Mini Valgrind

Entire Assignment due **2019-02-13 23:59**
Graded files:

- mini_valgrind.c

Content

Learning Objectives

The learning objectives for Mini Valgrind are:

- Using metadata for memory bookkeeping
- Memory management and linked lists
- Learning what Valgrind does
- Preparation for the Malloc MP

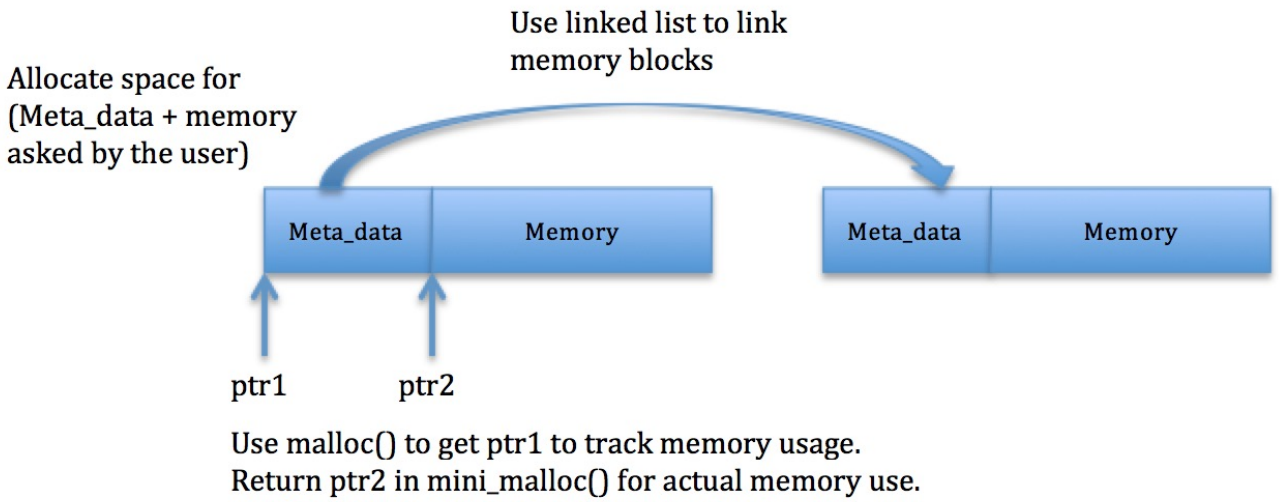
Overview

For this lab, you will be implementing a small version of Valgrind (http://valgrind.org/docs/manual/quick-start.html) called `mini_valgrind`. Valgrind is a great tool for monitoring memory usage, and you have likely used it earlier in this class. Your version will print out a summary of the memory leaks in a particular C program. This lab is meant in part as preparation for your Malloc MP, introducing some topics and techniques which you will find helpful there.

Main Concepts

The main concept of this lab is that we can track each block of memory using some extra space before each allocation (called *metadata*). We have provided you with a struct `meta_data` in `mini_valgrind.h`. The metadata is set up as a linked list of nodes which store information for each allocated block. Each node stores the amount of memory requested, the filename and location of the instruction that made the request, and a pointer to the next allocated block.

Here's an illustration:



When the program is about to exit, we can look at this metadata list to see what the user hasn't freed. These are your memory leaks.

If you feel that you need a refresher on linked lists or other prerequisite concepts, feel free to ask a CA or TA one-on-one.

mini_valgrind.c

We have set up `mini_valgrind` to dynamically replace every call to `malloc` (https://linux.die.net/man/3/malloc), `calloc` (https://linux.die.net/man/3/calloc), `realloc` (https://linux.die.net/man/3/realloc), and `free` (https://linux.die.net/man/3/free) with calls to `mini_malloc`, `mini_calloc`, `mini_realloc`, and `mini_free`, respectively. You will be implementing these four functions in order to track the memory the user allocates.

Inside `mini_valgrind.c`, it is safe to call the real versions of `malloc` (https://linux.die.net/man/3/malloc) and related functions, but you should not be writing your own implementation of `malloc` using `sbrk` (https://linux.die.net/man/2/sbrk).

See the `mini_valgrind.h` header file for details.

