# Programming Abstractions

CS106B

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# Topics:

- **Last time: Classes, Part 1**
  - BankAccount class
  - Ball class
- **Today: Classes, Part 2**
  - More practice making our own classes!
  - This time we will implement one of our ADTs from earlier in the quarter!!
    - A simple **Stack ADT** with unlimited capacity
  - In doing so, we need to learn about:
    - **C/C++ arrays**
    - **Dynamic memory allocation** (this is a huge topic in itself—much of CS107 is about this)

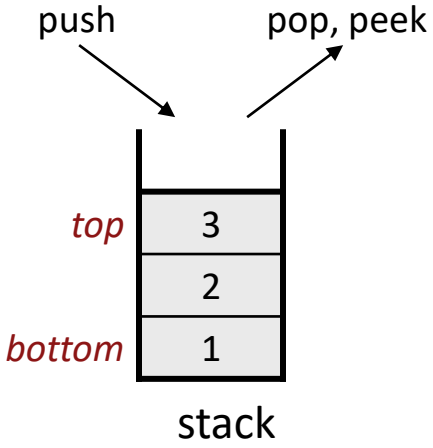
# Stack Implementation

BEHIND THE SCENES TOUR!

# Implementing a classic ADT: Stack

Today let's learn how to write a Stack class

- We will implement a stack
- Not *quite* like the one in Stanford library—for simplicity this only stores `int`
- The stack will use an array to store its elements
- The capacity will grow as needed




Recall the basic stack operations:

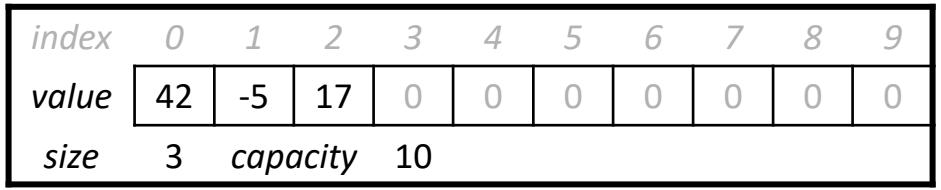
- push: Add an element to the top.
- pop: Remove the top element.
- peek: Examine the top element.

# Inside our Stack

Inside a Stack (also true of Queue and Vector) is an **array** storing the elements you have added.

- Typically the array is larger than the data added so far, so that it has some extra slots ready to go to put new elements later.
- Our stack will use the same array-based technique

```
// Diagram shows the internal state of the Stack class
// after 3 ints are pushed
Stack<int> s;
s.push(42);
s.push(-5);
s.push(17);
```



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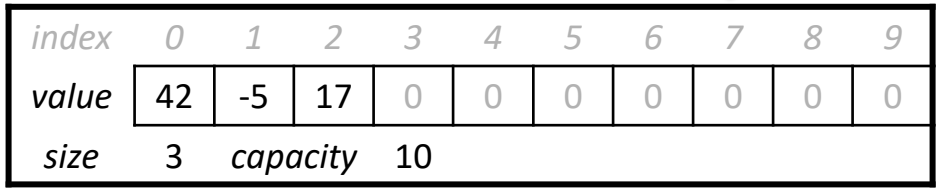

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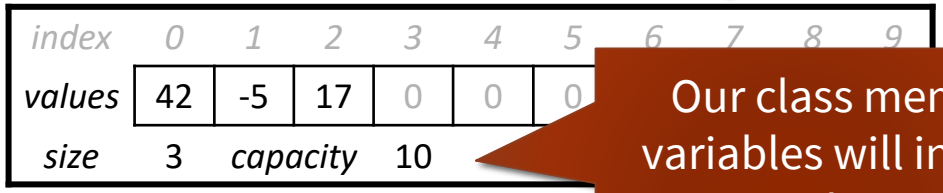



**Quick check:** which end will we consider the "top" of the stack?

Our class member variables will include `size` and `capacity`. And this storage area that is a C/C++ array.

# Arrays in C++

BEHIND THE SCENES TOUR!

