C++ Constructor Insanity

CSE 333 Winter 2021

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Administrative Request

Please fill out a mid-quarter assessment survey

https://docs.google.com/forms/d/e/1FAIpQLSeW05jSv2UvDFeOtTmlM-h5oRTBn8XWYoahWvXsmJhmjveUWA/viewform

Lecture Outline

- **Constructors / Destructors: The Issues**
- Constructors
- Copy Constructors
- Assignment
- Embedded and Global Objects

Constructors / Desructors Demonstration

- A constructor is **always** run when an object is created
  - Just like in Java
- A destructor is **always** run when an object is destroyed
  - Not at all familiar from Java

- Constructors/destructors are the source of a lot of complexity in C++
- We'll explain why

Example Class

```
class Example
{
public:

 Example(std::string &name)
 {
  my_name = name;
  std::cout << "Created '" << my_name << "'\n";
 }

 Example(Example& other)
 {
  my_name = "copy of " + other.my_name;
  std::cout << "Created '" << my_name << "'\n";
 }

 ~Example()
 {
  std::cout << "Destroying " << my_name << std::endl;
 }

private:
 std::string my_name;
};
```

A Java-like constructor, except broken

The “copy constructor”

The “destructor”

Example Use of Class

```
Example sub(Example arg)
{
  return arg;
}

int main(int argc, char *argv[])
{
  Example local("local");
  Example clone(local);

  Example *pExample = new Example("newed");

  {
    Example local_scope("local_scope");
  }

  Example arg("arg");
  sub(arg);

  delete pExample;

  Example *pNeverDeleted = new Example("never deleted");
  *pNeverDeleted = local;

  return EXIT_SUCCESS;
}
```

Example Use of Class

```
Example sub(Example arg)
{
  return arg;
}

int main(int argc, char *argv[])
{
  Example local("local");
  Example clone(local);

  Example *pExample = new Example("newed");

  {
    Example local_scope("local_scope");
  }

  Example arg("arg");
  sub(arg);

  delete pExample;

  Example *pNeverDeleted = new Example("never deleted");
  *pNeverDeleted = local;

  return EXIT_SUCCESS;
}
```

```
attu6> g++ -std=c++17 -g -Wall example.cc
example.cc: In function ‘int main(int, char**)’:
example.cc:37:17: error: cannot bind non-const lvalue reference of type ‘std::string&’ {aka ‘std::__cxx11::basic_string<char>&’} to an rvalue of type ‘std::string’ {aka ‘std::__cxx11::basic_string<char>’}
   37 |   Example local("local");
      |                 ^~~~~~~
In file included from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/string:55,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/locale_classes.h:40,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/ios_base.h:41,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ios:42,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ostream:38,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/iostream:39,
                 from example.cc:1:
/opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/basic_string.h:525:7: note:   after user-defined conversion: ‘std::__cxx11::basic_string<_CharT, _Traits, _Alloc>::basic_string(const _CharT*, const _Alloc&) [with <template-parameter-2-1> = std::allocator<char>; _CharT = char; _Traits = std::char_traits<char>; _Alloc = std::allocator<char>]’
  525 |       basic_string(const _CharT* __s, const _Alloc& __a = _Alloc())
      |       ^~~~~~~~~~~~
example.cc:9:24: note:   initializing argument 1 of ‘Example::Example(std::string&)’
    9 |   Example(std::string &name)
      |           ~~~~~~~~~~~~~^~~~
example.cc:40:35: error: cannot bind non-const lvalue reference of type ‘std::string&’ {aka ‘std::__cxx11::basic_string<char>&’} to an rvalue of type ‘std::string’ {aka ‘std::__cxx11::basic_string<char>’}
   40 |   Example *pExample = new Example("newed");
      |                                   ^~~~~~~
In file included from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/string:55,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/locale_classes.h:40,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/ios_base.h:41,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ios:42,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ostream:38,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/iostream:39,
                 from example.cc:1:
/opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/basic_string.h:525:7: note:   after user-defined conversion: ‘std::__cxx11::basic_string<_CharT, _Traits, _Alloc>::basic_string(const _CharT*, const _Alloc&) [with <template-parameter-2-1> = std::allocator<char>; _CharT = char; _Traits = std::char_traits<char>; _Alloc = std::allocator<char>]’
  525 |       basic_string(const _CharT* __s, const _Alloc& __a = _Alloc())
      |       ^~~~~~~~~~~~
example.cc:9:24: note:   initializing argument 1 of ‘Example::Example(std::string&)’
    9 |   Example(std::string &name)
      |           ~~~~~~~~~~~~~^~~~
example.cc:43:25: error: cannot bind non-const lvalue reference of type ‘std::string&’ {aka ‘std::__cxx11::basic_string<char>&’} to an rvalue of type ‘std::string’ {aka ‘std::__cxx11::basic_string<char>’}
   43 |     Example local_scope("local_scope");
      |                         ^~~~~~~~~~~~~
In file included from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/string:55,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/locale_classes.h:40,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/ios_base.h:41,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ios:42,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ostream:38,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/iostream:39,
                 from example.cc:1:
/opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/basic_string.h:525:7: note:   after user-defined conversion: ‘std::__cxx11::basic_string<_CharT, _Traits, _Alloc>::basic_string(const _CharT*, const _Alloc&) [with <template-parameter-2-1> = std::allocator<char>; _CharT = char; _Traits = std::char_traits<char>; _Alloc = std::allocator<char>]’
  525 |       basic_string(const _CharT* __s, const _Alloc& __a = _Alloc())
      |       ^~~~~~~~~~~~
example.cc:9:24: note:   initializing argument 1 of ‘Example::Example(std::string&)’
    9 |   Example(std::string &name)
      |           ~~~~~~~~~~~~~^~~~
example.cc:46:15: error: cannot bind non-const lvalue reference of type ‘std::string&’ {aka ‘std::__cxx11::basic_string<char>&’} to an rvalue of type ‘std::string’ {aka ‘std::__cxx11::basic_string<char>’}
   46 |   Example arg("arg");
      |               ^~~~~
In file included from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/string:55,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/locale_classes.h:40,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/ios_base.h:41,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ios:42,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ostream:38,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/iostream:39,
                 from example.cc:1:
/opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/basic_string.h:525:7: note:   after user-defined conversion: ‘std::__cxx11::basic_string<_CharT, _Traits, _Alloc>::basic_string(const _CharT*, const _Alloc&) [with <template-parameter-2-1> = std::allocator<char>; _CharT = char; _Traits = std::char_traits<char>; _Alloc = std::allocator<char>]’
  525 |       basic_string(const _CharT* __s, const _Alloc& __a = _Alloc())
      |       ^~~~~~~~~~~~
example.cc:9:24: note:   initializing argument 1 of ‘Example::Example(std::string&)’
    9 |   Example(std::string &name)
      |           ~~~~~~~~~~~~~^~~~
example.cc:51:40: error: cannot bind non-const lvalue reference of type ‘std::string&’ {aka ‘std::__cxx11::basic_string<char>&’} to an rvalue of type ‘std::string’ {aka ‘std::__cxx11::basic_string<char>’}
   51 |   Example *pNeverDeleted = new Example("never deleted");
      |                                        ^~~~~~~~~~~~~~~
In file included from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/string:55,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/locale_classes.h:40,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/ios_base.h:41,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ios:42,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ostream:38,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/iostream:39,
                 from example.cc:1:
/opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/basic_string.h:525:7: note:   after user-defined conversion: ‘std::__cxx11::basic_string<_CharT, _Traits, _Alloc>::basic_string(const _CharT*, const _Alloc&) [with <template-parameter-2-1> = std::allocator<char>; _CharT = char; _Traits = std::char_traits<char>; _Alloc = std::allocator<char>]’
  525 |       basic_string(const _CharT* __s, const _Alloc& __a = _Alloc())
      |       ^~~~~~~~~~~~
example.cc:9:24: note:   initializing argument 1 of ‘Example::Example(std::string&)’
    9 |   Example(std::string &name)
      |           ~~~~~~~~~~~~~^~~~
```

