内存管理

Memory management

Review: Constructors

- Method that is called when an instance is created

```
class Integer {
public:
    int val;
    Integer() {
      val = 0; cout << "default constructor" << endl;
    }
};
int main() {
    Integer i;
}
```

Output:
default constructor

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

```
class Integer {
public:
    int val;
    Integer() {
      val = 0; cout << "default constructor" << endl;
    }
};
int main() {
    Integer arr[3];
}
```

Output:

default constructor
default constructor
default constructor

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

```
class Integer {
public:
   int val;
   Integer() {
       val = 0; cout << "Integer default constructor" << endl;
   }
};
class IntegerWrapper {
public:
   Integer val;
   IntegerWrapper() {
        cout << "IntegerWrapper default constructor" << endl;
   }
};
int main() {
    IntegerWrapper q;
}
```

Output:

```
Integer default constructor
IntegerWrapper default constructor
```

- Constructors can accept parameters

```
class Integer {
public:
  int val;
  Integer(int v) {
    val = v; cout << "constructor with arg " << v << endl;
}
};
int main() {
    Integer i(3);
}
```

Output:
constructor with arg 3

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

```
class Integer {
public:
  int val;
  Integer(int v) {
    val = v; cout << "constructor with arg " << v << endl;
}
};
int main() {
    Integer i(3);
    Integer j = 5;
}
```

Output:

constructor with arg 3

constructor with arg 5

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

```
class Integer {
public:
  int val;
  Integer(int v) {
    val = v; cout << "constructor with arg " << v << endl;
}
};
int main() {
    Integer i(3);  //OK
    Integer j;
}
```

Error: No default constructor available for Integer

- 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 val;
  Integer(int v) {
    val = v; cout << "constructor with arg " << v << endl;
}
};
int main() {
    Integer i(3);  //OK
    Integer b[2];
}
```

Error: No default constructor available for Integer

- 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 val;
  Integer() {
     val = 0;
  }
  Integer(int v) {
     val = v;
  }
};
int main() {
   Integer i; // ok
   Integer j(3); // ok
}
```

- 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 val;
  Integer( int  v = 0) {
     val = v;
  }
};
int main() {
   Integer i; // ok
   Integer j(3); // ok
}
```

- 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;
    }
};
```

- 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;
    }
};
```

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() {
    int *p;
    if (true) {
        int x = 5;
        p = &x;
    }
    cout << *p << endl; // ???
}
```

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;
    }
    cout << *p << endl; // ???
}
```

int x

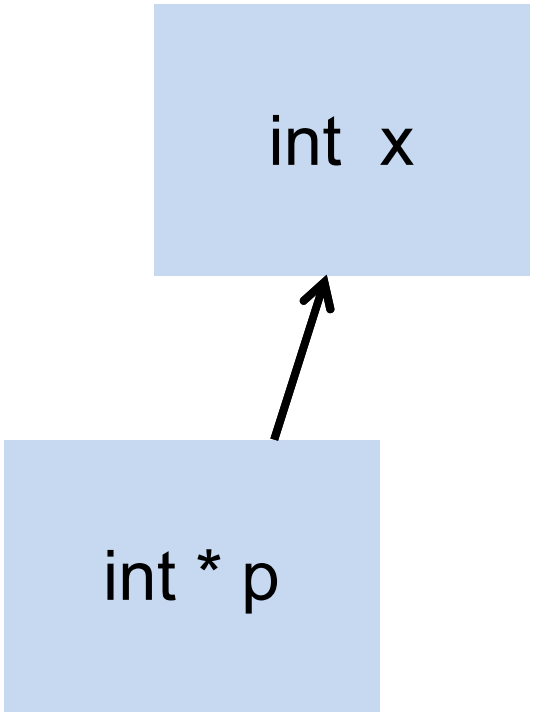
int * p

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;
    }
    cout << *p << endl; // ???
}
```

Here

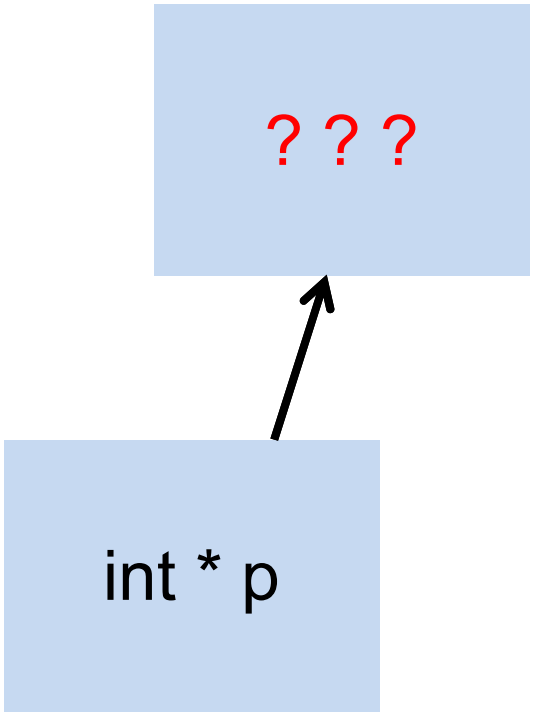


Scoping and Memory

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

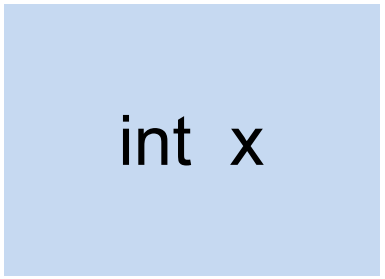
```
int main() {
    int *p;
    if (true) {
        int x = 5;
        p = &x;
    }
    cout << *p << endl; // ???
}
```

