CS11 Intro C++

FALL 2015-2016

LECTURE 6

C++ Strings

- C++ retains C notion of `char*` as a "string"
  - Array of `char` values, terminated with a 0 value (a.k.a. "the null character" or "NUL")
- Useful C functions for string manipulation in `<cstring>` header (C++ name for `string.h`)
- Typically difficult / bug-prone to manipulate in complex ways
  - Have to manually allocate and reallocate space to hold string data
  - Can easily write past end of string (buffer overflows, exploits!)
  - Can easily forget to free memory used by C strings

C++ Strings (2)

- C++ also introduces a new `std::string` type
  - Resizable string that keeps data in heap memory
  - `#include <string>`
- Provides many features over `char*` strings
  - Ability to insert/delete/replace/extract substrings easily, without manual memory management
  - Can access, mutate, and traverse characters using array access, or using iterators (!!)
  - Can convert to and from `char*` strings easily
  - Supports stream IO with >> and << operators
- Prefer `string` to `char*`, wherever possible!

C++ String Initialization

- C++ `string` objects can be initialized from other strings, or from `char*` values

```
string s1 = "green";   // Same as s1("green");
string s2 = s1;        // Same as s2(s1);
```

  - `s2` is an independent copy of `s1`
- Can also initialize to be a repeated character

```
string reps(5, 'a');     // reps == "aaaaa"
```

- Can also initialize to a substring

```
string s3(s1, 2, 2);     // s3 == "ee"
```

  - First number is the position (zero-based)
  - Second number is count
- Other constructor options too…

C++ String Assignment

- `string` supports assignment operator

```
string s1 = "orange";
string s2 = "yellow";
s2 = s1;
s1 = "gray";
```

- Can also use `assign()` member-function

```
s2.assign(s1);
s1.assign("gray");
```

- Strings do not share underlying storage
  - Assignment makes a copy of what is assigned

String Comparison and Concatenation

- `string` supports comparison operators
  - `== != < >` etc.
  - Case sensitive by default
  - Depends on locale!
- Use + or += for concatenation

```
string title = "purple";
title = title + " people";
title += " eater";
```

- Can also append individual characters

```
title += 's';
```

- Can also use `append()` member-function

String Lengths and Indexes

- `length()` member-function reports number of characters in string

```
string color = "chartreuse";
cout << color << " has " << color.length()
     << " characters." << endl;
```

  - `string` also has a `size()` member-function that does the same thing as `length()`
- Characters have indexes 0 to `length() - 1`
- `string::npos` indicates "invalid index"
- All strings have `length() < string::npos`

Individual Characters

- Individual character access with `[]`

```
string word = "far";
word[1] = 'o';    // now word == "for"
```

  - Indexes aren't checked for validity
  - (Not a big issue, but just be aware of it)
- `string` also provides iterators for traversing characters (!!)
  - "Strings are collections of characters."
  - `begin()` returns an iterator pointing to first char
  - `end()` returns an iterator pointing past last char
  - Can pass `string` iterators to STL algorithms

Finding Substrings

- Four versions of `find()` member function

```
size_type find(const string &, size_type start=0)
size_type find(const char *, size_type start,
                             size_type length)
size_type find(const char *, size_type start=0)
size_type find(char, size_type start=0)
```

  - Returns index of match, or `string::npos` for no match
- The `rfind()` member function searches backwards through a `string`
  - Provides same four versions, with appropriate default values for arguments

Variants of `find()`

- `find_first_of()`, `find_last_of()`
  - Unlike `find()`, matches if any character in argument appears in string
  - `find_first_of()` starts at beginning, goes forward
  - `find_last_of()` starts at end and goes backwards
- `find_first_not_of()`, `find_last_not_of()`
  - Finds first character not in argument
  - Again, can search from beginning, or from end

String Manipulation

- `substr()` extracts a substring

```
substr(size_type start = 0,
       size_type length = npos)
```

  - Returns a new `string` object containing the substring
  - Note that default arguments just copy entire string
- `replace()` modifies a substring
  - Again, many versions of `replace()`
  - Some take iterators; some take start+length arguments
- `erase()` removes a substring
  - "Replace with nothing"
  - Can call with start+length; or with iterators

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More String Manipulation!