Example Use of Class

```
Example sub(Example arg)
{
  return arg;
}

int main(int argc, char *argv[])
{
  Example local("local");
  Example clone(local);

  Example *pExample = new Example("newed");

  {
    Example local_scope("local_scope");
  }

  Example arg("arg");
  sub(arg);

  delete pExample;

  Example *pNeverDeleted = new Example("never deleted");
  *pNeverDeleted = local;

  return EXIT_SUCCESS;
}
```

```
attu6> g++ -std=c++17 -g -Wall example.cc
example.cc: In function ‘int main(int, char**)’:
example.cc:37:17: error: cannot bind non-const lvalue reference of type
‘std::string&’ {aka ‘std::__cxx11::basic_string<char>&’} to an rvalue of type
‘std::string’ {aka ‘std::__cxx11::basic_string<char>’}
   37 |   Example local("local");
      |                 ^~~~~~~
In file included from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/string:55,
                 from /opt/rh/gcc-toolset-
9/root/usr/include/c++/9/bits/locale_classes.h:40,
                 from /opt/rh/gcc-toolset-
9/root/usr/include/c++/9/bits/ios_base.h:41,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ios:42,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/ostream:38,
                 from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/iostream:39,
                 from example.cc:1:
/opt/rh/gcc-toolset-9/root/usr/include/c++/9/bits/basic_string.h:525:7: note:
after user-defined conversion: ‘std::__cxx11::basic_string<_CharT, _Traits,
_Alloc>::basic_string(const _CharT*, const _Alloc&) [with <template-
parameter-2-1> = std::allocator<char>; _CharT = char; _Traits =
std::char_traits<char>; _Alloc = std::allocator<char>]’
  525 |       basic_string(const _CharT* __s, const _Alloc& __a = _Alloc())
      |       ^~~~~~~~~~~~
example.cc:9:24: note:   initializing argument 1 of
‘Example::Example(std::string&)’
    9 |   Example(std::string &name)
      |           ~~~~~~~~~~~~~^~~~
example.cc:40:35: error: cannot bind non-const lvalue reference of type
‘std::string&’ {aka ‘std::__cxx11::basic_string<char>&’} to an rvalue of type
‘std::string’ {aka ‘std::__cxx11::basic_string<char>’}
   40 |   Example *pExample = new Example("newed");
      |                                   ^~~~~~~
In file included from /opt/rh/gcc-toolset-9/root/usr/include/c++/9/string:55,
                 from /opt/rh/
```

Example Use of Class

```
Example sub(Example arg)
{
  return arg;
}

int main(int argc, char *argv[])
{
  Example local("local");
  Example clone(local);

  Example *pExample = new Example("newed");

  {
    Example local_scope("local_scope");
  }

  Example arg("arg");
  sub(arg);

  delete pExample;

  Example *pNeverDeleted = new Example("never deleted");
  *pNeverDeleted = local;

  return EXIT_SUCCESS;
}
```

```
37 |   Example local("local");
   |                 ^~~~~~~~
```

```
40 |   Example *pExample = new Example("newed");
   |                                   ^~~~~~~~
```

Example Use of Class

```
class Example
{
public:

 Example(std::string &name)
 {
  my_name = name;
  std::cout << "Created '" << my_name << "'\n";
 }

 Example(Example& other)
 {
  my_name = "copy of " + other.my_name;
  std::cout << "Created '" << my_name << "'\n";
 }

 ~Example()
 {
  std::cout << "Destroying " << my_name << std::endl;
 }

private:
 std::string my_name;
};
```

```
37 |   Example local("local");
   |                 ^~~~~~~
```

```
40 |   Example *pExample = new Example("newed");
   |                                   ^~~~~~~
```

Example Use of Class

```
class Example
{
public:

 Example(const std::string &name)
 {
  my_name = name;
  std::cout << "Created '" << my_name << "'\n";
 }

 Example(Example& other)
 {
  my_name = "copy of " + other.my_name;
  std::cout << "Created '" << my_name << "'\n";
 }

 ~Example()
 {
  std::cout << "Destroying " << my_name << std::endl;
 }

private:
 std::string my_name;
};
```

