

# **CS100**

# **Introduction to Programming**

## **Lecture 15. Memory management**

# Today's learning objectives

- Learning about scopes and the different types of memory
- Learning about the problems resulting from lots of freedom to manipulate memory
  - Memory leaks
  - Segmentation faults
- Dynamic sizing

# Outline

- Constructors
- Scoping and Memory
- Memory Types
- Back to C++: The **new** operator
- Memory leaks: The **delete** operator
- Segmentation faults
- Dynamically sized arrays
- New & delete with classes

# Constructors

- Method that is called when an instance is created

```
class Integer {  
public:  
    int m_val;  
    Integer() {  
        m_val = 0; printf("default constructor\n");  
    }  
};
```

```
int main() {  
    Integer i;  
}
```

**Output:**  
default constructor

# Constructors

- When making an array of objects, default constructor is invoked on each

```
class Integer {  
public:  
    int m_val;  
    Integer() {  
        m_val = 0; printf("default constructor\n");  
    }  
};
```

```
int main() {  
    Integer arr[3];  
}
```

## Output:

```
default constructor  
default constructor  
default constructor
```

# Constructors

- When making a class instance, the default constructor of its fields are invoked

```
class Integer {
public:
    int m_val;
    Integer() {
        m_val = 0; printf("Integer default constructor\n");
    }
};

class IntegerWrapper {
public:
    Integer m_val;
    IntegerWrapper() {
        printf("IntegerWrapper default constructor\n");
    }
};

int main() {
    IntegerWrapper q;
}
```

## Output:

Integer default constructor  
IntegerWrapper default constructor

# Constructors

- Constructors can accept parameters

```
class Integer {  
public:  
    int m_val;  
    Integer(int v) {  
        m_val = v; printf("constructor with arg %d\n", v);  
    }  
};
```

```
int main() {  
    Integer i(3);  
}
```

**Output:**  
constructor with arg 3

# Constructors

- Constructors can accept parameters
  - Can invoke single-parameter constructor via assignment to the appropriate type

```
class Integer {  
public:  
    int m_val;  
    Integer( int v ) {  
        m_val = v; printf("constructor with arg %d\n");  
    }  
};
```

```
int main() {  
    Integer i(3);  
    Integer j = 5;  
}
```

## Output:

```
constructor with arg 3  
constructor with arg 5
```



# Constructors

- If a constructor with parameters is defined, the default constructor is no longer available

```
class Integer {  
public:  
    int m_val;  
    Integer(int v) {  
        m_val = v; printf("constructor with arg %d\n");  
    }  
};
```

```
int main() {  
    Integer i(3); // ok  
    Integer j;  
}
```



Error: No default constructor available for Integer

# Constructors

- If a constructor with parameters is defined, the default constructor is no longer available
  - Without a default constructor, can't declare arrays without initializing

```
class Integer {  
public:  
    int m_val;  
    Integer(int v) {  
        m_val = v; printf("constructor with arg %d\n");  
    }  
};
```

```
int main() {  
    Integer i(3); // ok  
    Integer b[2];  
}
```



Error: No default constructor available for Integer

# Constructors

- If a constructor with parameters is defined, the default constructor is no longer available
  - Can create a separate 0-argument constructor

```
class Integer {  
public:  
    int m_val;  
    Integer() {  
        m_val = 0;  
    }  
    Integer(int v) {  
        m_val = v;  
    }  
};
```

```
int main() {  
    Integer i;    // ok  
    Integer j(3); // ok  
}
```

# Constructors

- If a constructor with parameters is defined, the default constructor is no longer available
  - Can create a separate 0-argument constructor
  - Or, use default arguments


```
class Integer {  
public:  
    int m_val;  
    Integer(int v = 0) {  
        m_val = v;  
    }  
};
```

```
int main() {  
    Integer i;    // ok  
    Integer j(3); // ok  
}
```

# Constructors

- How do I refer to a field when a method argument has the same name?
- **this**: a pointer to the current instance

```
class Integer {  
  public:  
    int val;  
    Integer(int val = 0) {  
      this->val = val;  
    }  
};
```



this->val is a shorthand for (\*this).val

# Constructors

- How do I refer to a field when a method argument has the same name?
- **this**: a pointer to the current instance

```
class Integer {  
public:  
    int val;  
    Integer(int val = 0) {  
        this->val = val;  
    }  
    void setVal(int val) {  
        this->val = val;  
    }  
};
```

# Outline

- Constructors
- Scoping and Memory
- Memory Types
- Back to C++: The **new** operator
- Memory leaks: The **delete** operator
- Segmentation faults
- Dynamically sized arrays
- New & delete with classes

# Scoping and Memory

- Whenever we declare a new variable (`int x`), memory is allocated
- When can this memory be freed up (so it can be used to store other variables)?
  - When the variable goes out of scope



# Scoping and Memory

- When a variable goes out of scope, that memory is no longer guaranteed to store the variable's value

```
int main() {  
    if (true) {  
        int x = 5;  
    }  
    // x now out of scope, memory it used to occupy can be reused  
}
```

# Scoping and Memory

- When a variable goes out of scope, that memory is no longer guaranteed to store the variable's value

```
int main() {  
    int *p;  
    if (true) {  
        int x = 5;  
        p = &x;  
    }  
    printf("%d\n", *p); // ???  
}
```

# Scoping and Memory

- When a variable goes out of scope, that memory is no longer guaranteed to store the variable's value

```
int main() {  
    int *p;  
    if (true) {  
        int x = 5;  
        p = &x;  
    }  
    printf("%d\n", *p); // ???  
}
```



int \*p

# Scoping and Memory

- When a variable goes out of scope, that memory is no longer guaranteed to store the variable's value

```
int main() {  
    int *p;  
    if (true) {  
        int x = 5;  
        p = &x;  
    }  
    printf("%d\n", *p); // ???  
}
```



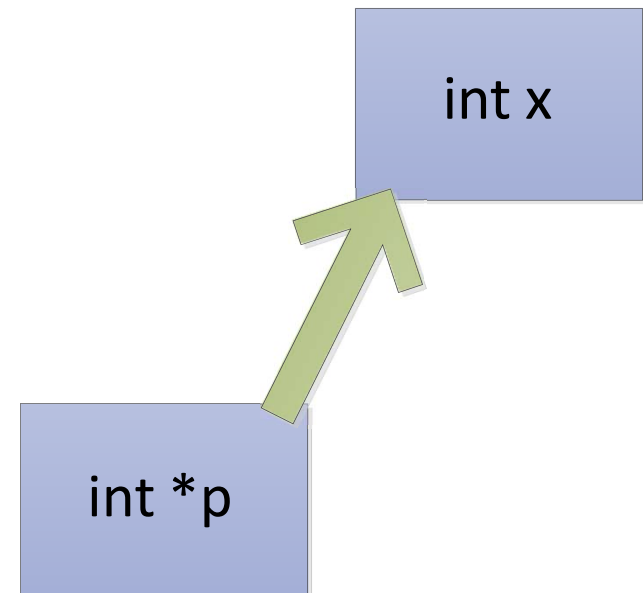
int x

int \*p

# Scoping and Memory

- When a variable goes out of scope, that memory is no longer guaranteed to store the variable's value

```
int main() {  
    int *p;  
    if (true) {  
        int x = 5;  
        p = &x; ← here  
    }  
    printf("%d\n", *p); // ???  
}
```



# Scoping and Memory

- When a variable goes out of scope, that memory is no longer guaranteed to store the variable's value
  - Here, p has become a **dangling pointer** (points to memory whose contents are undefined)

```
int main() {  
    int *p;  
    if (true) {  
        int x = 5;  
        p = &x;  
    }  
    printf("%d\n", *p); // ???  
}
```

← here

int \*p

???


