CS 3410 Lab 3

Fall 2025

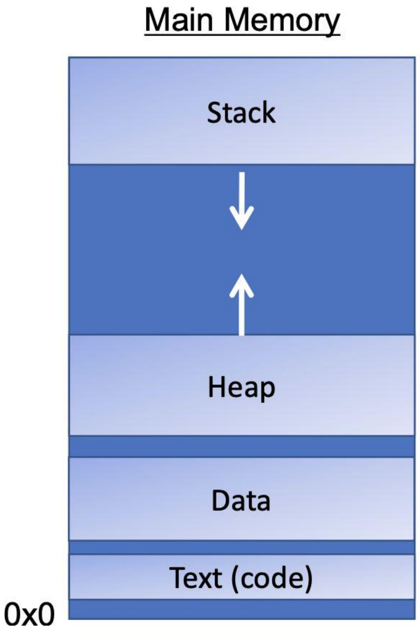
Agenda

1. C Memory Management
2. Linked List
3. Implementing Linked List in C
4. A3 Tips

C Memory Management

The Heap

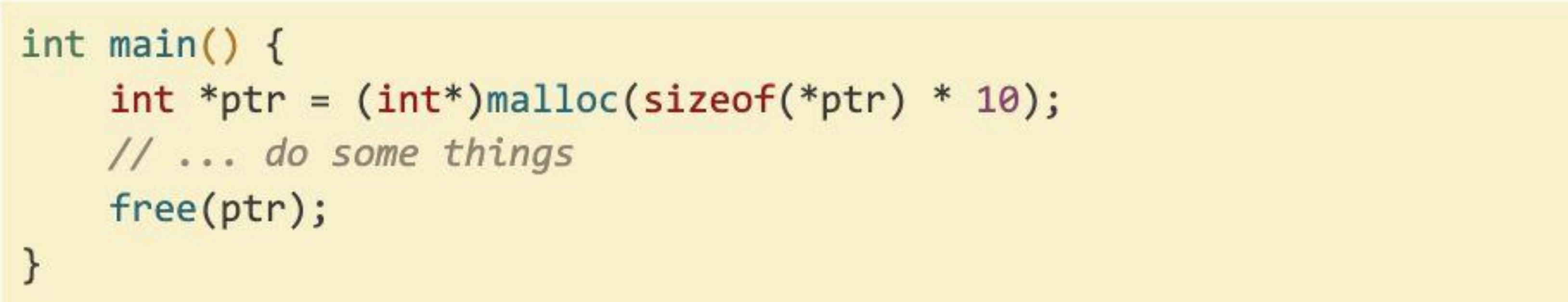
- The heap is an area of memory below the stack that grows up towards higher addresses
- Unlike the stack, where memory goes away when a function finishes, the heap provides memory that persists until the caller is done with it



How do we access memory on the heap?

- `malloc():` Request a pointer to a contiguous block of memory on the heap
- `free():` Release or deallocate the allocated memory back to the operating system

`malloc()` and `free()` syntax



```c
int main() {
    int *ptr = (int*)malloc(sizeof(*ptr) * 10);
    // ... do some things
    free(ptr);
}
```

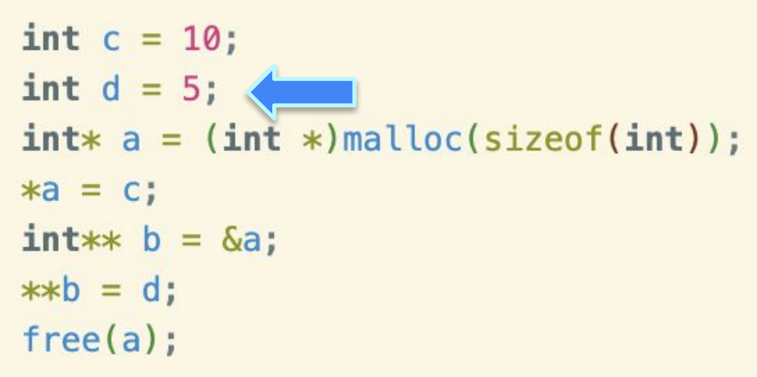
Rule of Thumb

Every call to `malloc()` should have a corresponding call to `free()`

- An allocation that is not freed by the time the program ends is called a **Memory Leak**

Exercise: Draw out the references between memory blocks.

Note: Assume all the addresses are of 2 bytes and the integer defaults to 4 bytes.



```
int c = 10;
int d = 5;
int* a = (int *)malloc(sizeof(int));
*a = c;
int** b = &a;
**b = d;
free(a);
```

Stack		
Address	Name	Value
0xFFFF		
0xFFFE		
0xFFFD		
0xFFFC		
0xFFFB		
0xFFFA		
0xFFF9		
0xFFF8		
0xFFF7		
0xFFF6		
0xFFF5		
0xFFF4		

0x0008		
0x0007		
0x0006		
0x0005		
0x0004		
0x0003		
0x0002		
0x0001		
0x0000		
Address	Name	Value
Heap		

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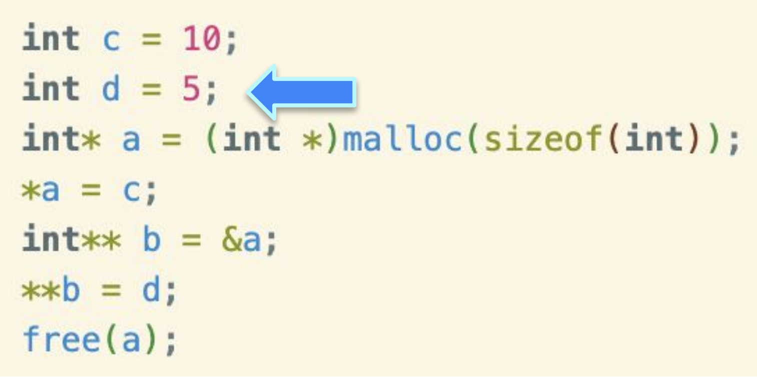

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free(a);
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Stack

Address	Name	Value
0xFFFF	c	10
0xFFFE		
0xFFFD		
0xFFFC		
0xFFFB	d	5
0xFFFA		
0xFFF9		
0xFFF8		
0xFFF7		
0xFFF6		
0xFFF5		
0xFFF4		

