CS 2110 Homework 11
Implementing Dynamic Memory Allocation

Maddie Brickell, Shannon Kek, Henry Harris, Bharat Srirangam

Fall 2018

Contents

1 Assignment

In this assignment, you will be writing the dynamic memory allocation and deallocation functions of malloc, free, realloc, and calloc. These functions are confusing to write, so we have provided an in-depth guide below. Please read through this entire pdf before beginning. The specifics for each function are located in `malloc.c` as well as subsections 1.6 - 1.9 below.

1.1 The Basics

It is the job of the memory allocator to process and satisfy the memory requests of the user. But where does the allocator get its memory? Let us recall the structure of a program's memory footprint.

```
+--------------------+ (low memory)
|       CODE         |
+--------------------+
|       DATA         |
+--------------------+ <-- Break
|                    |
|                    |
+--------------------+
|       STACK        |
+--------------------+ (high memory)
```

When a program is loaded into memory there are various "segments" created for different purposes: code, stack, data, etc. In order to create some dynamic memory space, otherwise known as the heap, it is possible to move the "break", which is the first address after the end of the process's uninitialized data segment. A function called `brk()` is provided to set this address to a different value. There is also a function called `sbrk()` which moves the break by some amount specified as a parameter.

For simplicity, a wrapper for the system call `sbrk()` has been provided for you as a function called `my_sbrk` located in `suites/malloc_suite.c`. **Make sure to use this call rather than a real call to sbrk, as doing this can potentially cause a lot of problems.** Note that any problems introduced by calling the real sbrk will not be regraded, so make sure that everything is correct before turning in.

If you glance at the code for `my_sbrk()`, you will quickly notice that upon the first call it always allocates 8 KiB. For the purposes of your program, you should treat the returned amount as whatever you requested. For instance, the first time I call `my_sbrk()` it will be done like this:

```
my_sbrk(SBRK_SIZE); /* SBRK_SIZE == 2 KB */

-----------------------------------------
|                  8 KB                  |
-----------------------------------------
^
|
\______ The pointer returned to me by my_sbrk
```

Even though you have a full 8 KiB, you should treat it as if you were only returned `SBRK_SIZE` bytes. Now when you run out of memory and need more heap space you will need to call `my_sbrk()` again. Once again, the call is simply:

```
my_sbrk(SBRK_SIZE);

-----------------------------------------
|    2 KB   |            6 KB            |
-----------------------------------------
            ^
            |
            \____ The pointer returned to me by my_sbrk
```

Notice how it returned a pointer to the address after the end of the 2 KB I had requested the first time. `my_sbrk()` remembers the end of the data segment you request each time and is able to return that value to you as the beginning of the new data segment on a following call. Keep this in mind as you write the assignment!

We've written my_sbrk to be able to only hand out a certain amount of memory before returning -1 to indicate that its done. This limit gives us the ability to test the behavior of the code when my_sbrk can't get more memory.

1.2 Block Allocation

Trying to use `sbrk()` (or `brk()`) exclusively to provide dynamic memory allocation to your program would be very difficult and inefficient. Calling sbrk involves a certain amount of system overhead, and we would prefer not to have to call it every single time a small amount of memory is required. In addition, deallocation would be a problem. Say we allocated several 100 byte chunks of memory and then decided we were done with the first. Where would the break be? There's no handy function to move the break back, so how could we reuse that first 100 byte chunk?

What we need are a set of functions that manage a pool of memory allowing us to allocate and deallocate efficiently. Typically, such schemes start out with no free memory at all. The first time the user requests memory, the allocator will call `sbrk()` as discussed above to obtain a relatively large chunk of memory. The user will be given a block with as much free space as they requested, and if there is any memory left over it will be managed by placing information about it in a data structure where information about all such free blocks is kept. This is called the freelist and we will return to this later.

In order to keep track of allocated blocks we will create a structure to store the information we need to know about a block. Where should we put this structure? Can we simply call `malloc()` to allocate space for the information?

No we can't! We're writing `malloc()`; we can't use it or we'd end up with infinite recursion. However, there's an easier way that will keep our bookkeeping structure right with the data we're allocating for easy access.

In order to keep track of allocated blocks, we will create a structure to store the information we need to know about a block. We will store this information about the block, called metadata, inside the block itself! A crucial part of the metadata is the canary. Canaries are integers that we generate via information about the block itself. They buffer the user data, so if the canary is incorrect, the user data has been altered. For more information about canaries see `https://en.wikipedia.org/wiki/Buffer_overflow_protection#Canaries`, but note that the canary we implement will be one for memory allocated by malloc, not static arrays.

Metadata (contains beg. canary)	User Data	End Canary

Figure 1. The beginning and end canaries buffer the area for user data, creating a 'block'

Whenever you malloc, you will set both of the beginning and end canaries. Since the canaries are psuedo-random numbers used for verification purposes, we will calculate them by xor'ing the address of the block with CANARY_MAGIC_NUMBER and adding 1 for fun.

```
unsigned long canary = ((uintptr_t)block ^ CANARY_MAGIC_NUMBER) + 1;
```

We will need to take into consideration the leading metadata and end canary whenever we allocate blocks. To let the user have as much space as they requested, when they request a block of size n bytes we will allocate a block of size `sizeof(the metadata) + n + sizeof(tail canary)`. Along with the beginning canary, this size will be stored in the metadata. As well, the metadata will contain four pieces of information that is critical for the freelist discussed in the next section. As depicted in my_malloc.h, this is the struct definition for the metadata:

```
typedef struct metadata {
    struct metadata *prev_addr;
    struct metadata *next_addr;
    struct metadata *prev_size;
    struct metadata *next_size;
    unsigned long size;
    unsigned long canary;
} metadata_t;
```