Here



- 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();
  cout << *p << endl; // ???
}
```



- 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() {
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}
int main() {
  int *p = getPtrToFive();
  cout << *p << endl; // ???
}
```
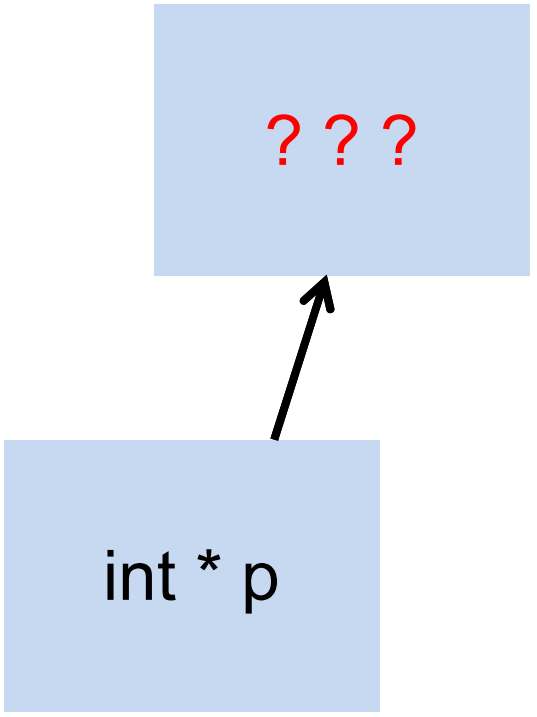



The **new** operator

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

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

Type parameter needed to determine how much memory to allocate

The **new** operator

- Returns a pointer to the newly allocated memory
- the memory will remain allocated until you manually de-allocate it
- Terminology note:
  - –If using **int x**; the allocation occurs on a region of memory called **the stack**
  - –If using **new int**; the allocation occurs on a region of memory called **the heap**

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

Type parameter needed to determine how much memory to allocate

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;
```

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

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

- Implement a function which returns a pointer to some memory containing the integer 5
  - –Allocate memory 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();
    cout << *p << endl;  // 5
    delete p;
}
```

Delete Memory When Done Using It

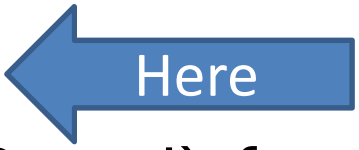
- If you don't use de-allocate memory using **delete, your application will waste memory**

```
int *getPtrToFive() {
    int *x = new int ;
    *x = 5;
    return x;
}
int main() {
   int *p
   for ( int i = 0; i < 3; ++i) {
       p = getPtrToFive();
       cout << *p << endl;
   }
}
```

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();
       cout << *p << endl;
   }
}
```



int * p

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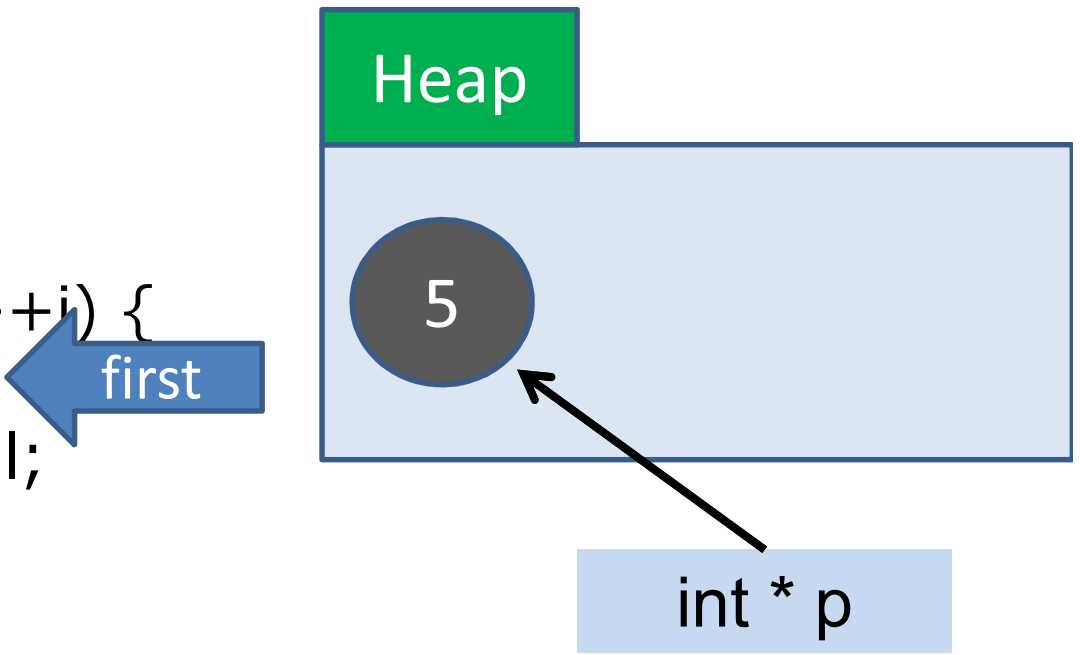
    return x;
}
int main() {
   int *p
   for ( int i = 0; i < 3; ++i) {
       p = getPtrToFive();
       cout << *p << endl;
   }
}
```