Address	Name	Value
0x0008		
0x0007		
0x0006		
0x0005		
0x0004		
0x0003		
0x0002		
0x0001		
0x0000		

Heap

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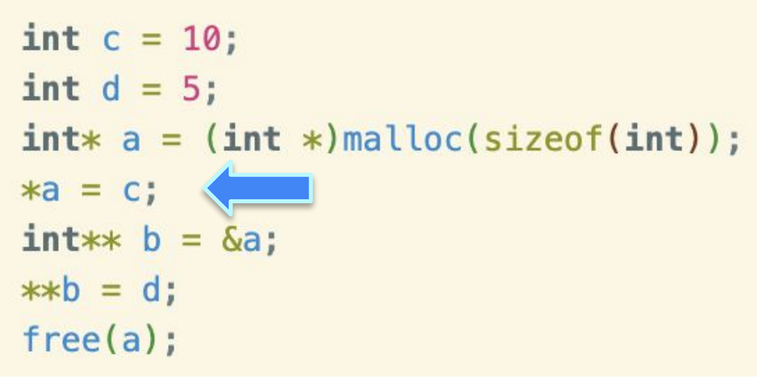

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int* a = (int *)malloc(sizeof(int));
*a = c;
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free(a);
```

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Address	Name	Value
Heap		

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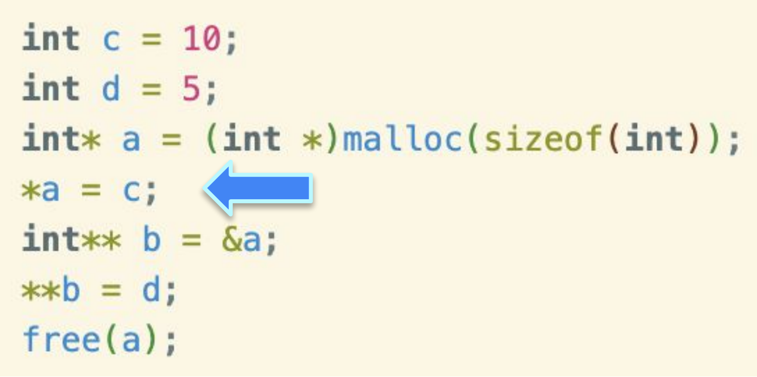

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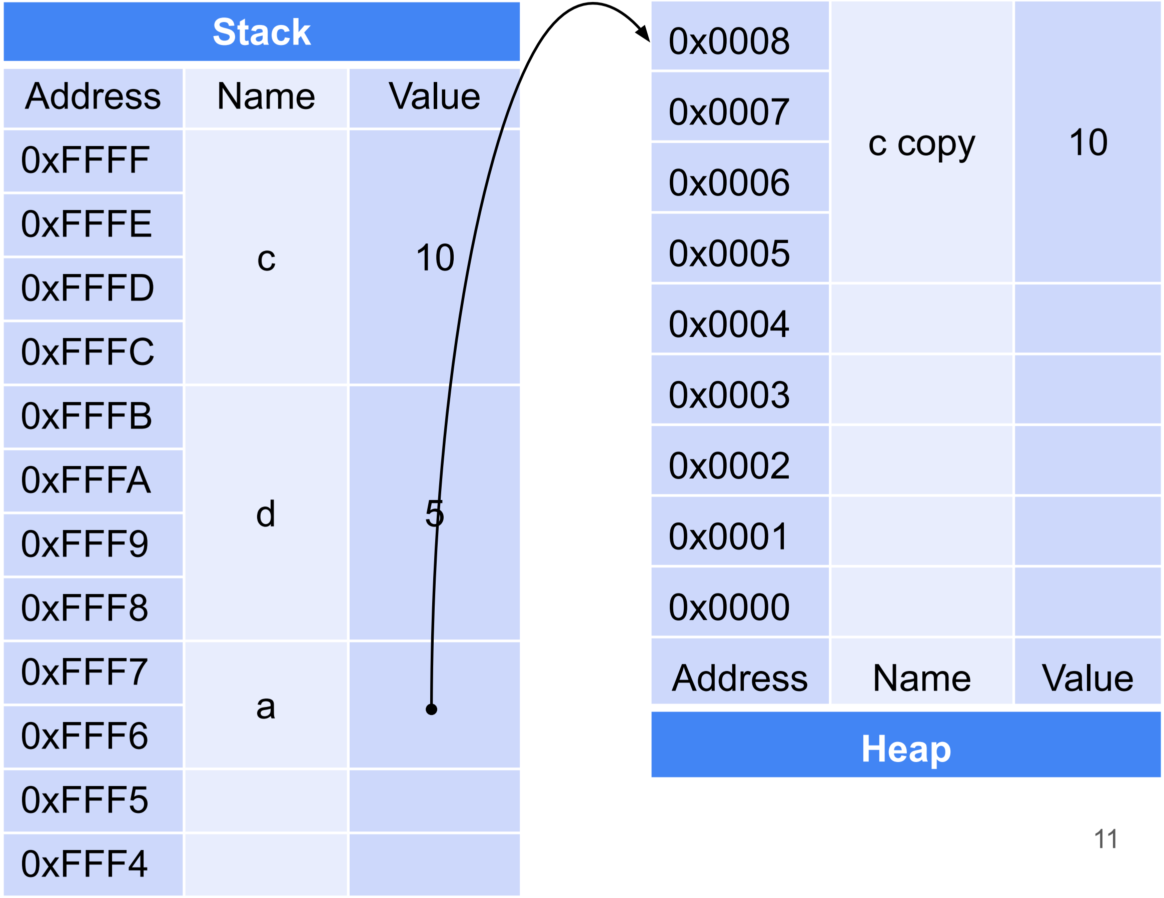