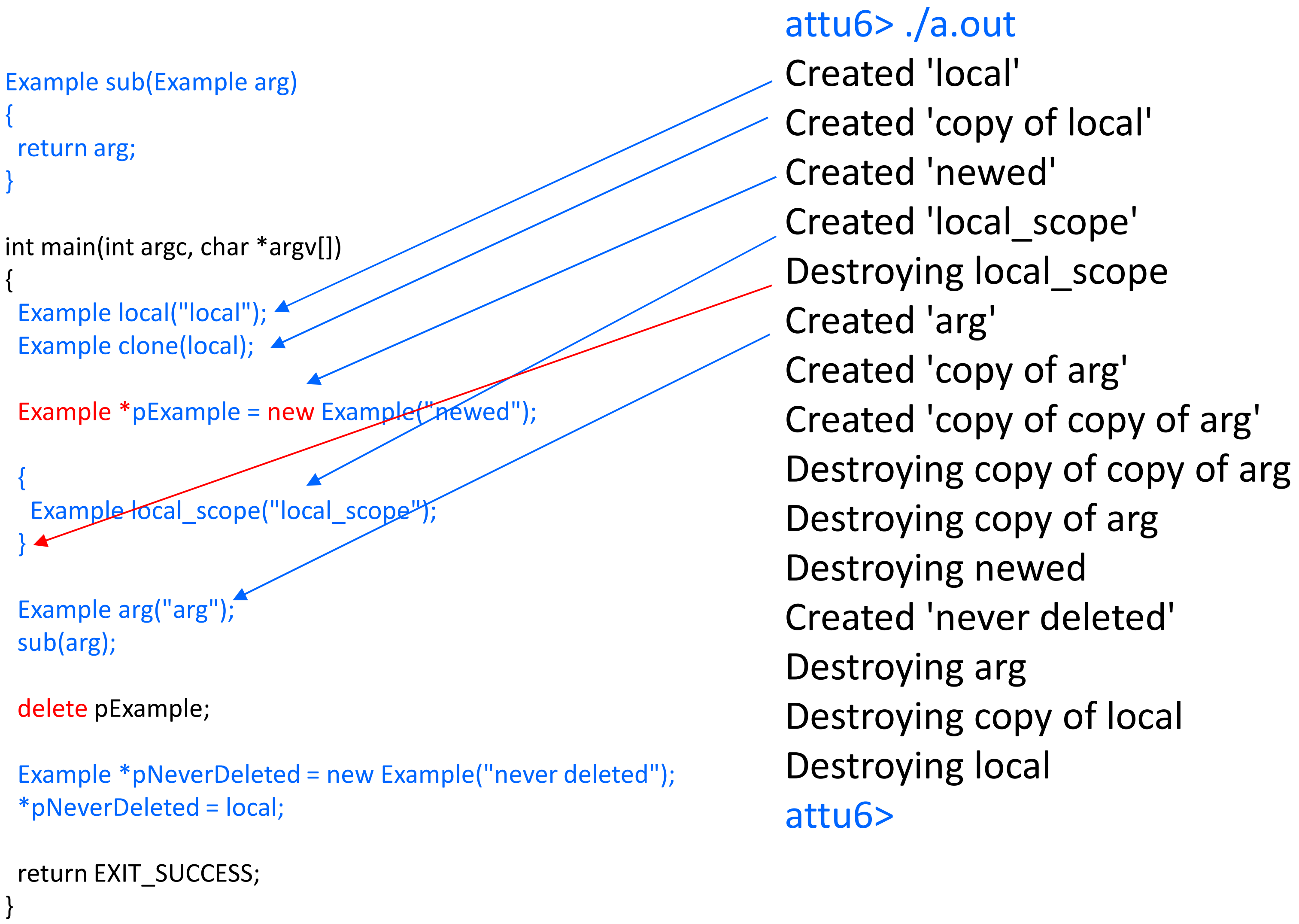
✓

```
Example local("local");
Example *pExample = new Example("newed");
```

✓

```
attu6> g++ -std=c++17 -g -Wall example.cc
attu6>
```

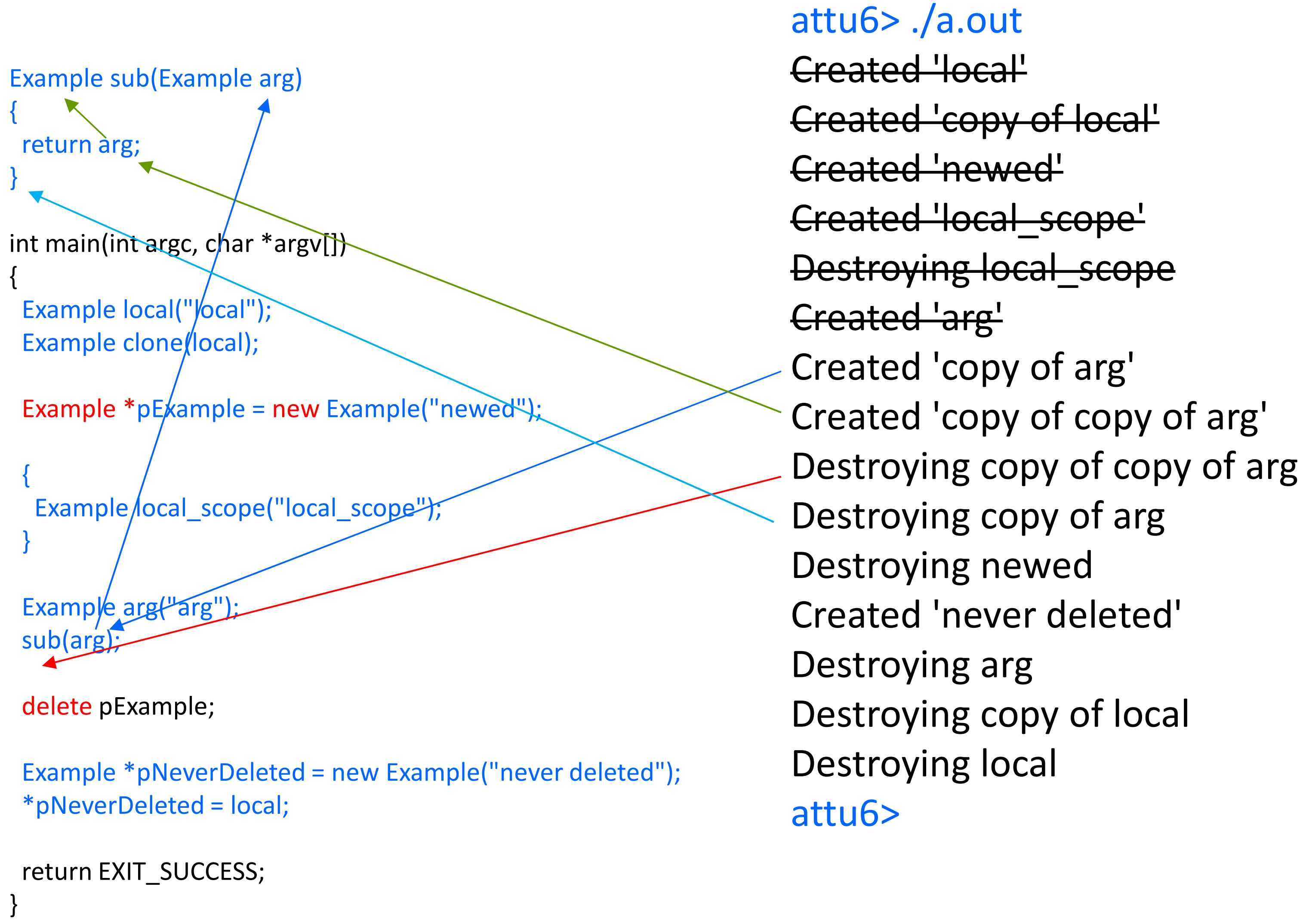
Let’s Run It – Part 1



```
Example sub(Example arg)
{
  return arg;
}

int main(int argc, char *argv[])
{
  Example local("local");
  Example clone(local);

  Example *pExample = new Example("newed");

  {
    Example local_scope("local_scope");
  }

  Example arg("arg");
  sub(arg);

  delete pExample;

  Example *pNeverDeleted = new Example("never deleted");
  *pNeverDeleted = local;

  return EXIT_SUCCESS;
}
```

```
attu6> ./a.out
Created 'local'
Created 'copy of local'
Created 'newed'
Created 'local_scope'
Destroying local_scope
Created 'arg'
Created 'copy of arg'
Created 'copy of copy of arg'
Destroying copy of copy of arg
Destroying copy of arg
Destroying newed
Created 'never deleted'
Destroying arg
Destroying copy of local
Destroying local
attu6>
```

