COMP1511 - Programming Fundamentals

Week 9 - Lecture 16

What did we cover yesterday?

Projects with Multiple Files

- Using and Compiling Multiple Files

Abstract Data Types - Queues

- Providing functionality and hiding the implementation
- typedef and how to use it
- A Queue as an example of an Abstract Data Type - rules with no set underlying structure

What are we covering today?

Finishing our Queue Implementation

- Destroying and Freeing
- Returning the number of items

Another Abstract Data Type

- Stacks
- Implementing with other data structures

Recap - Abstract Data Types

Making our own types with specific uses

- Declare our functionality in a Header (*.h) file
- Hide our Implementation in a *.c file

- The Header declares the type and the functions
- All the implementation is left out of the header

- The C file defines the underlying implementation

Finishing our Queue

Continuing the example

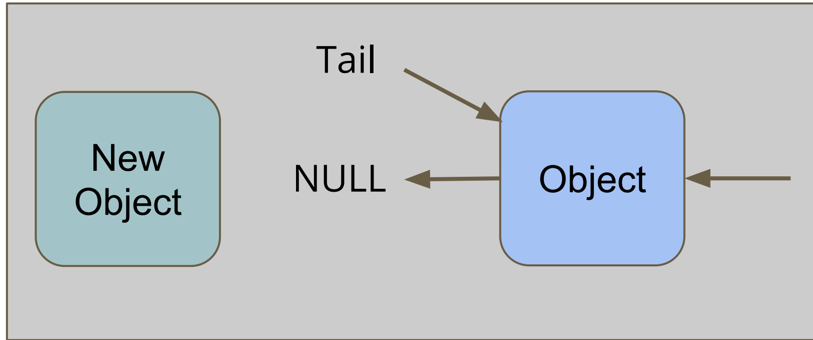
- We need a main file to use the Queue
- Let's try adding and removing

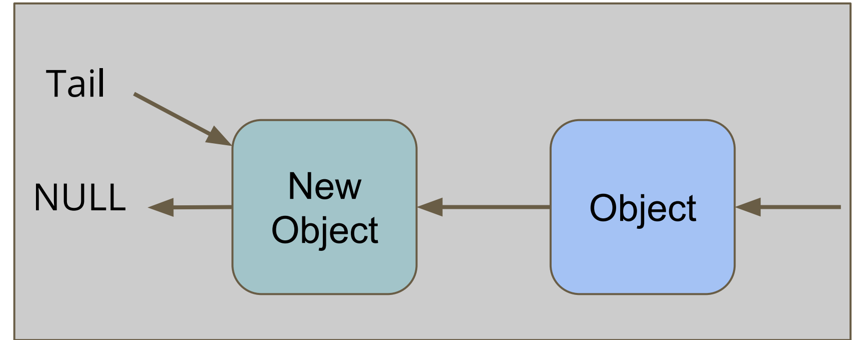
- We're not cleaning our memory properly yet
- So we need a function that frees an entire queue

- Also, a function that returns how many items are in the queue
- This makes it easier for someone to use without risking errors

Adding to the tail

- Connect the new object to the current tail
- Move the tail pointer to the new last object
- We no longer need to loop through the whole queue to find the tail