# Basic Array in C/C++

```
type name[length];
```

- An array is has enough space for multiple values of a type
  - If a regular variable is a single-family home, arrays are an apartment building
  - Similar concept as a Vector, but much more basic
    - Can't ever be resized
    - No methods
    - Really just several adjacent spaces of the same type

Example:

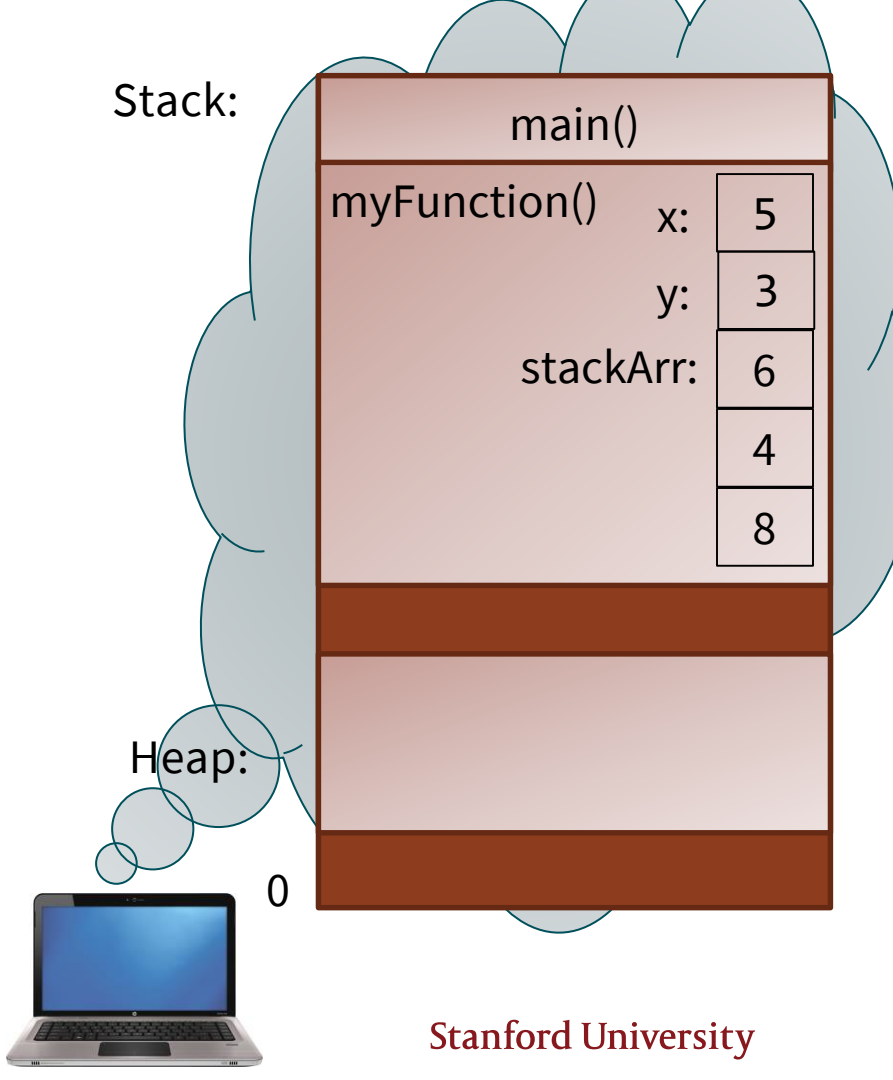
```
int homeworkGrades[7];
homeworkGrades[0] = 90;
homeworkGrades[3] = 95;
```

# Arrays in a memory diagram

```
int myFunction() {
    int x = 5;
    int y = 3;
    int stackArr[3];
    stackArr[0] = x + 1;
    stackArr[1] = y + 1;
    stackArr[2] = x + y;

    return y;
}
```

What happens when `myFunction()` returns?