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    return x;
}
int main() {
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       cout << *p << endl;
   }
}
```

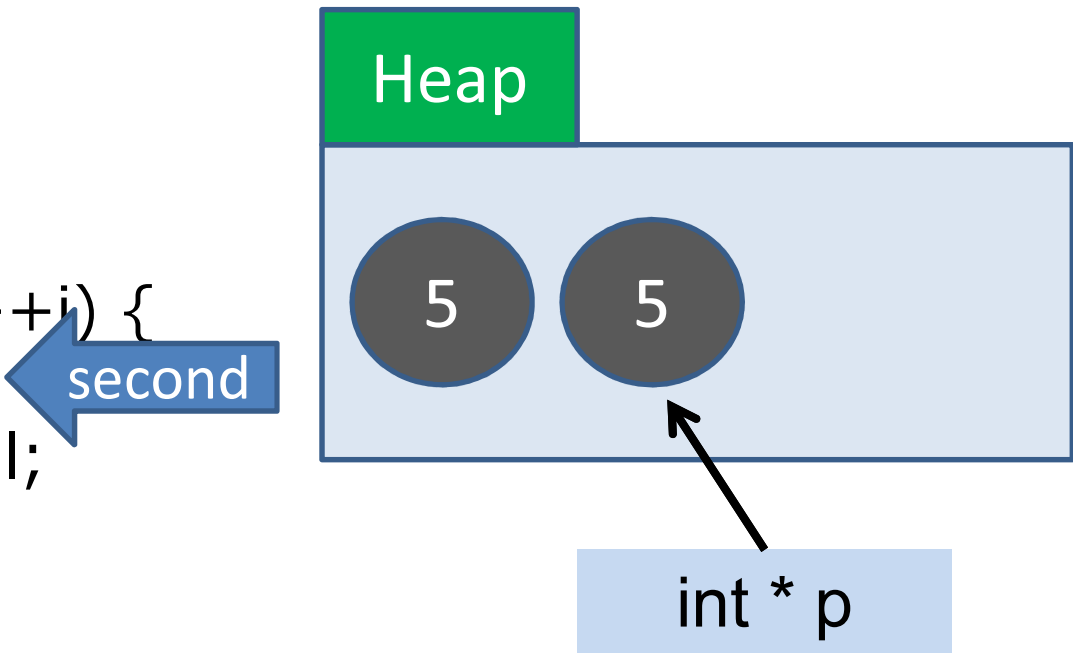

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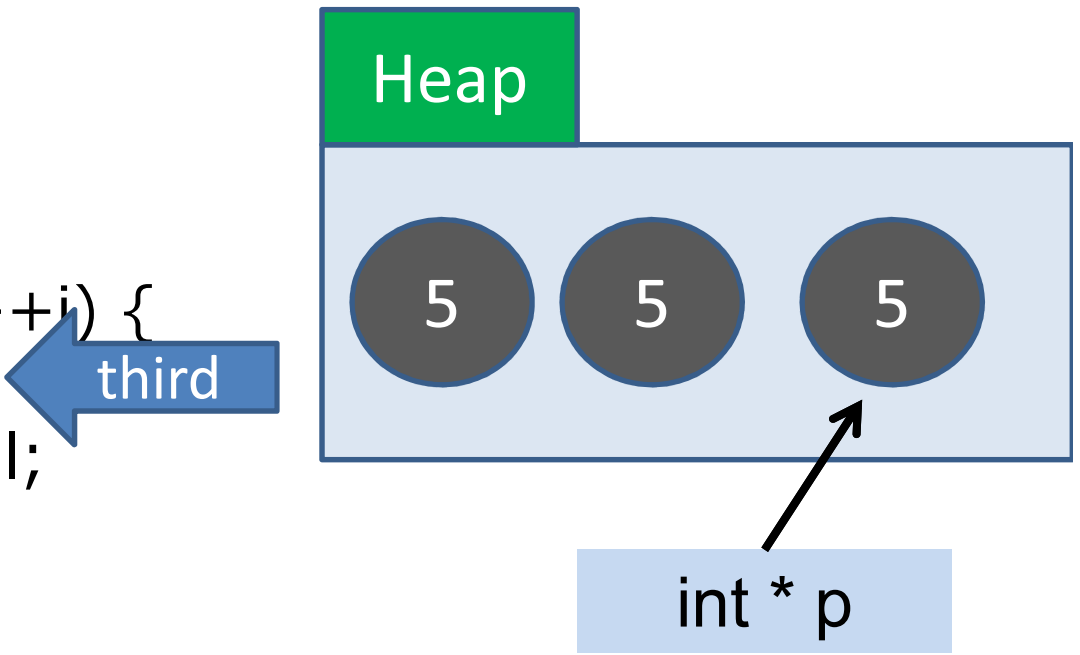
   }
}
```



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   }
   delete p;
}
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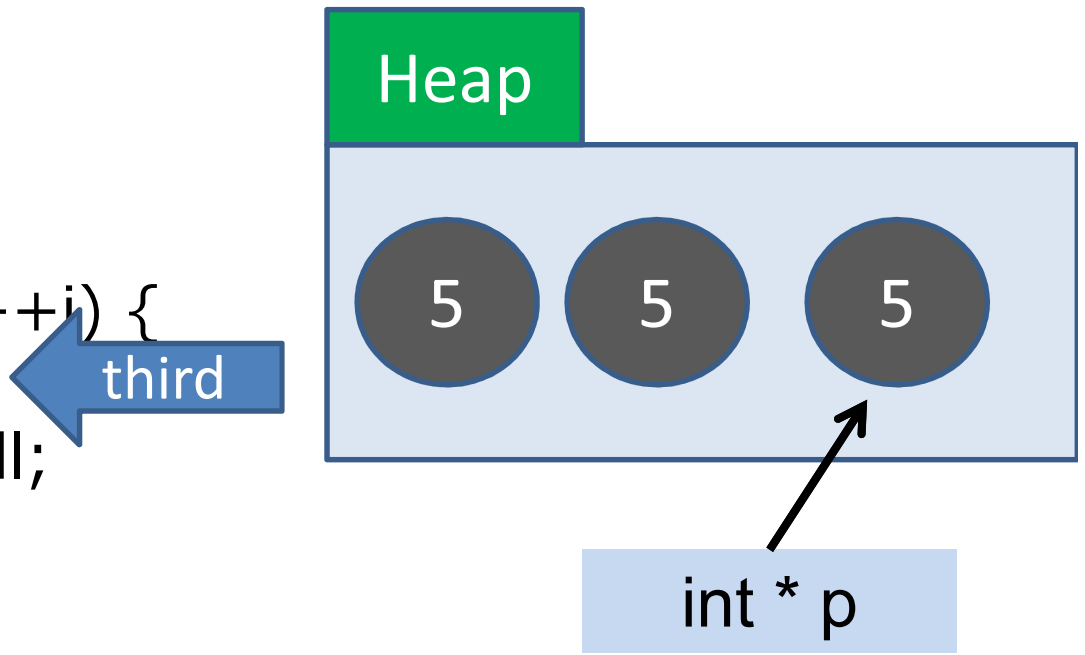

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       cout << *p << endl;
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   delete p;
}
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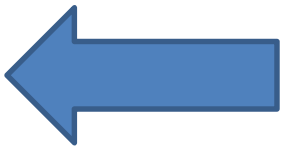

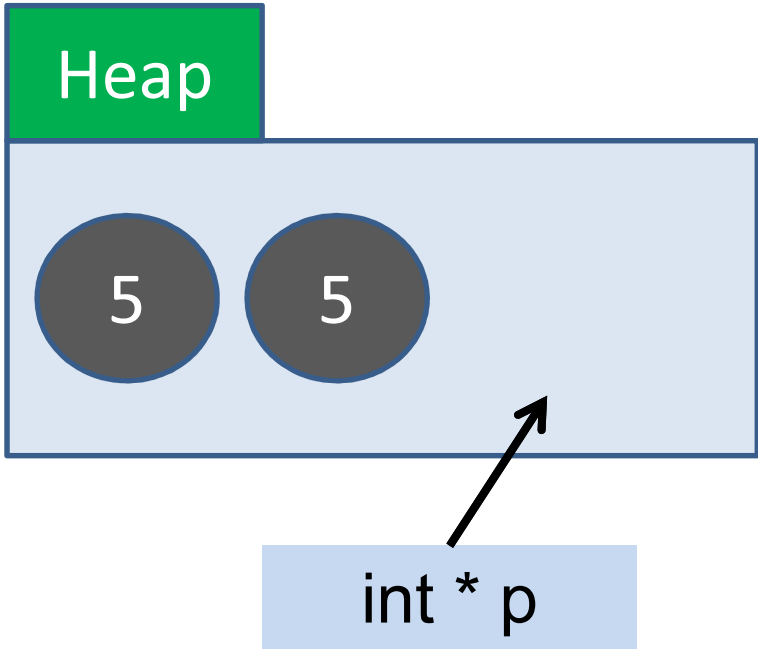

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   }
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```

