CSE 374 Programming concepts and tools

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Review: Classes

Class definition syntax (in a `.h` file):

```
class Name {
 public:
  // public member definitions & declarations go here

 private:
  // private member definitions & declarations go here
};  // class Name
```

- Members can be functions (methods) or data (variables)

Class member function definition syntax (in a `.cc` file):

```
retType Name::MethodName(type1 param1, …, typeN paramN) {
  // body statements
}
```

Demo: `usepoint.cc`

Rule of Three

If you define any of:

- Destructor
- Copy Constructor
- Assignment (`operator=`)

Then you should normally define all three

- Can explicitly ask for default synthesized versions (C++11):

```
class Point {
 public:
  Point() = default;                              // the default ctor
  ~Point() = default;                             // the default dtor
  Point(const Point& copyme) = default;           // the default cctor
  Point& operator=(const Point& rhs) = default;  // the default "="
  ...
```

Non-member Functions

"Non-member functions" are just normal functions that happen to use some class

- Called like a regular function instead of as a member of a class object instance

These do *not* have access to the class' private members

- Can access fields via getters (if they are there)

Useful non-member functions often included as part of interface of a class

- Declaration goes in header file, but **outside** of class definition
- Operators that are commutative should typically be non-members
  (non-commutative things can be non members too)

Example

Member function

```
double Point::distance(Point&)
pt1.distance(pt2);

float Vector::operator*(Vector&)
vec1 * vec2;
```

Non-member function

```
double distance(Point&, Point&)
distance(pt1, pt2);

float operator*(Vector&, Vector&)
vec1 * vec2;
```

Access Control

Access modifiers for members:

- `public`: accessible to *all* parts of the program
- `private`: accessible to the member functions of the class
- `protected`: accessible to member functions of the class and any *derived* classes (subclasses – more to come, later)

Reminders:

- Access modifiers apply to *all* members that follow until another access modifier is reached
- If no access modifier is specified, `struct` members default to `public` and `class` members default to `private`

Operator Overloading

Can overload operators using **member functions**

- Restriction: left-hand side argument must be a class you are implementing

```
Complex& operator+=(const Complex& a) { ... }
```

Can overload operators using **non-member functions**

- No restriction on arguments (can specify any two)
  - **Our only option** when the left-hand side is a class you do not have control over, like `ostream` or `istream`.
- But no access to private data members

```
Complex operator+(const Complex& a, const Complex& b) { ... }
```

`friend` non-member Functions

A class can give a **non-member** function (or class) access to its non-public members by declaring it as a `friend` within its definition

- Not a class member, but has access privileges as if it were
  - `friend` functions are usually unnecessary if your class includes appropriate “getter” public functions

Complex.h

```
class Complex {
  ...
  friend std::istream& operator>>(std::istream& in, Complex& a);
  ...
}; // class Complex
```

```
std::istream& operator>>(std::istream& in, Complex& a) {
  ...
}
```

Note: no Complex::

Complex.cc

Demo: `Complex` Walkthrough

When to use non-member and `friend`

Member Functions

- Operators that modify the object being called on
  - Assignment operator (`operator=`)
- "Core" non-operator functionality that is part of the class interface

Nonmember Functions

- Used for commutative operators
  - *e.g.*, so `v1 + v2` is invoked as `operator+(v1, v2)` instead of `v1.operator+(v2)`
- If operating on two types and the class is on the right-hand side
  - *e.g.*, `cin >> complex;`
- Returning a "new" object, not modifying an existing one
- Only grant `friend` permission if you NEED to, and if you are not modifying

Poll Question: Pollev.com/cs374

If we wanted to overload operator== to compare two points, what type of function should it be?

Reminder that Point has getters and a setter.

A. non-friend + member
B. friend + member
C. non-friend + non-member
D. friend + non-member

Poll Question Explained

If we wanted to overload operator== to compare two points, what type of function should it be?

Reminder that Point has getters and a setter.