The size portion of the metadata struct contains the size that the user requested and the `TOTAL_METADATA_SIZE`, a macro holding the size in bytes of the metadata and end canary which will be described in detail in the next section. For ease of reading, this macro will be represented as `TMS` in all of our block representations. The user does not care about the metadata for the block, they just want the size they requested. Therefore, when you return a block to the user, you will need to use pointer arithmetic to 'step over' the metadata and return the address of the data. What this looks like:

Pointer returned to the user

Metadata (contains beg. canary)	User Data	End Canary

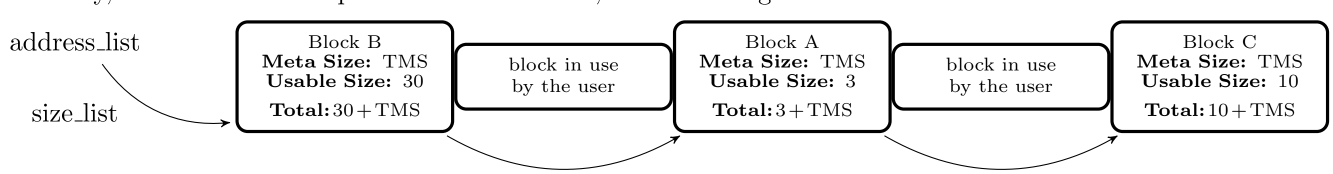
Figure 2. When a block is returned to the user, the pointer returned points to the address of the area used by the user

1.3 The Freelist

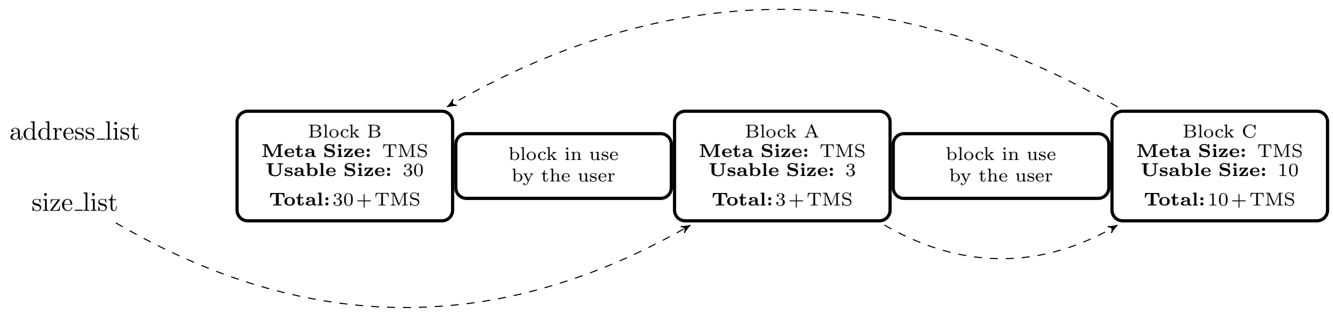
When we split up memory, we give one piece/block to the user. The remaining pieces/blocks are placed in a linked list, called the freelist, to be used at a later time. For this semester, we are representing our freelist as two separate doubly linked lists, one organized by address, the other organized by size. Both of these linked lists should be defined as global file variables and to help you out, we have already defined them for you.

```
metadata_t *address_list;
metadata_t *size_list;
```

This may be a source of some confusion, as we have two linked lists for the representation of our freelist. In reality, each block will be placed two linked lists, one ascending in address:

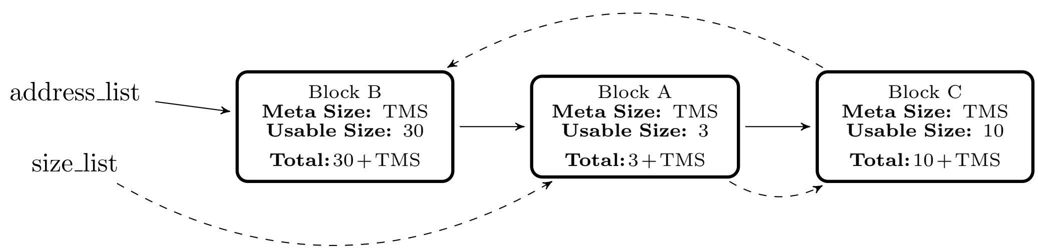


The other ascending by size:



Note: If two blocks are the same size, place the newer block before the older block in the `size_list`.

For the remainder of the pdf, we will represent the freelist without spaces for the blocks currently in use by the user like so:



A Quick Note: The node representations in our freelists should be read as the following:

1. First Line: The name of the block ("Block B")
2. Second Line: Meta Size → The size of the metadata for that block
3. Third Line: Usable Size → The size of the space available to the user
4. Fourth Line: Total → The total size of the memory taken up by this block

Both the address_list and size_list are doubly linked, which is why each block has both a previous and next pointer for both of the lists. Whenever you remove or add to the lists, make sure to update all four of the pointers present in the metadata.

1.4 Simple Linked List: Allocating

When we first allocate space for the heap, it is in our best interest not to just request what we need immediately but rather to get a sizable amount of space, use a piece of it now, and keep the rest around in the freelist until we need it. This reduces the amount of times we need to call `sbrk()`, the real version of which, as we discussed earlier, involves significant system overhead. So how do we know how much to allocate, how much to give to the user, and how much to keep?