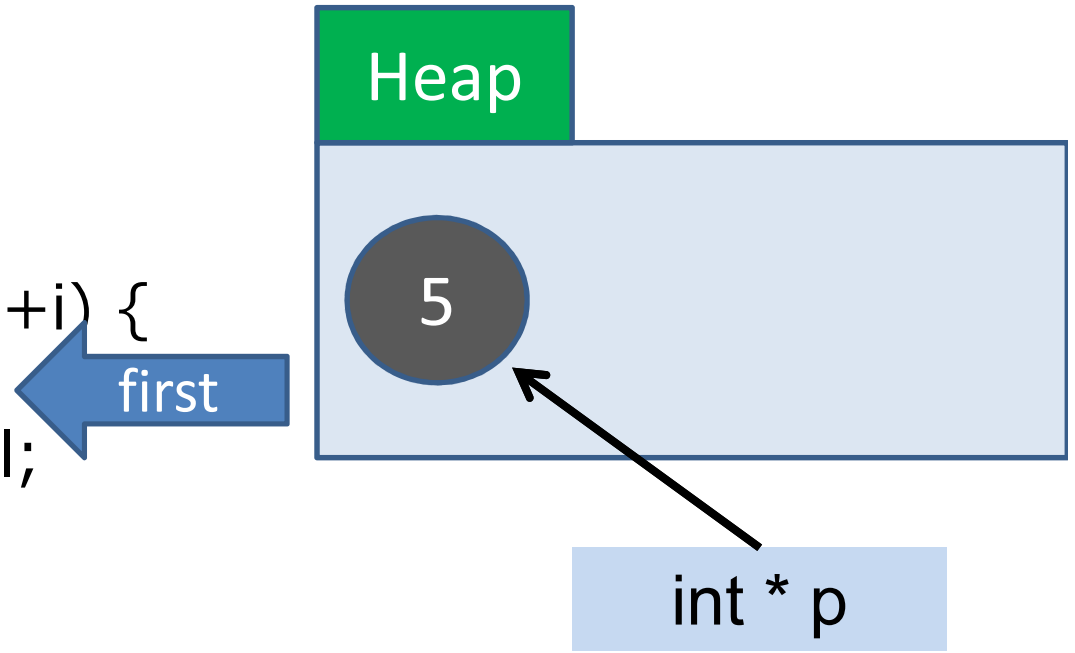

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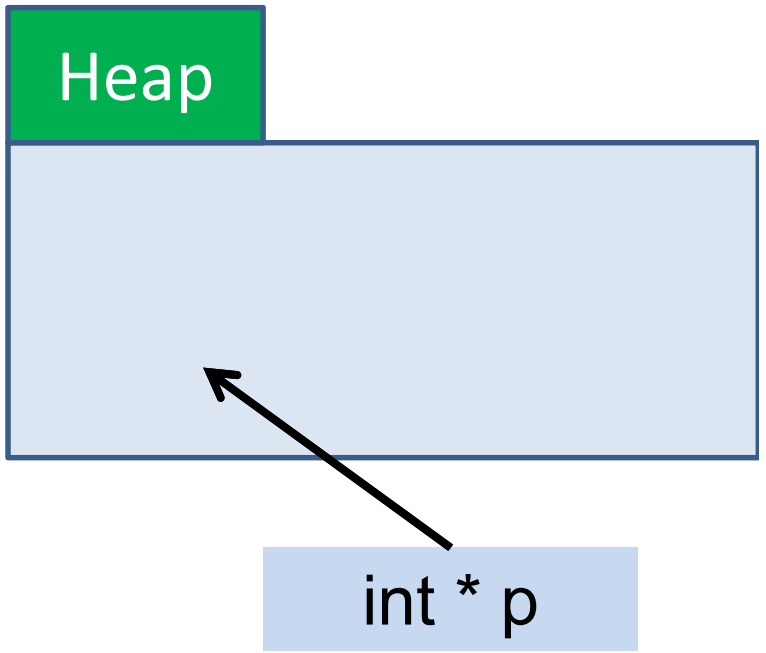
    *x = 5;
    return x;
}
int main() {
   int *p
   for ( int i = 0; i < 3; ++i) {
       p = getPtrToFive();
       cout << *p << endl;
       delete p;
   }
}
```



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    *x = 5;
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}
int main() {
   int *p
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       p = getPtrToFive();
       cout << *p << endl;
       delete p;
   }
}
```