Let’s Run It – Part 2



```
Example sub(Example arg)
{
  return arg;
}

int main(int argc, char *argv[])
{
  Example local("local");
  Example clone(local);

  Example *pExample = new Example("newed");

  {
   Example local_scope("local_scope");
  }

  Example arg("arg");
  sub(arg);

  delete pExample;

  Example *pNeverDeleted = new Example("never deleted");
  *pNeverDeleted = local;

  return EXIT_SUCCESS;
}
```

```
attu6> ./a.out
~~Created 'local'~~
~~Created 'copy of local'~~
~~Created 'newed'~~
~~Created 'local_scope'~~
~~Destroying local_scope~~
~~Created 'arg'~~
Created 'copy of arg'
Created 'copy of copy of arg'
Destroying copy of copy of arg
Destroying copy of arg
Destroying newed
Created 'never deleted'
Destroying arg
Destroying copy of local
Destroying local
attu6>
```

Let’s Run It – Part 3

```
Example sub(Example arg)
{
  return arg;
}

int main(int argc, char *argv[])
{
  Example local("local");
  Example clone(local);

  Example *pExample = new Example("newed");

  {
    Example local_scope("local_scope");
  }

  Example arg("arg");
  sub(arg);

  delete pExample;

  Example *pNeverDeleted = new Example("never deleted");
  *pNeverDeleted = local;

  return EXIT_SUCCESS;
}
```

```
attu6> ./a.out
~~Created 'local'~~
~~Created 'copy of local'~~
~~Created 'newed'~~
~~Created 'local_scope'~~
~~Destroying local_scope~~
~~Created 'arg'~~
~~Created 'copy of arg'~~
~~Created 'copy of copy of arg'~~
~~Destroying copy of copy of arg~~
~~Destroying copy of arg~~
Destroying newed
Created 'never deleted'
Destroying arg
Destroying copy of local
Destroying local
attu6>
```

Let’s Run It – Part 4

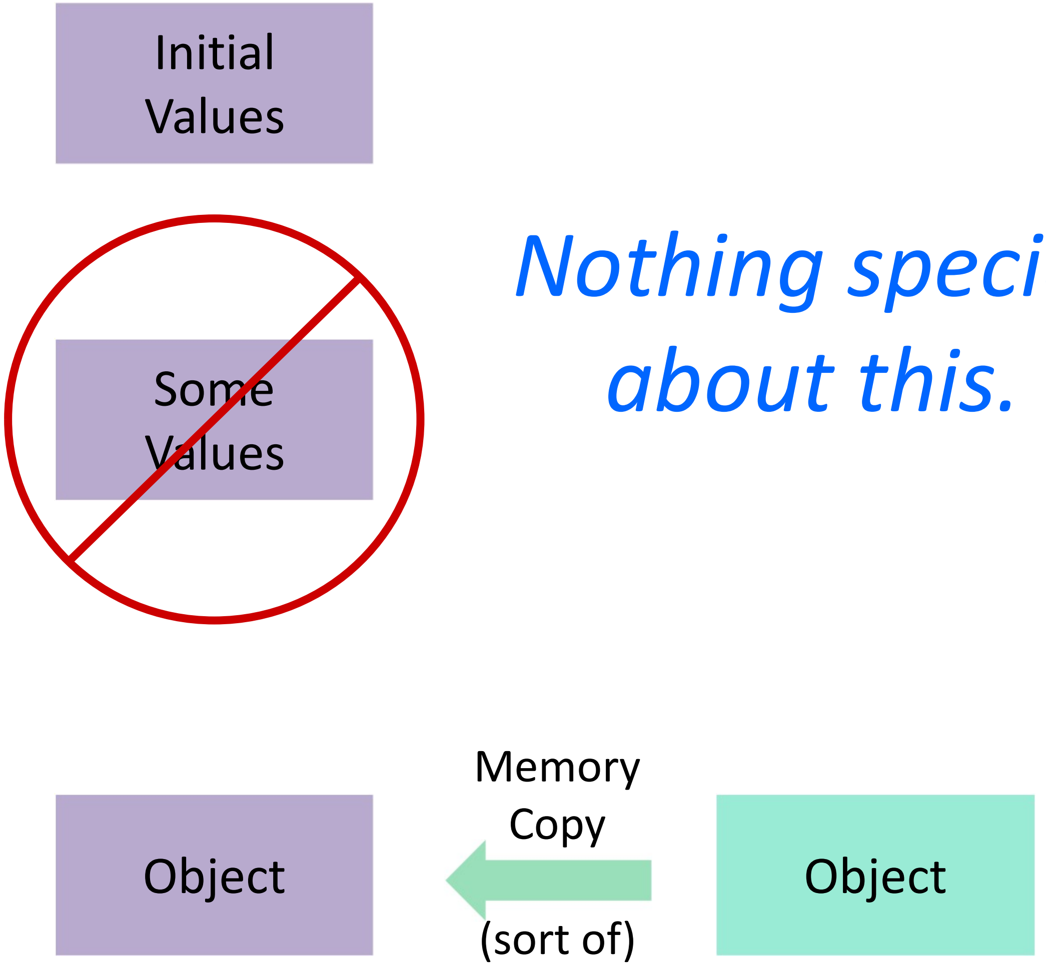
```
Example sub(Example arg)
{
  return arg;
}

int main(int argc, char *argv[])
{
  Example local("local");
  Example clone(local);

  Example *pExample = new Example("newed");

  {
    Example local_scope("local_scope");
  }

  Example arg("arg");
  sub(arg);

  delete pExample;

  Example *pNeverDeleted = new Example("never deleted");
  *pNeverDeleted = local;

  return EXIT_SUCCESS;
}
```

```
attu6> ./a.out
~~Created 'local'~~
~~Created 'copy of local'~~
~~Created 'newed'~~
~~Created 'local_scope'~~
~~Destroying local_scope~~
~~Created 'arg'~~
~~Created 'copy of arg'~~
~~Created 'copy of copy of arg'~~
~~Destroying copy of copy of arg~~
~~Destroying copy of arg~~
~~Destroying newed~~
~~Created 'never deleted'~~
~~Destroying arg~~
~~Destroying copy of local~~
~~Destroying local~~
attu6>
```

This is *assignment*. No construction. No destruction.