For this assignment we will request blocks of size 2048 bytes from `my_sbrk()`. We don't want to waste space, though, so we want to give to the user the smallest size block in which their request would fit. For example, the user may request 256 bytes of space. It is tempting to give them a block that is 256 bytes, but remember we are also storing the metadata inside the block. If our metadata and canaries takes up `sizeof (metadata_t) + sizeof (int) = 20` bytes for example, we need at least a

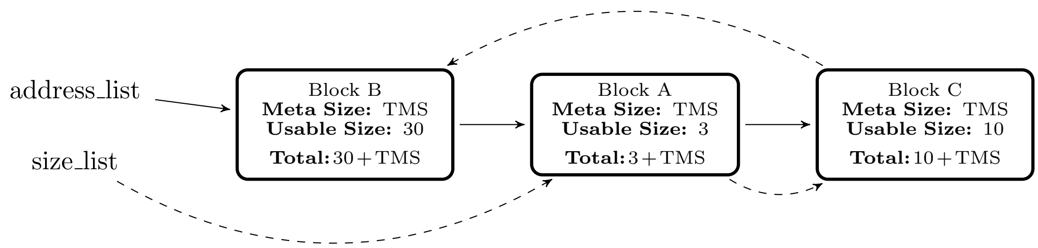
$$256 + 20 = 276$$

byte block.

Note that the size of your metadata will vary based on your computer's architecture and platform. Use `sizeof()` to avoid depending on the platform, and the macro `TOTAL_METADATA_SIZE` that sums the beginning metadata and end canary so you don't have to worry about it.

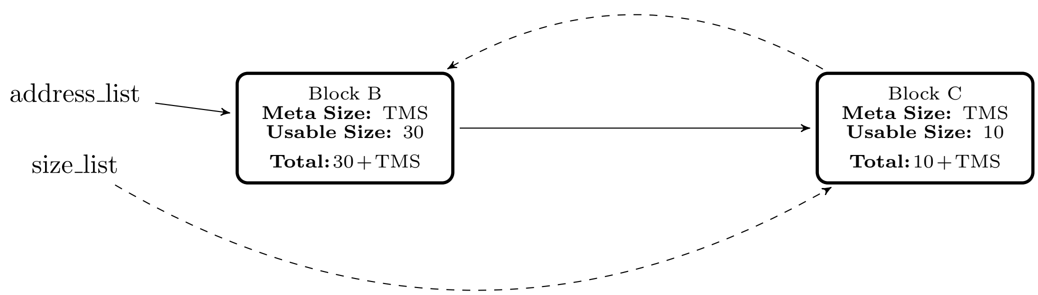
How do we get from one big free block of size 2048 bytes to the block of size 276 bytes we want to give to the user? In this simple implementation, you will traverse the `size_list` to find the best block to satisfy the user's request, which should be equal or greater than the size requested, and "split" off however much you need from the front or the back. For this assignment, you must split off from the back.

Say we have the following situation:



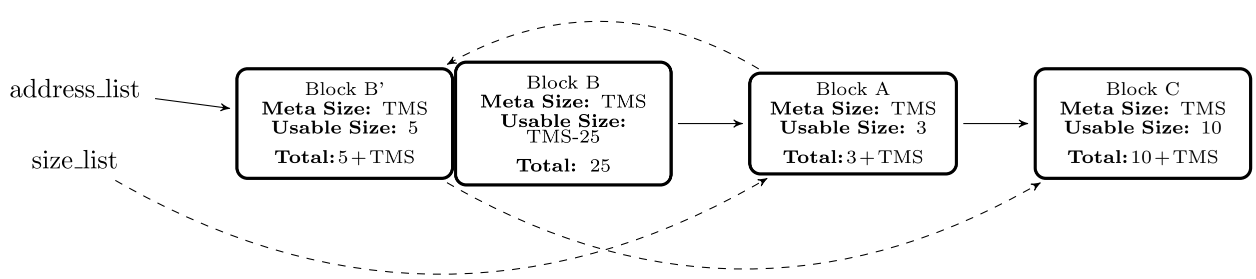
When we malloc for a certain size, we first want to use a block of that exact size, remove it from both the `address_list` and `size_list` and return it to the user.

Ex: malloc(3) would leave the freelist as so:

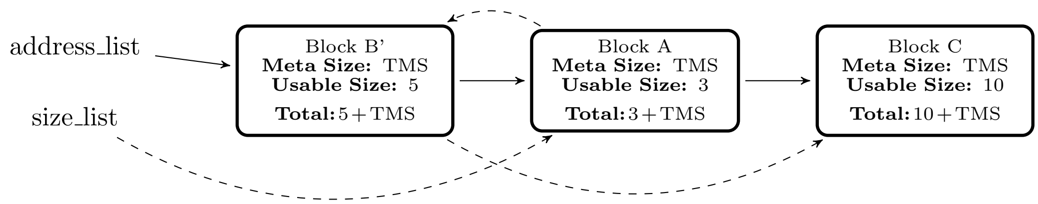


If we do not have a perfectly sized block, then find the next block that is big enough to split. i.e. A block that is big enough for the size of the malloc call + TMS with room for another block, `MIN_BLOCK_SIZE`. (In our case, `MIN_BLOCK_SIZE` is defined to be 1 byte + TMS)

Ex: my_malloc(25) would split block B into two blocks B(size 25) and B'(size 5). Remember to split your block from the back, in which the left portion of the block will remain in the freelist.



Once Block B is returned to the user, this call will leave the freelist as such:



Don't forget to set both canaries and move the pointer to the beginning of the space the user uses after the end of the metadata before returning the block to the user.