Stack

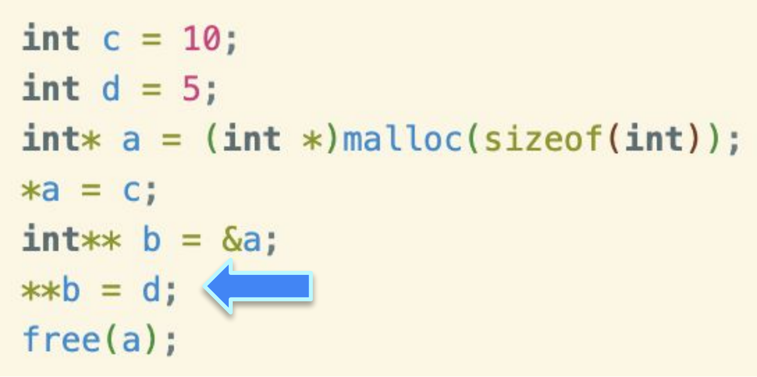
Address	Name	Value
0xFFFF	c	10
0xFFFE		
0xFFFD		
0xFFFC		
0xFFFB	d	5
0xFFFA		
0xFFF9		
0xFFF8		
0xFFF7	a	
0xFFF6		
0xFFF5		
0xFFF4		

Address	Name	Value
0x0008	c copy	10
0x0007		
0x0006		
0x0005		
0x0004		
0x0003		
0x0002		
0x0001		
0x0000		

Heap

Exercise: Draw out the references between memory blocks.

Note: Assume all the addresses are of 2 bytes and the integer defaults to 8 bytes.



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int c = 10;
int d = 5;
int* a = (int *)malloc(sizeof(int));
*a = c;
int** b = &a;
**b = d;
free(a);
```
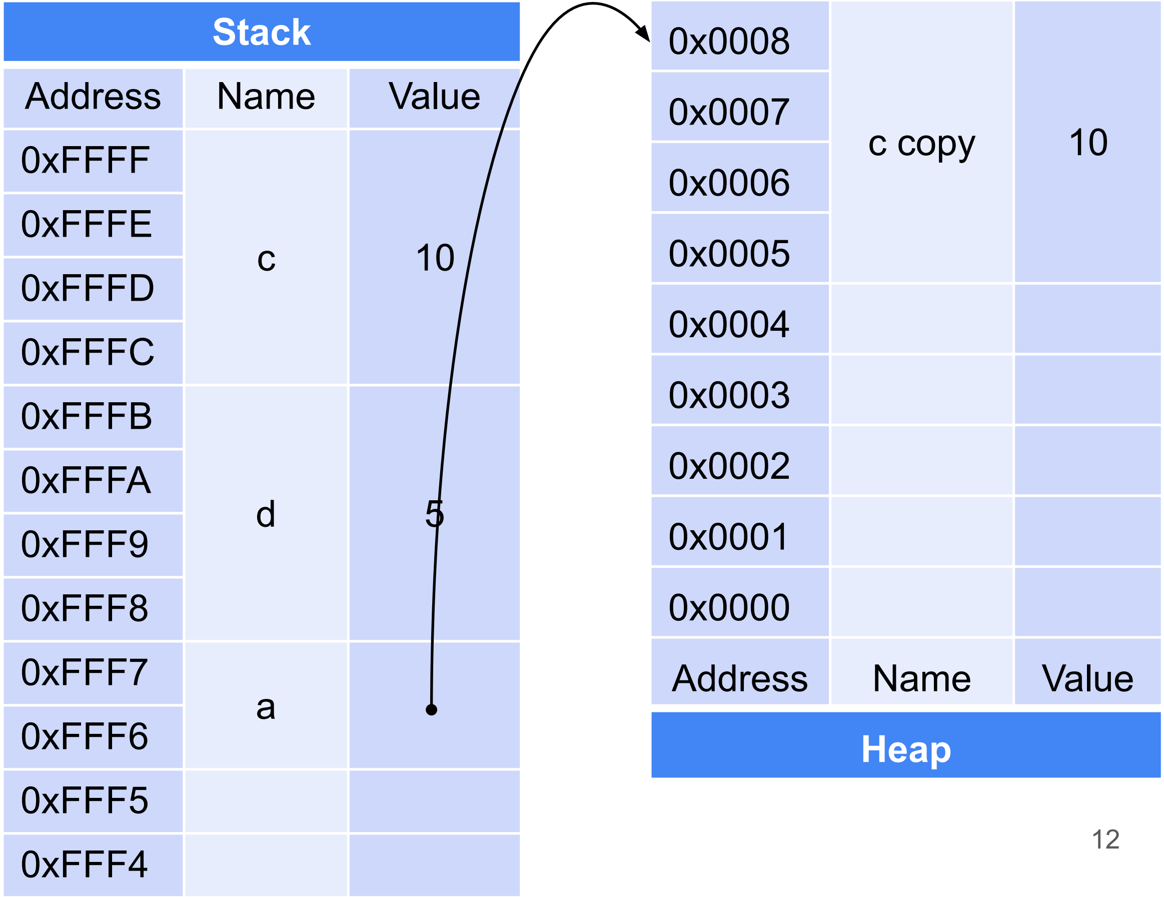