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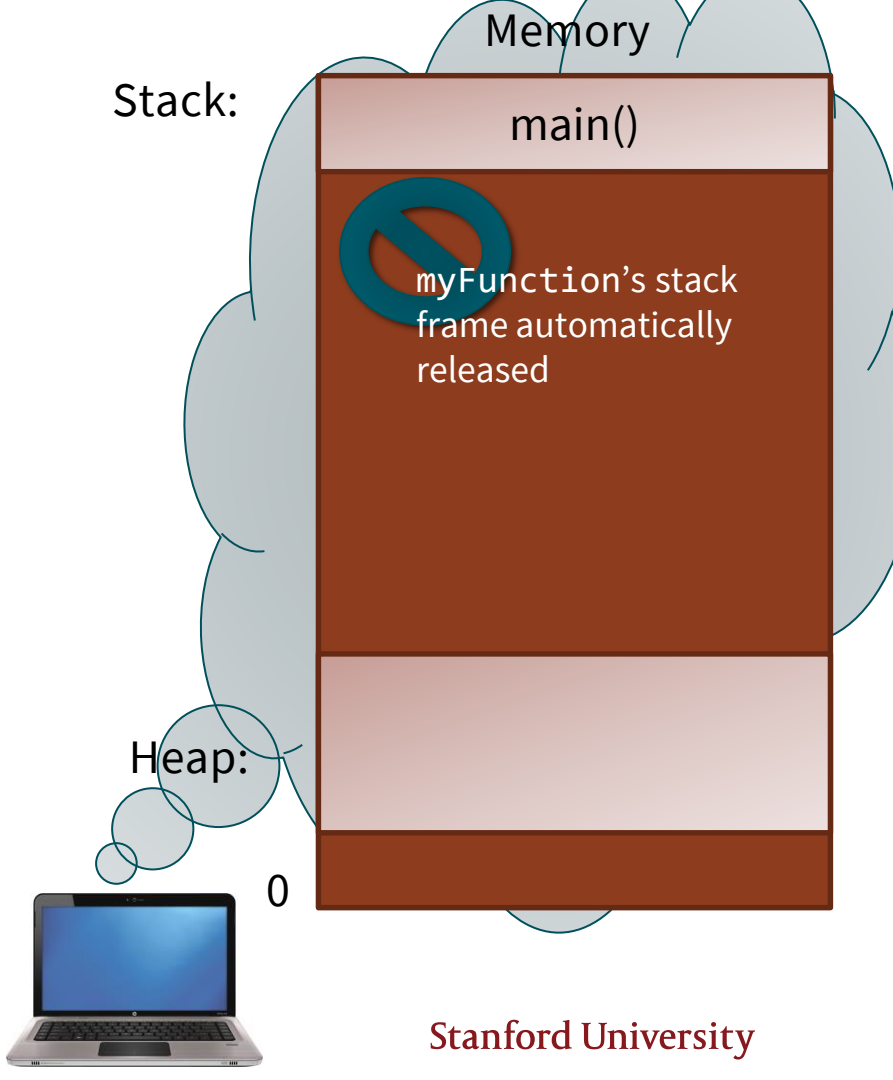

# A second kind of array in C/C++

```
type name[length];
```

Basic array we just saw

- **Basic array (AKA statically allocated or stack allocated)**
- Stored in the stack frame alongside other local variables

Example: `int homeworkGrades[7];`

New kind of array!

```
type* name = new type[length];
```

new!

- **Dynamically allocated array (AKA heap allocated)**