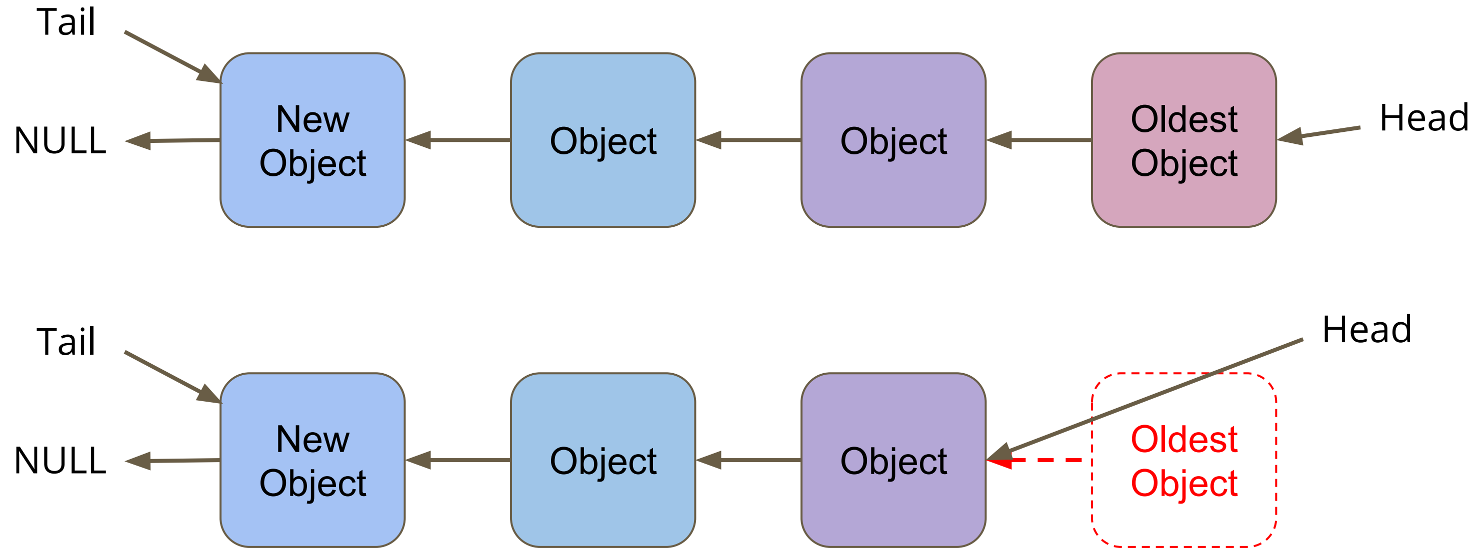
Code for Adding

```
void queueAdd(Queue q, int item) {
    struct queueNode *newNode = malloc(sizeof(struct queueNode));
    newNode->data = item;
    newNode->next = NULL;

    if (q->tail == NULL) {
        // Queue is empty
        q->head = newNode;
        q->tail = newNode;
    } else {
        q->tail->next = newNode;
        q->tail = newNode;
    }
}
```

Removing a Node

The only node that can be removed is the head (the oldest node)



Code for Removing

```
// Remove the head from the list and free the memory used
int queueRemove(Queue q) {
    if (q->head == NULL) {
        printf("Attempt to remove an element from an empty queue.\n");
        exit(1);
    }
    // Keep track of the old head
    int returnData = q->head->data;
    struct queueNode *remNode = q->head;

    // move the queue to the new head and free the old
    q->head = q->head->next;
    free(remNode);

    return returnData;
}
```

Testing Code in our Main.c

```
int main(void) {
    printf("Creating the Queue for Ice Cream.\n");
    Queue iceQueue = queueCreate();
    int id = 1;
    printf("Person %d joins the queue!\n", id);
    queueAdd(iceQueue, id);
    id = 2;
    printf("Person %d joins the queue!\n", id);
    queueAdd(iceQueue, id);
    id = 3;
    printf("Person %d joins the queue!\n", id);
    queueAdd(iceQueue, id);

    printf("Person %d just got their ice cream!\n", queueRemove(iceQueue));
    printf("Person %d just got their ice cream!\n", queueRemove(iceQueue));
    printf("Person %d just got their ice cream!\n", queueRemove(iceQueue));
    return 0;
}
```

Our queue.h Header File

```
// queue type hides the struct that it is
// implemented as
typedef struct queueInternals *Queue;

// functions to create and destroy queues
Queue queueCreate(void);
void queueFree(Queue q);

// Add and remove items from queues
// Removing the item returns the item for use
void queueAdd(Queue q, int item);
int queueRemove(Queue q);

// Check on the size of the queue
int queueSize(Queue q);
```

queueFree()

Free all the memory in the linked list that we're using

- Loop through the list
- free() each node as we go

```
// Destroy and Free the entire queue
void queueFree(Queue q) {
    while (q->head != NULL) {
        struct queueNode *current = q->head;
        q->head = q->head->next;
        free(current);
    }
}
```

Testing for memory leaks

Let's use dcc --leakcheck

```
int main(void) {
    Queue iceQueue = queueCreate();
    queueAdd(iceQueue, 1);
    queueAdd(iceQueue, 2);
    queueAdd(iceQueue, 3);

    queueFree(iceQueue);
}
```

- What happens when we run with memory leak checking?
- Remember that all memory allocated with **`malloc()`** must be freed!

queueFree() Improved

Remember to free all the memory allocations!

```
// Destroy and Free the entire queue
void queueFree(Queue q) {
    while (q->head != NULL) {
        struct queueNode *current = q->head;
        q->head = q->head->next;
        free(current);
    }
    free(q);
}
```

Number of items in the Queue

Our last function is queueSize()

- Loop through the list until the end
- Count how many elements are in it

```
// Return the number of items in the queue
int queueSize(Queue q) {
    struct queueNode *iterator = q->head;
    int counter = 0;
    while(iterator != NULL) {
        counter++;
        iterator = iterator->next;
    }
    return counter;
}
```

Can we be trickier?