Stack

Address	Name	Value
0xFFFF	c	10
0xFFFE		
0xFFFD		
0xFFFC		
0xFFFB	d	5
0xFFFA		
0xFFF9		
0xFFF8		
0xFFF7	a	
0xFFF6		
0xFFF5		
0xFFF4		

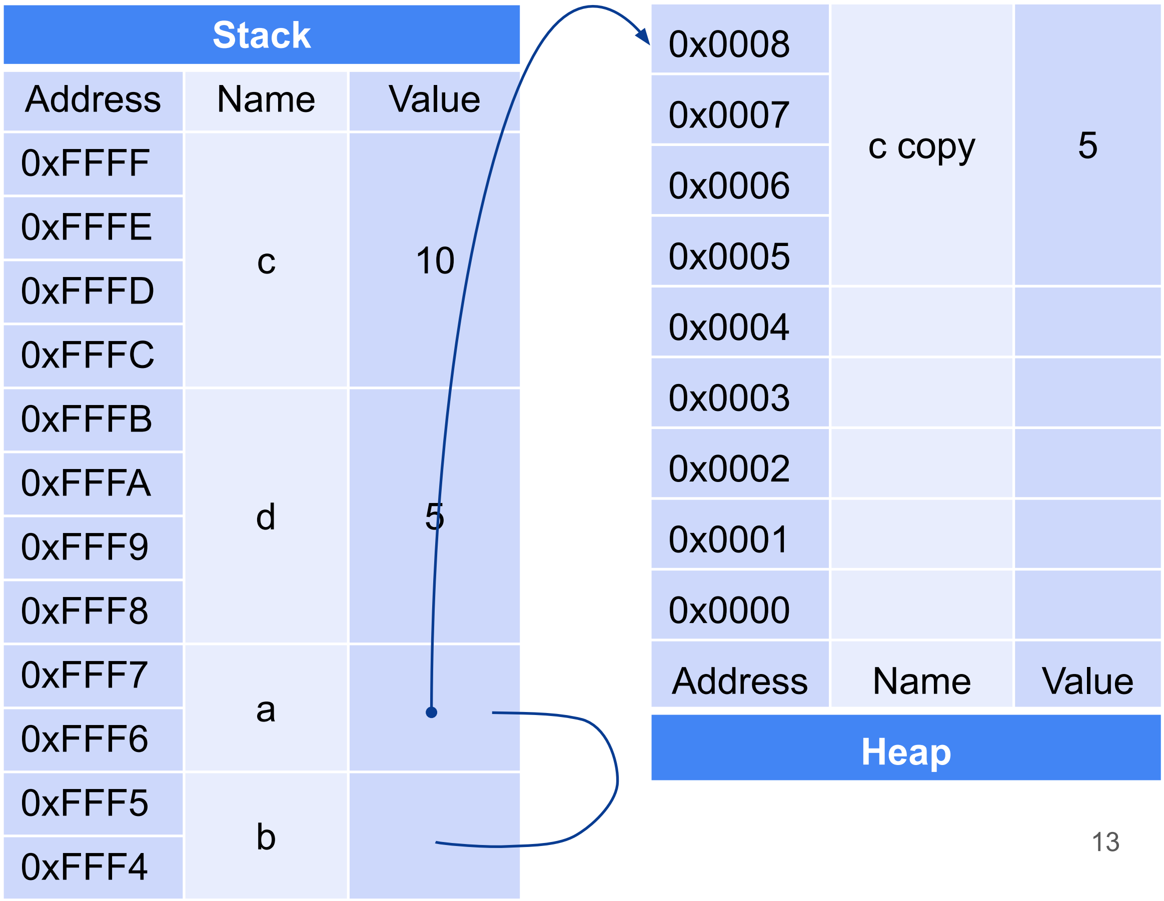
Heap

Address	Name	Value
0x0008	c copy	10
0x0007		
0x0006		
0x0005		
0x0004		
0x0003		
0x0002		
0x0001		
0x0000		

Exercise: Draw out the references between memory blocks.

Note: Assume all the addresses are of 2 bytes and the integer defaults to 4 bytes.

```c
int c = 10;
int d = 5;
int* a = (int *)malloc(sizeof(int));
*a = c;
int** b = &a;
**b = d;
free(a);
```



Stack		
Address	Name	Value
0xFFFF	c	10
0xFFFE		
0xFFFD		
0xFFFC		
0xFFFB	d	5
0xFFFA		
0xFFF9		
0xFFF8		
0xFFF7	a	
0xFFF6		
0xFFF5	b	
0xFFF4		

Address	Name	Value
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Heap

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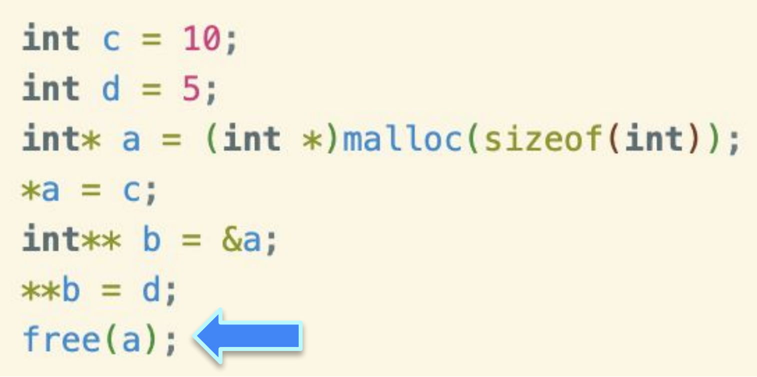

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**b = d;
free(a);
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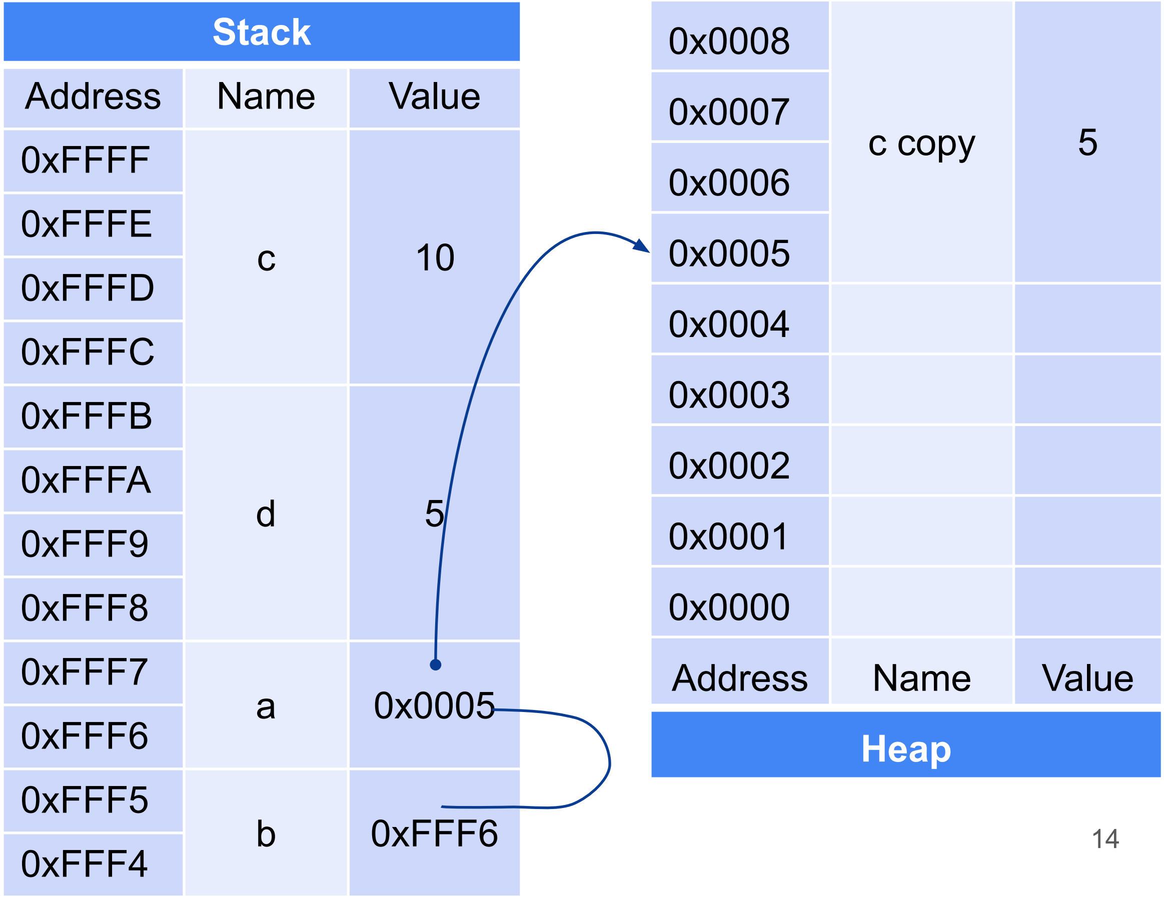