Global Variables

In addition to the four functions above, you'll need to maintain the following global variables:

- `head` (https://en.wikipedia.org/wiki/Linked_list): a pointer to the head of a linked list storing all the metadata corresponding to allocated memory blocks
- `total_memory_requested`: stores the total number of bytes of memory requested by the user throughout the lifetime of the program (excluding metadata)
- `total_memory_freed`: stores the total number of bytes of memory freed by the user throughout the lifetime of the program
- `invalid_addresses`: stores the number of times the user has tried to `realloc` (https://linux.die.net/man/3/realloc) or `free` (https://linux.die.net/man/3/free) invalid addresses

Since we keep track of this data, we can show the user how much memory they've allocated, just like the real Valgrind. We can also find out how much memory a user might be leaking, by subtracting `total_memory_freed` from `total_memory_requested`.

If you look in `mini_valgrind.h`, you'll notice that these are declared as `extern` variables. This allows variables to live somewhere else beside the line where you are 'declaring' them, pushing the responsibility of providing a real location in memory for these variables elsewhere and letting the linker (https://stackoverflow.com/questions/496448/how-to-correctly-use-the-extern-keyword-in-c) has a nice explanation of how to use this. **In order to prevent your code from crashing, you will have to declare these variables as globals in `mini_valgrind.c`.** resolve the variable name to where memory is actually reserved. This link (https://stackoverflow.com/questions/496448/how-to-correctly-use-the-extern-keyword-in-c) do-linkers-do)

Testing

You'll want to test your `mini_valgrind` thoroughly.

We've provided you with a `test.c` file that you can put test cases in. Running `make` (https://linux.die.net/man/1/make) will create a `test` executable alongside `mini_valgrind`. You can use it like the regular Valgrind:

```
./mini_valgrind ./test
```

The output should look familiar!

Note that we always build `./test` with debugging symbols (`gcc -g`), so `mini_valgrind` can find the line numbers corresponding to memory leaks.

To debug `mini_valgrind` itself, you can use `gdb` (https://www.gnu.org/software/gdb/). We've also provided a `make debug` command to generate a version of `mini_valgrind` with debugging symbols:

```
gdb --args ./mini_valgrind-debug ./test
```

Warning: printf()

Be careful with `printf` (https://linux.die.net/man/3/printf) by default, stdout is buffered, so `printf` (https://linux.die.net/man/3/printf) inside of `mini_malloc` (https://linux.die.net/man/3/malloc) its buffer using the *real* `malloc` (https://linux.die.net/man/3/malloc) (since it calls `malloc` (https://linux.die.net/man/3/malloc) in order to allocate real version), **but then free it using *your*** `mini_free` since the cleanup happens outside of `mini_valgrind.c` . As you can imagine, this results in unexpected behavior.

Instead, you can use `fprintf(stderr, ...)` , which is unbuffered, or use `write` (https://linux.die.net/man/3/write) to turn off buffering for stdout:

```
setvbuf(stdout, NULL, _IONBF, 0);
```

Warning: extra free() call

Note that there will be some extra calls to your `mini_free` function at the end of the program.

This is an unfortunate side effect of how we implement mini_valgrind internally. In mini_hacks.c, we call a cleanup function defined in the C library (`__libc_freeres`) at the end of the program, which calls `free` (https://linux.die.net/man/3/free) on several internal buffer created by the C library. Here is an example of what the backtrace looks like in gdb:

```
Breakpoint 1, mini_free (payload=0x0) at mini_valgrind.c:142
(gdb) bt
#0  mini_free (payload=0x0) at mini_valgrind.c:142
#1  0x00007ffff7bd3d4a in free (ptr=0x0) at mini_hacks.c:193
#2  0x00007ffff797c380 in __GI___libc_freeres () at set-freeres.c:42
#3  0x00007ffff7bd44ba in finalize () at mini_hacks.c:334
#4  0x00007ffff7bd3fa0 in print_leak_info () at mini_hacks.c:365
...
```

This should not affect your implementation of `mini_free` . However, do be aware of the extra free calls when you're debugging your program, just so that you're not confused about where they're coming from.

Example

Here's a basic test case to check your progress.

