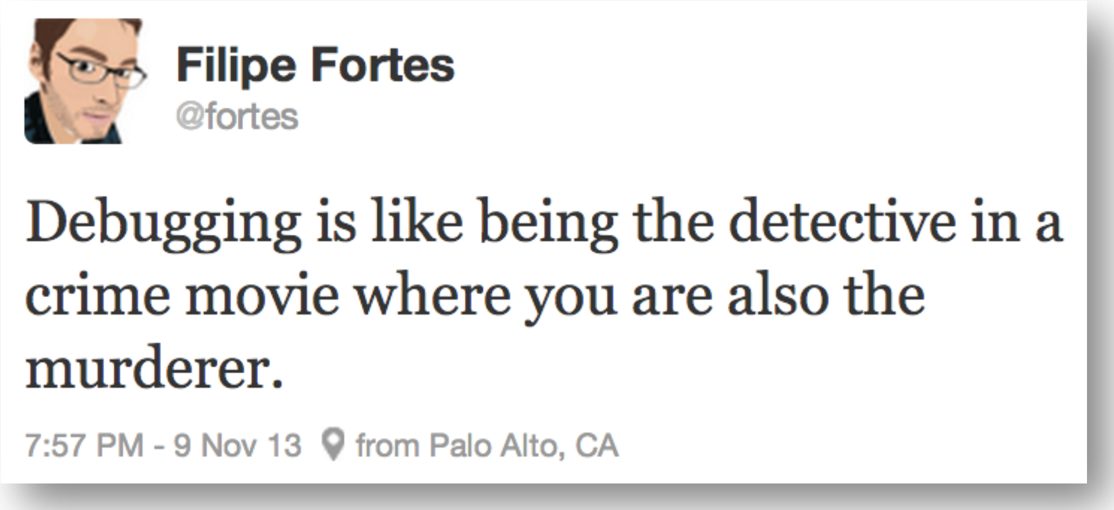

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Beyond Debugging: Error Prevention

- It is hard to write code that is completely correct the first time, but certain practices can make your code less error-prone.
- Plan what each function does *before* writing your code.
  - Draw pictures when a linked list is involved.
  - Consider edge cases (when the block is at start/end of list; when you only have one item in your free list; etc.).
- Write pseudocode first.
- Document your code as (or before!) you write it.

Beyond Debugging: Version Control

- "I had 60 util points just 5 minutes ago!"
- Save mm.c after each major milestone.
  - Most basic: copy files around using the `cp` command.
  - More efficient: keep different versions in separate c files, and use `ln –sf mm-version-x.c mm.c` to start using a particular version
  - Better: use git/svn/cvs… *Make sure your repository is private.*

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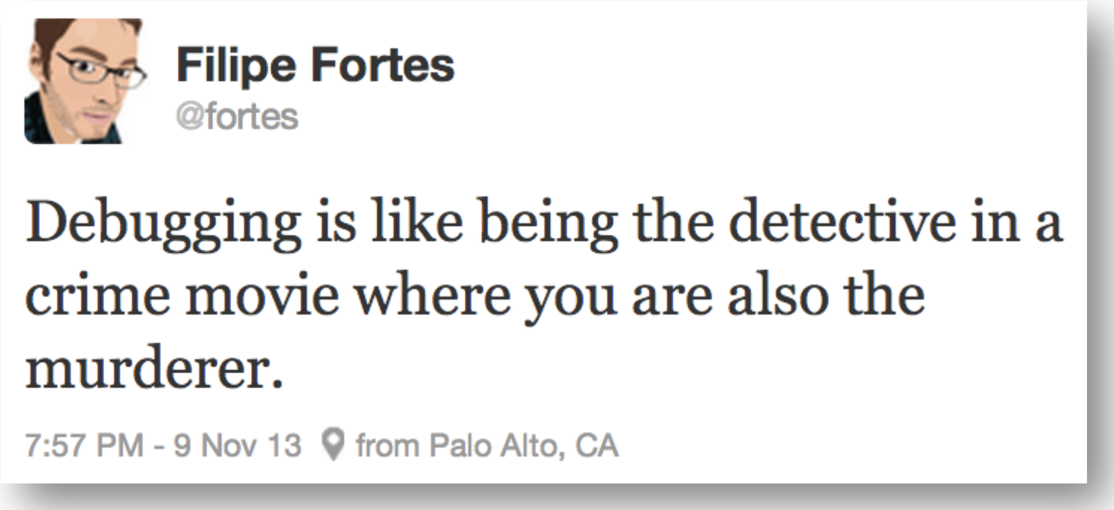

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Optimization: Good Coding

- To achieve better performance, sometimes you'll want to tweak certain parameters.
  - Number of size classes
  - Size parameters of size classes
  - CHUNKSIZE
  - …

- It's better to write modular and encapsulated code so that changing the parameters only requires changing a few lines of code.
  - Use macros wisely!