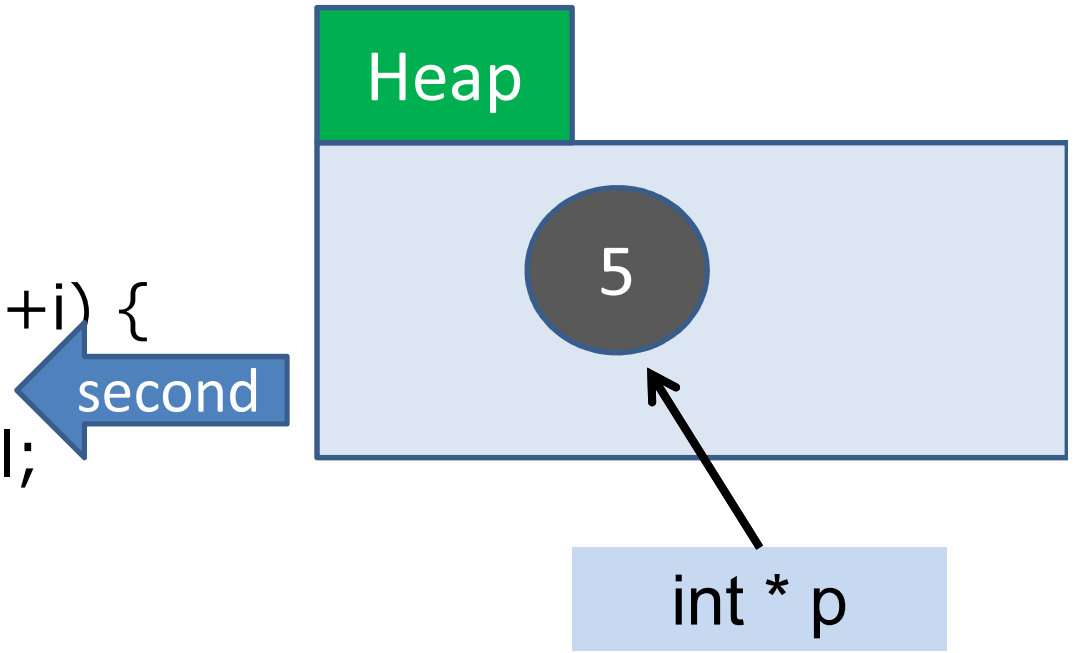

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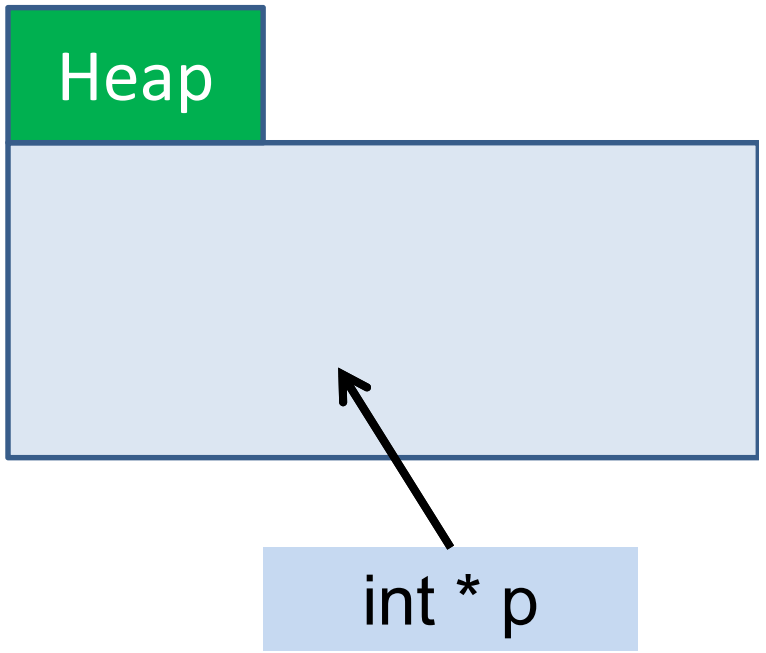
       p = getPtrToFive();
       cout << *p << endl;
       delete p;
   }
}
```



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int main() {
   int *p
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       p = getPtrToFive();
       cout << *p << endl;
       delete p;
   }
}
```

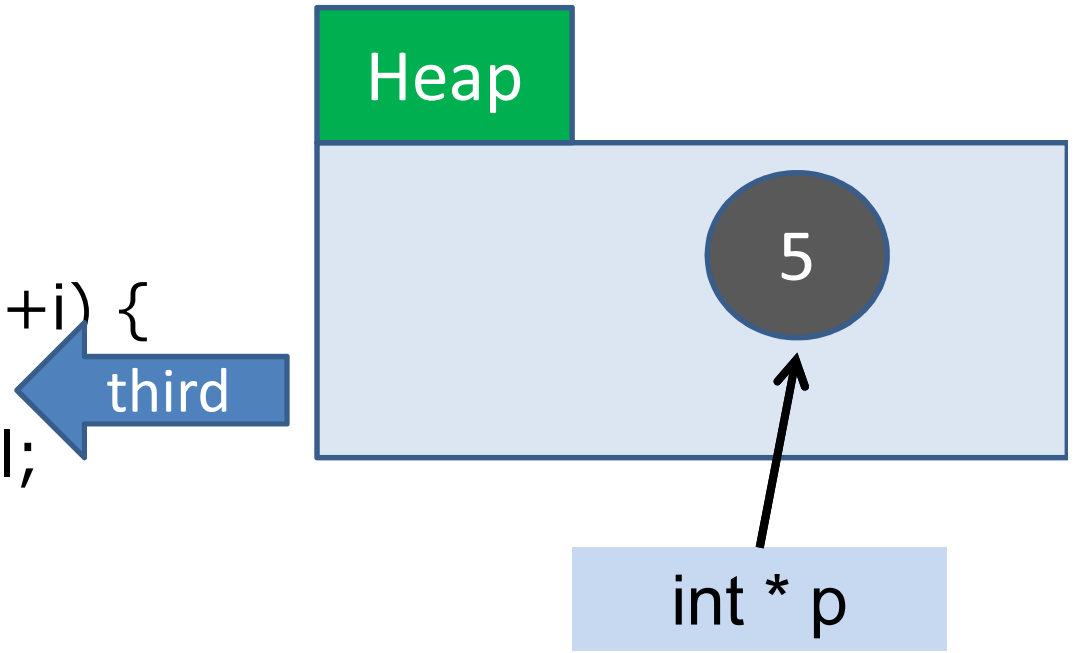

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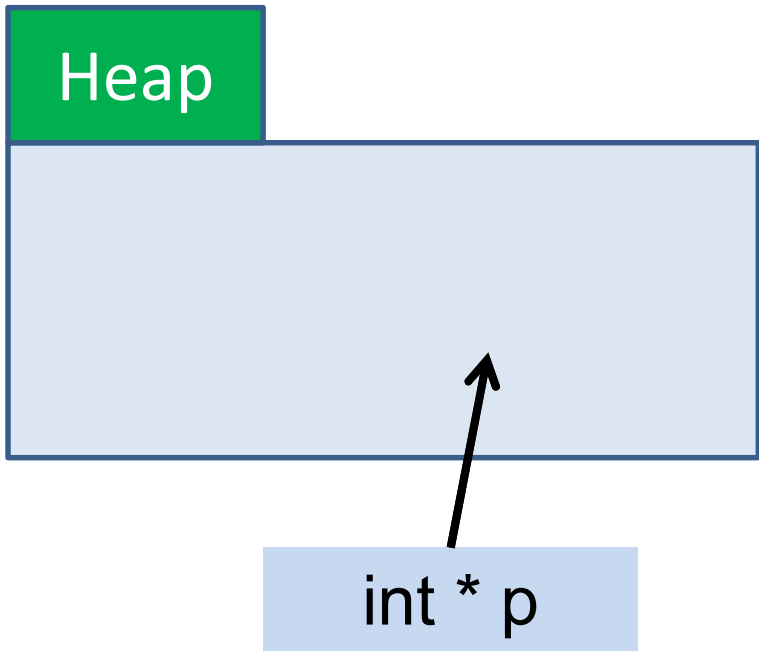
```
int *getPtrToFive() {
    int *x = new int ;
    *x = 5;
    return x;
}
int main() {
   int *p
   for ( int i = 0; i < 3; ++i) {
       p = getPtrToFive();
       cout << *p << endl;
       delete p;
   }
}
```



