CS100 Recitation 10

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Contents

Review: Inheritance

Inheritance:

- **'is-a'** relationship
- Every object of subclass type contains an object of the base type. Every member except ctors and dtors is inherited, no matter what access level it is of.
- Subclass cannot affect behaviors of operations performed on base objects.

Review: Inheritance

Inheritance:

- **'is-a'** relationship
- Every object of subclass type contains an object of the base type. Every member except ctors and dtors is inherited, no matter what access level it is of.
- Subclass cannot affect behaviors of operations performed on base objects.
- Behavior of ctors and dtors?

Review: Dynamic Binding

Dynamic binding:

- A reference or pointer to the base class can be bound to an object of the subclass.
- When a `virtual` function is called **through the reference or pointer to the base class**, it will call the correct version according to the dynamic type of that object.
- Any polymorphic class must have a `virtual` dtor. Why?

Review: Abstract Class

Pure virtual functions and abstract classes:

- Definition of pure `virtual` functions.
- A class with at least one pure `virtual` function is an **abstract class**.
- Abstract classes cannot be instantiated. Pure virtual function without definition cannot be called.
- The subclass is still abstract if one of the pure `virtual` functions in its base class is not overridden.

Review: Abstract Class

Pure virtual functions and abstract classes:

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- A class with at least one pure `virtual` function is an **abstract class**.
- Abstract classes cannot be instantiated. Pure virtual function without definition cannot be called.
- The subclass is still abstract if one of the pure `virtual` functions in its base class is not overridden.
- **Inheritance of interface** vs **inheritance of implementation**

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Swap of Vector

The `std::swap` (defined in `<algorithm>`):

```
template <typename T>
inline void swap(T &lhs, T &rhs) {
  T tmp = lhs;
  lhs = rhs;
  rhs = tmp;
}
```

- Swap is done by three copies.
- Inefficient on some special objects, like `Vector`.

Swap of Vector

Specialize the template function `std::swap`.

- Non-template $>$ template-specialization $>$ template.

```
namespace std {
template <>
inline void swap<Vector>(Vector &lhs, Vector &rhs) {
  // What should we do here?
}
} // namesapce std
```

It seems that `std::swap<Vector>` needs to access the private members.

Swap of Vector

By convention, we define a public member:

```
class Vector {
 public:
  void swap(Vector &other) noexcept {
    using std::swap;
    swap(m_size, other.m_size);
    swap(m_capacity, other.m_capacity);
    swap(m_data, other.m_data);
  }
  // other members
};
```

Swap of Vector

Then we can let `std::swap<Vector>` call that member:

```
namespace std {
template <>
inline void swap<Vector>
    (Vector &lhs, Vector &rhs) noexcept {
  lhs.swap(rhs);
}
} // namespace std
```

Note that

- we are not adding any more things to `std`.
- in contrast to the default version, our `swap` functions are **exception-free**.

Copy and Swap

Surprisingly, we obtain a copy assignment operator that is both self-assignment-safe and exception-safe!

```
class Vector {
 public:
  Vector &operator=(const Vector &other) {
    auto temp = other;
    swap(temp);
    return *this;
  }
};
```

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Prevent Copying

Make the compiler unable to synthesize the copying oeprations?

- If the class has an uncopyable base class.
- If the class has an uncopyable member.

Which one is better?

Prevent Copying

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- If the class has an uncopyable member.

Which one is better?
Empty Base Optimization (EBO).

Uncopyable Class

```
class Uncopyable {
  Uncopyable(const Uncopyable &);
  Uncopyable &operator=(const Uncopyable &);
};
class Widget : public Uncopyable {
  // We don't define the copy operations.
  // The compiler is unable to synthesize them,
  // because the copy operations of the base class are
      inaccessible.
};
```

Private Inheritance

Such definition causes problem: A reference or pointer to `Uncopyable` can be bound to objects of every such class!

Private Inheritance

Such definition causes problem: A reference or pointer to `Uncopyable` can be bound to objects of every such class!

- `private` inheritance: **The inheritance relationship is a secret.**
- Every operation that relies on such relationship cannot be performed, unless in the subclass or `friend` of the subclass.
  - upcasting and downcasting
  - accessing base members
  - dynamic binding
  - ......

Private Inheritance

```
class Uncopyable {
  Uncopyable(const Uncopyable &);
  Uncopyable &operator=(const Uncopyable &);
};
class Widget : private Uncopyable {
  // ...
};
```

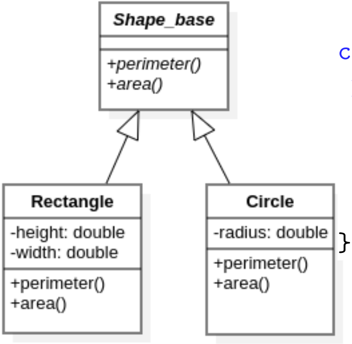
Private Inheritance

```
class Uncopyable {
  Uncopyable(const Uncopyable &);
  Uncopyable &operator=(const Uncopyable &);
};
class Widget : private Uncopyable {
  // ...
};
```

- This method is outdated from the perspective of C++11, but the way it uses inheritance is inspiring.

Contents

Shape




```
class Shape_base {
 public:
  virtual double perimeter() const = 0;
  virtual double area() const = 0;
  virtual ~Shape_base() = default;
  Shape_base() = default;
};
```

Shape

```
class Rectangle : public Shape_base {
  double height, width;
 public:
  Rectangle(double h, double w);
  virtual double perimeter() const override;
  virtual double area() const override;
};
class Circle : public Shape_base {
  double radius;
 public:
  Circle(double r);
  virtual double perimeter() const override;
  virtual double area() const override;
};
```

Problem

How can we define an array of shapes? (also `new`ed arrays, containers, ...)