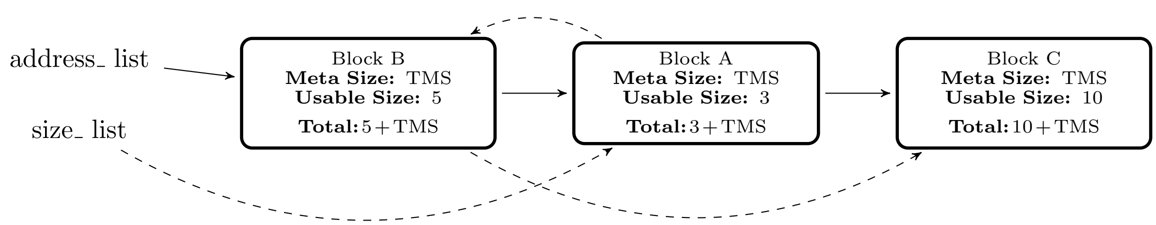
1.5 Simple Linked List: Deallocating

When we deallocate memory, we simply check the block's canaries and return the block to the `address_list` and `size_list` in the appropriate position. When the user calls the free function with a block body pointer, we do some pointer arithmetic to find the starting point of the entire block (i.e. the metadata). Notice we don't clear out all the data. That really just takes too long when we're not supposed to care about what's in memory after we free it anyway. For all of you who were wondering why sometimes you can still access data in a dynamically allocated block even after you call free on its pointer, this is why! We like the freelists to contain fairly large blocks so that large requests can be allocated quickly, so if the block on either side of the block we're freeing is also free, we can coalesce them, or join them into the bigger block like they were before we split them.

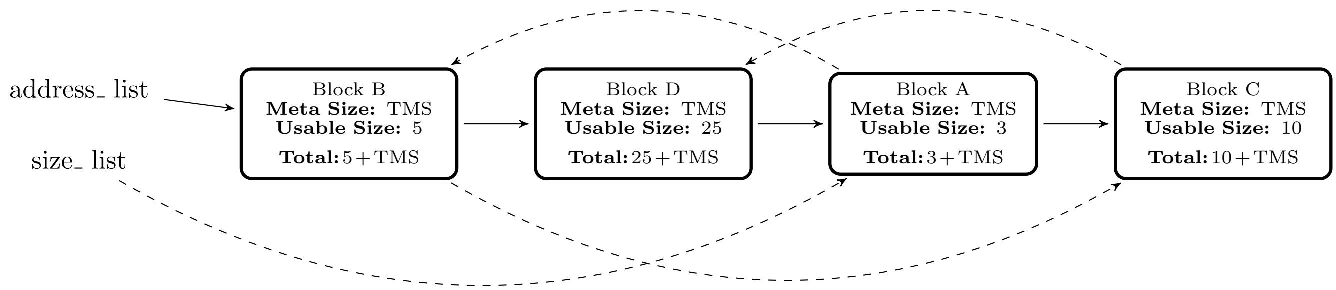
How do we know what blocks we can join with? The left side one will have its address + its size = your block's address, and the right one will be your block's size + it's address.

To deallocate blocks, we would first iterate through the `address_list` for the correct location of the block. If the block could be merged with a curr_block to the right or left, we would remove the curr_block from the `size_list`, combine the blocks and re-enter it into the `size_list`. If the block could not be merged, we would insert it in the appropriate positions in both the `size_list` and `address_list`. The following examples demonstrate a few of the possibilities with deallocation.

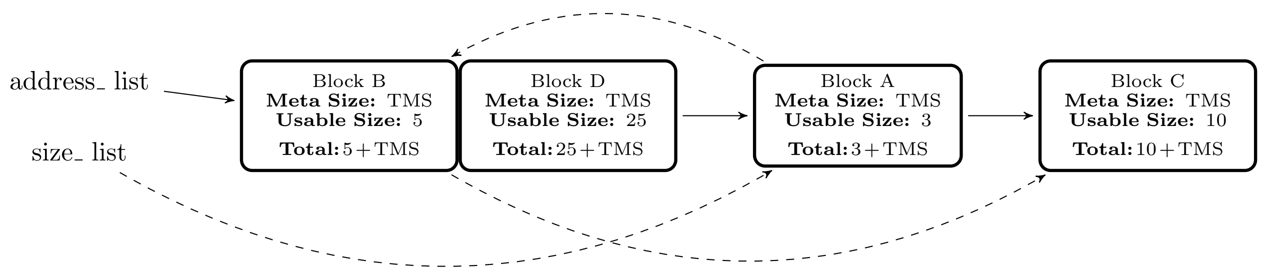
Let's start with this situation:

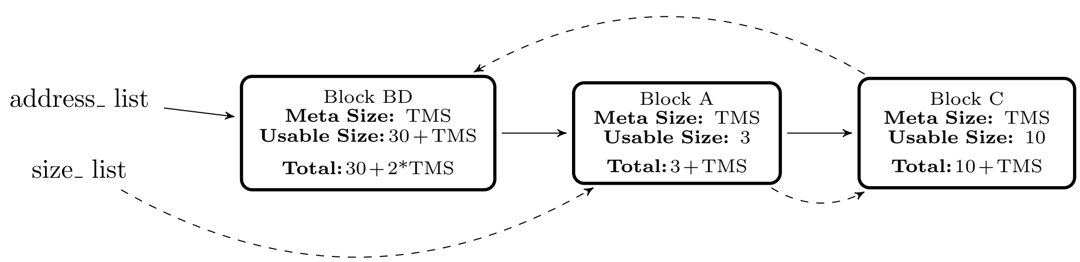


If we deallocated a block of size 25, we would first iterate through the `address_list` for the correct location of the block and check to see if the block needs to be merged either to the right of left. In this example, the block to be entered is not directly next to any other blocks, address wise, so we would just insert it into the `address_list`. Finally, we would insert the block in the correct position in the `size_list` leaving the freelist as seen below (assuming Block D's address places it in between Blocks B and A)