Optimization: gprof

- When you hit a bottleneck, find which part is limiting your performance.
- A profiler is good for this kind of job.
- To use `gprof`:
  - Change the Makefile to add `-pg` to the compilation flag.
  - Type `make` to recompile the driver. (You may need to change something in your file to force it to recompile, since it won't detect changes.)
  - Run the driver. This will generate a file called `gmon.out`.
  - Run `gprof ./mdriver` to see the result.
  - Don't forget to change the Makefile back afterwards!

Optimization: gprof flat profile

```
%   cumulative   self              self     total
time   seconds   seconds    calls  ns/call  ns/call  name
51.81      3.92     3.92                             add_range
15.46      5.09     1.17                             run_tests
 8.99      5.77     0.68                             randomize_block
 7.93      6.37     0.60                             check_index
 7.20      6.92     0.55                             get_counter
 2.38      7.10     0.18                             access_counter
 2.38      7.28     0.18                             callibrate
 1.45      7.39     0.11  2370377    46.43    53.98  mm_malloc
 0.79      7.45     0.06  2169016    27.68    34.09  coalesce
 0.66      7.50     0.05                             eval_mm_speed
 0.26      7.52     0.02  4261340     4.70     4.70  extract
 0.20      7.53     0.02                             start_counter
 0.13      7.54     0.01  4320821     2.32     2.32  insert
 0.13      7.55     0.01                             clear
 0.13      7.56     0.01                             main
 0.13      7.57     0.01                             set_fcyc_epsilon
 0.00      7.57     0.00  2118313     0.00     0.00  mm_free
 0.00      7.57     0.00    52343     0.00     0.00  extend_heap
 0.00      7.57     0.00     6761     0.00    82.36  mm_realloc
 0.00      7.57     0.00      185     0.00    34.09  mm_init
```

Optimization: gprof call graph

```
index % time    self  children    called     name
                                                 <spontaneous>
[1]     51.8    3.92    0.00                 add_range [1]
-----------------------------------------------
                                                 <spontaneous>
[2]     16.5    1.17    0.08                 run_tests [2]
                0.04    0.01  916464/2370377     mm_malloc [9]
                0.02    0.01  824212/2169016     coalesce [10]
                0.00    0.00    2486/6761        mm_realloc [17]
                0.00    0.00      58/185         mm_init [18]
                0.00    0.00  824848/2118313     mm_free [19]
-----------------------------------------------
                                                 <spontaneous>
[3]      9.0    0.68    0.00                 randomize_block [3]
-----------------------------------------------
                                                 <spontaneous>
[4]      7.9    0.60    0.00                 check_index [4]
-----------------------------------------------
                                                 <spontaneous>
[5]      7.2    0.55    0.00                 get_counter [5]
-----------------------------------------------
                                                 <spontaneous>
[6]      2.4    0.18    0.00                 access_counter [6]
-----------------------------------------------
                                                 <spontaneous>
[7]      2.4    0.18    0.00                 callibrate [7]
-----------------------------------------------
                                                 <spontaneous>
[8]      2.3    0.05    0.12                 eval_mm_speed [8]
                0.07    0.01 1447593/2370377     mm_malloc [9]
                0.04    0.01 1286132/2169016     coalesce [10]
                0.00    0.00    4275/6761        mm_realloc [17]
                0.00    0.00     127/185         mm_init [18]
```

Final Words

- Start *now* (if not already)!
- Come to office hours *early*.
- Write the heap checker *well*.
- Be prepared to start over several times.
- Before handing in, check:
  - Does the header comment contain a detailed description of your approach?
  - Is each function commented?
  - Is the indentation correct? (Configure your text editor to use spaces instead of tabs.)
  - Are any line over 80 characters? (Go to autolab to verify these.)

Questions?

- Good luck!