- `append()` member functions allow for appending characters or strings
  - Can append a C++ `string`, a C `char*` string, or an individual `char` value
  - (Or you can use += operator, as discussed earlier!)
- `insert()` member functions for inserting characters into a string
  - Can insert at a specific index
  - Can use an iterator to indicate location

Converting C++ Strings to `char*`

- Can convert strings to `char*` values
  - `c_str()` and `data()` both return a zero-terminated `char*`
  - (Before C++11, `data()` returned a non-terminated `char*` value, which wasn't generally very useful)
- Example:

```
string value = "orange";
printf("%s\n", value.c_str());
```

- Also, the `copy(...)` member function copies a string into a `char*` buffer the caller provides
  - Useful when the caller has their own buffer to use

c_str() Gotchas!

- Don't cache pointers returned by `c_str()` or `data()` member functions
  - May not have valid data after a non-`const` call to `string` member function
- Example:

```
string s = "hello";
char *p = s.c_str();
s += " world!";   // p no longer trustworthy
printf("%s\n", p);
```

  - Last line may print garbage, or it may crash, or it may work fine! **Whatever it does, it's a bug!**

c_str() Gotchas! (2)

- Don't return `c_str()` or `data()` value from a `string` local variable!
  - Memory is managed by the `string` object
  - It goes away when the `string` variable goes out of scope!
- A (bad) example:

```
char * getUserName() {
    string name;
    cout << "Enter username:  ";
    cin >> name;
    return name.c_str();  // BAD!
}
```

Shape Classes

- Want to write classes to represent 2D shapes
  - Circle: radius
  - Triangle: base + height
  - Rectangle: width + height
- All these shapes have common features, but also special characteristics
- Common themes:
  - All shapes have an area
- Differences:
  - Shapes have different properties to describe them
  - Each shape has a different way to compute area

Shape Classes (2)

- One approach: one class to represent all kinds of shapes we want to support

```
class Shape {
    string type;  // What kind of shape is it?
    float radius; // For circles only!
    float height; // For triangles, rectangles
    float base;   // For triangles only!
    float width;  // For rectangles only!
public:
    Shape(const string &t); // Specify type
    string getType() const;
    float getArea() const;
};
```

Shape Classes (3)

- **This approach has several drawbacks.**

- Not a clean abstraction!
  - Both data and operations for different shapes are mixed together
- Hard to understand what is going on
  - Very likely to lead to bugs
- Also wastes space
  - For each type of shape, some data members won't be used at all

C++ Class Inheritance

- C++ provides **class inheritance**
  - (as do most OOP languages)
- Base class provides generalized capabilities
  - A generic "shape" type specifying common features
- Derived classes inherit state/behavior of base class
  - All kinds of shapes provide the same general set of operations, e.g. `float getArea() const;`
- Derived classes also provide specialized capabilities
  - Each kind of shape can specify what fields it needs
  - Each kind of shape specifies how to compute its area

C++ Class Inheritance (2)

- Class inheritance models an "is-a" relationship
  - A circle "is a" shape
  - A rectangle "is a" shape
  - A triangle "is a" shape
- Terminology:
  - Base class, parent class, superclass
  - Derived class, child class, subclass

Shape Base-Class


```
class Shape {
public:
    enum class Type {
        CIRCLE, RECTANGLE, TRIANGLE };
private:
    Type type;
public:
    Shape(Type t);
    Shape::Type getType() const;
    float getArea() const;
};
```

- All shapes will have these common traits

Circle Subclass


```
class Circle : public Shape {
    float radius;
public:
    Circle(float r);
    float getArea() const;
};
```

- `Circle` class inherits "shape type" member, and `getType()` / `getArea()` accessors, from `Shape`
- Can also specify that circles need a radius, and how to compute the area of a circle

Rectangle Subclass


```
class Rectangle : public Shape {
    float width;
    float height;
public:
    Rectangle(float w, float h);
    float getArea() const;
};
```