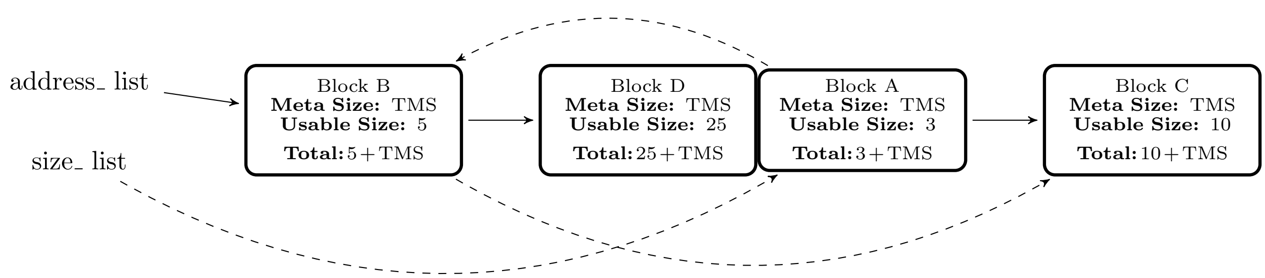


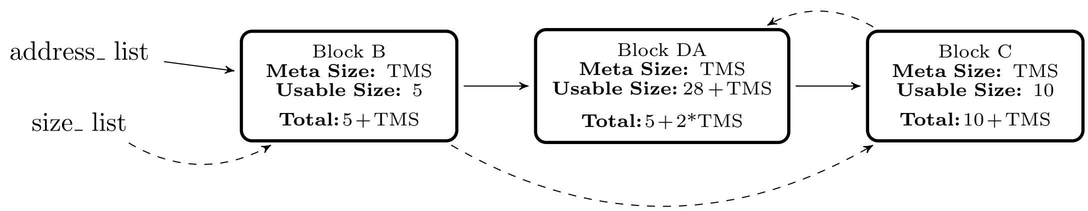
If Block B and D were right next to eachother in memory (i.e. the address at end of block B is equal to the address at the beginning of block D), then we would need to perform a merge. To perform this left merge, pop block B from the `size_list` , add block D to it, reset the size and canaries, and find the new block its' proper home in the `size_list` (Note: there is a way to perform a left merge without removing and inserting blocks from the `address_list`).





If Block D and A were right next to eachother in memory (i.e. the address at the end of block D is equal to the address at the beginning of block A), then we would need to perform a merge. To perform this right merge, pop block A from the `size_list`, add block D to it, move block A's metadata to block D, reset the size and canaries, and find the new block its' proper home in the `size_list`.





Note: To compare pointers, cast them to uintptr_t first

1.6 my_malloc()

You are to write your own version of malloc that implements simple linked-list based allocation:

1. Figure out what size block you need to satisfy the user's request by adding `TOTAL_METADATA_SIZE` to the requested block body size to include the size of the metadata and the tail canary, that will be the real block size we need. (Note: if this size in bytes is over `SBRK_SIZE`, set the error `SINGLE_REQUEST_TOO_LARGE` and return `NULL`. If the request size is 0, then mark `NO_ERROR` and return `NULL`).

2. Now that we have the size we care about, we need to iterate through our freelist to find a block that best fits. Best fit is defined as a block that is exactly the same size, or the smallest block big enough to split and house a new block (`MIN_BLOCK_SIZE` is defined for you). If the block is not big enough to split, it is not a valid block and cannot be used.

   (a) If the block is exactly the same size, you can simply remove it from the both the `address_list` and `size_list`, set the canaries, and return a pointer to the body of the block.

   (b) If the block is big enough to house a new block, we need to split off the portion we will use. Remember: pointer arithmetic can be tricky, make sure you are casting to a `uint8_t *` before adding the size (in bytes) to find the split pointer!

   (c) If no suitable blocks are found at all, then call `my_sbrk()` with `SBRK_SIZE` to get more memory. You must use this macro; failure to do so will result in a lower grade. After setting up its metadata and merging it if possible (in this assignment, there must never be two different blocks in the freelist who are directly adjacent in memory), go through steps (a)-(c). In the event that `my_sbrk()` returns failure (by returning `NULL`), you should set the error code `OUT_OF_MEMORY` and return `NULL`.

   Remember that you want the address you return to be at the start of the block body, not the metadata. This is `sizeof (metadata_t)` bytes away from the metadata pointer. Since pointer arithmetic is in multiples of the sizeof the data type, you can just add 1 to a pointer of type `metadata_t*` pointing to the metadata to get a pointer to the body. If you have not specifically set the error code during this operation, set the error code to `NO_ERROR` before returning.

3. The first call to `my_malloc()` should call `my_sbrk()`. Note that malloc should call `my_sbrk()` when it doesn't have a block to satisfy the user's request anyway, so this isn't a special case.

1.7 my_free()

You are also to write your own version of free that implements deallocation. This means:

1. Calculate the proper address of the block to be freed, keeping in mind that the pointer passed to any call of `my_free()` is a pointer to the block body and not to the block's metadata.

2. Check the canaries of the block, starting with the head canary (so that if it is wrong you don't try to use corrupted metadata to find the tail canary) to make sure they are still their original value. If the canary has been corrupted, set the `CANARY_CORRUPTED` error and return.