Construction / Destruction / Assignment

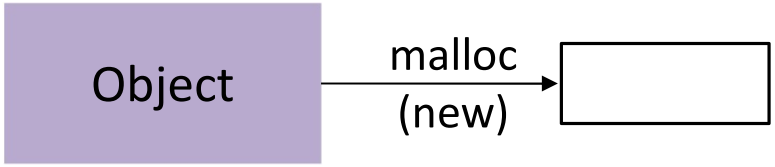
- Construction
- Destruction
- Assignment



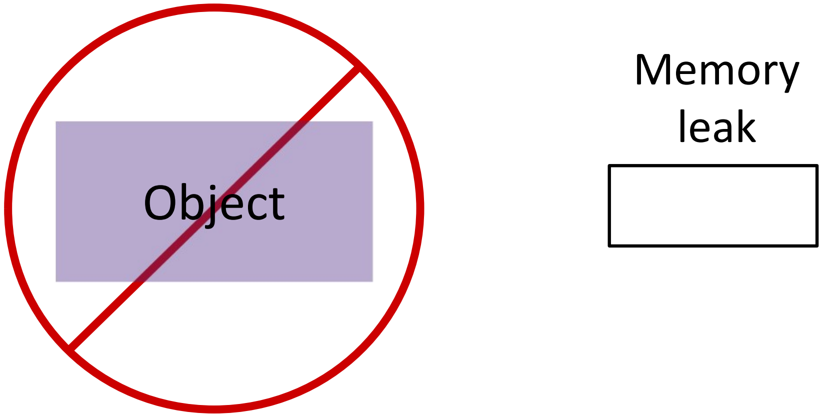
Nothing special about this.

Destruction – Something Special

- Construction



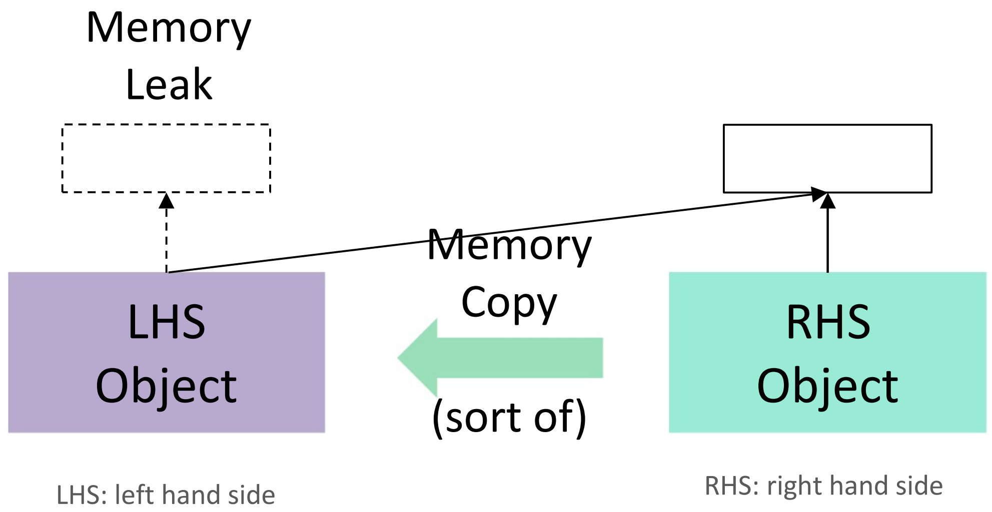
- Destruction



Might have to deallocate on destruction →
destructor method: ~classname()

Assignment – Something Special

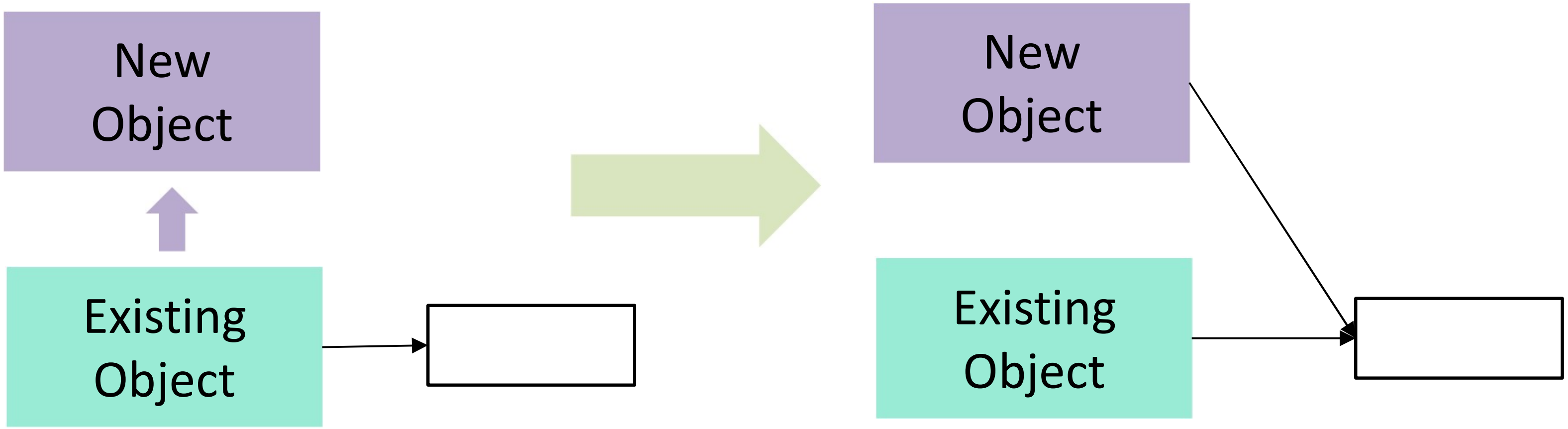
- Assignment



Might have to deallocate on assignment →
overloaded assignment operator method: *operator=()*