A. non-friend + member
B. friend + member
C. non-friend + non-member
D. friend + non-member

We have getters to access the values of both points, and we aren’t modifying either point.

Namespaces

Each namespace is a separate scope

- Useful for avoiding symbol collisions!

`LL:Iterator`
`HT:Iterator`
Same name, but different namespace

Namespace definition:

```
namespace name {
// declarations go here
}  // namespace name
```

- Doesn’t end with a semicolon and doesn’t add to the indentation of its contents
- Creates a new namespace name if it did not exist, otherwise **adds** *to the existing namespace* (**!**)
  - This means that components (*e.g.* classes, functions) of a namespace can be defined in multiple source files

Classes vs. Namespaces

They seems somewhat similar, but classes are *not* namespaces:

- There are no instances/objects of a namespace; a namespace is just a group of logically-related things (classes, functions, etc.)
- To access a member of a namespace, you must use the fully qualified name (*i.e.* `namespace_name::member`)
  - Unless you are `using` that namespace
  - You only used the fully qualified name of a class member when you are defining it outside of the scope of the class definition

Questions?

Using the Heap

C++11 `nullptr`

C and C++ have long used `NULL` as a pointer value that references nothing

C++11 introduced a new literal for this: **`nullptr`**

- New reserved word
- Interchangeable with `NULL` for all practical purposes, but it has type `T*` for any/every `T`, and is not an integer value
  - Still can convert to/from integer `0` for tests, assignment, etc.
- Advice: prefer **`nullptr`** in C++11 code
  - Though `NULL` will also be around for a long, long time

`new/delete`

To allocate on the heap using C++, you use the `new` keyword instead of **`malloc`**`()` from `stdlib.h`

- You can use new to allocate an object (*e.g.* `new Point`)
- You can use new to allocate a primitive type (*e.g.* `new int`)

To deallocate a heap-allocated object or primitive, use the `delete` keyword instead of **`free`**`()` from `stdlib.h`

- Don't mix and match!
  - *Never* **`free`**`()` something allocated with `new`
  - *Never* `delete` something allocated with **`malloc`**`()`
  - Careful if you're using a legacy C code library or module in C++

`new`/`delete` Behavior

`new` behavior:

- When allocating you can specify a constructor or initial value
  - (e.g. `new Point(1, 2)`) or (e.g. `new int(333)`)
- If no initialization specified, it will use default constructor for objects, garbage for primitives (integer, float, character, boolean, double)
  - You don't need to check that `new` returns `nullptr`
  - When an error is encountered, an exception is thrown (that we won't worry about)

`delete` behavior:

- If you `delete` already `deleted` memory, then you will get undefined behavior. (Same as when you double **`free`** in c)

new/delete Example

```
int* AllocateInt(int x) {
  int* heapy_int = new int;
  *heapy_int = x;
  return heapy_int;
}
```

```
Point* AllocatePoint(int x, int y) {
  Point* heapy_pt = new Point(x,y);
  return heapy_pt;
}
```

heappoint.cc

```
#include "Point.h"
using namespace std;

...  // definitions of AllocateInt() and AllocatePoint()

int main() {
  Point* x = AllocatePoint(1, 2);
  int* y = AllocateInt(3);

  cout << "x's x_ coord: " << x->get_x() << endl;
  cout << "y: " << y << ", *y: " << *y << endl;

  delete x;
  delete y;
  return EXIT_SUCCESS;
}
```

Dynamically Allocated Arrays

To dynamically allocate an array:

- Default initialize: `type* name = new type[size];`

To dynamically deallocate an array:

- Use `delete[] name;`
- It is an *incorrect* to use "`delete name;`" on an array
  - The compiler probably won't catch this, though (!) because it can't always tell if `name*` was allocated with `new type[size];` or `new type;`
    - Especially inside a function where a pointer parameter could point to a single item or an array and there's no way to tell which!
  - Result of wrong `delete` is undefined behavior

arrays.cc

```
#include "Point.h"

int main() {
  int stack_int;                          // stack (garbage)
  int* heap_int = new int;                // heap (garbage)
  int* heap_int_init = new int(12);       // heap (12)

  int stack_arr[3];                 // stack (garbage)
  int* heap_arr = new int[3];       // heap(garbage)

  int* heap_arr_init_val = new int[3]();   // heap(0, 0, 0)
  int* heap_arr_init_lst = new int[3]{4, 5};  // C++11 syntax, heap(4, 5, 0)

  ...

  delete heap_int;                  // ok
  delete heap_int_init;             // ok
  delete heap_arr;                  // BAD
  delete[] heap_arr_init_val;       // ok

  return EXIT_SUCCESS;
}
```

Arrays Example (primitive)

arrays.cc

```
#include "Point.h"

int main() {
  ...

  Point stack_pt(1, 2);              // stack 2-arg constructor
  Point* heap_pt = new Point(1, 2);   // heap 2-arg constructor

  Point* heap_pt_arr_err = new Point[2]; // heap default ctor?
                                          // fails cause no default ctor

  Point* heap_pt_arr_init_lst = new Point[2]{{1, 2}, {3, 4}};
                                                         // C++11

  ...

  delete heap_pt;
  delete[] heap_pt_arr_init_lst;

  return EXIT_SUCCESS;
}
```

Arrays Example (class objects)

`malloc` vs. `new`

	`malloc()`	`new`
What is it?	a function	an operator / keyword
How often used (in C)?	often	never
How often used (in C++)?	rarely	often
Allocated memory for	anything	arrays, structs, objects, primitives
Returns	a `void*` (*should be cast*)	appropriate pointer type (*doesn't need a cast*)
When out of memory	returns `NULL`	throws an exception
Deallocating	`free()`	`delete` or `delete[]`

Questions?

Poll Question (PollEv.com/cs374)

This code has a memory error.

How should we fix it?

A. Add "`delete ptr2`"

B. Add "`delete ref3`"

C. Remove "`delete ptr1`"

D. Move "`delete ptr1`" to the end

```
void print_int_ptr(int* ptr2) {
  cout << *ptr2 << endl;
  // delete ptr2;
}

void print_int_ref(int& ref3) {
  cout << ref3 << endl;
  // delete ptr3;
}

int main() {
  int* ptr1 = new int;
  *ptr1 = 42;
  print_int_ptr(ptr1);
  delete ptr1;
  print_int_ref(*ptr1);
}
```

Heap Member Example

Let's build a class to simulate some of the functionality of the C++ string

- Internal representation: c-string to hold characters

What might we want to implement in the class?

Str Class Walkthrough

Str.h

```
#include <iostream>
using namespace std;

class Str {
 public:
  Str();                    // default ctor: create empty string
  Str(const char* s);       // c-string ctor: create Str from c-string s
  Str(const Str& s);        // copy ctor: initialize this to be a copy of s
  ~Str();                   // dtor

  int length() const;       // return length of string
  char* c_str() const;      // return a copy of st_ on heap
  void append(const Str& s); // append contents of s to the end of this
string

  Str& operator=(const Str& s);   // string assignment

  friend std::ostream& operator<<(std::ostream& out, const Str& s); // output

 private:
  char* st_;   // c-string on heap (terminated by '\0')
};  // class Str
```

Demo: `Str` Example Walkthrough

Questions?

Ex18 due Friday, HW7 due Sunday!

Ex18 is due before the beginning of the next lecture

- Link available on the website: https://courses.cs.washington.edu/courses/cse374/24wi/exercises/

HW7 due Sunday at 11.59pm!

- Much lighter than HW6.
- Instructions on course website: https://courses.cs.washington.edu/courses/cse374/24wi/homeworks/hw7/

Extra Exercise 💻

Extra Exercise #1

Write a C++ function that:

- Uses `new` to dynamically allocate an array of strings and uses `delete[]` to free it
- Uses `new` to dynamically allocate an array of pointers to strings
  - Assign each entry of the array to a string allocated using `new`
- Cleans up before exiting
  - Use `delete` to delete each allocated string
  - Uses `delete[]` to delete the string pointer array
  - (whew!)