3. Attempt to merge the block with blocks that are consecutive in address space with it if those blocks are free. That is, try to merge with the block to its left and its right in memory if they are in the freelist. Finally, place the resulting block in both the `address_list` and `size_list` by setting the respective previous and next address pointers for both the `address_list` and `size_list` in each node.

Just like the `free()` in the C standard library, if the pointer is `NULL`, no operation should be performed.

1.8 my_realloc()

You are to write your own version of realloc that will use your `my_malloc()` and `my_free()` functions. `my_realloc()` should accept two parameters, `void *ptr` and `size_t size`. **If the block's canaries are valid**, it will attempt to effectively change the size of the memory block pointed to by `ptr` to `size` bytes, and return a pointer to the beginning of the new memory block. If the canaries are invalid, it returns NULL and sets `my_malloc_errno` to `CANARY_CORRUPTED`.

Do **not** directly change the freelist or blocks in `my_realloc()` — leave that to `my_malloc()` and `my_free()`. This means you don't need to worry about shrinking or extending blocks in place[1]; if `size` is nonzero, just always call `my_malloc()` to attempt to allocate a new block of the new size. Make sure to copy as much data as will fit in the new block from the old block to the new block. The rest of the data in the new block (if any) should be uninitialized.

Your `my_realloc()` implementation must have the same features as the `realloc()` function in the standard library. Specifically:

1. If the pointer is null - make a call to malloc using the size argument (i.e. malloc(size))
2. If the canaries are corrupted - set the CANARY_CORRUPTED error code and return null
3. If the size is equal to zero, and pointer is non-null - make a call to free using the ptr argument and return to null (i.e. free(ptr))
4. Else, create a new block via my_malloc and and copy the old block's data to the new block up to min(new block data size, old block data size)

1.9 my_calloc()

You are to write your own version of calloc that will use your `my_malloc()` function. `my_calloc()` should accept two parameters, `size_t nmemb` and `size_t size`. It will allocate a region of memory for `nmemb` number of elements, each of size `size`, zero out the entire block, and return a pointer to that block.

If `my_malloc()` returns `NULL`, do not set any error codes (as `my_malloc()` will have taken care of that) and just return `NULL` directly.

1.10 Error Codes

For this assignment, you will also need to handle cases where users of your malloc do improper things with their code. For instance, if a user asks for 12 gigabytes of memory, this will clearly be too much for your 8 kilobyte heap. It is important to let the user know what they are doing wrong. This is where the enum in the `my_malloc.h` comes into play. You will see the four types of error codes for this assignment listed inside of it. They are as follows:

- **NO_ERROR**: set whenever `my_calloc()`, `my_malloc()`, `my_realloc()`, and `my_free()` complete successfully.

[1] Even though we don't extend or shrink blocks in place in this homework, keep in mind that real-world implementations (which are not written in a panic right before finals) very well could.

- **OUT_OF_MEMORY**: set whenever the user's request cannot be met because there's not enough heap space.
- **SINGLE_REQUEST_TOO_LARGE**: set whenever the user's requested size plus the total metadata size is beyond `SBRK_SIZE`.
- **CANARY_CORRUPTED**: set whenever either canary is corrupted in a block passed to `free()` or `realloc()`.

Inside the .h file, you will see a variable of type `enum my_malloc_err` called `my_malloc_errno`. Whenever any of the cases above occur, you are to set this variable to the appropriate type of error. You may be wondering what happens if a single request is too large AND it causes malloc to run out of memory. In this case, we will let the `SINGLE_REQUEST_TOO_LARGE` take precedence over `OUT_OF_MEMORY`. So in the case of a request of 9kb, which is clearly beyond our biggest block and total heap size, we set `ERRNO` to `SINGLE_REQUEST_TOO_LARGE`.

1.11 Using the Makefile

If you are not on docker, before running the Makefile, you need to install Check, a C unit testing library the provided tests use. The following command should install the packages you need for this homework (you should already have them installed but here it is again):

```
sudo apt-get install pkg-config check gdb
```

You can run the provided tests with `make run-tests` and run gdb with `make run-gdb`.

1.12 Deliverables

Submit only `my_malloc.c` to ***GRADESCOPE*** under "Homework 11." Please don't zip it.

Do **NOT** modify or submit the header file, `my_malloc.h`. We will grade with the original copy. Any functions or variables you add should be marked `static` so they do not conflict with the grader.

Also, please note that the tests are not weighted, so the grade you get in your terminal will NOT be the grade you get on this assignment. You can submit to Gradescope to get a better idea of that, but we reserve the right to add test cases later.

1.13 Suggested Helper Methods

Coding malloc can seem like quite a daunting challenge, but your debugging process can be helped along tremendously if you do not write all of malloc in one method and instead split it up into helper methods! Helper methods are incredibly useful for understanding what is going on and also results in cleaner code, so it's a win-win strategy. Below are some TA recommended helper methods to implement, and while they are not required and will not be tested with the autograder, we advise that you use them.

All helper methods must be declared `static`:

- `static metadata_t* find_right(metadata_t*)`
- `static metadata_t* find_left(metadata_t*)`
- `static void merge(metadata_t* left, metadata_t* right)`
- `static void double_merge(metadata_t* left, metadata_t* middle, metadata_t* right)`
- `static metadata_t* split_block(metadata_t* block, size_t size)`

- `static void add_to_address_list(metadata_t* add_block)`
- `static void add_to_size_list(metadata_t* add_block)`
- `static void remove_from_address_list(metadata_t* remove_block)`
- `static void remove_from_size_list(metadata_t* remove_block)`
- `static void set_canary(metadata_t* block)`

Remember, this is not an exhaustive list of operations that can performed with helper methods. Feel free to implement helper methods for any aspect of malloc that works for you.