Stack

Address	Name	Value
0xFFFF	c	10
0xFFFE		
0xFFFD		
0xFFFC		
0xFFFB	d	5
0xFFFA		
0xFFF9		
0xFFF8		
0xFFF7	a	0x0005
0xFFF6		
0xFFF5	b	0xFFF6
0xFFF4		

Address	Name	Value
0x0008	c copy	5
0x0007		
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0x0004		
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0x0001		
0x0000		

Heap

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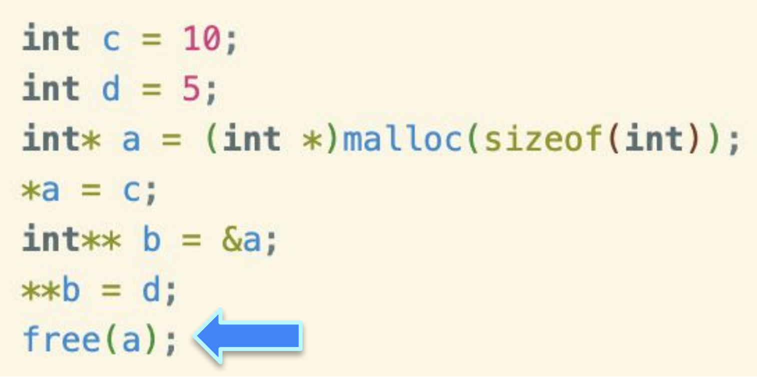

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0xFFF6		
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0xFFF4		

Address	Name	Value
0x0008	~~c copy~~	~~5~~
0x0007		
0x0006		
0x0005		
0x0004		
0x0003		
0x0002		
0x0001		
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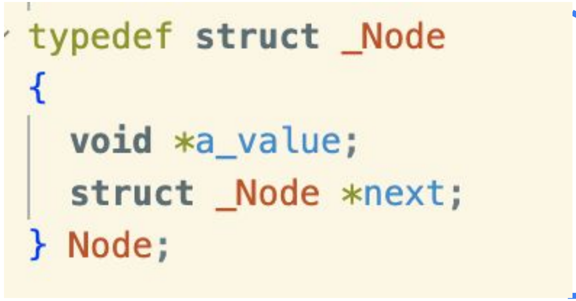
Heap		

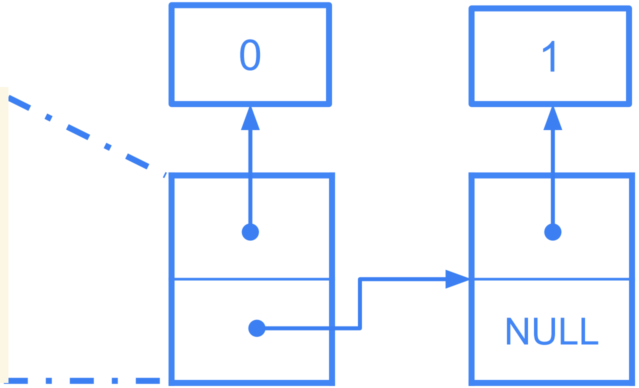
Linked List

Allocating space for more complex data structures

Consider the definition of a Linked List Node as follows:



```
typedef struct _Node
{
    void *a_value;
    struct _Node *next;
} Node;
```



Allocating space for more complex data structures

Exercise: Draw out the memory allocation for the tiny linked list.

Mind that an address takes up 2 bytes

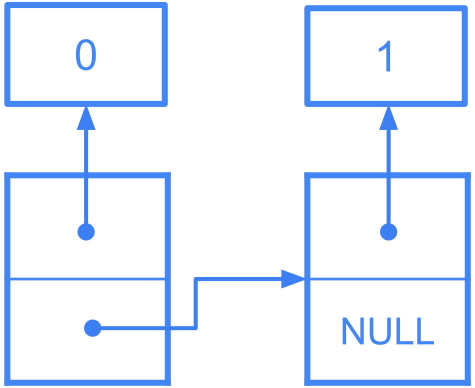
```
Node *n0 = (Node *) malloc(sizeof(Node));
Node *n1 = (Node *) malloc(sizeof(Node));
int *v0 = (int *)malloc(sizeof(int));
int *v1 = (int *)malloc(sizeof(int));
*v0 = 0; *v1 = 1;

n0->a_value = (void *)v0;
n1->a_value = (void *)v1;
n0->next = n1;
n1->next = NULL;

free(n0->a_value);
free(n1->a_value);
free(n0);
free(n1);
```