Don’t Use Memory After Deletion


```
int *getPtrToFive() {
    int *x = new int ;
    *x = 5;
    return x;
}
int main() {
    int *p = getPtrToFive();
    delete p;
    cout << *p << endl;  // ???
}
```

Don’t Use Memory After Deletion

Incorrect

```
int *getPtrToFive() {
    int *x = new int ;
    *x = 5;
    return x;
}
int main() {
    int *p = getPtrToFive();
    delete p;
    cout << *p << endl;  // ???
}
```

correct

```
int *getPtrToFive() {
    int *x = new int ;
    *x = 5;
    return x;
}
int main() {
    int *p = getPtrToFive();
    cout << *p << endl;
    delete p;
}
```

Don’t delete memory twice

Incorrect

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

Don’t delete memory twice

Incorrect

```
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}
int main() {
    int *p = getPtrToFive();
    cout << *p << endl;
    delete p;
    delete p;
}
```

correct

```
int *getPtrToFive() {
    int *x = new int ;
    *x = 5;
    return x;
}
int main() {
    int *p = getPtrToFive();
    cout << *p << endl;
    delete p;
}
```

Only **delete** if memory was allocated by **new**


```
int *getPtrToFive() {
    int x = 5;
    int *xPtr = &x;
    cout << *xPtr << endl;
    delete xPtr;
}
```

Only **delete** if memory was allocated by **new**

Incorrect

```
int *getPtrToFive() {
    int x = 5;
    int *xPtr = &x;
    cout << *xPtr << endl;
    delete xPtr;
}
```

Incorrect

```
int *getPtrToFive() {
    int x = 5;
    int *xPtr = &x;
    cout << *xPtr << endl;

}
```

Allocating Arrays

- When allocating arrays on the stack (using “int arr[SIZE]”), size must be a constant

```
int numItems;
cout << "how many items?";
cin >> numItems;
int arr[numItems]; // not allowed
```

Allocating Arrays

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

```
int numItems;
cout << "how many items?";
cin >> 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;
cout << "how many items?";
cin >> 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;
cout << "how many items?";
cin >> numItems;
int *arr = new int[numItems];
delete[] arr;
```

Ex: Storing values input by the user

```
int main() {
  int numItems;
  cout << "how many items? ";
  cin >> numItems;
  int *arr = new int[numItems];
  for (int i = 0; i < numItems; ++i) {
    cout << "enter item " << i << ": ";
    cin >> arr[i];
  }
  for (int i = 0; i < numItems; ++i) {
    cout << arr[i] << endl;
  }
  delete[] arr;
}
```

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

Allocating Class Instances using **new**

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

```
class Point {
public:
  int x, 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 x, y;
  Point() {
    x = 0; y = 0; cout << "default constructor" << endl;
  }
};

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 x, y;
  Point(int nx, int ny) {
    x = ny; x = ny; cout << "2-arg constructor" << endl;
  }
};

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 x, y;
  Point() {
    cout << "constructor invoked" << endl;
  }
  ~Point() {
    cout << "destructor invoked" << endl;
  }
}
```

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

```
class Point {
public:
  int x, y;
  Point() {
    cout << "constructor invoked" << endl;
  }
  ~Point() {
    cout << "destructor invoked" << endl;
  }
};
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 x, y;
  Point() {
    cout << "constructor invoked" << endl;
  }
  ~Point() {
    cout << "destructor invoked" << endl;
  }
};
int main() {
  if (true) {
    Point p;
  }
  cout << "p out of scope" << endl;
}
```

Output:
constructor invoked
destructor invoked
p out of scope

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 *data;
  int size;
};
```

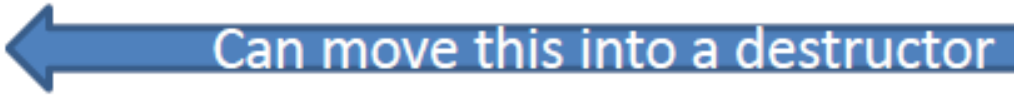
Number of elements in the array

```
class IntegerArray {
public:
  int *data;
  int size;
};

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

```
class IntegerArray {
public:
  int *data;
  int size;
};

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

```
class IntegerArray {
public:
  int *data;
  int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
};

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

```
class IntegerArray {
public:
  int *data;
  int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
};

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

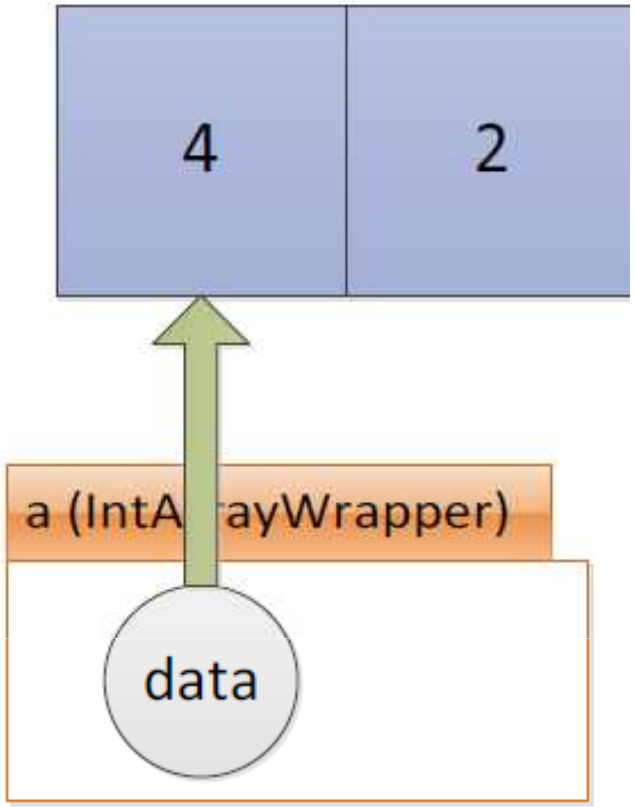