Note: We are declaring these functions to be static because we want them to be private to my_malloc.c. DO NOT put any function prototypes in my_malloc.h

1.14 Debugging

```
Yes, we assigned malloc
which makes us pretty cruel.
But here are some debugging tips
because we are actually kind of cool
```

When you run the tests, you will see a pretty hefty output in your terminal. Each line of the output provides critical information depicting which tests you are failing/passing. The general format of:

`suite_filename.c:420:fun_test_case:test_description`

states a test named `test_description` is failing/passing in an individual test case named `fun_test_case`, located in that specific test suite `suite_filename.c` at line 420. That is, test suites contain test cases which contain tests. For example,

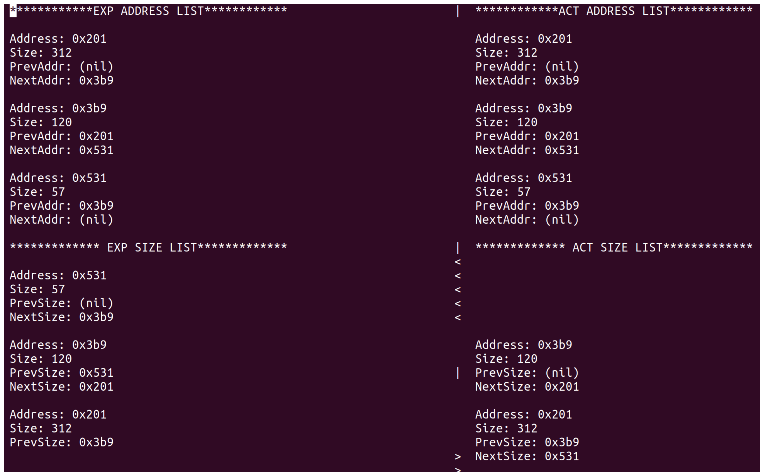
`malloc_suite.c:37:Malloc_Perf_Block1:test_malloc_perf_block1_lists`

tells us whether the address_list and size_list is correct when we malloc for a perfectly sized block. More information about the test is written in malloc_suite.c, and the assertion that failed is on line 37.

To run an individual test case, run

```
make run-tests TEST=Malloc_Perf_Block1
```

Every time you run the tests - a function will print out your address list and size list to the `test.txt` file located in the actual folder. To see the difference between your address/size list and the expected address/size list, look at the `text.txt` file located in the diff directory. Below is a sample diff:



From the image above, please note that the expected address and size list is on the left hand side, while the address and size list generated by your code is located on the right hand side. As well, the `'<'` symbol denotes that the expected lists contained something that the actual lists did not. Furthermore, the `'>'` symbol denotes that the actual list contained an extra block. Finally, the `'|'` symbol denotes an change in the line from expected to actual lists.

To debug an individual test case with gdb, run

```
make run-gdb TEST=Malloc_Perf_Block1
```

When debugging with gdb, anytime you want to print out a `metadata_t` pointer, call the `pp_pointer()` function to pretty-print your pointer. For example, if you wanted to see what the head of the `address_list` was:

```
(gdb) p/x pp_pointer(address_list)
```

2 Frequently Asked Questions

1. **I have a segfault, will you debug it for me?**

   No, debug it yourself with gdb. Here is the gdb video one of the TA's created:

   `https://www.youtube.com/playlist?list=PLsK1fComPkFiYc4oX8Ef9QUyiWVM5BaKe`

   Here are some other gdb tutorials:

   - `https://www.cs.cmu.edu/~gilpin/tutorial/`
   - `http://www.cs.yale.edu/homes/aspnes/pinewiki/C%282f%29Debugging.html`
   - `http://heather.cs.ucdavis.edu/~matloff/UnixAndC/CLanguage/Debug.html`
   - `http://heather.cs.ucdavis.edu/~matloff/debug.html`
   - `http://www.delorie.com/gnu/docs/gdb/gdb_toc.html`

2. **Can we build our freelists with list heads/dummy nodes?**

   No. No dummy nodes. The autograder checks the state of the freelist and if you have dummy nodes it will throw it off.

3. **Should we first initialize the freelist to NULL?**

   No, it is static and is therefore already initialized to NULL by the compiler.

4. **The assignment says to just call `my_sbrk()` again. But won't this mean we then have 2 heaps?**

   Not exactly, it will expand the heap by another 2KB. You don't get two heaps. Once it has been expanded to 8KB, calls to `my_sbrk()` will return `NULL`.

5. **Are the provided tests comprehensive?**

   Yes. We reserve the right to change our mind on this, but if you get a 100 on the tester, you should expect 100 on the homework. Just keep in mind that the tests may be weighted differently when grading than in the provided student tester.

6. **Can I use the `malloc()` from the C standard library?**

   No. Absolutely not.

3 Rules and Regulations

3.1 General Rules

1. Starting with the assembly homeworks, any code you write must be meaningfully commented. You should comment your code in terms of the algorithm you are implementing; we all know what each line of code does.
2. Although you may ask TAs for clarification, you are ultimately responsible for what you submit. This means that (in the case of demos) you should come prepared to explain to the TA how any piece of code you submitted works, even if you copied it from the book or read about it on the internet.
3. Please read the assignment in its entirety before asking questions.
4. Please start assignments early, and ask for help early. Do not email us the night the assignment is due with questions.
5. If you find any problems with the assignment it would be greatly appreciated if you reported them to the author (which can be found at the top of the assignment). Announcements will be posted if the assignment changes.