Maybe we don't want to loop through the whole list every time?

- We have a queueInternals struct that can store information
- How about we store the size there?

```
// Queue internals holds a pointer to the start of a linked list
struct queueInternals {
    struct queueNode *head;
    struct queueNode *tail;
    int size;
};
```

- Then, whenever we add or remove a node, we add or subtract 1 from this variable

Completing our Queue

To go along with our size variable . . .

- queueCreate will set the size to 0
- queueAdd will add 1
- queueRemove will subtract 1

In our testing main(), we can now show this working with a loop:

```
    while(queueSize(iceQueue) > 0) {
        printf("Person %d just got their ice cream!\n", queueRemove(iceQueue));
        printf("There are %d people in the queue.\n", queueSize(iceQueue));
    }
```

More thoughts on the Queue

Whatever includes the queue only sees the header

- When we're using ADTs we don't know (or need to know) the implementation
- What if this queue had been implemented using an array?

Challenge

- Implement queue.c using an array instead of a Linked List
- There are several different ways to make that work!

Break Time

Where to find further information about programming?

- There are a lot of online resources that can help with programming
- Teaching yourself can help to go beyond course content
- Stack Overflow is a question and answer site
    - It can sometimes be useful but sometimes be confusing or argumentative
- There are several free online courses that will teach you different languages
    - Too many to list!
- Experimentation will always teach you something!

Stacks - another Abstract Data Type

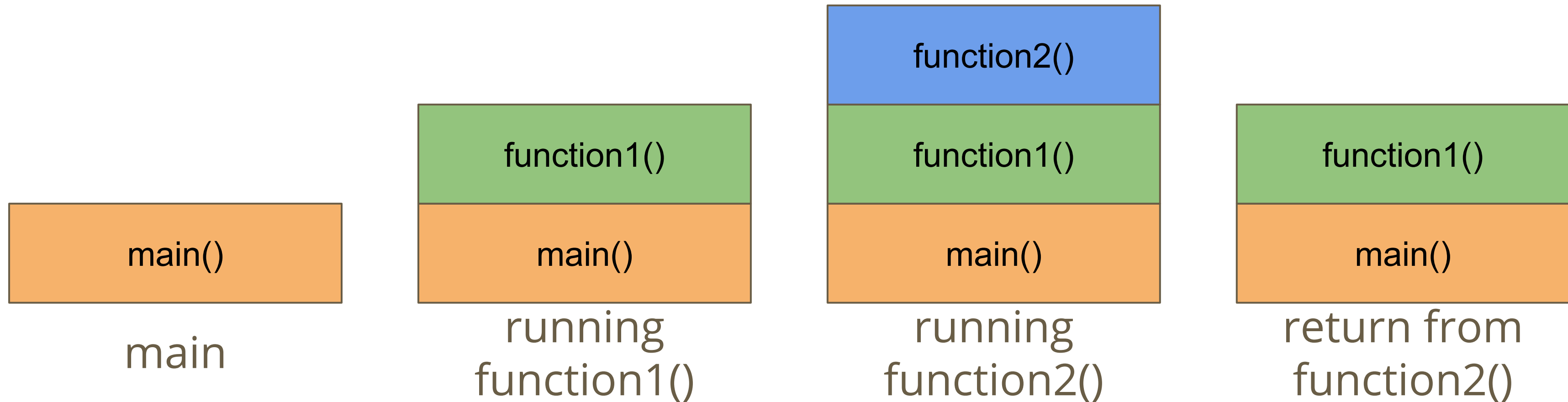
A stack is a very common data structure in programming

- It is a "Last in first out" structure
- You can put something on top of a stack
- You can take something off the top of a stack
- You can't access anything underneath

This is actually how functions work!

The currently running code is on the top of the stack

- main() calls function1() - only function1() is accessible
- function1() calls function2() - only function2() is accessible
- control returns to function1() when function2() returns



What kind of functions does a stack need?