- Similarly, specify that rectangles need a width and a height

Initialization Details

- When a subclass of `Shape` is initialized, the `Shape` constructor must also be invoked
  - Reason: subclass constructor body might access or call superclass members
- If the parent class has a default constructor, this initialization will happen automatically
  - e.g. when a `Circle` is initialized, it would automatically call the `Shape` default constructor

- But, `Shape` doesn't have a default constructor

```
Shape(Type  t);
```

Initialization Details (2)

- `Shape` doesn't have a default constructor

```
Shape(Type t);
```

- `Circle` and `Rectangle` must use a **base-class initializer** to call the `Shape` constructor

```
Circle::Circle(float r) : Shape(Type::CIRCLE) {
    radius = r;
}
```

  - `Circle` constructor specifies that `Shape` constructor should be called first, with `Type::CIRCLE` as the argument
  - Once base-class initialization is complete, `Circle` constructor can continue its work

Initialization Details (3)

- This is only required if the parent class doesn't have a default constructor

```
Circle::Circle(float r) : Shape(Type::CIRCLE) {
    radius = r;
}
```

- If parent class has a default constructor, it will be called automatically when subclass is initialized

- (Also, subclass may simply not want to use the parent class' default constructor…)

Shape Areas

- `Shape` base-class doesn't have an area to compute

```
float Shape::getArea() const {
    return 0;  // do this for now...
}
```

- Subclasses can override the parent-class version

```
float Circle::getArea() const {
    return 3.14159 * radius * radius;
}
float Rectangle::getArea() const {
    return width * height;
}
```

Shape Areas (2)

- Example:

```
Rectangle r(8, 7);
Circle c(5);

cout << "Rectangle area = "
     << r.getArea() << endl;
cout << "Circle area = "
     << c.getArea() << endl;
```

- Prints:

```
Rectangle area = 56
Circle area = 78.53...
```

Shape Areas (3)

- Add a helper function to print shape areas

```
void printArea(Shape &s) {
    cout << "Shape area = "
         << s.getArea() << endl;
}
Rectangle r(8, 7);
Circle c(5);
printArea(r);
printArea(c);
```

- Prints:

```
Rectangle area = 0
Circle area = 0
```

Which `getArea()`?

- By default, C++ uses the variable's type to figure out which function to call

```
void printArea(Shape &s) {
    cout << "Shape area = "
         << s.getArea() << endl;
}
```

- The `getArea()` function is being called on a variable of type `Shape&`...
  - ...so the compiler calls `Shape::getArea()`, which returns 0
  - ...even when `s` actually refers to a subclass of `Shape`
- This is called **static dispatch**, since the compile-time type of the variable (aka the "static type") is used

The `virtual` Keyword

- The `virtual` keyword tells C++ to choose the function to call, based on the type of the object that is referenced, rather than the variable's type
  - This is called **dynamic dispatch**, because it uses the "dynamic type" or the "runtime type" of the value
- In `Shape` class declaration:

```
virtual float getArea() const;
```

- Don't need to restate `virtual` on subclass version of function – the "virtualness" is inherited

- Why not just specify `virtual` on all parent-class functions?

How `virtual` Works

- When a member function is marked `virtual`, C++ stores extra information in the object
  - **The object itself** knows which version of the function to use
- Imposes a [typically very] small size overhead
- Calling virtual functions takes [very] slightly longer