3.2 Submission Conventions

1. All files you submit for assignments in this course should have your name at the top of the file as a comment for any source code file, and somewhere in the file, near the top, for other files unless otherwise noted.
2. When preparing your submission you may either submit the files individually to Canvas/Gradescope or you may submit an archive (zip or tar.gz only please) of the files. You can create an archive by right clicking on files and selecting the appropriate compress option on your system. Both ways (uploading raw files or an archive) are exactly equivalent, so choose whichever is most convenient for you.
3. Do not submit compiled files, that is .class files for Java code and .o files for C code. Only submit the files we ask for in the assignment.
4. Do not submit links to files. The autograder does not understand it, and we will not manually grade assignments submitted this way as it is easy to change the files after the submission period ends.

3.3 Submission Guidelines

1. You are responsible for turning in assignments on time. This includes allowing for unforeseen circumstances. If you have an emergency let us know **IN ADVANCE** of the due time supplying documentation (i.e. note from the dean, doctor's note, etc). Extensions will only be granted to those who contact us in advance of the deadline and no extensions will be made after the due date.

2. You are also responsible for ensuring that what you turned in is what you meant to turn in. After submitting you should be sure to download your submission into a brand new folder and test if it works. No excuses if you submit the wrong files, what you turn in is what we grade. In addition, your assignment must be turned in via Canvas/Gradescope. Under no circumstances whatsoever we will accept any email submission of an assignment. Note: if you were granted an extension you will still turn in the assignment over Canvas/Gradescope.

3. There is a 6-hour grace period added to all assignments. You may submit your assignment without penalty up until 11:55PM, or with 25% penalty up until 5:55AM. So what you should take from this is not to start assignments on the last day and plan to submit right at 11:54AM. You alone are responsible for submitting your homework before the grace period begins or ends; neither Canvas/Gradescope, nor your flaky internet are to blame if you are unable to submit because you banked on your computer working up until 11:54PM. The penalty for submitting during the grace period (25%) or after (no credit) is non-negotiable.

3.4 Syllabus Excerpt on Academic Misconduct

Academic misconduct is taken very seriously in this class. Quizzes, timed labs and the final examination are individual work.

Homework assignments are collaborative, In addition many if not all homework assignments will be evaluated via demo or code review. During this evaluation, you will be expected to be able to explain every aspect of your submission. Homework assignments will also be examined using computer programs to find evidence of unauthorized collaboration.

What is unauthorized collaboration? Each individual programming assignment should be coded by you. You may work with others, but each student should be turning in their own version of the assignment. Submissions that are essentially identical will receive a zero and will be sent to the Dean of Students' Office of Academic Integrity. Submissions that are copies that have been superficially modified to conceal that they are copies are also considered unauthorized collaboration.

You are expressly forbidden to supply a copy of your homework to another student via electronic means. This includes simply e-mailing it to them so they can look at it. If you supply an electronic copy of your homework to another student and they are charged with copying, you will also be charged. This includes storing your code on any site which would allow other parties to obtain your code such as but not limited to public repositories (Github), pastebin, etc. If you would like to use version control, use github.gatech.edu

3.5 Is collaboration allowed?

Collaboration is allowed on a high level, meaning that you may discuss design points and concepts relevant to the homework with your peers, share algorithms and pseudo-code, as well as help each other debug code. What you shouldn't be doing, however, is pair programming where you collaborate with each other on a single instance of the code. Furthermore, sending an electronic copy of your homework to another student for them to look at and figure out what is wrong with their code is not an acceptable way to help them, because it is frequently the case that the recipient will simply modify the code and submit it as their own. Consider instead using a screen-sharing collaboration app, such as `http://webex.gatech.edu/`, to help someone with debugging if you're not in the same room.

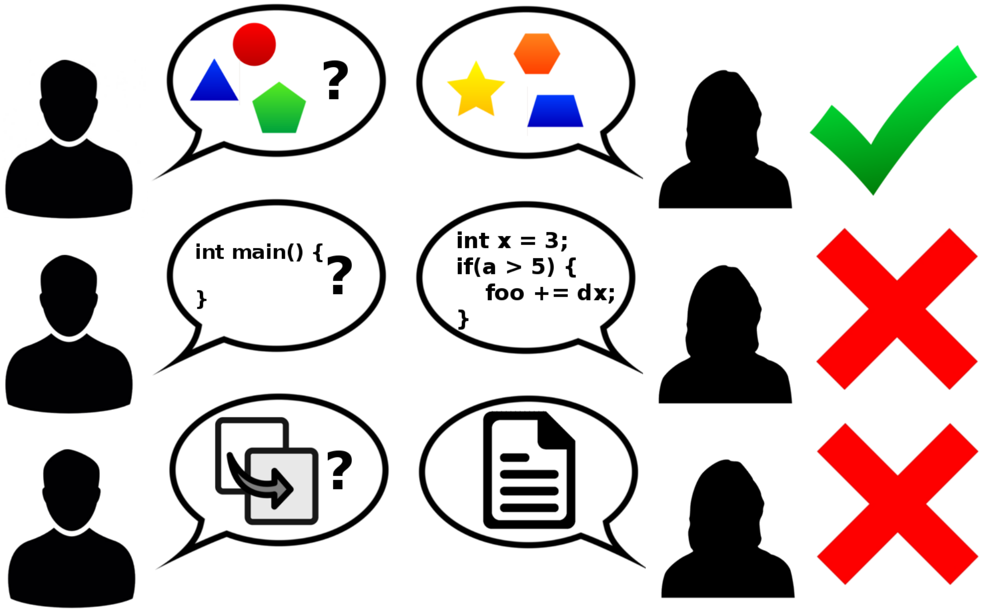


Figure 1: Collaboration rules, explained colorfully