ECE650 ASSIGNMENT 2 REPORT

1. THREAD-SAFE MALLOC IMPLEMENTATION

In the previous assignments, we were asked to implement our own malloc libraries that achieve the same functionality as the stdlib in C. My previous implementation makes use of a doubly linked list to store the meta-information of each block allocated and freed. Although the implementation works as excepted, the runtime of this implementation is drastically slowed down. The main reason is that whenever we need to find an available free block for a new requested block, the implementation has to iterate through the entire list that contains a lot of unhelpful information. Now, for this assignment, we are no longer interested in computing segment size. So, to improve the performance, we could take advantage of this and achieve the malloc functionality by manipulating a doubly linked list that stores information of free blocks.

A. Locking Version Implementation

To make sure that the program is thread-safe, we could introduce mutex lock from pthread library to synchronize threads and prevent race conditions. The mutex lock variable is declared as a global variable. As for the malloc/free function, all of the algorithms are pretty much the same as the previous assignment with slight change regarding manipulating the linked list. A thread must acquire the mutex lock before trying to execute the main algorithm, which is also the critical section for the multi-threaded implementation. That same thread must release the lock before the malloc/free function returns. The head node of the linked list is also declared as a global variable in this case. The main difference between the two implementations turns out to be the declaration of mutex variable and the limitations of mutex lock usage.

When malloc is called, it first checks whether we have any free blocks available by checking the head of the list. If there are blocks available, the function uses best-fit policy to find an available free region that fits the newly requested memory size. The function searches for the available block by iterating through the linked list of free blocks, so runtime could be vastly reduced relative to my own Assigment 1 implementation. After iteration, if a proper block is found, it is popped out of the linked list. And we then try to split the block if the block size exceeds the sum of the requested memory size plus the size of meta-information structure. This action needs to manipulate the linked list since the remaining portion of the original block is now free, and we have to update the linked list. If an available block is found but its size is not large enough to be split, we just remove the node from the linked list. In case that no such proper free space is available, we call sbrk() to get a brand new block and directly return the starting address of newly sbrk'd memory block.

The free function basically has the same structure as the non-thread-safe version as well. Given an arbitrary address, we first find the corresponding meta-information structure, and then we are able to add this block to the linked list to mark it as a free region. Next, we try to merge the adjacent free blocks. In order to do that, we need to check if the blocks are actually adjacent to each other.

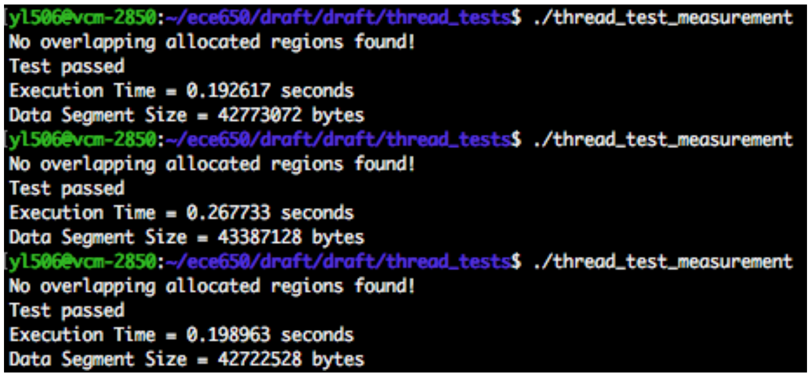
We could locate the adjacent blocks of a certain block, but we still cannot decide if the adjacent blocks are physically adjacent to that certain block in memory. Here, a little trick that is used is maintaining the order of the linked list by the address of each memory block, given the fact that all the memory is allocated on the heap and later allocated memory has a larger address. This additional feature ensures that the linked list can always be well ordered, and it then helps our program to easily and efficiently determine whether adjacent blocks in linked list are actually adjacent. We could use some pointer manipulations to locate the real address of real adjacent blocks, and then verify if the adjacent blocks are included the linked list. If the answer is true, then the adjacent blocks are physically adjacent to each other and we could merge them. Given a block to be freed, we check both its previous block and its next block and try to merge them. The entire free process is completed after merging.