# A Problematic Task

- Implement a function which returns a pointer to some memory containing the integer 5
- Incorrect implementation:

```
int* getPtrToFive() {  
    int x = 5;  
    return &x;  
}
```

# A Problematic Task

- Implement a function which returns a pointer to some memory containing the integer 5
- Incorrect implementation:
  - x is declared in the function scope

```
int* getPtrToFive() {  
    int x = 5;   
    return &x;  
}  
int main() {  
    int *p = getPtrToFive();  
    printf("%d\n", *p); // ???  
}
```




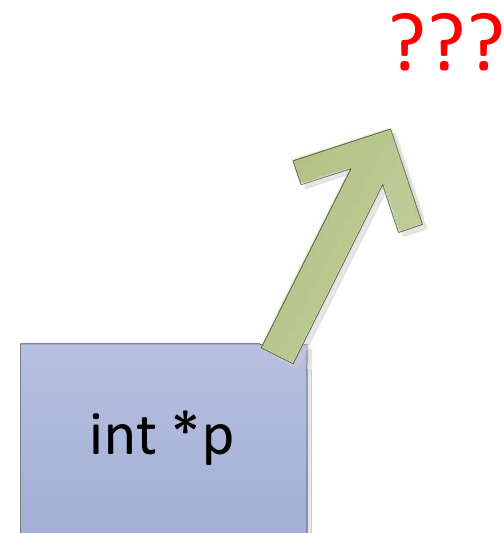
int x



# A Problematic Task

- Implement a function which returns a pointer to some memory containing the integer 5
- Incorrect implementation:
  - x is declared in the function scope
  - As getPtrToFive() returns, x goes out of scope. So a dangling pointer is returned

```
int* getPtrToFive() {  
    int x = 5;  
    return &x;  here  
}  
int main() {  
    int *p = getPtrToFive();  
    printf("%d\n", *p); // ???  
}
```

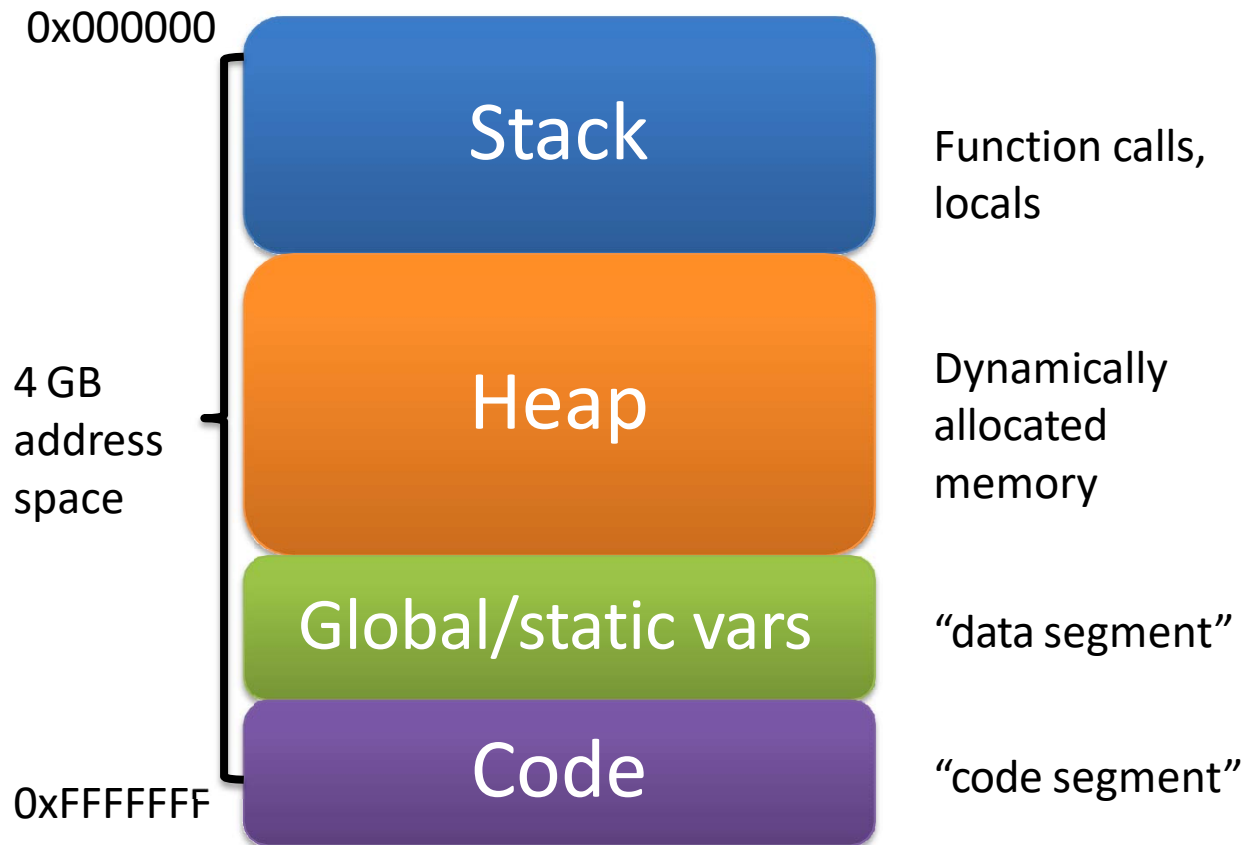


# Outline

- Constructors
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- **Memory Types**
- Back to C++: The **new** operator
- Memory leaks: The **delete** operator
- Segmentation faults
- Dynamically sized arrays
- New & delete with classes

# Memory Types

- each process gets its own memory chunk, or *address space*



# Stack Allocation

- memory allocated by the program as it runs
  - local variables
  - function calls
- fixed at compile time



Stack

# Heap Allocation

- dynamic memory allocation
  - memory allocated at run-time
- Function for allocating memory:
  - `malloc()`
    - Requires `#include <stdlib.h>` to work

An orange rounded rectangle with a slight gradient and a thin white border, containing the word "Heap" in white text.

Heap

# malloc()

```
void* malloc ( <size to be allocated> )
```

```
char *letters;
```

```
letters = (char*) malloc(userVariable *  
                          sizeof(char));
```

- malloc returns a pointer to a ***contiguous*** block memory of the size requested

# Casting Allocated Memory

- `malloc()` return a pointer of type `void`, so you must cast the memory to match the given type

```
letters = (char*) malloc(userVariable *  
                          sizeof(char));
```

# Handling Allocated Memory

- **IMPORTANT**: before using allocated memory make sure it's *actually been allocated*
- if memory wasn't correctly allocated, the address that is returned will be **null**
  - this means there isn't a contiguous block of memory large enough to handle request



# Exiting in Case of NULL

- if the address returned is `null`, your program should exit
  - `exit( )` takes an integer value
  - non-zero values are used as error codes

```
if (grades == NULL) {  
    printf("Memory not allocated,  
          exiting.\n");  
    exit(-1);  
}
```

# Managing Your Memory

- ***stack*** allocated memory is automatically freed when functions **return**
  - including **main( )**

A blue rounded rectangle with a slight gradient and a drop shadow, containing the word "Stack" in white text.

Stack

- memory on the ***heap*** was allocated by you – so it must also be freed by you

An orange rounded rectangle with a slight gradient and a drop shadow, containing the word "Heap" in white text.