```
class IntegerArray {
public:
  int *data;
  int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  ~IntegerArray () {
    delete[] data;
  }
};

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

De-allocate memory used by fields in destructor


```
class IntegerArray {
public:
  int *data;
  int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  ~IntegerArray() {
    delete[] data;
  }
};

int main() {
  IntegerArray a(2);
  a.data[0] = 4; a.data[1] = 2;
  if (true) {
    IntegerArray b = a;
  }
  cout << a.data[0] << endl; // not 4!
}
```

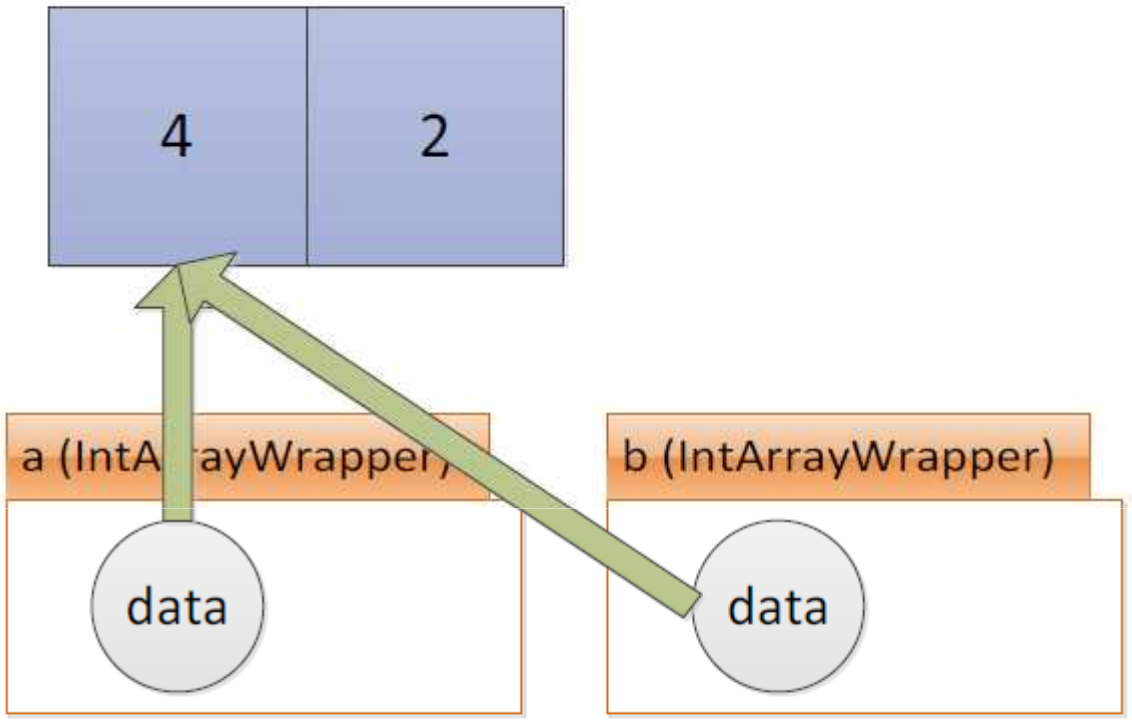
```
class IntegerArray {
public:
  int *data;
  int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  ~IntegerArray() {
    delete[] data;
  }
};

int main() {
  IntegerArray a(2);
  a.data[0] = 4; a.data[1] = 2;
  if (true) {
    IntegerArray b = a;
  }
  cout << a.data[0] << endl; // not 4!
}
```



here

- Default copy constructor copies fields

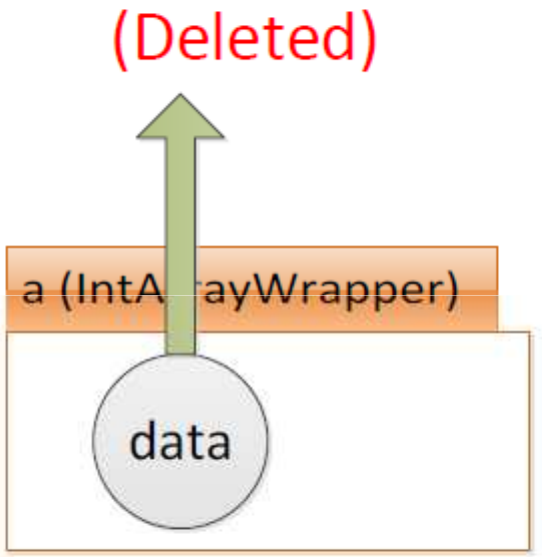
```
class IntegerArray {
public:
  int *data;
  int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  ~IntegerArray() {
    delete[] data;
  }
};

int main() {
  IntegerArray a(2);
  a.data[0] = 4; a.data[1] = 2;
  if (true) {
    IntegerArray b = a;
  }
  cout << a.data[0] << endl; // not 4!
}
```



here

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

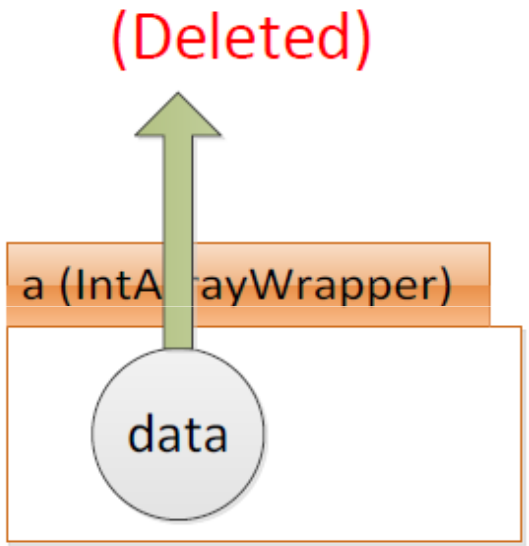
```
class IntegerArray {
public:
  int *data;
  int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  ~IntegerArray() {
    delete[] data;
  }
};

int main() {
  IntegerArray a(2);
  a.data[0] = 4; a.data[1] = 2;
  if (true) {
    IntegerArray b = a;
  }
  cout << a.data[0] << endl; // not 4!
}
```



here

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

```
class IntegerArray {
public:
  int *data;
  int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  ~IntegerArray() {
    delete[] data;
  }
};

int main() {
  IntegerArray a(2);
  a.data[0] = 4; a.data[1] = 2;
  if (true) {
    IntegerArray b = a;
  }
  cout << a.data[0] << endl; // not 4!
}
```

