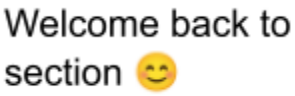
CSE 351 Welcome back to section
Section 9 Worksheet: Memory Allocation
To understand the computer, you must become the computer.



For this problem, you will use a heap simulator to answer questions about heap memory allocation in C using malloc and free. First, access the heap simulator, either by going to the Lab 5 page on the course website, or by following the link:

https://courses.cs.washington.edu/courses/cse351/heapsim/

Read through the information on the page so you can understand how the simulator works. If you check "simulation mode" it will walk you through each step in the process of allocating a block of memory on the heap. Notice that each header (and footer) contains three fields. They correspond to:

```
block size : preceding block allocated? : this block allocated?
```

where 1 means "allocated" and 0 means "unallocated." Remember that block size **includes** the size of the headers and footers. In Lab 5, all of this will be stored within 8 bytes using the last few bits of the size (see the spec for more information).

Now, answer the following questions:

1. Starting with an empty heap (you can empty the heap by refreshing the page), "Execute" the following code:

```
void* ptr1 = malloc(30);
void* ptr2 = malloc(40);
void* ptr3 = malloc(70);
```

   a. What pointer is returned if we execute another `malloc` now?
   176 (the beginning of the free list + 8 bytes for the header.)
   b. Which block(s) could you free that would cause fragmentation in the heap?
   The block with the pointer 48. Neither of the other blocks have an allocated block on both sides. (note: you could argue that freeing the first block with pointer 8 causes fragmentation if you consider the space between the beginning of heap to first allocated block as external fragmentation, but this distinction isn't too important)
   c. Which block(s) could you free that would cause coalescing to occur?
   Just the block with the pointer 96. It's the only block bordered by an unallocated block.
   d. Suppose `free(ptr2)` is run immediately after `malloc(70)`. Draw a diagram of what the free list looks like afterwards.

   ⇔ `48 : 1 : 0` ⇔ `88 : 1 : 0` ⇔

   e. What is the maximum size **payload** that we could allocate (i.e. the argument to `malloc`) such that we are returned a pointer to the address 48 (0x30)
   40. We have 48 bytes of free space starting at address 40 (which will return a pointer to 48 when allocated).The header consumes 8 bytes; so we have at most 40 bytes left over that we can use as a client.

Lab 5

In Lab 5, we will implement a memory management system that uses an explicit free list. Each block has pointers to the next and previous blocks. This is the block struct we will use:

```
struct block_info {
  // Size of the block (in the high bits) and tags for whether the
  // block and its predecessor in memory are in use.
  size_t size_and_tags;
  struct block_info* next;
  struct block_info* prev;
};
typedef struct block_info block_info;
```

Macros & Static Inline Functions:

We provide you with a lot of resources (helper functions, macros and static inline functions , read fully through mm.c for all of them). Here are some of them:

UNSCALED_POINTER_ADD(p,x) Add without using "pointer arithmetic", returns void*
UNSCALED_POINTER_SUB(p,x) Subtract without using "pointer arithmetic", returns void*
SIZE(x) Extracts the size from the size_and_tags field
MIN_BLOCK_SIZE The size of the smallest block that is safe to allocate
TAG_USED Mask for the used tag (1 = 0b1)
TAG_PRECEDING_USED Mask for the preceding used tag (2 = 0b10)
WORD_SIZE Size of a word on this architecture

2. Given that **void* ptr** is a pointer to the ***beginning*** of a free block.
   a. Give a C expression that sets the ***previous*** block's ***next pointer*** to ***ptr's*** next block, as would be done if we were removing **ptr** from the free list.

```
((block_info*)ptr)->prev->next = ((block_info*)ptr)->next. Must
cast to block_info* before trying to dereference the fields.
```

3. Assume **void* ptr** is now a pointer to the ***payload*** of an allocated block. Using above macros and functions to provide C expressions that get the following in terms of **ptr**:

   a. Size of allocated block

```
size_t size_curr_blk = SIZE((block_info*)UNSCALED_POINTER_SUB(ptr,
                       WORD_SIZE))->size_and_tags);
```

   b. Set **TAG_PRECEDING_USED** of following block to **True** (can use answer from part a)

```
block_info* flw_blk = (block_info*)UNSCALED_POINTER_ADD(ptr,
                      size_curr_blk - WORD_SIZE);

flw_blk->size_and_tags = (flw_blk->size_and_tags)|
TAG_PRECEDING_USED;
```

4. Implement the following functions. Try using bitwise operators to access the tags in size_and_tags.

```
// Bit masks used to retrieve tags from size_and_tags.
#define TAG_USED 1
#define TAG_PRECEDING_USED 2
// SIZE(ptr->size_and_tags) extracts size from 'size_and_tags'
static inline size_t SIZE(size_t x) {return ((x) & ~(ALIGNMENT -
1));}
// Copies tags (TAG_PRECEDING_USED and TAG_USED) from block_to_copy
to // original_block. Leaves the size of original_block unchanged.
void copy_tags(block_info* original_block, block_info*
block_to_copy){
      size_t copy_used = (block_to_copy->size_and_tags) & TAG_USED;
      size_t copy_preceding_used = (block_to_copy->size_and_tags) &
      TAG_PRECEDING_USED;
      original_block->size_and_tags =
      SIZE(original_block->size_and_tags) | copy_preceding_used |
      copy_used;
}

block_info *FREE_LIST_HEAD;
// Removes a block from the free list.
void remove_free_block(block_info* free_block) {
      block_info *next_free, *prev_free;

      next_free = free_block->next;
      prev_free = free_block->prev;

      // If the next block is no NULL, patch its prev pointer
      if (next_free != NULL)
            next_free->prev = prev_free;

      // If we're removing the head of the free list, patch the head
      // Otherwise, patch the previous block's next pointer
      if (FREE_LIST_HEAD == free_block)
            FREE_LIST_HEAD = next_free;
      else
            prev_free->next = next_free;
}
```