Heap

# Freeing Memory

- done using the **free( )** function
  - free takes a pointer as an argument: **free(grades) ;**  
**free(letters) ;**
- **free( )** does not work recursively
  - for each individual allocation, there must be an individual call to free that allocated memory
  - called in a sensible order

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# Back to C++: The new operator

- Another way to allocate memory, where the memory will remain allocated until you manually de-allocate it
- Returns a pointer to the newly allocated memory

```
int *x = new int;
```

# The new operator

- Another way to allocate memory, where the memory will remain allocated until you manually de-allocate it
- Returns a pointer to the newly allocated memory

```
int *x = new int;
```

Type parameter needed to determine how much memory to allocate

# The new operator

- Another way to allocate memory, where the memory will remain allocated until you manually de-allocate it
- Returns a pointer to the newly allocated memory:
  - If using **int x**; the allocation occurs on **the stack**
  - If using **new int**; the allocation occurs **the heap**

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# The delete operator

- De-allocates memory that was previously allocated using **new**
- Takes a pointer to the memory location

```
int *x = new int;  
// use memory allocated by new  
delete x;
```

# The delete operator

- Implement a function which returns a pointer to some memory containing the integer 5
  - Allocate using **new** to ensure it remains allocated

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

# The delete operator

- Implement a function which returns a pointer to some memory containing the integer 5
  - Allocate using **new** to ensure it remains allocated
  - When done, de-allocate the memory using **delete**

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}  
  
int main() {  
    int *p = getPtrToFive();  
    printf("%d\n", *p); // 5  
    delete p;  
}
```

# Delete Memory When Done Using It

- If you don't use de-allocate memory using **delete**, your application will waste memory

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
    }  
}
```



incorrect

# Delete Memory When Done Using It

- If you don't use de-allocate memory using **delete**, your application will waste memory

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
    }  
}
```



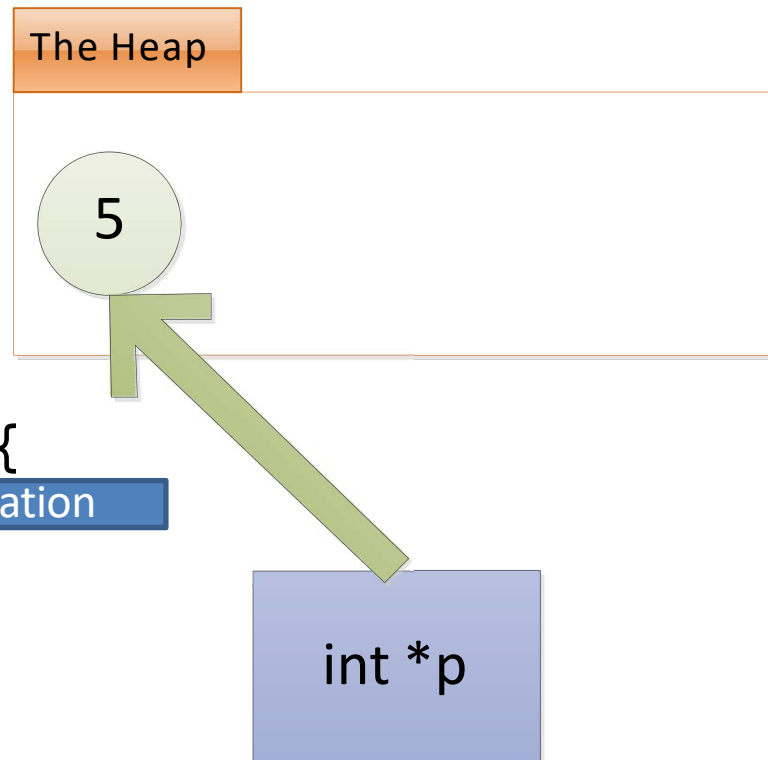
int \*p

# Delete Memory When Done Using It

- If you don't use de-allocate memory using **delete**, your application will waste memory

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
    }  
}
```

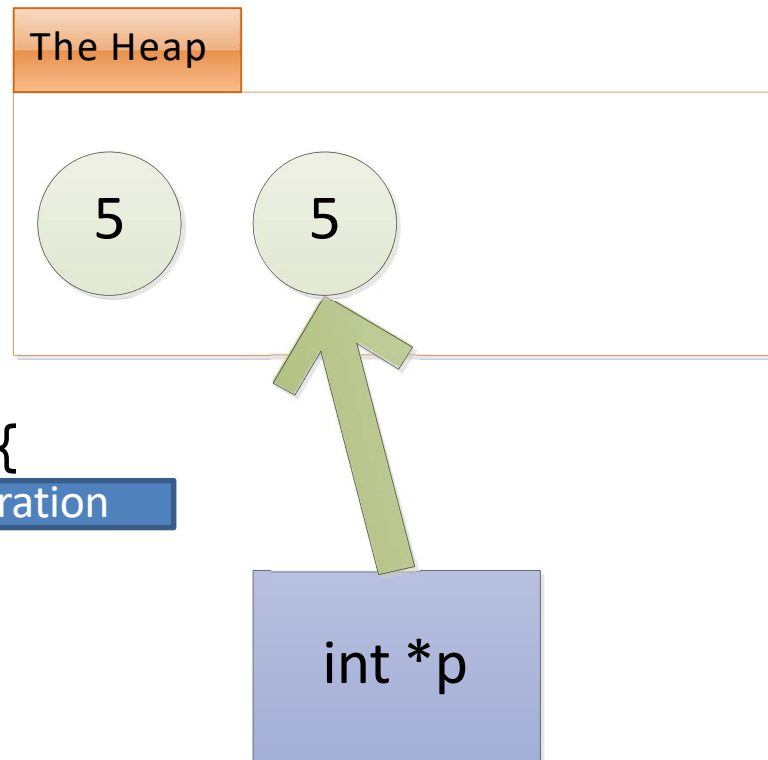


# Delete Memory When Done Using It

- If you don't use de-allocate memory using **delete**, your application will waste memory

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
    }  
}
```

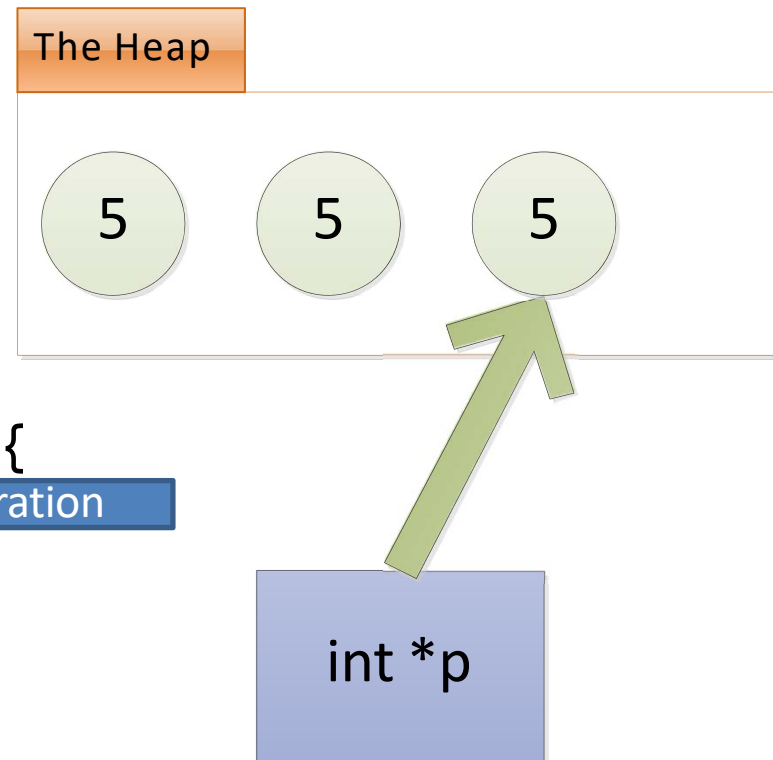


# Delete Memory When Done Using It

- When your program allocates memory but is unable to de-allocate it, this is a **memory leak**

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
    }  
}
```