Stack

Address	Name	Value
0xFFFF		
0xFFFE		
0xFFFD		
0xFFFC		



0x000A		
0x0009		
0x0008		
0x0007		
0x0006		
0x0005		
0x0004		
0x0003		
0x0002		
0x0001		
0x0000		
Address	Name	Value

Heap

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Node *n1 = (Node *) malloc(sizeof(Node));
int *v0 = (int *)malloc(sizeof(int));
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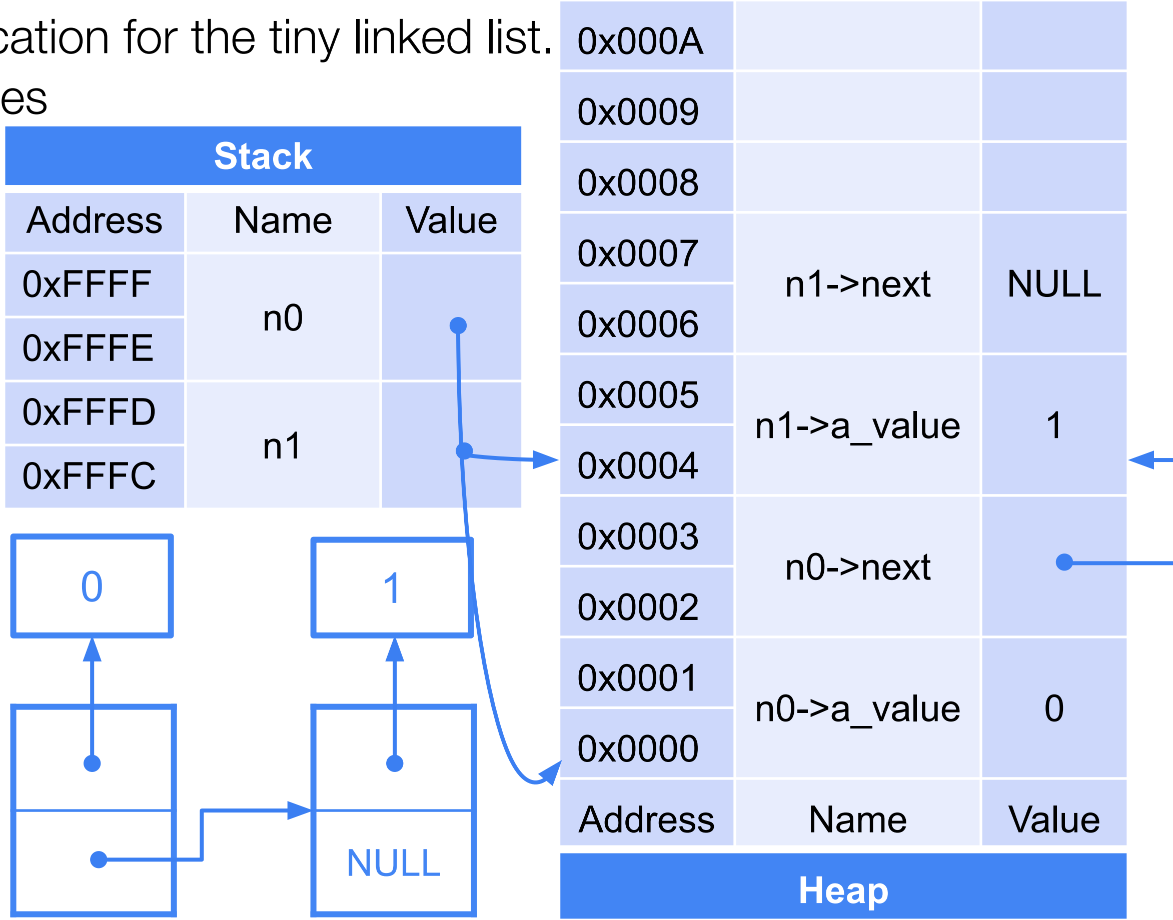
*v0 = 0; *v1 = 1;

n0->a_value = (void *)v0;
n1->a_value = (void *)v1;
n0->next = n1;
n1->next = NULL;

free(n0->a_value);
free(n1->a_value);
free(n0);
free(n1);
```



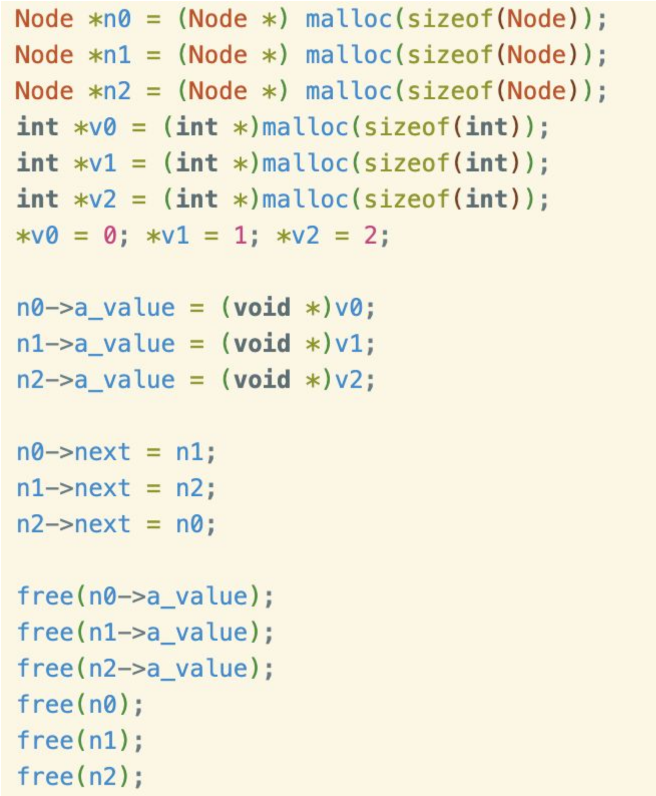
Stack

Address	Name	Value
0xFFFF	n0	
0xFFFE		
0xFFFD	n1	
0xFFFC		

Address	Name	Value
0x000A		
0x0009		
0x0008		
0x0007	n1->next	NULL
0x0006		
0x0005	n1->a_value	1
0x0004		
0x0003	n0->next	
0x0002		
0x0001	n0->a_value	0
0x0000		

Heap

Exercise: draw the linked list created by the following code

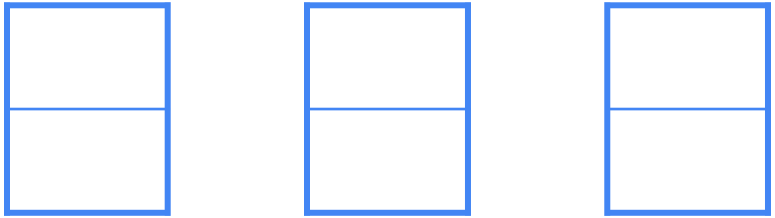