Extra Exercise #2

What will happen when we invoke `bar()`?

- If there is an error, how would you fix it?

A. Bad dereference

B. Bad delete

C. Memory leak

D. “Works” fine

```
Foo::Foo(int val) { Init(val); }
Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
   foo_ptr_ = new int;
  *foo_ptr_ = val;
}

Foo& Foo::operator=(const Foo& rhs) {
  delete foo_ptr_;
  Init(*(rhs.foo_ptr_));
  return *this;
}

void bar() {
  Foo a(10);
  Foo b(20);
  a = a;
}
```

Dynamically Allocated Class Members

Stack

Heap

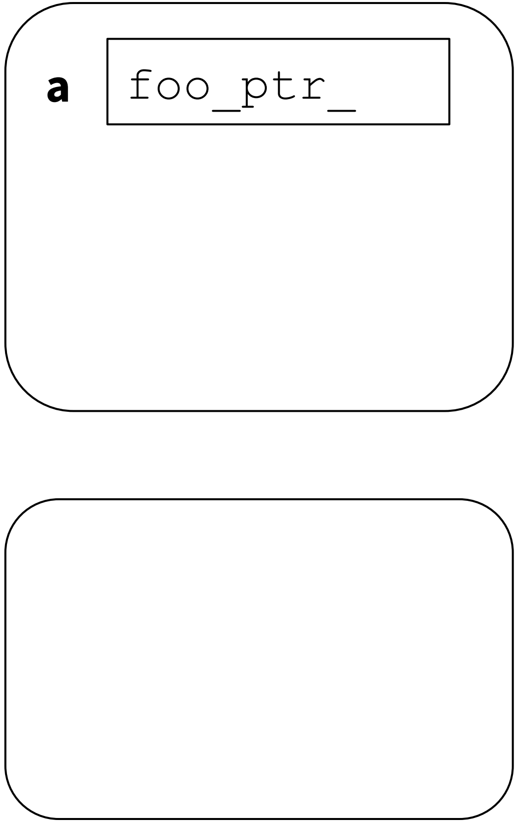
```
Foo::Foo(int val) { Init(val); }
Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
    foo_ptr_ = new int;
   *foo_ptr_ = val;
}

Foo& Foo::operator=(const Foo& rhs) {
  delete foo_ptr_;
  Init(*(rhs.foo_ptr_));
  return *this;
}

void bar() {
  Foo a(10);
  Foo b(20);
  a = a;
}
```