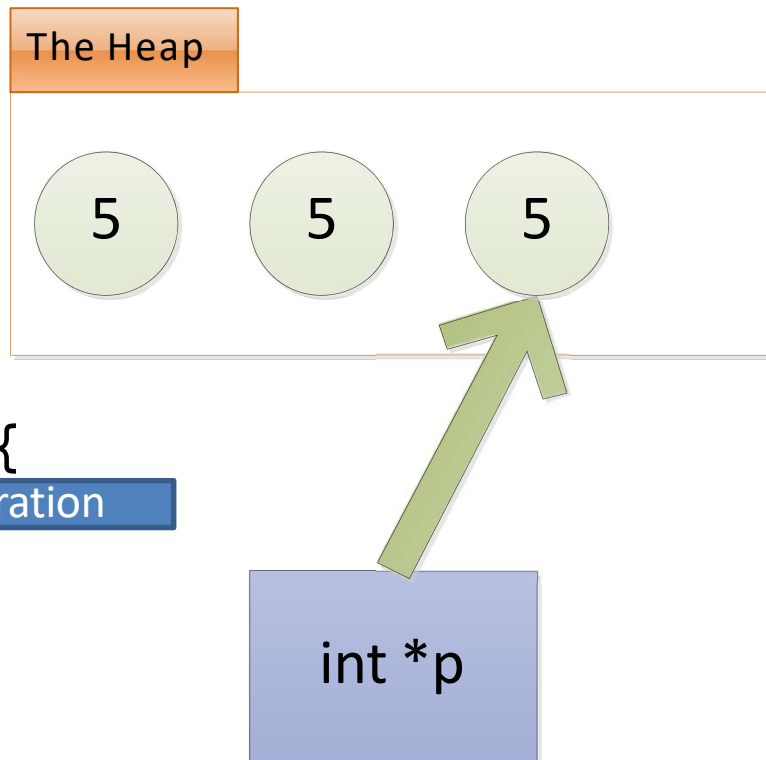


# Delete Memory When Done Using It

- Does adding delete after loop fix memory leak?

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

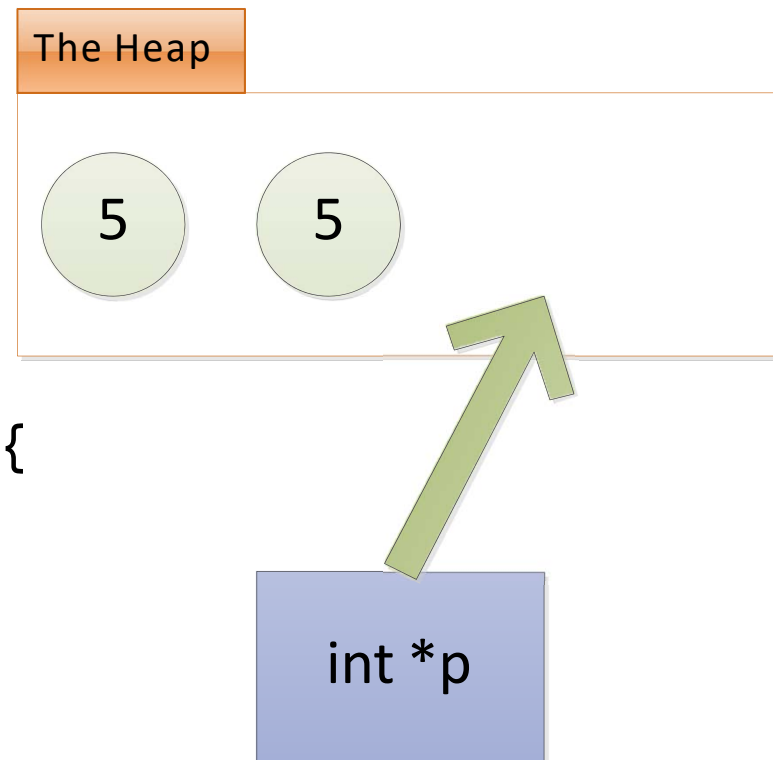
```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
    }  
    delete p;  
}
```



# Delete Memory When Done Using It

- Does adding delete after loop fix memory leak?
  - Only memory allocated on last iteration is de-allocated

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}  
  
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
    }  
    delete p;  
}
```



# Delete Memory When Done Using It

- To fix the memory leak, de-allocate memory within the loop

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}  
  
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
        delete p;  
    }  
}
```

# Delete Memory When Done Using It

- To fix the memory leak, de-allocate memory within the loop

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
        delete p;  
    }  
}
```



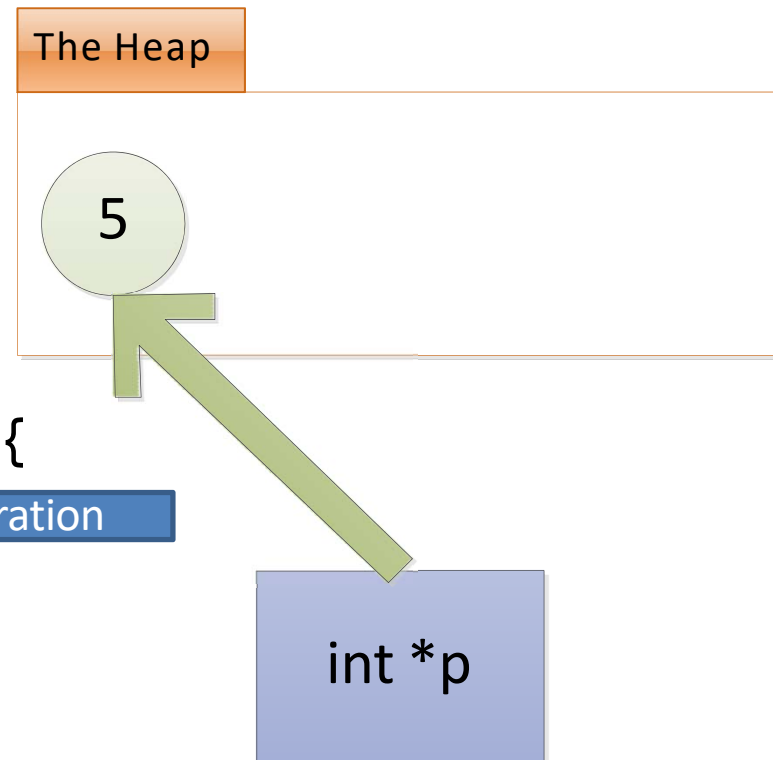
int \*p

# Delete Memory When Done Using It

- To fix the memory leak, de-allocate memory within the loop

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
        delete p;  
    }  
}
```