- The variable that refers to the array is called a pointer, and it is on the stack
- But the actual array is stored in the heap!

new!

Example: `int* homeworkGrades = new int[7];`

Literally the word “new”!

# Arrays in a memory diagram

```
int myFunction() {
    int x = 5;
    int y = 3;
    int* heapArr = new int[3];
    heapArr[0] = x + 1;
    heapArr[1] = y + 1;
    heapArr[2] = x + y;

    return y;
}
```

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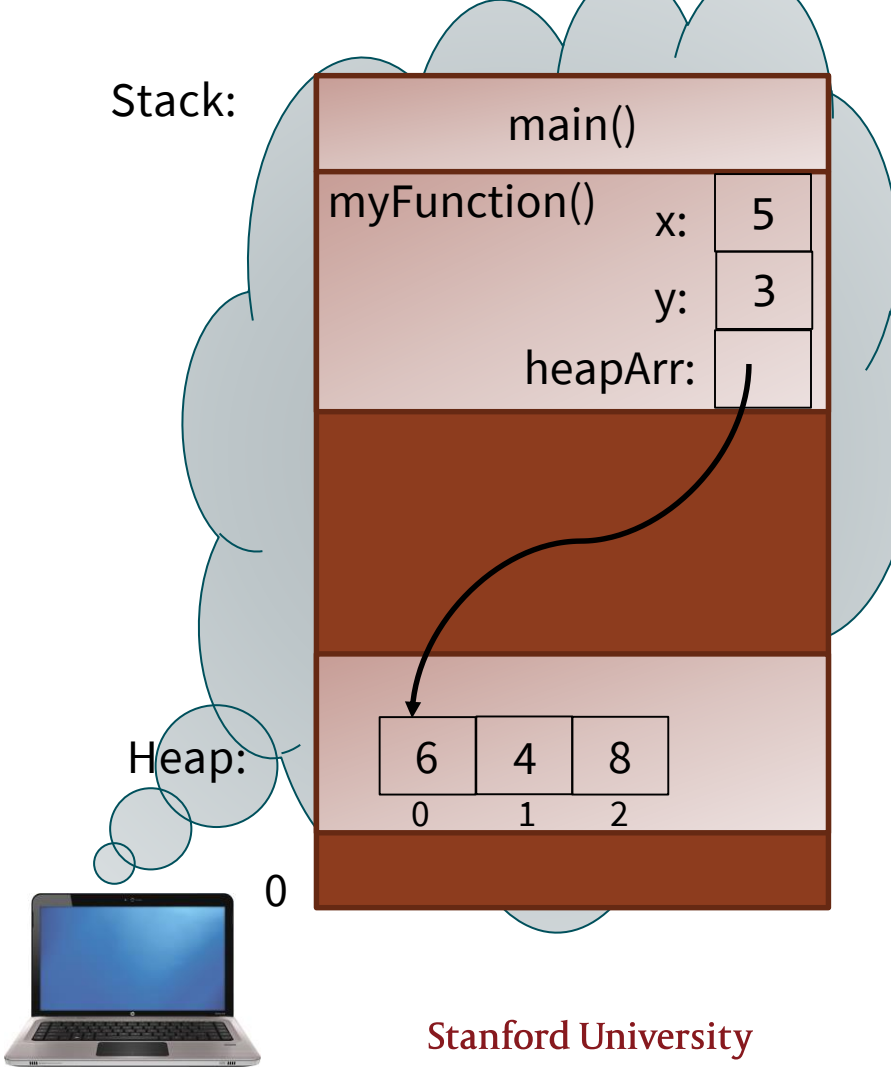