Dynamically Allocated Class Members

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Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
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   *foo_ptr_ = val;
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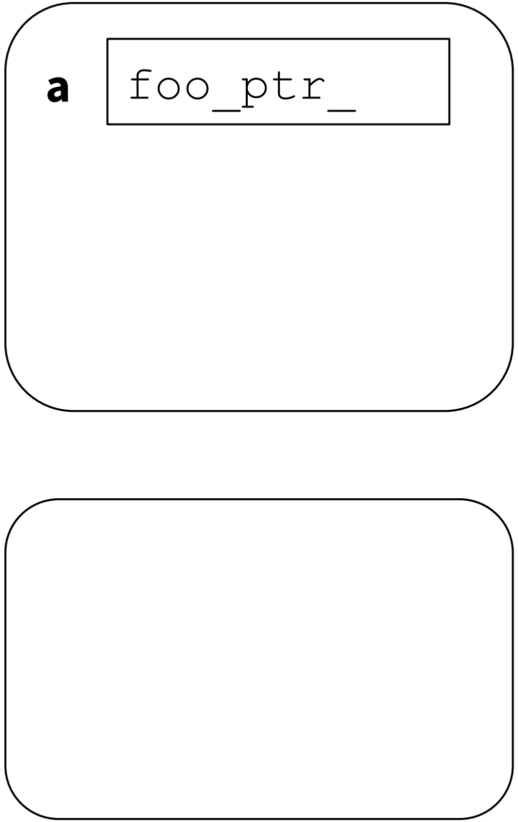
```

Dynamically Allocated Class Members

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Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
   foo_ptr_ = new int;
  *foo_ptr_ = val;
}

Foo& Foo::operator=(const Foo& rhs) {
  delete foo_ptr_;
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  return *this;
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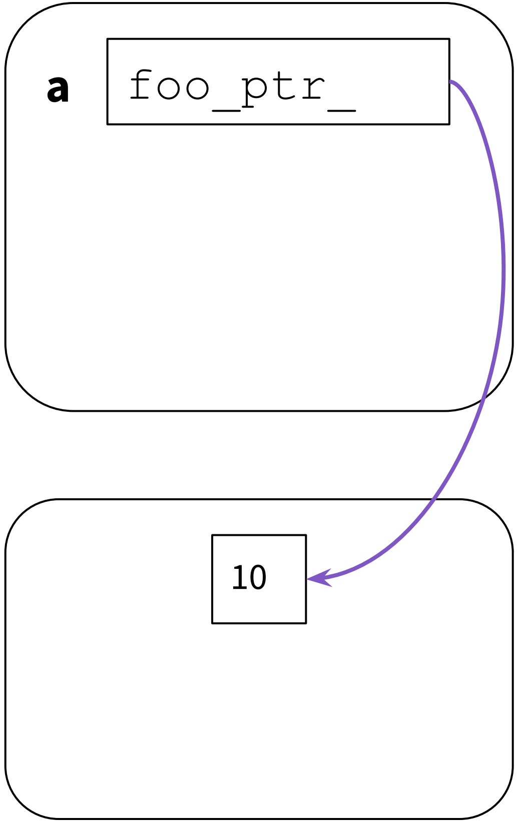
}
```

Dynamically Allocated Class Members

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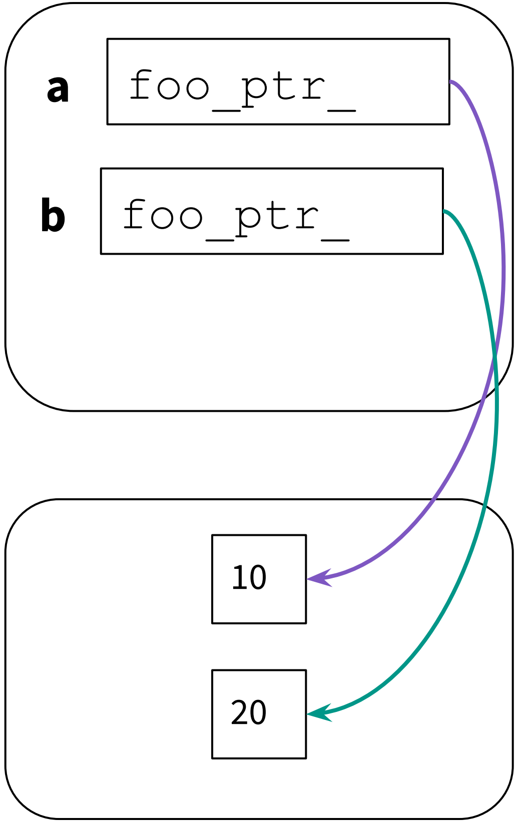
Foo::Foo(int val) { Init(val); }
Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
    foo_ptr_ = new int;
   *foo_ptr_ = val;
}