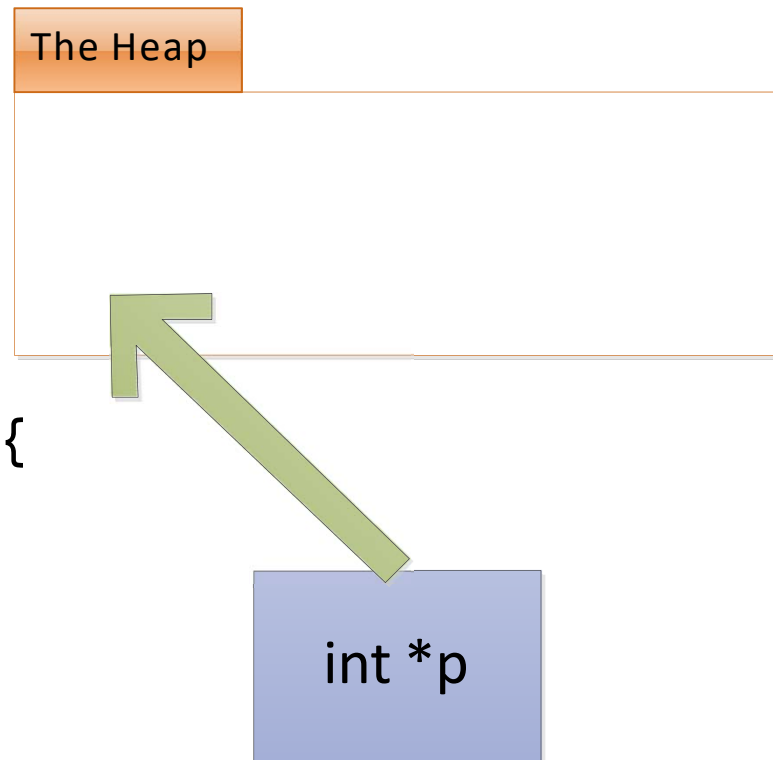
# Delete Memory When Done Using It

- To fix the memory leak, de-allocate memory within the loop

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
        delete p;  
    }  
}
```

1<sup>st</sup> iteration

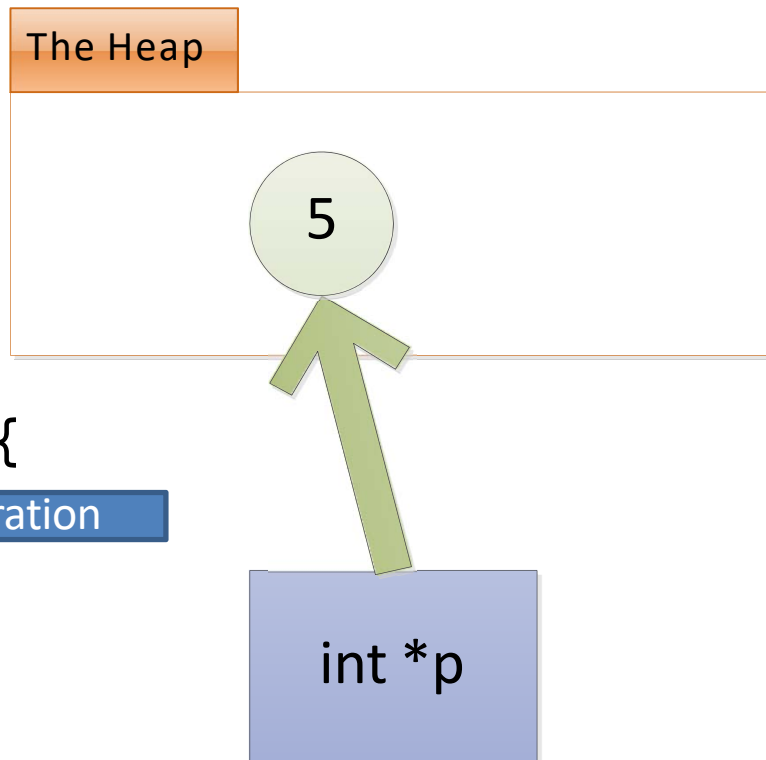


# Delete Memory When Done Using It

- To fix the memory leak, de-allocate memory within the loop

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
        delete p;  
    }  
}
```

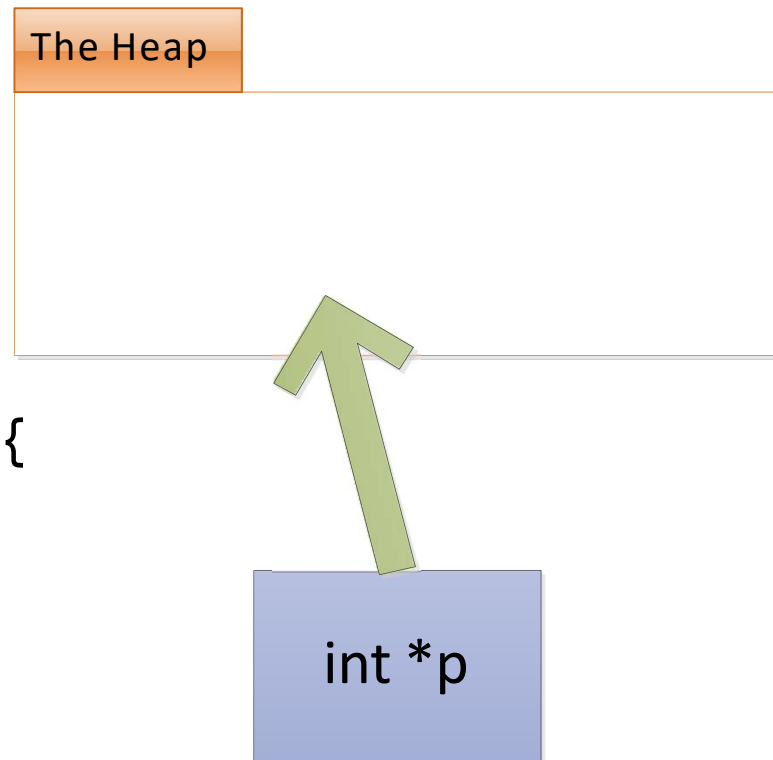


# Delete Memory When Done Using It

- To fix the memory leak, de-allocate memory within the loop

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
        delete p; ← 2nd iteration  
    }  
}
```



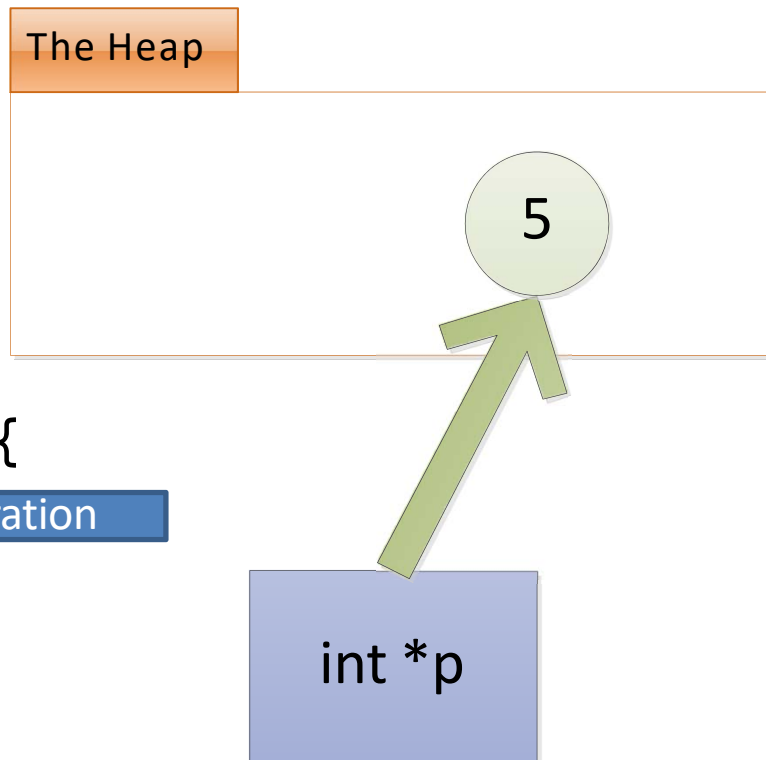


# Delete Memory When Done Using It

- To fix the memory leak, de-allocate memory within the loop

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
        delete p;  
    }  
}
```