Copy Construction – Something Special

- Copy Construction



What happens when either object is destroyed?
Destructor frees allocated space, and remaining object has a dangling pointer

Need a Copy Constructor: *myclass(myclass& other)*

Lecture Outline

- Constructors / Destructors: The Issues
- **Constructors**
- Copy Constructors
- Assignment
- Embedded and Global Objects

Constructors

- A constructor (ctor) initializes a newly-instantiated object
  - A class can have multiple constructors that differ in parameters
    - Which one is invoked depends on *how* the object is instantiated
- Declared with the class name as the method name and no return type:

```
Point(const int x, const int y);
```

- A constructor that "requires no arguments" is called the default constructor

```
Point();
Point(const int x=0, const int y=0);
```

Default arguments

Aside: Ambiguities and Surprises

```
class Point {
public:
  Point() { x=-1; y=-1;}
  Point(const int x=0, const int y=0) {}

  int x;
  int y;
};


int main(int argc, char *argv[])
{
  Point p;
  Point q();
  Point r(1);

  std::cout << "p: " << p.x << " " << p.y << std::endl;
  std::cout << "q: " << q.x << " " << q.y << std::endl;
  std::cout << "r: " << r.x << " " << r.y << std::endl;
}
```

```
attu> g++ -std=c++17 –g –Wall defcon.cc
```

What happens?

Aside: Ambiguities and Surprises

```
class Point {
public:
  Point() { x=-1; y=-1;}
  Point(const int x=0, const int y=0) {}

  int x;
  int y;
};


int main(int argc, char *argv[])
{
  Point p;
  Point q();
  Point r(1);

  std::cout << "p: " << p.x << " " << p.y << std::endl;
  std::cout << "q: " << q.x << " " << q.y << std::endl;
  std::cout << "r: " << r.x << " " << r.y << std::endl;
}
```

attu> g++ -std=c++17 –g –Wall defcon.cc

```
[attu2] ~/cse333-21wi/lectures/09-constructor-code> !g
g++ -std=c++17 -g -Wall defaultCons.cc
defaultCons.cc: In function ‘int main(int, char**)’:
defaultCons.cc:15:9: error: call of overloaded ‘Point()’ is ambiguous
   15 |   Point p;
      |         ^
defaultCons.cc:6:3: note: candidate: ‘Point::Point(int, int)’
    6 |   Point(const int x=0, const int y=0);
      |   ^~~~~
defaultCons.cc:5:3: note: candidate: ‘Point::Point()’
    5 |   Point() { x=-1; y=-1;}
      |   ^~~~~
defaultCons.cc:20:27: error: request for member ‘x’ in ‘q’, which is
 of non-class type ‘Point()’
   20 |   std::cout << "q: " << q.x << " " << q.y << std::endl;
      |                           ^
defaultCons.cc:20:41: error: request for member ‘y’ in ‘q’, which is
 of non-class type ‘Point()’
   20 |   std::cout << "q: " << q.x << " " << q.y << std::endl;
      |                                         ^
```

Aside: Ambiguities and No Surprise

```
class Point {
public:
  Point() { x=-1; y=-1;}
  Point(const int x=0, const int y=0) {}

  int x;
  int y;
};


int main(int argc, char *argv[])
{
  Point p;
  Point q{};
  Point r(1);

  std::cout << "p: " << p.x << " " << p.y << std::endl;
  std::cout << "q: " << q.x << " " << q.y << std::endl;
  std::cout << "r: " << r.x << " " << r.y << std::endl;
}
```

```
attu> g++ -std=c++17 –g –Wall defcon.cc
```

```
defCon.cc: In function ‘int main(int, char**)’:
defCon.cc:15:9: error: call of overloaded ‘Point()’ is ambiguous
  15 |   Point p;
     |         ^
defCon.cc:6:3: note: candidate: ‘Point::Point(int, int)’
    6 |   Point(const int x=0, const int y=0);
      |   ^~~~~
defCon.cc:5:3: note: candidate: ‘Point::Point()’
    5 |   Point() { x=-1; y=-1;}
      |   ^~~~~
defCon.cc:16:11: error: call of overloaded
‘Point(<brace-enclosed initializer list>)’ is ambiguous
  16 |   Point q{};
     |           ^
defCon.cc:6:3: note: candidate: ‘Point::Point(int, int)’
    6 |   Point(const int x=0, const int y=0);
      |   ^~~~~
defCon.cc:5:3: note: candidate: ‘Point::Point()’
    5 |   Point() { x=-1; y=-1;}
      |   ^~~~~
```

Synthesized Default Constructor

- If you don’t define any constructors, C++ will create one for you: the synthesized default
  - Takes no arguments
  - Calls the default constructor on all object member variables
  - Leaves primitive type (e.g., int) members uninitialized

- Synthesized default constructor will fail to compile if initialization of any member fails to compile
  - There are non-initialized const or reference data members
  - There is an embedded object for which no default constructor exists
    - *(And it hasn’t been explicitly initialized)*

Synthesized Default Constructor / POD

```
class SimplePoint {
 public:
  // no constructors declared!
  int get_x() const { return x_; }      // inline member function
  int get_y() const { return y_; }      // inline member function

 private:
  int x_;  // data member - no default initialization
  int y_;  // data member - no default initialization
};  // class SimplePoint
```

```
#include "SimplePoint.h"

int main(int argc, char** argv) {
  SimplePoint p;  // invokes synthesized default constructor
  std::cout << "(" << p.get_x() << ", " << p.get_y() << ")\n";
  return 0;
}
```

```
Output:    (4198528, 0)
```

Synthesized Default Constructor / object

```
class SimplePoint {
 public:
  // no constructors declared!
  int get_x() const { return pt_.first; }
  int get_y() const { return pt_.second; }
 private:
  std::pair<int,int> pt_;
};  // class SimplePoint
```

```
#include "SimplePoint.h"

int main(int argc, char** argv) {
  SimplePoint p;
  std::cout << "(" << p.get_x() << ", " << p.get_y() << ")\n";
  return 0;
}
```

Output: (0, 0)

Synthesized Default Constructor

- If there are any explicitly defined constructors, C++ will not synthesize additional ones

```
#include "SimplePoint.h"

// defining a constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
  x_ = x;
  y_ = y;
}

void func() {
  SimplePoint x;        // error:  no constructor matches
  SimplePoint y(1, 2);  // ok:  invokes the 2-int-arguments
                        // constructor
}
```