Functionality to put in a header file

- create
- free
- push (add to the top of the stack)
- pop (remove from the top of the stack)
- top (show the top without removing it)
- size

We'll only have time for some of these today

A Stack Header

Looks eerily familiar to Queue . . .

```
// stack type hides the struct that it is implemented as
typedef struct stackInternals *Stack;

// functions to create and destroy stacks
stack stackCreate(void);
void stackFree(Stack s);

// Push and Pop items from stacks
// Removing the item returns the item for use
void stackPush(Stack s, int item);
int stackPop(Stack s);

// Check on the size of the queue
int stackSize(Stack s);
```

Implementation

What is our internal data structure going to be?

- We could use a linked list again
- We could use an array
- Whichever it is, it should be invisible to whoever includes the stack.h file

- For this example, let's use an array (just for a change)
- Our data will be stored in an array with a large maximum size
- We'll keep track of where the top is with an int

Array Implementation of a stack

A large array where only some of it is used

- Top is a particular index
- Top signifies where our data ends
- It also happens to be exactly the number of elements in the stack!

Top is 5

Undefined data . . . we might use these cells if the stack grows larger

65	23	15	3	8											

stack.c

```c
// Struct representing the stack using an array
struct stackInternals {
    int stack[MAX_STACK_SIZE];
    int top;
};

// create a new stack
stack stackCreate() {
    stack s = malloc(sizeof(struct stackInternals));
    s->top = 0;
    return s;
}
```

Push and Pop

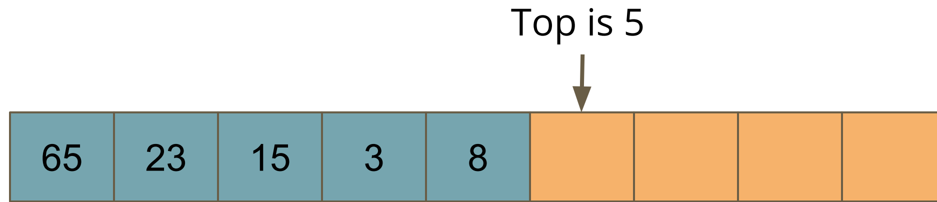
These should only interact with the top of the stack

- **Push** should add an element after the end of the stack
- It should then move the top index to that new element

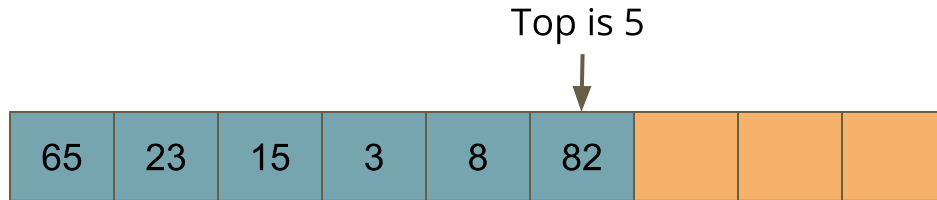
- **Pop** should return the element on the top of the stack
- It should then move the top index down one