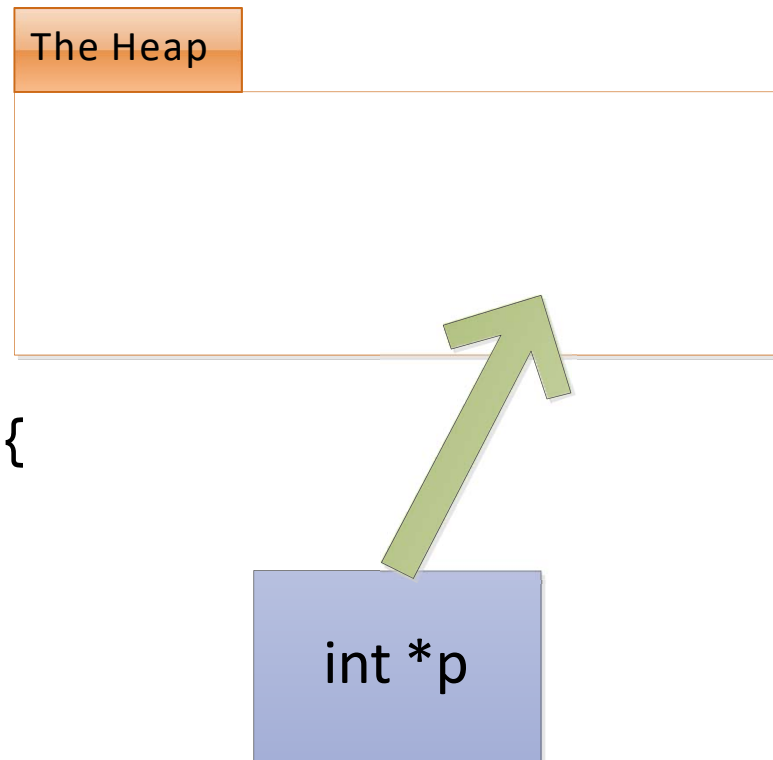


# Delete Memory When Done Using It

- To fix the memory leak, de-allocate memory within the loop

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *p;  
    for (int i = 0; i < 3; ++i) {  
        p = getPtrToFive();  
        printf("%d\n", *p);  
        delete p; ← 3rd iteration  
    }  
}
```



# Outline

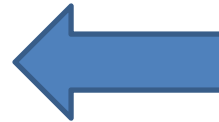
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- Memory Types
- Back to C++: The **new** operator
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- **Segmentation faults**
- Dynamically sized arrays
- New & delete with classes

# Don't Use Memory After Deletion

incorrect

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}
```

```
int main() {  
    int *x = getPtrToFive();  
    delete x;  
    printf("%d\n", *x); // ???  
}
```



# Don't Use Memory After Deletion

incorrect

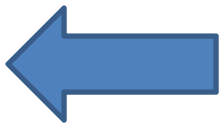
```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}  
  
int main() {  
    int *x = getPtrToFive();  
    delete x;  
    printf("%d\n", *x); // ???  
}
```

correct

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}  
  
int main() {  
    int *x = getPtrToFive();  
    printf("%d\n", *x); // 5  
    delete x;  
}
```

# Don't delete memory twice

incorrect

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}  
  
int main() {  
    int *x = getPtrToFive();  
    printf("%d\n", *x); // 5  
    delete x;  
    delete x;   
}
```

# Don't delete memory twice

incorrect

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}  
  
int main() {  
    int *x = getPtrToFive();  
    printf("%d\n", *x); // 5  
    delete x;  
    delete x;  
}
```


correct

```
int *getPtrToFive() {  
    int *x = new int;  
    *x = 5;  
    return x;  
}  
  
int main() {  
    int *x = getPtrToFive();  
    printf("%d\n", *x); // 5  
    delete x;  
}
```

# Only delete if memory was allocated by new

incorrect

```
int main() {  
    int x = 5;  
    int *xPtr = &x;  
    printf("%d\n", *xPtr);  
    delete xPtr;  
}
```





# Only delete if memory was allocated by new

incorrect

```
int main() {  
    int x = 5;  
    int *xPtr = &x;  
    printf("%d\n", *xPtr);  
    delete xPtr;  
}
```

correct

```
int main() {  
    int x = 5;  
    int *xPtr = &x;  
    printf("%d\n", *xPtr);  
}
```

# Outline

- Constructors
- Scoping and Memory
- Memory Types
- Back to C++: The **new** operator
- Memory leaks: The **delete** operator
- Segmentation faults
- Dynamically sized arrays
- New & delete with classes

# Allocating Arrays

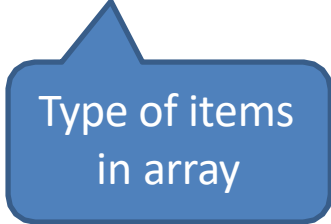
- When allocating arrays on the stack (using “int arr[SIZE]”), size must be a constant  
(Note: C99 standard may allow this, to have C++ standard imposed strictly, use compiler option **-pedantic!**)

```
int numItems;  
printf("how many items?\n");  
scanf("%d", &numItems);  
int arr[numItems]; // not allowed
```

# Allocating Arrays

- If we use **new[]** to allocate arrays, they can have variable size

```
int numItems;  
printf("how many items?\n");  
scanf("%d", &numItems);  
int *arr = new int[numItems];
```




Type of items  
in array

# Allocating Arrays

- If we use **new[]** to allocate arrays, they can have variable size

```
int numItems;  
printf("how many items?\n");  
scanf("%d", &numItems);  
int *arr = new int[numItems];
```



Number of items  
to allocate

# Allocating Arrays

- If we use **new[]** to allocate arrays, they can have variable size
- De-allocate arrays with **delete[]**

```
int numItems;  
printf("how many items?\n");  
scanf("%d", &numItems);  
int *arr = new int[numItems];  
delete[] arr;
```

# Ex: Storing values input by the user

```
int main() {  
    int numItems;  
    printf("how many items?\n");  
    scanf("%d", &numItems);  
    int *arr = new int[numItems];  
    for (int i = 0; i < numItems; ++i) {  
        printf("enter item %d: ", i);  
        scanf("%d", &arr[i]);  
    }  
    for (int i = 0; i < numItems; ++i) {  
        printf("%d\n", arr[i]);  
    }  
    delete[] arr;  
}
```

how many items? 3  
enter item 0: 7  
enter item 1: 4  
enter item 2: 9  
7  
4  
9

# Outline

- Constructors
- Scoping and Memory
- Memory Types
- Back to C++: The **new** operator
- Memory leaks: The **delete** operator
- Segmentation faults
- Dynamically sized arrays
- **New & delete with classes**



# Allocating Class Instances using new

- **new** can also be used to allocate a class instance

```
class Point {  
public:  
    int m_x, m_y;  
};
```

```
int main() {  
    Point *p = new Point;  
    delete p;  
}
```

# Allocating Class Instances using new

- **new** can also be used to allocate a class instance
- The appropriate constructor will be invoked

```
class Point {  
public:  
    int m_x, m_y;  
    Point() {  
        m_x = 0; m_y = 0; printf("default constructor\n");  
    }  
};
```

```
int main() {  
    Point *p = new Point;  
    delete p;  
}
```

**Output:**  
default constructor

# Allocating Class Instances using new

- **new** can also be used to allocate a class instance
- The appropriate constructor will be invoked

```
class Point {  
public:  
    int m_x, m_y;  
    Point( int nx, int ny) {  
        m_x=nx; m_y= ny; printf("2-arg constructor\n");  
    }  
};
```

```
int main() {  
    Point *p = new Point(2, 4);  
    delete p;  
}
```

**Output:**  
2-arg constructor

# Destructor

- Destructor is called when the class instance gets de-allocated

```
class Point {  
public:  
    int m_x, m_y;  
    Point() {  
        printf("constructor invoked\n");  
    }  
    ~Point() {  
        printf("destructor invoked\n");  
    }  
}
```

- Destructor is called when the class instance gets de-allocated
  - If allocated with **new**, when **delete** is called

```
class Point {  
public:  
    int m_x, m_y;  
    Point() {  
        printf("constructor invoked\n");  
    }  
    ~Point() {  
        printf("destructor invoked\n");  
    }  
};  
int main() {  
    Point *p = new Point;  
    delete p;  
}
```

**Output:**

constructor invoked  
destructor invoked

- Destructor is called when the class instance gets de-allocated
  - If allocated with **new**, when **delete** is called
  - If stack-allocated, when it goes out of scope

```
class Point {  
public:  
    int m_x, m_y;  
    Point() {  
        printf("constructor invoked\n");  
    }  
    ~Point() {  
        printf("destructor invoked\n");  
    }  
};  
int main() {  
    if (true) {  
        Point p;  
    }  
    printf("p out of scope\n");  
}
```

**Output:**

constructor invoked  
destructor invoked  
p out of scope

**Example:**  
**Representing an**  
**Array of Integers**

- When representing an array, often pass around both the pointer to the first element and the number of elements
  - Let's make them fields in a class