Multiple Constructors (overloading)

```
// (explicit) default constructor
SimplePoint::SimplePoint() {
  x_ = 0;
  y_ = 0;
}

// constructor with two arguments
SimplePoint::SimplePoint(const int x, const int y) {
  x_ = x;
  y_ = y;
}

void sub() {
  SimplePoint x;        // invokes the default constructor
  SimplePoint a[3];     // invokes the default ctor 3 times
  SimplePoint y(1, 2);  // invokes the 2-int-arguments ctor
}
```

Initialization Lists

- C++ lets you *optionally* declare an initialization list as part of a constructor definition
  - Initializes fields according to parameters in the list
  - The following are (nearly) identical:

```
Point::Point(const int x, const int y)
{
  x_ = x;
  y_ = y;
}
```

```
// x_ and y_ are instance variables of Points
Point::Point(const int x, const int y) : x_(x), y_(y)
{
}
```

Initialization vs. Construction

```
class Point3D {
 public:
  // constructor with 3 int arguments
  Point3D(const int x, const int y, const int z) : y_(y), x_(x) {
    z_ = z;
  }

 private:
  int x_, y_, z_;  // data members
};  // class Point3D
```

First, initialization list is applied.

Next, constructor body is executed.

- Data members in initializer list are initialized in the order they are defined in the class, not by the initialization list ordering (**!**)
  - Data members that don't appear in the initialization list are *default initialized/constructed* before body is executed
- *"Initialization preferred to assignment to avoid extra steps of default initialization (construction) followed by assignment"*

Sometimes Initialization is Required

```
class Artificial
{
private:
   int    my_a;
   int& my_b;
   int const my_c;
public:
   Artificial(int a, int b, in c) : my_b(b), my_c(c)
    {
       my_a = a;
     }
};
```

Must be initialized because can’t be modified after creation

Sometimes Initialization is Required

```
class Artificial
{
private:
  int   my_a;
  int& my_b;
  int const my_c;
public:
  Artificial(int a, int b, in c)
   {
     my_a = a;
     my_b = b;
     my_c = c;
   }
};
```

```
[attu6] > g++ -std=c++17 Artificial.cc
Artificial.cc: In constructor ‘Artificial::Artificial(int, int, int)’:
Artificial.cc:11:3: error: expected identifier before ‘{’ token
  11 |   {
     |   ^
Artificial.cc:10:3: error: uninitialized reference member in
‘int&’ [-fpermissive]
  10 |   Artificial(int a, int b, int c) :
     |   ^~~~~~~~~~
Artificial.cc:7:13: note: ‘int& Artificial::my_b’ should be
initialized
   7 |   int&      my_b;
     |             ^~~~
Artificial.cc:10:3: error: uninitialized const member in ‘const
int’ [-fpermissive]
  10 |   Artificial(int a, int b, int c) :
     |   ^~~~~~~~~~
Artificial.cc:8:13: note: ‘const int Artificial::my_c’ should be
initialized
   8 |   int const my_c;
     |             ^~~~
Artificial.cc:14:10: error: assignment of read-only member
‘Artificial::my_c’
  14 |     my_c = c;
     |     ~~~~~^~~
```

Lecture Outline

- Constructors
- **Copy Constructors**
- Assignment
- Destructors
- Embedded and Global Objects

Copy Constructors

- C++ has the notion of a copy constructor (cctor)
  - Used to create a new object as a copy of an existing object

```
Point::Point(const int x, const int y) : x_(x), y_(y) { }

// copy constructor
Point::Point(const Point& other) {
  x_ = other.x_;
  y_ = other.y_;
}

void foo() {
  Point x(1, 2);  // invokes the 2-int-arguments constructor

  Point y(x);     // invokes the copy constructor
                  // could also be written as "Point y = x;"
}
```

  - Initializer lists can also be used in copy constructors (preferred)

Aside: Object Initialization

- What's the difference between

  ```
  Point y(x);     // direct initialization
  ```

  and

  ```
  Point y = x;    // copy initialization
  ```

  `?`

- Neither is assignment!

  Both are construction.

- Rules changed with c++17…

- The difference has to do with something we haven't seen yet (but will)
  - Direct initialization is willing to use all type conversions available to coerce x into a type for which there is a Point constructor defined
  - Copy initialization will not use constructors or conversion operators that have been declared `explicit`

When Do Copies Happen?

- The copy constructor is invoked if:
  - You *initialize* an object from another object of the same type:

```
Point x;          // default ctor
Point y(x);       // copy ctor
Point z = y;      // copy ctor
z = y;            // assignment
```

  - You call a method that has a non-reference object parameter

```
void foo(Point x) { ... }

Point y;          // default ctor
foo(y);           // copy ctor
```

  - You return a non-reference object value from a function:

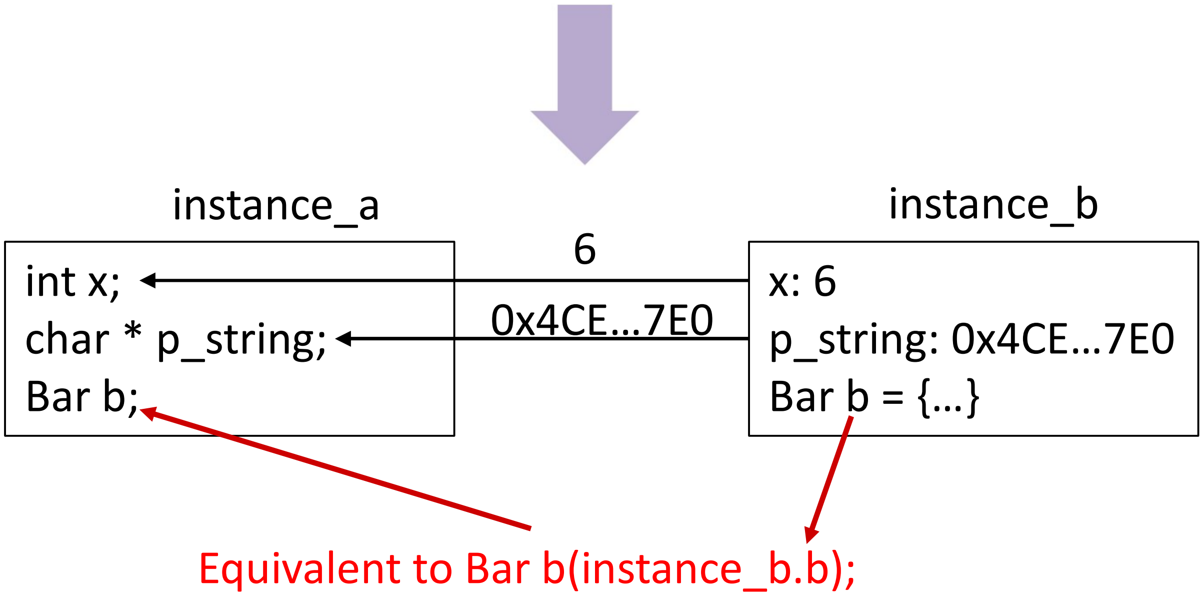
```
Point foo() {
  Point y;        // default ctor
  return y;       // copy ctor
}
```