type	CIRCLE
getArea	Circle::getArea

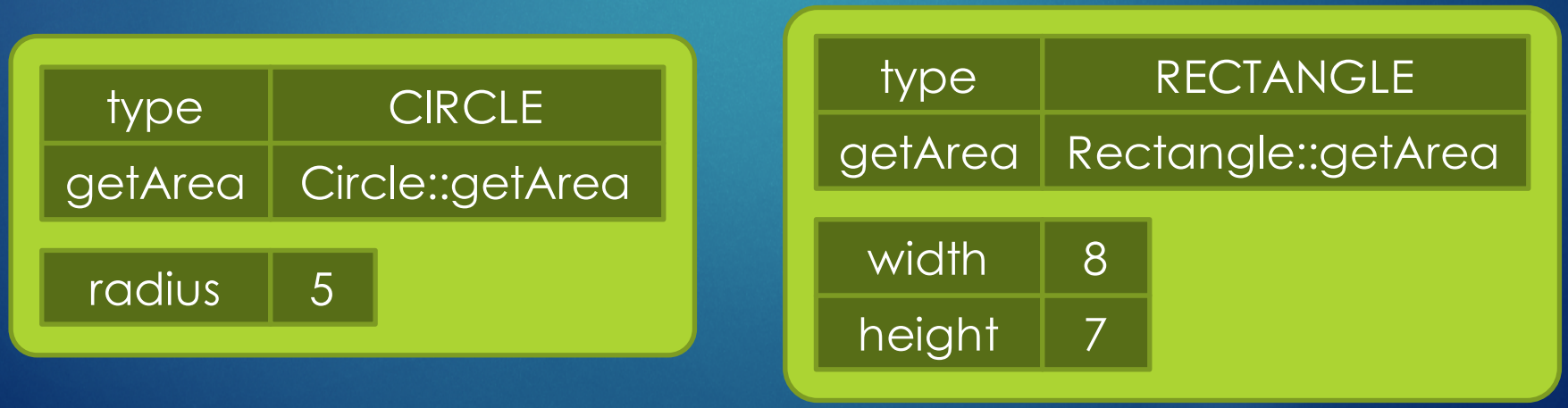
radius	5

type	RECTANGLE
getArea	Rectangle::getArea

width	8
height	7

How `virtual` Works (2)

- You should only mark member functions `virtual` when you intend them to be overridden
- Corollary: if a function isn't marked `virtual`, don't override it!



Class Hierarchies and Destructors

- Final example:

```
Shape *s1 = new Rectangle(8, 7);
Shape *s2 = new Circle(5);
delete s1;
delete s2;
```

- Which destructor will this code call?
  - Both lines will invoke the `Shape` destructor ☹

- The behavior of this code is undefined
  - Typically results in a memory leak, or possibly a crash

Class Hierarchies and Destructors (2)

- **Anytime you create a class hierarchy, you must make sure the base-class destructor is `virtual`**

```
class Shape {
    ...
    virtual ~Shape() { }
};
```

  - If destructor doesn't need to do anything, still give it an empty body so the linker doesn't complain
- When you intend a class to be subclassed, give it a virtual destructor
- Corollary: if a class should not be subclassed, do not give it a virtual destructor!

Shape::getArea()

- This didn't really make sense:

```
float Shape::getArea() {
    return 0;
}
```

- "Shape" is too general a concept for us to define this function
  - We know that all shapes have an area…
  - …but we need a specific kind of shape before we can actually compute the area!

Pure-Virtual Functions

- Can declare functions to be **pure-virtual**
- The function is only declared in the base-class, but it must be defined in subclasses

```
class Shape {
    ...
    virtual float getArea() const = 0;
};
```

  - The "= 0" part makes it pure-virtual
- Now, the `Shape` class cannot be instantiated
  - Part of its implementation is now missing!
  - Compiler will report an error

Abstract Classes

- Shape is now called an **abstract class**
  - It declares behaviors, but doesn't define all of them
- Can still create variables and arguments of type `Shape*` or `Shape&`
  - Variable can reference any object that provides everything that `Shape` declares…
- Allows us to create generic functions that can take any kind of Shape

```
Shape * findLargestArea(
    const vector<Shape *> &shapes);
```

  - Can pass in a vector of pointers to triangles, rectangles, and spheres

Object-Oriented Programming Concepts

- So far, we have seen:
  - **Encapsulation**: hiding and guarding internal state
  - **Abstraction**: presenting a simple, high-level interface
- Class hierarchies introduce two more:
  - **Inheritance**: a child class gets its parent class' members/behavior
    - …and a child-class can customize parent-class behavior
  - **Polymorphism**: calling a function on an object can exhibit different behaviors, based on object's type
    - In C++, this requires the use of virtual functions