```
Node *n0 = (Node *) malloc(sizeof(Node));
Node *n1 = (Node *) malloc(sizeof(Node));
Node *n2 = (Node *) malloc(sizeof(Node));
int *v0 = (int *)malloc(sizeof(int));
int *v1 = (int *)malloc(sizeof(int));
int *v2 = (int *)malloc(sizeof(int));
*v0 = 0; *v1 = 1; *v2 = 2;

n0->a_value = (void *)v0;
n1->a_value = (void *)v1;
n2->a_value = (void *)v2;

n0->next = n1;
n1->next = n2;
n2->next = n0;

free(n0->a_value);
free(n1->a_value);
free(n2->a_value);
free(n0);
free(n1);
free(n2);
```



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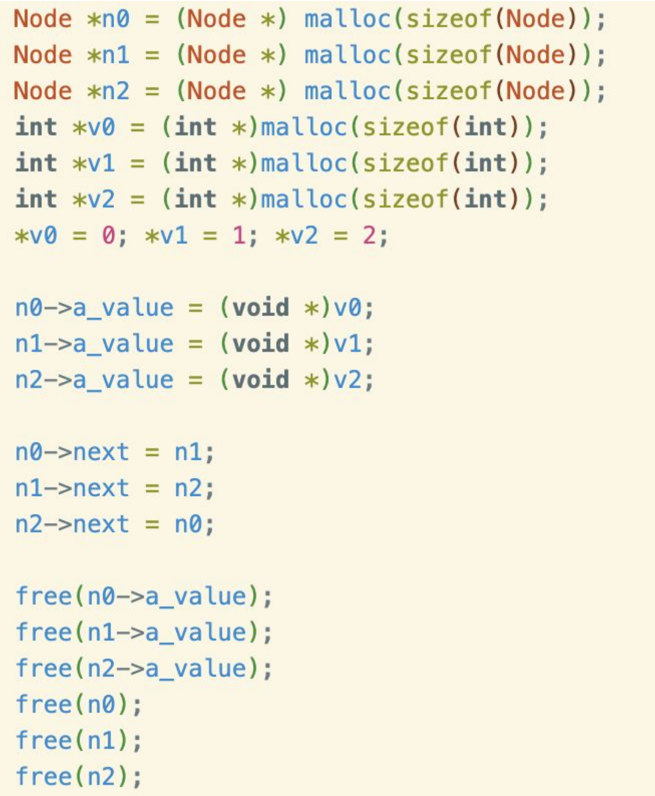

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int *v0 = (int *)malloc(sizeof(int));
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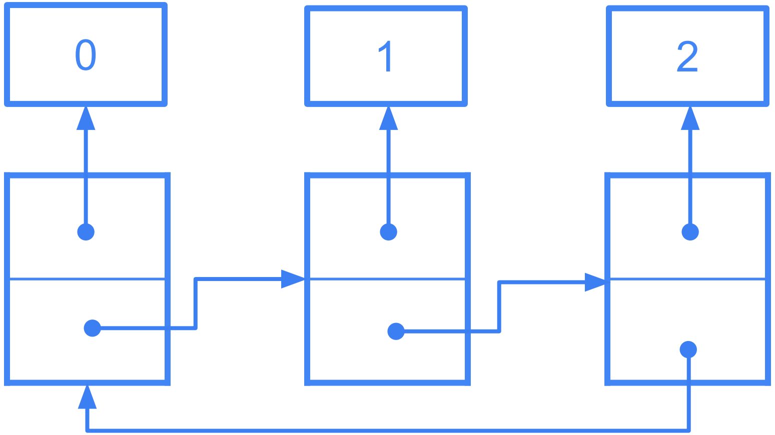
*v0 = 0; *v1 = 1; *v2 = 2;

n0->a_value = (void *)v0;
n1->a_value = (void *)v1;
n2->a_value = (void *)v2;

n0->next = n1;
n1->next = n2;
n2->next = n0;

free(n0->a_value);
free(n1->a_value);
free(n2->a_value);
free(n0);
free(n1);
free(n2);
```



Implement a linked list

Exercise: Implement the functionalities below in lab3.c

- `Node *list_create(void *a_value)` Initialize a Node containing the int value.
- `Node *list_push_to_front(Node *a_head, void *a_value)` Wrap the value in a node and make it the new head of the list.
- `Node *list_pop_last(Node *a_head)` Pop the last node of the list.
- `void list_free(Node *a_head)` Free the memory taken by the entire linked list.

Memory Management of the linked list

- Allocate node memory in `list_init` or `list_add_to_front`.
- To free your memory:
  - Remember to manually free all the nodes and the integer pointers that they contain after popping them from the list.
  - Before exiting your main, always free all the nodes left in the queue via `list_free`.

A3 Tips

Start early, start early, start early!