Push

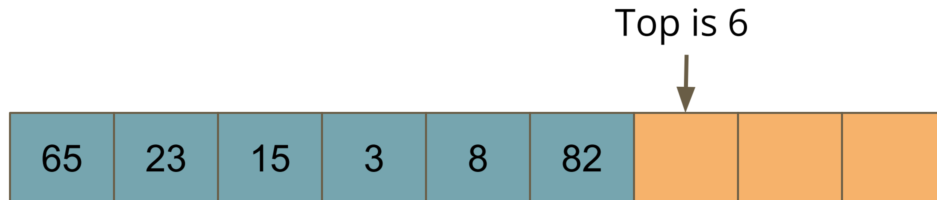
Push a new element "82" onto the stack



The stack starts like this



82 is added at top's index



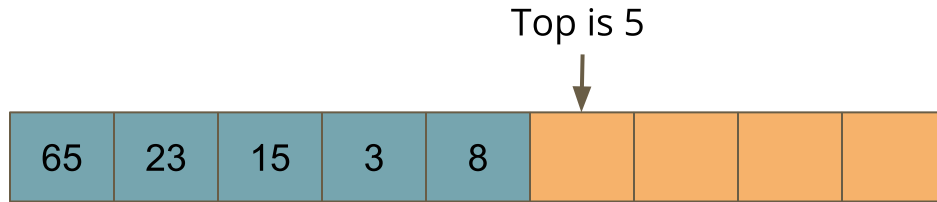
Top then moves up one

Push code

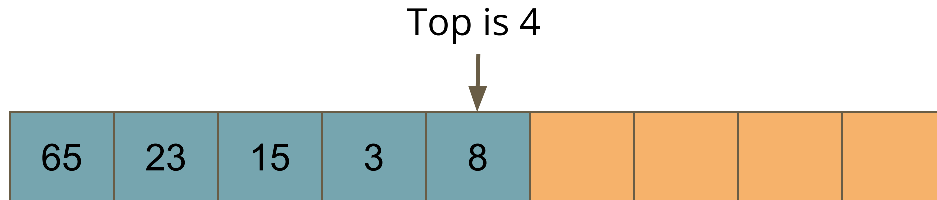
```c
// Add an element to the top of the stack
void stackPush(stack s, int item) {
    // check to see if we've used up all our memory
    if(s->top == MAX_STACK_SIZE) {
        printf("Maximum stack size reached, cannot push.\n");
        exit(1);
    }
    s->stackData[s->top] = item;
    s->top++;
}
```

Pop

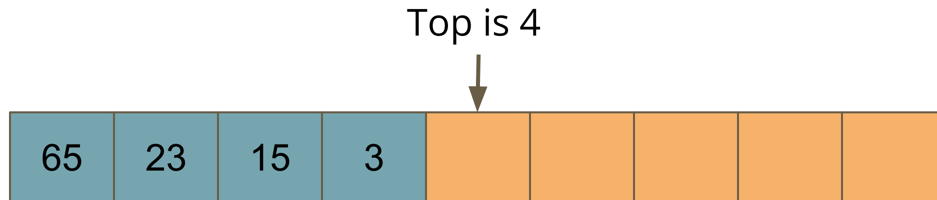
Pop removes the top element from the stack



The stack starts like this



Top moves down one



Read the element at top and return it

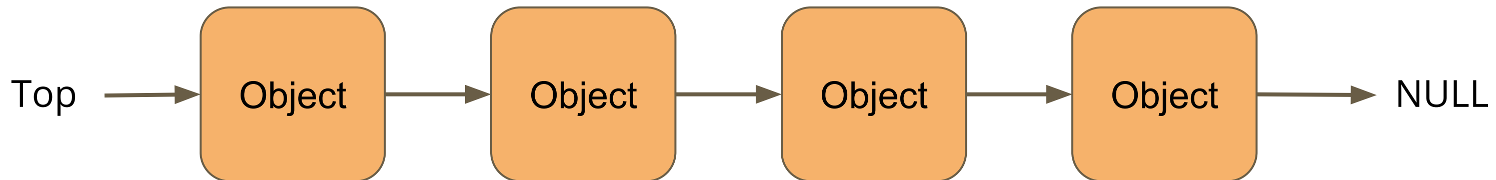
Pop code

```
// Remove an element from the top of the stack
int stackPop(stack s) {
    // check to see if the stack is empty
    if(s->top <= 0) {
        printf("Stack is empty, cannot pop.\n");
        exit(1);
    }
    s->top--;
    return s->stackData[s->top];
}
```

What if this were a linked list?

Implementation should be invisible to the including code

- Let's try to implement the same functions with a linked list
- We'll add elements to the end
- We'll also remove elements from the same end



Linked List Implementation

```
struct stackInternals {
    struct node *top;
};
struct node {
    struct node *next;
    int data;
};

stack stackCreate() {
    stack s = malloc(sizeof(struct stackInternals));
    s->top = NULL;
    return s;
}
```

Push and Pop with a Linked List

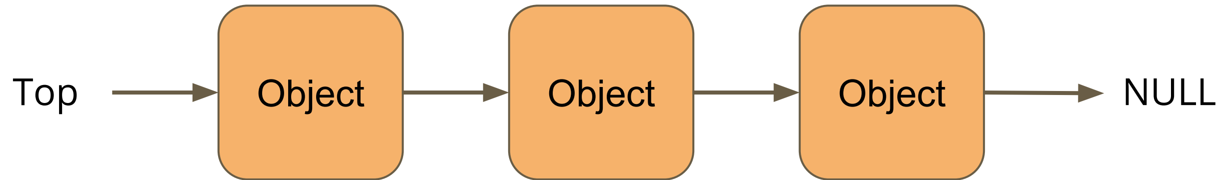
All of our changes will apply to the top of the list