# Arrays in a memory diagram

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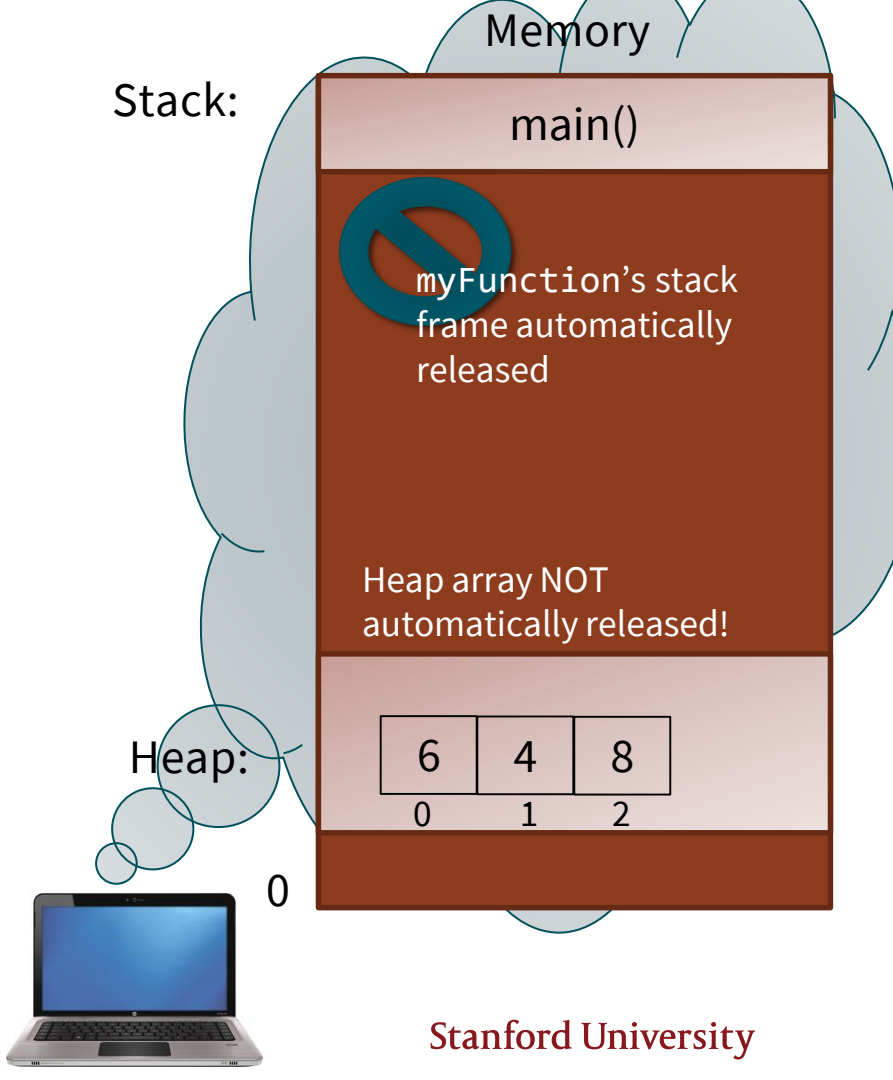
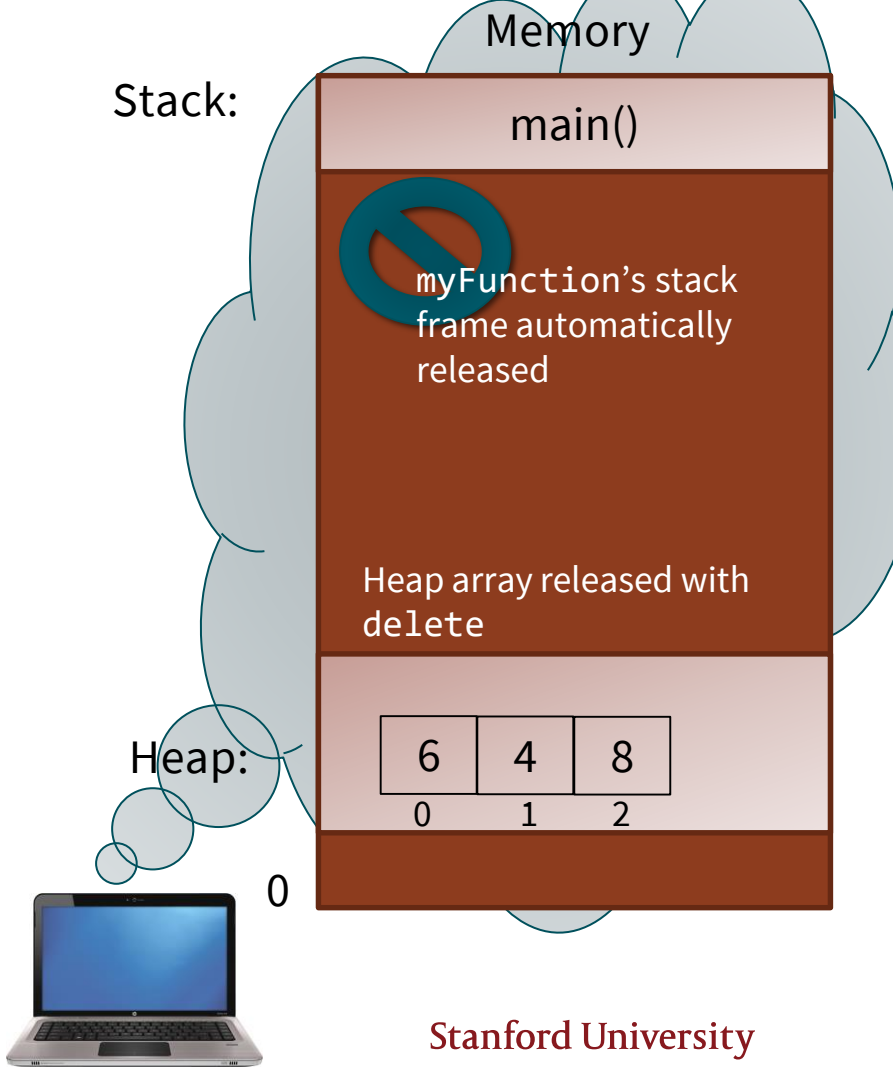