Foo& Foo::operator=(const Foo& rhs) {
  delete foo_ptr_;
  Init(*(rhs.foo_ptr_));
  return *this;
}

void bar() {
  Foo a(10);
  Foo b(20);
  a = a;
}
```

Dynamically Allocated Class Members

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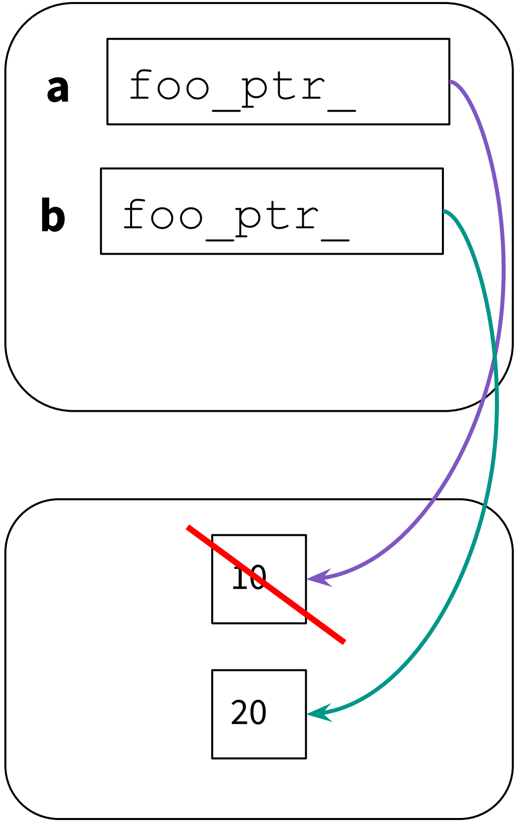
Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
    foo_ptr_ = new int;
   *foo_ptr_ = val;
}

Foo& Foo::operator=(const Foo& rhs) {
  delete foo_ptr_;
  Init(*(rhs.foo_ptr_));
  return *this;
}

void bar() {
  Foo a(10);
  Foo b(20);
  a = a;
}
```

Dynamically Allocated Class Members

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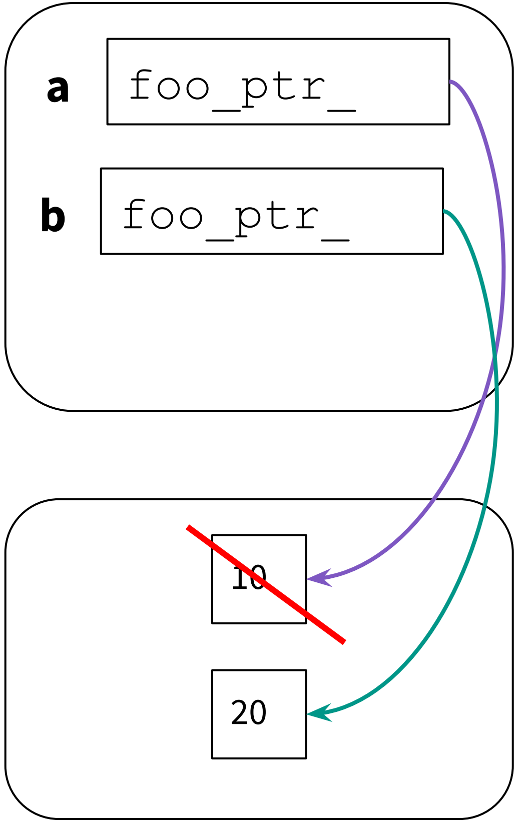
Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
    foo_ptr_ = new int;
   *foo_ptr_ = val;
}

Foo& Foo::operator=(const Foo& rhs) {
  delete foo_ptr_;
  Init(*(rhs.foo_ptr_));
  return *this;
}

void bar() {
  Foo a(10);
  Foo b(20);
  a = a;
}
```

Dynamically Allocated Class Members




```
Foo::Foo(int val) { Init(val); }
Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
    foo_ptr_ = new int;
   *foo_ptr_ = val;
}

Foo& Foo::operator=(const Foo& rhs) {
  delete foo_ptr_;
  Init(*(rhs.foo_ptr_));
  return *this;
}

void bar() {
  Foo a(10);
  Foo b(20);
  a = a;
}
```

```
if(&rhs!=this){

}
```