```
class IntegerArray {  
public:  
    int *m_data;  
    int m_size;  
};
```



Pointer to the first element



- When representing an array, often pass around both the pointer to the first element and the number of elements
  - Let's make them fields in a class

```
class IntegerArray {  
public:  
    int *m_data;  
    int m_size;   
};
```

```
class IntegerArray {
public:
    int *m_data;
    int m_size;
};

int main() {
    IntegerArray arr;
    arr.m_size = 2;
    arr.m_data = new int[arr.size];
    arr.m_data[0] = 4; arr.m_data[1] = 5;
    delete[] a.m_data;
}
```

```
class IntegerArray {  
public:  
    int *m_data;  
    int m_size;  
};
```

```
int main() {  
    IntegerArray arr;  
    arr.m_size = 2;  
    arr.m_data = new int[arr.m_size];  
    arr.m_data[0] = 4; arr.m_data[1] = 5;  
    delete[] a.m_data;  
}
```



Can move this into a constructor

```
class IntegerArray {
public:
    int *m_data;
    int m_size;
    IntegerArray(int size) {
        m_data = new int[size];
        m_size = size;
    }
};

int main() {
    IntegerArray arr(2);
    arr.m_data[0] = 4; arr.m_data[1] = 5;
    delete[] arr.m_data;
}
```

```
class IntegerArray {  
public:  
    int *m_data;  
    int m_size;  
    IntegerArray(int size) {  
        m_data = new int[size];  
        m_size = size;  
    }  
};
```


```
int main() {  
    IntegerArray arr(2);  
    arr.m_data[0] = 4; arr.m_data[1] = 5;  
    delete[] arr.m_data;  
}
```



Can move this into a destructor

```
class IntegerArray {
public:
    int *m_data;
    int m_size;
    IntegerArray(int size) {
        m_data = new int[size];
        m_size = size;
    }
    ~IntegerArray () {
        delete[] m_data
    }
};

int main() {
    IntegerArray arr(2);
    arr.m_data[0] = 4; arr.m_data[1] = 5;
}
```



De-allocate memory used by fields in destructor

incorrect

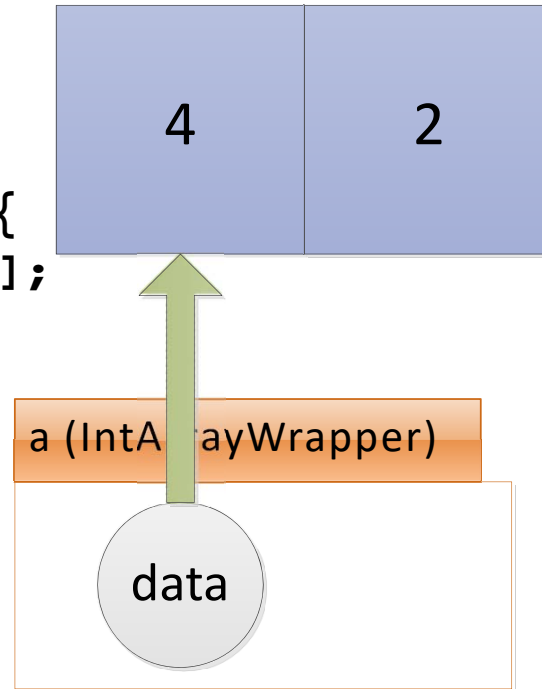
```
class IntegerArray {
public:
    int *m_data;
    int m_size;
    IntegerArray(int size) {
        m_data = new int[size];
        m_size = size;
    }
    ~IntegerArray() {
        delete[] m_data;
    }
};

int main() {
    IntegerArray a(2);
    a.m_data[0] = 4; a.m_data[1] = 2;
    if (true) {
        IntegerArray b = a;
    }
    printf("%d\n", a.m_data[0]); // not 4!
}
```

```

class IntegerArray {
public:
    int *m_data;
    int m_size;
    IntegerArray(int size) {
        m_data = new int[size];
        m_size = size;
    }
    ~IntegerArray() {
        delete[] m_data;
    }
};

```



```

int main() {
    IntegerArray a(2);
    a.m_data[0] = 4; a.m_data[1] = 2;
    if (true) {
        IntegerArray b = a;
    }
    printf("%d\n", a.m_data[0]); // not 4!
}

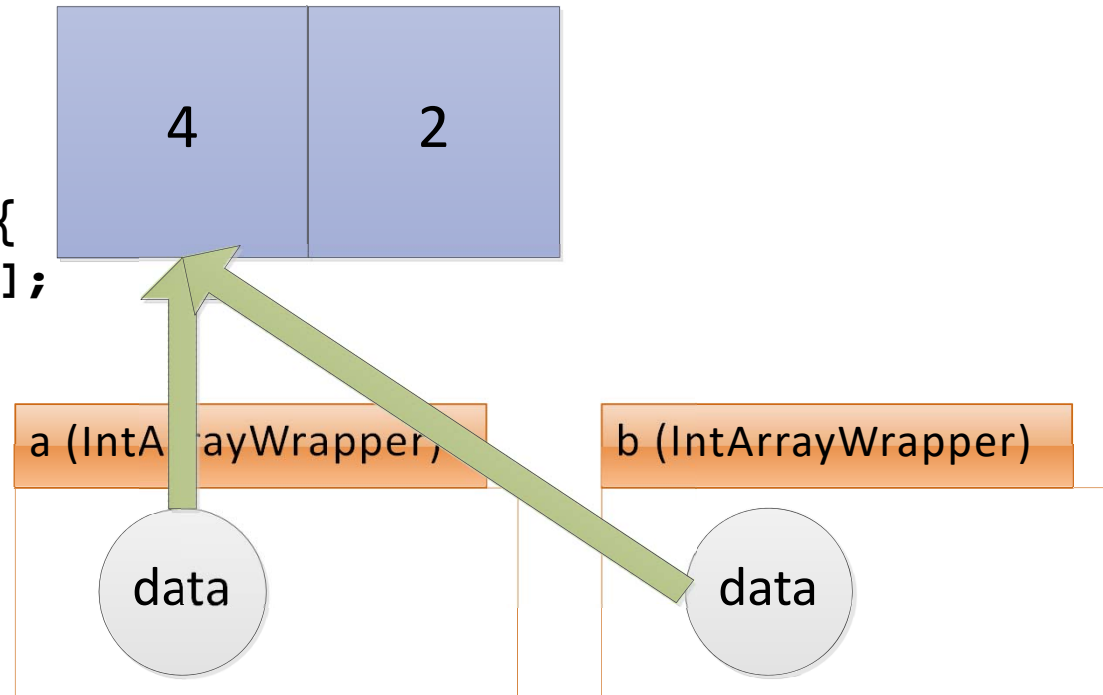
```





- Default copy constructor copies fields

```
class IntegerArray {  
public:  
    int *m_data;  
    int m_size;  
    IntegerArray(int size) {  
        m_data = new int[size];  
        m_size = size;  
    }  
    ~IntegerArray() {  
        delete[] m_data;  
    }  
};
```



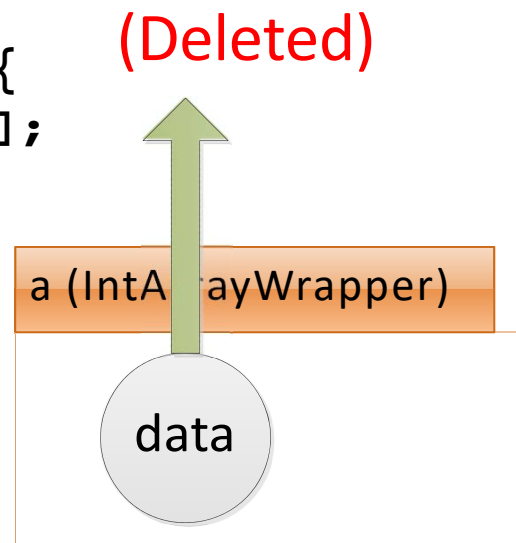
```
int main() {  
    IntegerArray a(2);  
    a.m_data[0] = 4; a.m_data[1] = 2;  
    if (true) {  
        IntegerArray b = a;  
    }  
    printf("%d\n", a.m_data[0]); // not 4!  
}
```



This call uses the default copy constructor, which simply copies all fields of the object

- When b goes out of scope, destructor is called (deallocates array), a.data now a dangling pointer