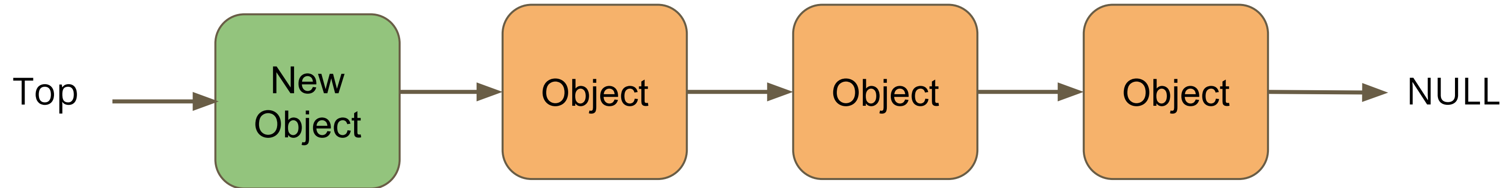
- **Push** adds an element to the top of the list
- Top will then point at that element

- **Pop** removes the top element of the list and returns it
- Top will then point at the next element

Push

Add a node to the top of the list



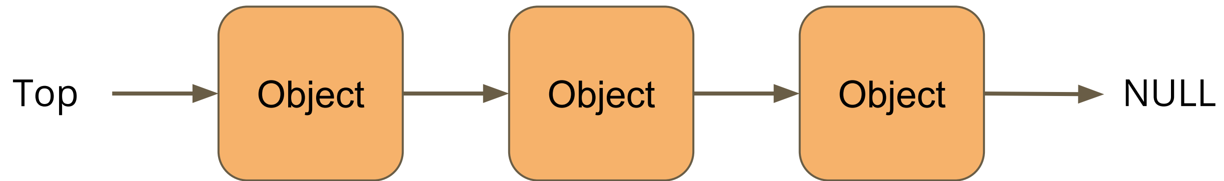


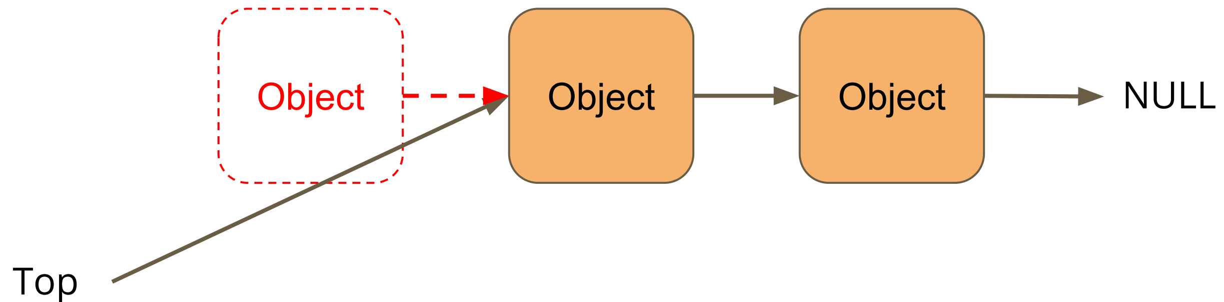
Push Code

```
// Add an element on top of the stack
void stackPush(stack s, int item) {
    struct node *n = malloc(sizeof (struct node));
    if (n == NULL) {
        printf("Cannot allocate memory for a node.\n");
        exit(1);
    }
    n->data = item;
    n->next = s->top;
    s->top = n;
}
```

Pop

Remove the node from the top of the list





Pop code

```
// Remove the top element from the stack
int stackPop(stack s) {
    if(s->top == NULL) {
        printf("Stack is empty, cannot pop.\n");
        exit(1);
    }
    // keep a pointer to the node so we can free it
    struct node *n = s->top;
    int item = n->data;
    s->top = s->top->next;
    free(n);
    return item;
}
```

Hidden Implementations

Neither Implementation needs to change the Header

- The main function doesn't know the difference!
- The structures and implementations are hidden from the header file and the rest of the code that uses it
- If we want or need to, we can change the underlying implementation without affecting the main code

What did we learn today?

Abstract Data Types

- Complete implementation of the Queue using a Linked List
- Partial implementation of a Stack using an Array
- Showing that we can also implement the Stack using a Linked List
- Hidden implementations mean they can change if we want!

We're finished for new content for COMP1511

- Next week's lectures will be a recap and strategies for the exam