# Arrays in a memory diagram

```
int myFunction() {
    int x = 5;
    int y = 3;
    int* heapArr = new int[3];
    heapArr[0] = x + 1;
    heapArr[1] = y + 1;
    heapArr[2] = x + y;
    delete [] heapArr;
    return y;
}
```

What happens when `myFunction()` returns?

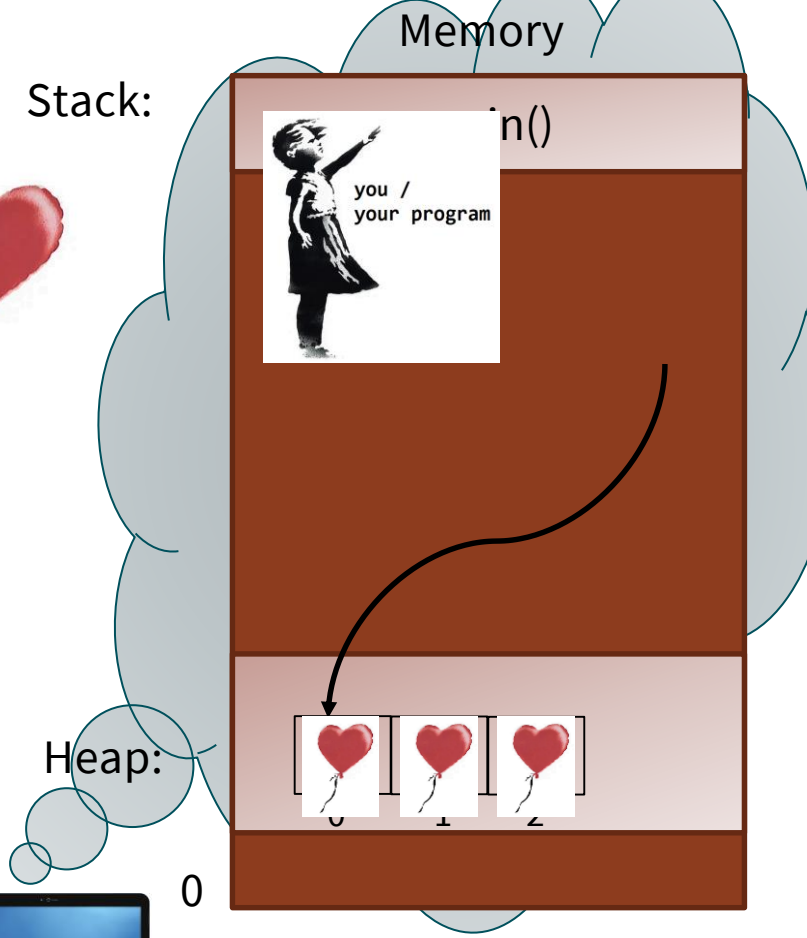


# Dynamic Memory Allocation

Keywords **new** and **delete**

# Memory leaks

- The pointer variable that points to heap allocated memory is like the string on a helium balloon.
- If you let go of the string (or lose that pointer variable), the balloon still exists out there somewhere, but it's never yours to play with ever again. 😭
  - Also it's polluting the environment.



# Always a pair: `new` and `delete`

- Think of `new` as making a hotel room reservation.
  - **`new int[5]`**
  - "I'd like 5 connecting rooms, each big enough for 1 `int` value, please."


- Think of `delete` as checking out of the hotel room.
  - **`delete [] arr`**
  - "My trip is done. Stop charging me for these rooms, and you can give them to other guests."

# Always a pair: `new` and `delete`

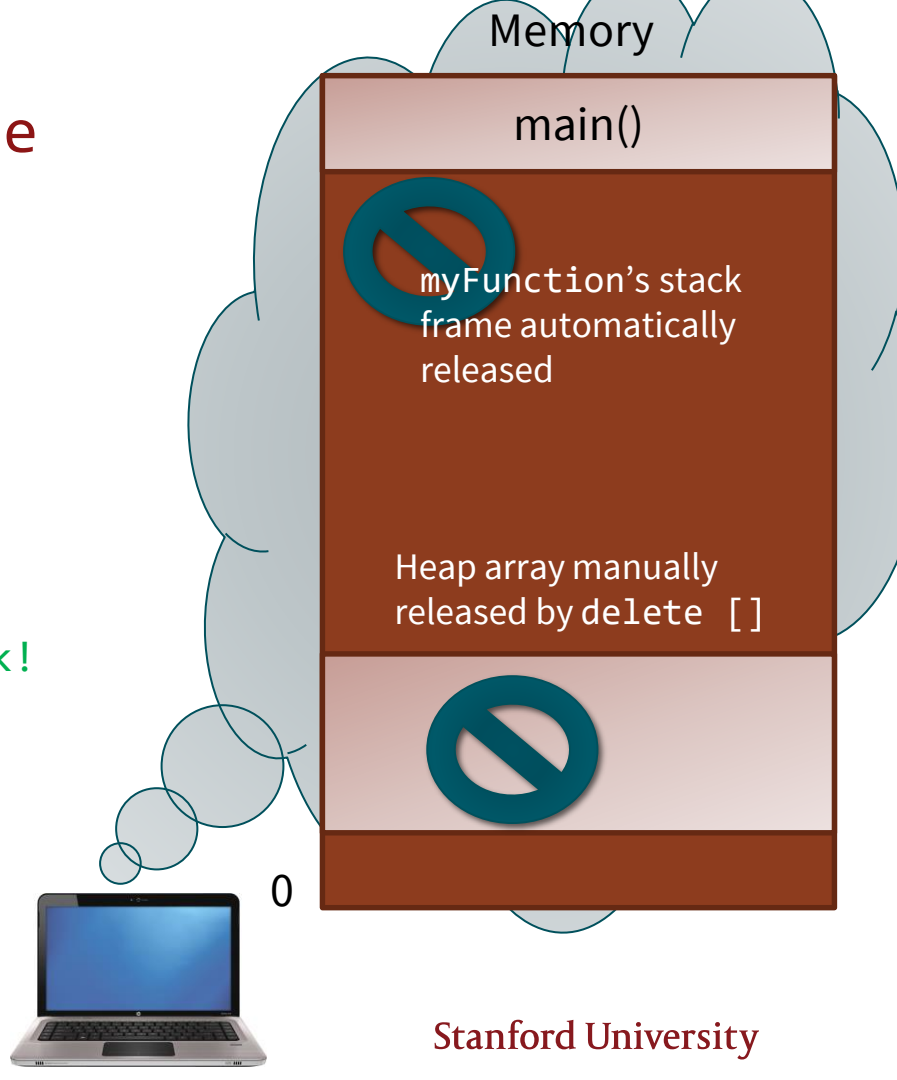
Many things can go wrong with dynamic memory that are analogous to the hotel situation:

- Leave town but forget to check out—you'll keep getting charged for the room and it can't go to another guest
  - When you forget `delete`, you get a memory leak
- Check out of the room but then try to go back in—another guest might already be using it and will be very angry!
  - After you call `delete`, be sure not to try to use that memory again!


```
int* arr = new int[10];
 …
delete [] arr;
arr[0] = 5; // no!!
```

# Always a pair: new and delete

```
int myFunction() {
    int x = 5;
    int y = 3;
    int* heapArr = new int[3];
    heapArr[0] = x + 1;
    heapArr[1] = y + 1;
    heapArr[2] = x + y;
    delete [] heapArr; // fixed leak!
    return y;
}
```



# Always a pair: new and delete

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int myFunction() {
    int x = 5;
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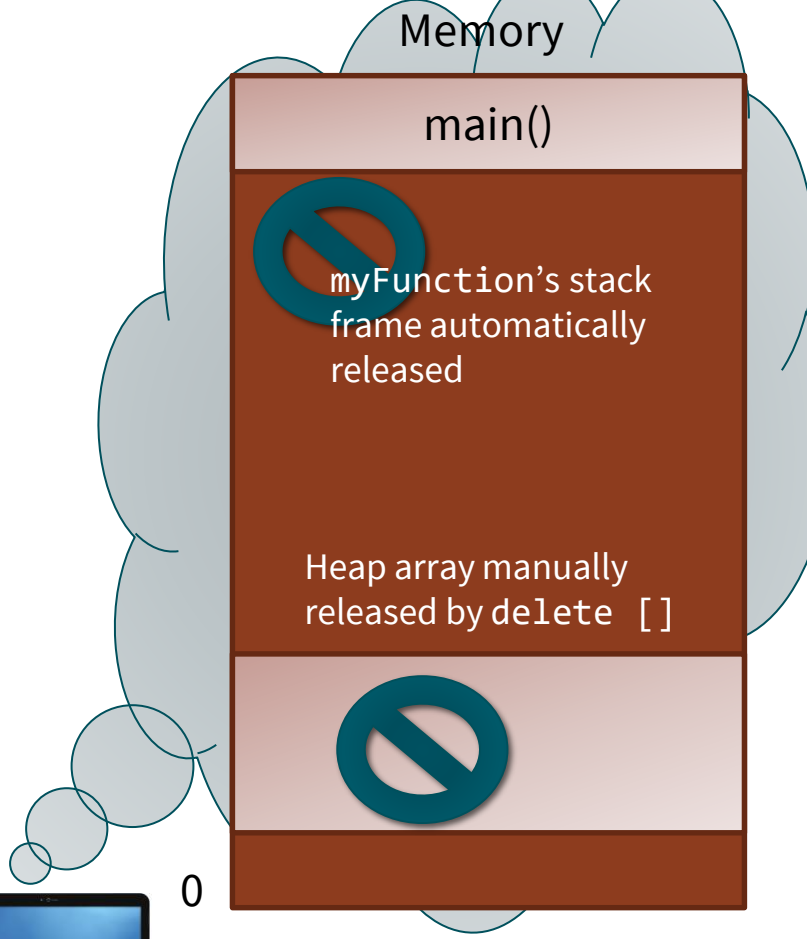
    heapArr[1] = y + 1;
    heapArr[2] = x + y;
    delete [] heapArr; // fixed leak!
    return y;
}
```

**Q: "Why would you want to do that?"**

A: It's true that there's no point to using dynamic allocation if we are just deleting at the end of the function. Choose a static array instead to automatically release. Dynamic allocation is for when you want the data to last so you can keep using it.



# Destructor (12.3)

```
// ClassName.h
~ClassName();
```

```
// ClassName.cpp
ClassName::~ClassName() { ...
```

Destructor: Called when the object is deleted by the program

- When the object goes out of {} scope;  opposite of a constructor
- (or when you expressly call “delete” on the object, if heap-allocated)

- Useful if your object needs to do anything important as it dies, such as freeing any array memory used by its fields

# arraystack.h

```
#ifndef _arraystack_h
#define _arraystack_h

class ArrayStack {
public:
    ArrayStack();
    ~ArrayStack();
    void push(int n);
    int pop();
    int peek() const;
    bool isEmpty() const;

private:
    int* _elements;
    int _capacity;
    int _size;

    void checkResize();
};

#endif
```

# arraystack.cpp (part 1)

```
#include "arraystack.h"

ArrayStack::ArrayStack() {
    _elements = new int[10];
    _capacity = 10;
    _size = 0;
}