Say you had the following in your `test.c` file:

```
#include <stdlib.h>
int main() {
    void *p1 = malloc(30);
    void *p2 = malloc(40);
    void *p3 = malloc(50);
    free(p2);
    return 0;
}
```

`mini_valgrind` 's output should look like this (of course, your process ID and addresses might be different):

```
==25219== Mini-Valgrind
==25219==
==25219== LEAK REPORT:
==25219==    Leak origin: main (test.c:5)
==25219==    Leak size: 50 bytes
==25219==    Leak memory address: 0x1009790
==25219==
==25219==    Leak origin: main (test.c:3)
==25219==    Leak size: 30 bytes
==25219==    Leak memory address: 0x10096f0
==25219==
==25219== Program made 0 bad call(s) to free or realloc.
==25219==
==25219== HEAP SUMMARY:
==25219==    Total memory requested: 120 bytes
==25219==    Total memory freed: 40 bytes
==25219==    Total leak: 80 bytes
```

Notice that leaks are reported most-recent-first. This is because we insert new metadata at the head of the linked list.

Other Programs

You can also run `mini_valgrind` on other programs, like `echo` (https://linux.die.net/man/3/echo)

```
$ ./mini_valgrind echo 'Hello, world!'
==19506== Mini-Valgrind
Hello, world!
==19506==
==19506== Program made 0 bad call(s) to free or realloc.
==19506==
==19506== HEAP SUMMARY:
==19506==    Total memory requested: 1068 bytes
==19506==    Total memory freed: 1068 bytes
==19506==    No leaks, all memory freed. Congratulations!
```

It should work on most standard utilities, but just be aware that it won't work on everything. You'll notice it may generate different output than Valgrind or may even crash when run on complex software like `python` (https://linux.die.net/man/1/python). *This is okay, writing a memory checker is hard!* You only need to implement what we've described above and in `mini_valgrind.h`.

Optional Fun: Sentinel Value!

This part of the assignment in this section is **not graded**. However, sentinel value is a pretty cool concept and we encourage you to try to implement it.

So, suppose that our users of `mini_valgrind` are terrible at coding. They wrote past the end of their allocation (buffer overflow) and corrupted the memory beyond what's allocated to them. Can we detect this kind of memory corruption and warn them? The answer is yes, by using sentinel value!

Sentinel value is a chunck of *pre-defined bits* at the end of an allocated memory. In other word, each allocation would look like this:

```
[meta_data][---actual data---][sentinel_value]
```

On every operation, we would check that the sentinel value is still the same as it was pre-defined. If the sentinel value has changed, then we know for certain that the user has corrupted memory.

In your `mini_valgrind`, you will use the magic number `0xCAFEBABE` for sentinel value (https://en.wikipedia.org/wiki/Magic_number_(programming)). (Why x0CAFEBABE?) (http://www.artima.com/insidejvm/whyCAFEBABE.html)

Implementation:

- Add the bits `0xCAFEBABE` to the end of every allocation. (Do you need to do it for `realloc` (https://linux.die.net/man/3/realloc)?)
- Check if the sentinel value of a previously allocated buffer has changed in `mini_realloc` and `mini_free`.
- If so, print out a warning to the user with `fprintf(stderr, ...)`. (Do not print to stdout!)

If you want to test out your implementation, you can add the following code to your `test.c` and see if you get any warning when running `./mini_valgrind ./test`:

```
char* ptr = malloc(10);
*(ptr + 10) = 'a';
free(ptr);
```

Behind the Scenes

This section describes some details of how we've implemented `mini_valgrind`. You are encouraged, but not required, to understand this.

We compile your `mini_` functions, along with some extra code from `mini_hacks.c`, into a *shared object* (https://en.wikipedia.org/wiki/Library_%28computing%29) called `mini_valgrind.so`.

`mini_hacks.c` has two main jobs:

- Create wrappers around `malloc` (https://linux.die.net/man/3/malloc) and the other functions, so that they use your replacement functions when the user's program calls them, while still letting you use the real versions within your code
- Print out leak info at program exit

The actual `./mini_valgrind` program is implemented in `mini_main.c`. When you run `./mini_valgrind ./test`, we use an environment variable `LD_PRELOAD` (https://rafalcieslak.wordpress.com/2013/04/02/dynamic-linker-tricks-using-ld_preload-to-cheat-inject-features-and-investigate-programs/) to run the `./test` program using the code in `mini_valgrind.so`. Essentially, it replaces normal references to the built-in `malloc` (https://linux.die.net/man/3/malloc) with references to our own version of `malloc`.

"But," you may ask, "*how do we call the real version of `malloc` if we've replaced it with our own version of it?*" The trick is a function called `dlsym` (https://linux.die.net/man/3/dlsym) which allows us to bypass `LD_PRELOAD` and ask for a function pointer to the real `malloc` (https://linux.die.net/man/3/malloc). This is all handled within `mini_malloc.c`.