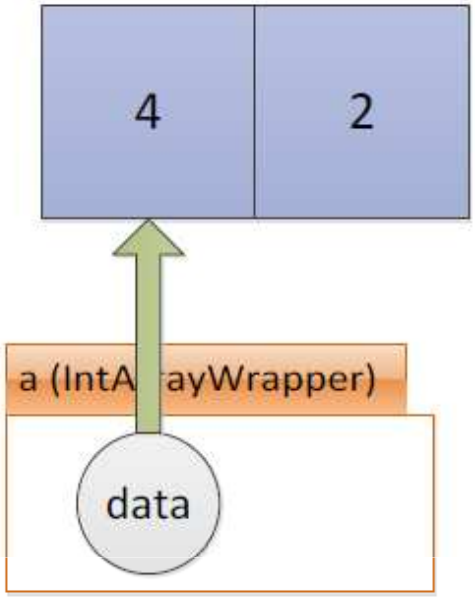


Program crashes as it terminates

- Write your own a copy constructor to fix these bugs

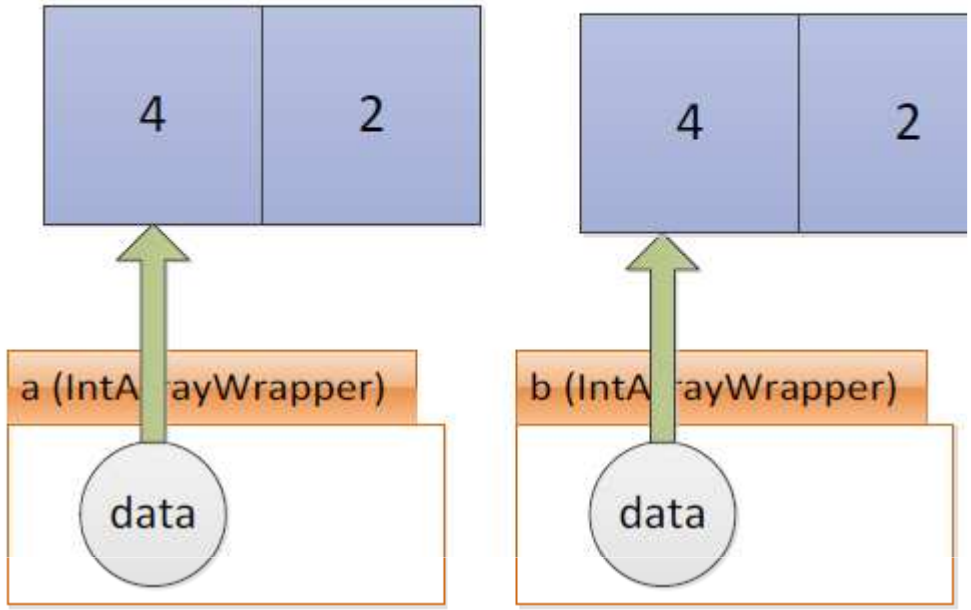
```
class IntegerArray {
public:
  int *data;
  int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  IntegerArray(IntegerArray &o) {
    data = new int[o.size];
    size = o.size;
    for (int i = 0; i < size; ++i)
      data[i] = o.data[i];
  }
  ~IntegerArray()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

```
class IntegerArray {
public:
  int *data; int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  IntegerArray(IntegerArray &o) {
    data = new int[o.size];
    size = o.size;
    for (int i = 0; i < size; ++i)
      data[i] = o.data[i];
  }
  ~IntegerArray() {
    delete[] data;
  }
};
int main() {
  IntegerArray a(2);
  a.data[0] = 4; a.data[1] = 2;
  if (true) {
    IntegerArray b = a;
  }
  cout << a.data[0] << endl; // 4
}
```



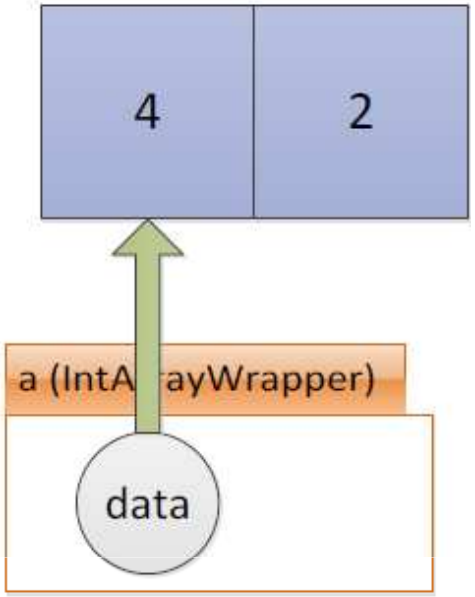
here

```
class IntegerArray {
public:
  int *data; int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  IntegerArray(IntegerArray &o) {
    data = new int[o.size];
    size = o.size;
    for (int i = 0; i < size; ++i)
      data[i] = o.data[i];
  }
  ~IntegerArray() {
    delete[] data;
  }
};
int main() {
  IntegerArray a(2);
  a.data[0] = 4; a.data[1] = 2;
  if (true) {
    IntegerArray b = a;
  }
  cout << a.data[0] << endl; // 4
}
```



Copy constructor invoked

```
class IntegerArray {
public:
  int *data; int size;
  IntegerArray(int size) {
    data = new int[size];
    this->size = size;
  }
  IntegerArray(IntegerArray &o) {
    data = new int[o.size];
    size = o.size;
    for (int i = 0; i < size; ++i)
      data[i] = o.data[i];
  }
  ~IntegerArray() {
    delete[] data;
  }
};
int main() {
  IntegerArray a(2);
  a.data[0] = 4; a.data[1] = 2;
  if (true) {
    IntegerArray b = a;
  }
  cout << a.data[0] << endl; // 4
}
```



here

作业

- 实现上述的IntegerArray 或字符串类String