Synthesized Copy Constructor

- If you don't explicitly provide a copy constructor and your code contains something that requires one, then
  - C++ will make one for you
- The synthesized copy constructor will copy values for instance variables of primitive type
  - E.g., int's, pointers, …
- For embedded objects, the synthesized copy constructor will use the copy constructor for embedded object's type
  - And, yes, it will synthesize one if it needs to

Synthesized Copy Constructor Example

- MyClass instance_a(instance_b);



instance_a

int x;
char * p_string;
Bar b;

instance_b

x: 6
p_string: 0x4CE…7E0
Bar b = {…}

Equivalent to Bar b(instance_b.b);

Synthesized Copy Constructor

- The synthesized copy constructor does a *shallow copy*
  - Sometimes the right thing; sometimes the wrong thing

- If the objects contain pointers to dynamically allocated memory, the shallow copy results in two objects both pointing to the same memory
  - Makes it tricky to figure out which should free/delete the memory…
    - So tricky you probably get it wrong!

- Solution is usually to write the copy constructor yourself and do a deep copy

A Detail: Return Value Optimization

- The compiler sometimes uses a "return value optimization" to eliminate unnecessary copies
  - Sometimes a constructor isn't invoked when you might expect it to be

```
Point sub() {
  Point y;            // default ctor
  return y;           // copy ctor? optimized?
}

Point y;              // default ctor
y = sub();            // return value optimized?
```

Lecture Outline

- Constructors
- Copy Constructors
- **Assignment**
- Destructors
- Embedded Global Objects

Two Things to Keep In Mind

- "=" is not always assignment
  - It is an assignment operator when it occurs inside an expression
    - x = y + 6;
- "=" indicates initialization when it occurs in a declaration

```
Point w;             // default ctor
Point x(w);          // copy ctor
Point y = w;         // initialization (copy ctor)
y = x;               // assignment operator
```

Overloading the "=" Operator

- You can define a procedure (code) to be run when the assignment operator needs to be evaluated in an expression
  - But there are some rules you should follow:

```
Point& Point::operator=(const Point& rhs) {
  if (this != &rhs) {   // (1) always check against this
    x_ = rhs.x_;
    y_ = rhs.y_;
  }
  return *this;         // (2) always return *this from op=
}

Point a;        // default constructor
a = b = c;      // works because = return *this
a = (b = c);    // equiv. to above (= is right-associative)
(a = b) = c;    // "works" but different
```

When To Overload Assignment

- When default assignment isn't correct for your app
  - Often because the object contains pointers to dynamically allocated memory and so you need to do a deep copy on assignment

- *"The Rule of Three"*
  If you define any of the copy constructor, the assignment operator, or the destructor you ***very likely*** *need to define all of them*
  - Whatever problem made you define one is a problem for the other two as well

Synthesized Assignment Operator

- If you don’t define the assignment operator, C++ will synthesize one for you
  - It will do a *shallow copy* of all of the fields (*i.e.* member variables) of your class
    - Does object assignment for embedded objects
- Sometimes the right thing; sometimes the wrong thing

Lecture Outline

- Constructors
- Copy Constructors
- Assignment
- **Destructors**
- Embedded Global Objects

Destructors

- C++ has the notion of a destructor
  - Invoked automatically when a new’ed class instance is deleted or a stack allocated local goes out of scope (even due to exceptions or other causes!)
    - Note: Constructors are run for globals before any of your code runs. Destructors are run for globals after your code is done running.
- Place to put your cleanup code – free any dynamic storage or other resources owned by the object

```
Point::~Point() {    // destructor
  // do any cleanup needed when a Point object goes away
  // (nothing to do here since we have no dynamic resources)
}
```

Resource Acquisition Is Initialization

- If you wrap a resource in an object declared as a local variable
  and
  you define a destructor for that object's class that release the resource
  then
  you are guaranteed that your code will release the resource, even when errors are encountered and/or exceptions thrown
- Example: OpenFile in_file("fileToOpen.txt");
  Constructor does an fopen() and saves FILE* value returned.
  in_file provides FILE* value whenever needed.
  Destructor does an fclose().

- You can use this pattern in your code.
- The STL uses it in some important ways (notably for dynamic memory allocation)

RAII

- Common C++ idiom for managing dynamic resources

```
class OpenFile
{
  public:
   OpenFile(const std::string fname) { pFile_ = fopen(…);
…}
   FILE* file() { return pFile_; }
   int close() { return fclose(pFile_); }
   ~OpenFile() { close(); }
  private:
   FILE* pFile_;
};

void sub()
{
   OpenFile in_file(“example.txt”);
   // no chance the file won’t be closed when we leave sub
   …
}
```

Lecture Outline

- Constructors
- Copy Constructors
- Assignment
- Destructors
- **Embedded and Global Objects**

Embedded Objects

```
class Embedee
{
public:
  Embedee() { std::cout << "Embedee constructor running\n"; }
  ~Embedee() { std::cout << "Embedee destructor running\n"; }
};

class Embeder
{
public:
  Embeder() { std::cout << "Embeder constructor running\n"; }
  ~Embeder() { std::cout << "Embeder destructor running\n"; }
private:
  Embedee myEe;
};

int main(int argc, char *argv[])
{
  Embeder e;
  return 0;
}
```

```
attu> ./a.out
Embedee constructor running
Embeder constructor running
Embeder destructor running
Embedee destructor running
```

Embedded objects are *constructed before* object constructor is run

Embedded objects are *destroyed after* object destructor is run

Global Objects

```
/* Changed Embeder and Embedee classes to
   accept a const char* name argument to the
   constructors and to label output with it */
…

Embeder global("global");

int main(int argc, char *argv[])
{
  std::cout << “In main” << std::endl;
  Embeder e("local");
  std::cout << “Leaving main” << std::endl;
  return 0;
}
```

```
attu> ./a.out
global embedee constructor running
global embeder constructor running
In main
local embedee constructor running
local embeder constructor running
Leaving main
local embeder destructor running
local embedee destructor running
global embeder destructor running
global embedee destructor running
```

Global objects are *constructed before* main() is entered

Global objects are *destroyed after* main() is exited