- This assignment has many intricacies. To give yourself enough time to test the functionality end-to-end, you'll want to start early.
- **Test thoroughly!** We've provided a unit-testing framework for you to use with test files already started for you. Add more tests as you need them to make sure your code is correct.
    - This applies to `huffman.c` as the complete test suite for Priority Queue is already given

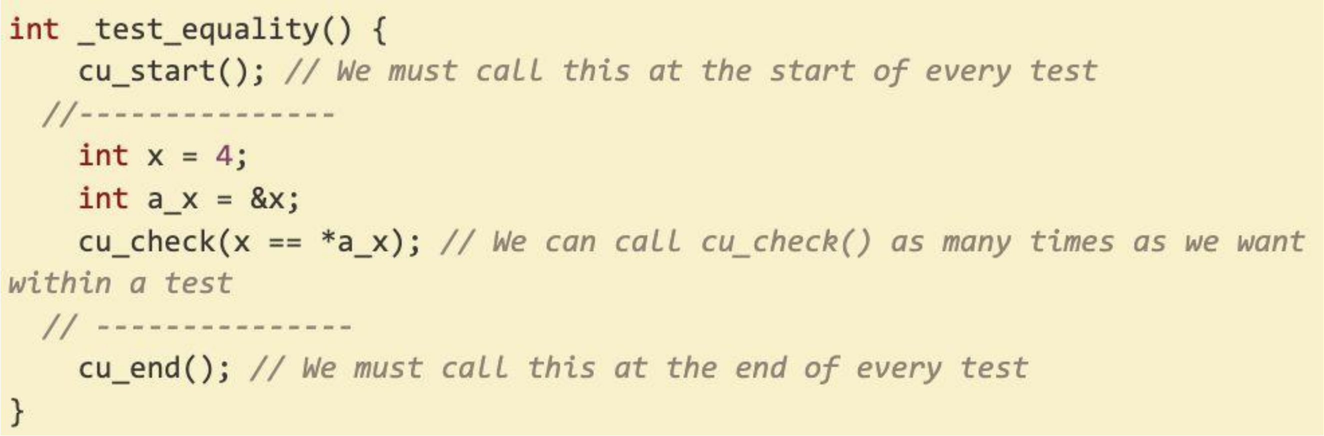
Hints

- In Task 1, you can implement `stack_push` by calling `pq_enqueue` and passing in `NULL` as the compare function. If you do this, you'll need to think carefully about your implementation for `pq_enqueue.`
- In Task 1, you'll also need to write a compare function to order the nodes in your priority queue. Nodes are sorted in *ascending* order, first by frequency, then by ASCII value. Follow this convention when implementing the function:
  - `cmp_fn(a, b) < 0  -> a` is ordered before `b`
  - `cmp_fn(a, b) >= 0 -> a` is ordered after `b`

  The `_cmp_int(...)` function implemented in `test_priority_queue.c` follows this too
- Freeing memory for a `TreeNode` is different from freeing memory for a `PQNode`.
- Use the functions in `utils.h` to print out priority queues. You can make your own custom print function for `TreeNode`.

Test your code!

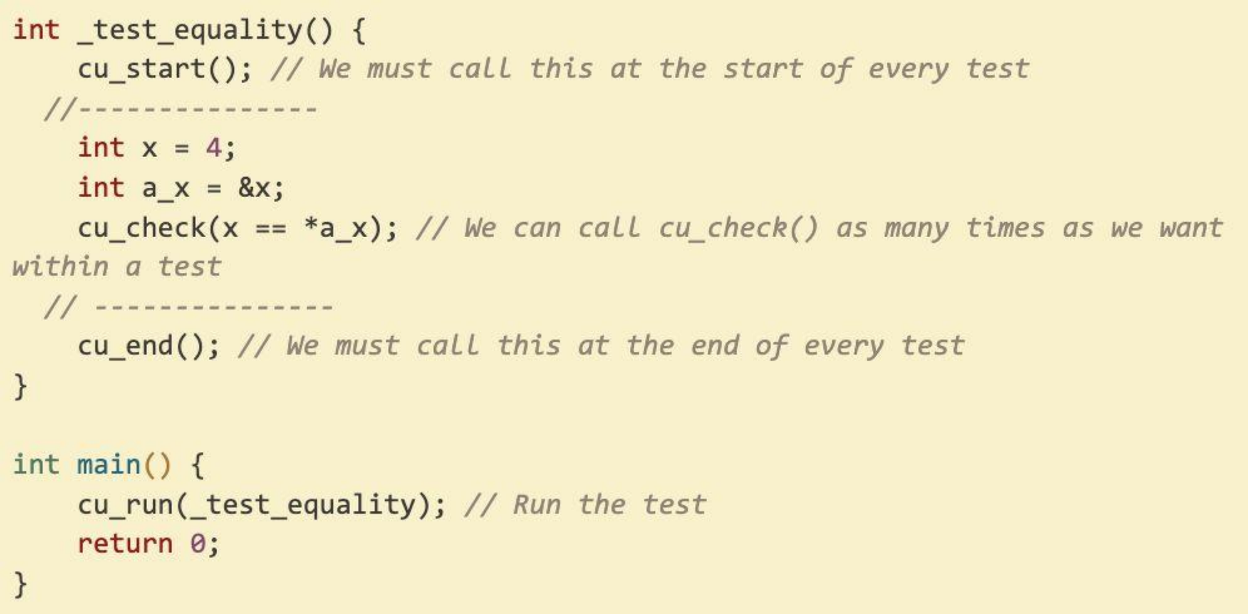
- Testing before you get to Task 2 will be crucial. We’ve provided you with a simple unit-testing library called `cu_unit`.
- The structure of a unit test is as follows:



```
int _test_equality() {
    cu_start(); // We must call this at the start of every test
  //---------------
    int x = 4;
    int a_x = &x;
    cu_check(x == *a_x); // We can call cu_check() as many times as we want
within a test
  // ---------------
    cu_end(); // We must call this at the end of every test
}
```

Test your code!

- We can run the test by adding it to `main()`:



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    cu_start(); // We must call this at the start of every test
  //---------------
    int x = 4;
    int a_x = &x;
    cu_check(x == *a_x); // We can call cu_check() as many times as we want
within a test
  // --------------
    cu_end(); // We must call this at the end of every test
}

int main() {
    cu_run(_test_equality); // Run the test
    return 0;
}
```

Test your code!

- Tests will not be graded for this assignment, but it’s a good idea to test your code before moving on to the next task, as we’ll be grading your code for each section individually.
- Test your priority queue with different types, comparison functions, etc.
- Test your Huffman tree on different files (C programs, for instance), and with a variety of characters.

Remember!

- **In A3 (not this lab), you must** use our wrapper functions `my_malloc()` and `my_free()` for any allocations or deallocations.
- They follow the exact same syntax as `malloc()` and `free()` and perform the same kind of allocation/deallocation.
- The only thing extra is that they log the operation, which will help you and us detect and pinpoint memory leaks in your implementation.

Good luck!