```
class IntegerArray {  
public:  
    int *m_data;  
    int m_size;  
    IntegerArray(int size) {  
        m_data = new int[size];  
        m_size = size;  
    }  
    ~IntegerArray() {  
        delete[] m_data;  
    }  
};
```

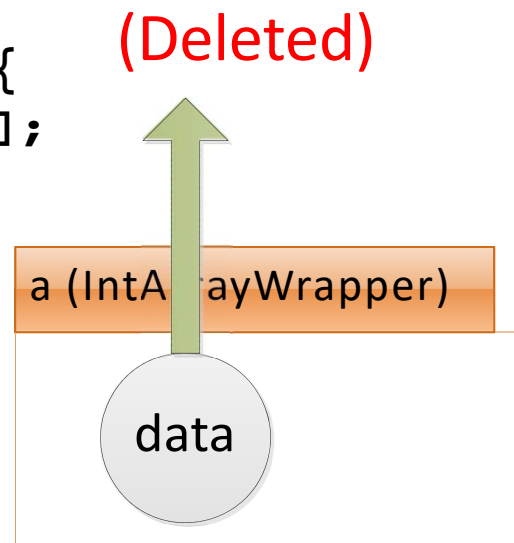


```
int main() {  
    IntegerArray a(2);  
    a.m_data[0] = 4; a.m_data[1] = 2;  
    if (true) {  
        IntegerArray b = a;  
    }  
    printf("%d\n", a.m_data[0]); // not 4!  
}
```

here

- 2<sup>nd</sup> bug: when a goes out of scope, its destructor tries to delete the (already-deleted) array

```
class IntegerArray {  
public:  
    int *m_data;  
    int m_size;  
    IntegerArray(int size) {  
        m_data = new int[size];  
        m_size = size;  
    }  
    ~IntegerArray() {  
        delete[] m_data;  
    }  
};
```



```
int main() {  
    IntegerArray a(2);  
    a.m_data[0] = 4; a.m_data[1] = 2;  
    if (true) {  
        IntegerArray b = a;  
    }  
    printf("%d\n", a.m_data[0]); // not 4!  
}
```

Program crashes as it terminates

- Write your own copy constructor to fix these bugs

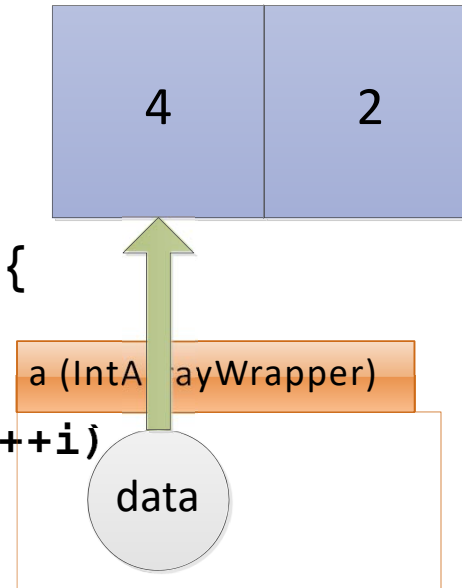
```
class IntegerArray {
public:
    int *m_data;
    int m_size;
    IntegerArray(int size) {
        m_data = new int[size];
        m_size = size;
    }
    IntegerArray(IntegerArray &o) {
        m_data = new int[o.m_size];
        m_size = o.m_size;
        for (int i = 0; i < m_size; ++i)
            m_data[i] = o.m_data[i];
    }
    ~IntegerArray() {
        delete[] m_data;
    }
};
```

```

class IntegerArray {
public:
    int *m_data; int m_size;
    IntegerArray(int size) {
        m_data = new int[size];
        m_size = size;
    }
    IntegerArray(IntegerArray &o) {
        m_data = new int[o.m_size];
        m_size = o.m_size;
        for (int i = 0; i < m_size; ++i)
            m_data[i] = o.m_data[i];
    }
    ~IntegerArray() {
        delete[] m_data;
    }
};

int main() {
    IntegerArray a(2);
    a.m_data[0] = 4; a.m_data[1] = 2;
    if (true) {
        IntegerArray b = a;
    }
    printf("%d\n", a.m_data[0]); // 4
}

```

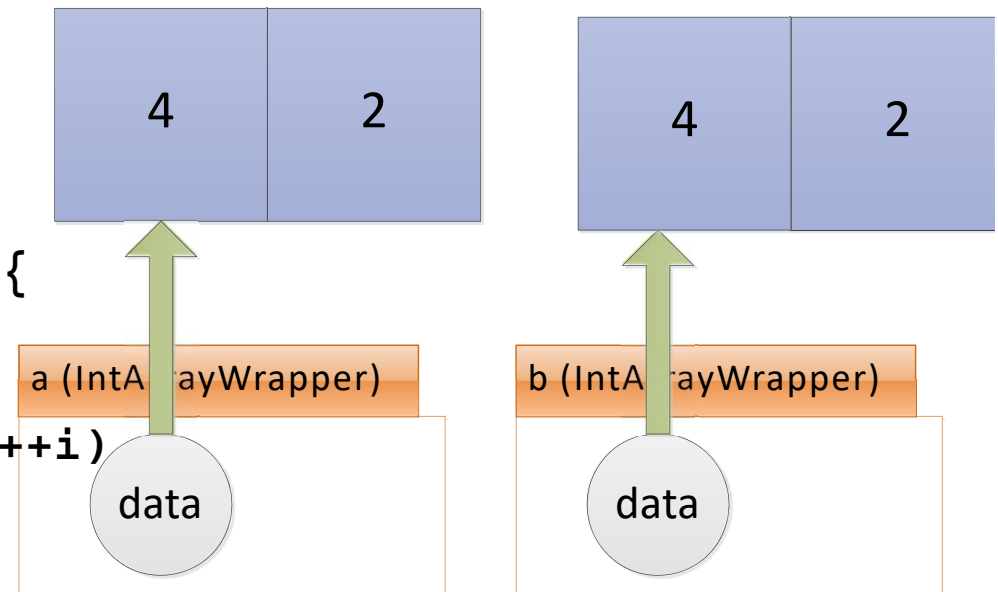


```

class IntegerArray {
public:
    int *m_data; int m_size;
    IntegerArray(int size) {
        m_data = new int[size];
        m_size = size;
    }
    IntegerArray(IntegerArray &o) {
        m_data = new int[o.m_size];
        m_size = o.m_size;
        for (int i = 0; i < m_size; ++i)
            m_data[i] = o.m_data[i];
    }
    ~IntegerArray() {
        delete[] m_data;
    }
};

int main() {
    IntegerArray a(2);
    a.m_data[0] = 4; a.m_data[1] = 2;
    if (true) {
        IntegerArray b = a;
    }
    printf("%d\n", a.m_data[0]); // 4
}

```



```

class IntegerArray {
public:
    int *m_data; int m_size;
    IntegerArray(int size) {
        m_data = new int[size];
        m_size = size;
    }
    IntegerArray(IntegerArray &o) {
        m_data = new int[o.m_size];
        m_size = o.m_size;
        for (int i = 0; i < m_size; ++i)
            m_data[i] = o.m_data[i];
    }
    ~IntegerArray() {
        delete[] m_data;
    }
};

int main() {
    IntegerArray a(2);
    a.m_data[0] = 4; a.m_data[1] = 2;
    if (true) {
        IntegerArray b = a;
    }
    printf("%d\n", a.m_data[0]); // 4
}

```