B. Non-locking Version Implementation

The non-locking version implementation prohibits the usage of mutex lock around malloc/free function. But the implementation virtually has the same algorithms as locking version, with one major exception -- the global head variable used before now becomes invalid for non-locking implementation. To solve this, we make use of the Thread-local storage to replace the head of our linked list which was previously shared globally. By declaring the head as TLS variable, we allocate the variable such that there is 1 per thread locally so that each thread sees its own list. However, this implementation lowers the efficiency of memory segment layout since each thread handles its own small list.

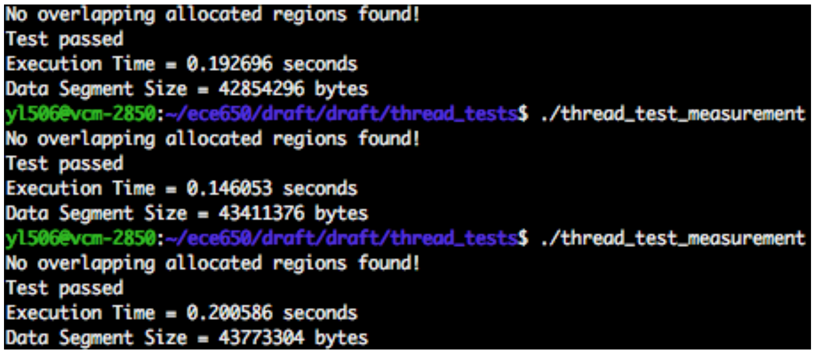
2. PERFORMANCE EVALUATION

Both implementations were tested for multiple times using the provided test program. Some of results were shown below.



```
yl506@vcm-2850:~/ece650/draft/draft/thread_tests$ ./thread_test_measurement
No overlapping allocated regions found!
Test passed
Execution Time = 0.192617 seconds
Data Segment Size = 42773072 bytes
yl506@vcm-2850:~/ece650/draft/draft/thread_tests$ ./thread_test_measurement
No overlapping allocated regions found!
Test passed
Execution Time = 0.267733 seconds
Data Segment Size = 43387128 bytes
yl506@vcm-2850:~/ece650/draft/draft/thread_tests$ ./thread_test_measurement
No overlapping allocated regions found!
Test passed
Execution Time = 0.198963 seconds
Data Segment Size = 42722528 bytes
```

Fig.1 Lock version output



```
No overlapping allocated regions found!
Test passed
Execution Time = 0.192696 seconds
Data Segment Size = 42854296 bytes
yl506@vcm-2850:~/ece650/draft/draft/thread_tests$ ./thread_test_measurement
No overlapping allocated regions found!
Test passed
Execution Time = 0.146053 seconds
Data Segment Size = 43411376 bytes
yl506@vcm-2850:~/ece650/draft/draft/thread_tests$ ./thread_test_measurement
No overlapping allocated regions found!
Test passed
Execution Time = 0.200586 seconds
Data Segment Size = 43773304 bytes
```

Fig.2 Non-locking version output

Here I listed 3 test results for each implementation, due to the space limitation. But we could still see the general trends of the two implementations: Locking version has longer runtime but smaller data segment size, while non-locking version has faster runtime but larger data segment size. This conclusion is in agreement with the mechanisms of multi-threaded implementation. For the locking version, mutex lock is utilized but it introduces performance overhead and makes our programs more serial/sequential, since other threads are blocked when the lock has been taken. And this actually opposes the objective of multi-threaded programming and results in slower runtime. In contrast, non-locking version makes good use of multi-threaded computing that results in faster runtime. But, since each thread maintains its local scope, the memory utilization efficiency decreases especially when free is called. In this case, it should be common that some of the real adjacent free regions could not be merged together due to the fact that they may be visible to different threads. Also, the fact that there are multiple linked lists with smaller size also reduces the probability of finding an available free block relative to a single large list with many nodes. So the tradeoff is apparent, and if one cares more about runtime, he probably better choose non-locking implementation, while people who do care about the memory usage efficiency would prefer locking implementation.