ArrayStack::~ArrayStack() {
    delete[] _elements;
}

bool ArrayStack::isEmpty() const {
    return _size == 0;
}

void ArrayStack::push(int n) {
    _elements[_size] = n;
    _size++;
}
```

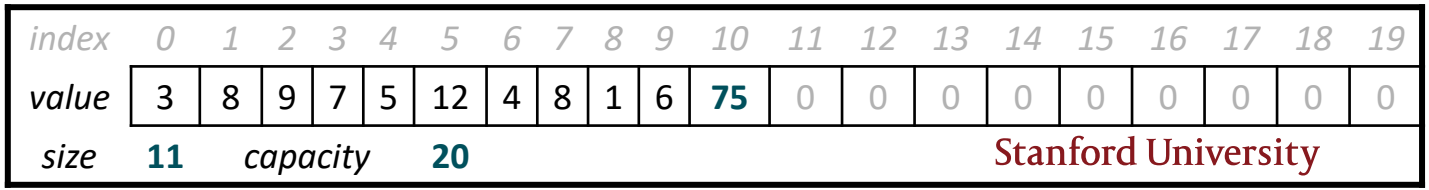
# arraystack.cpp (part 2)

```
int ArrayStack::pop() {
    if (isEmpty()) {
        throw "Can't pop from an empty stack!";
    }
    int result = _elements[_size - 1];
    _elements[_size - 1] = 0;
    _size--;
    return result;
}

int ArrayStack::peek() const {
    if (isEmpty()) {
        throw "Can't peek from an empty stack!";
    }
    return _elements[_size - 1];
}
```

# Resize when out of space

```
// grows array to twice the capacity if needed
void ArrayStack::checkResize() {
    if (_size == _capacity) {
        // create bigger array and copy data over
        int* bigger = new int[2 * _capacity]();
        for (int i = 0; i < _capacity; i++) {
            bigger[i] = _elements[i];
        }
        delete[] _elements;
        _elements = bigger;
        _capacity *= 2;
    }
}
```



# Overflow (extra) slides

FOR THE ADVANCED AND/OR CURIOUS STUDENT

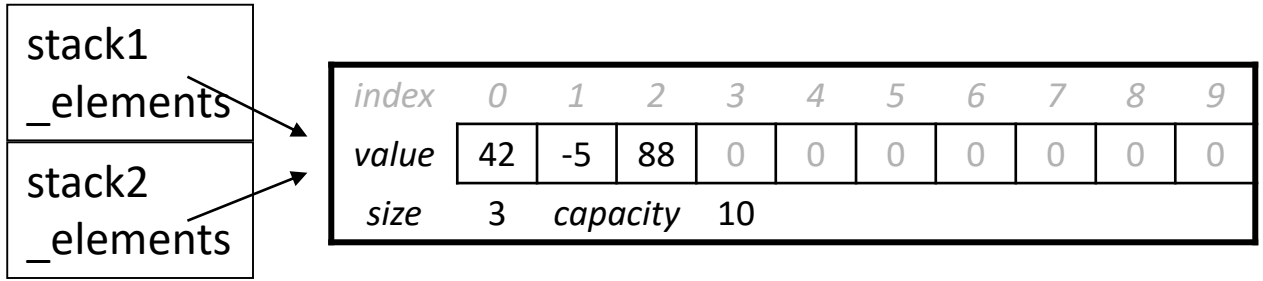
# Shallow copy bug (12.7)

If one stack is assigned to another, they will share one array.

- `ArrayStack stack1;`
- `ArrayStack stack2 = stack1;`

A change to one will affect the other. (That's bad!)

- `stack2.pop();`
- `stack1.push(88);`




When they fall out of scope, memory could get freed twice (error!)

# Deep copy

To correct the shallow copy bug, we must define:

- a copy constructor (constructor that takes a list as a parameter)

```
ArrayStack(const ArrayStack& stack);
```

- an assignment operator (overloaded = op between two lists)

```
ArrayStack& operator =(const ArrayStack& stack);
```

  - in both of these, we will make a deep copy of the array of elements.

Rule of Three: In C++, when you define one of these three items in your class, you probably should define all three:

- 1) copy constructor 2) assignment operator 3) destructor

# Advanced: Forbid copying

One quick fix is to just forbid your objects from being copied.

- Declare a private copy constructor and = operator in the .h file.
- Don't give them any actual definition/body in the .cpp file.

```
// in arraystack.h
private:
    ArrayStack(const ArrayStack& stack);
    ArrayStack& operator =(const ArrayStack& stack);
```

- Now if the client tries `stack2 = stack1;` it will not compile.
- Solves the shallow copy problem, but restrictive and less usable.