- `Shape_base shapes[100];` does not work.
  - Abstract base class.
  - Object slicing.
  - The sting of coworkers' derision.
- `Shape_base *shapes[100];` seems to work, but...
  - What happens when `shapes[i] = shapes[j];`?
  - The burden of memory management is on the user's part.

Virtual Copy Function

How can we copy an object correctly?

Virtual Copy Function

How can we copy an object correctly?
DO NOT use downcasting like this!!

```
Shape_base *clone(Shape_base const *ptr) {
  if (typeid(*ptr) == typeid(Rectangle))
    return new Rectangle(dynamic_cast<Rectangle &>(*ptr));
  else
    return new Circle(dynamic_cast<Circle &>(*ptr));
}
```

Virtual Copy Function

Use a group of virtual functions instead.

```
class Shape_base {
 public:
  virtual Shape_base *clone() const = 0;
};
class Rectangle : public Shape_base {
 public:
  virtual Shape_base *clone() const override
    { return new Rectangle(height, width); }
};
class Circle : public Shape_base {
 public:
  virtual Shape_base *clone() const override
    { return new Circle(radius); }
};
```

Covariant Return-type

```
class Shape_base {
 public:
  virtual Shape_base *clone() const = 0;
};
class Rectangle : public Shape_base {
 public:
  virtual Rectangle *clone() const override
    { return new Rectangle(height, width); }
};
class Circle : public Shape_base {
 public:
  virtual Circle *clone() const override
    { return new Circle(radius); }
};
```

Defining a Surrogate

Avoid manual memory management, while still keep the dynamic binding properties.

```
class Shape {
  Shape_base *bp;
 public:
  Shape_base() : bp(nullptr) {}
  double perimeter() const {
    return bp->perimeter();
  }
  double area() const {
      return bp->area();
  }
};
```

Defining a Surrogate

- All other classes are **implementation details**, so all their members should be `private` (or `protected`).
- Declare `Shape` as a `friend` of `Shape_base`.
- Provide two interfaces `make_rectangle` and `make_circle`.
- Resource Aquisition Is Initialization, RAII.

Defining a Surrogate

- All other classes are **implementation details**, so all their members should be `private` (or `protected`).
- Declare `Shape` as a `friend` of `Shape_base`.
- Provide two interfaces `make_rectangle` and `make_circle`.
- Resource Aquisition Is Initialization, RAII.
- Since we allow default construction (so that we can define an array of `Shape`), we can provide an interface to tell whether bp is `nullptr`.

```
bool is_null() const { return !bp; }
```

Interfaces

```
class Shape {
  friend Shape make_rectangle(double, double);
  friend Shape make_circle(double);
 private:
  Shape(Shape_base *p) : bp(p) {}
};
inline Shape make_rectangle(double h, double w)
  { return new Rectangle(h, w); }
inline Shape make_circle(double r)
  { return new Circle(r); }
```

Make sure your surrogate is not influenced by outsider raw pointers!

Copy Control

Call the virtual `clone` function.

```
class Shape {
 public:
  Shape(const Shape &other)
    : bp(other.bp ? other.bp->clone() : nullptr) {}
  Shape &operator=(const Shape &other) {
    // Be careful with self-assignment!
    auto p = other.bp ? other.bp->clone() : nullptr;
    delete bp;
    bp = p;
    return *this;
  }
  ~Shape() { delete bp; }
};
```

Homework Exercise

Use the copy-and-swap technique to define an assignment operator.

Modification

Suppose we have some form of modification:

```
class Shape_base {
  virtual void stretch(double) = 0;
};
class Rectangle : public Shape_base {
  virtual void stretch(double m) override {
    height *= m; width *= m;
  }
};
class Circle : public Shape_base {
  virtual void stretch(double m) override {
    radius *= m;
  }
};
```

Modification

Bitwise-const vs logical-const.

```
class Shape {
 public:
  void stretch(double m) { // Should this be const?
    if (bp)
      bp->stretch(m);
  }
};
```

Use the Surrogate

Now we can use the shapes smoothly.

```
Shape shapes[SIZE];
for (int i = 0; i < n; ++i) {
  if (some_condition(i))
    shapes[i] = make_rectangle(f(), g());
  else
    shapes[i] = make_circle(h());
}
for (int i = 0; i < n; ++i) {
  std::cout << "perimeter == " << shapes[i].perimeter()
            << ", area == " << shapes[i].area()
            << std::endl;
}
```

The annoying pointers suddenly disappear!

Use of the Original Design

```
Shape_base *shapes[SIZE];
for (int i = 0; i < n; ++i) {
  if (some_condition(i))
    shapes[i] = new Rectangle(f(), g());
  else
    shapes[i] = new Circle(h());
}
for (int i = 0; i < n; ++i) {
  std::cout << "perimeter == " << shapes[i]->perimeter()
            << ", area == " << shapes[i]->area()
            << std::endl;
}
for (int i = 0; i < n; ++i)
  delete shapes[i];
```

Value Semantics and Reference Semantics

What will happen when we copy a surrogate object?

```
Shape a = somevalue(), b = somevalue();
a = b;
```

- Value semantics: The object that `b` points to is copied. (The object is **unique**.)
- Reference sematics: `a` and `b` point to the same object. (The object is **shared**.)

Value Semantics and Reference Semantics

Pros and cons?

- Value semantics: always copy the object. Time- and space-costing.
- Reference semantics: avoid copying.
  - But if `b` is destroyed, should we destroy the object that `b` points to?

Value Semantics and Reference Semantics

Pros and cons?

- Value semantics: always copy the object. Time- and space-costing.
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  - But if `b` is destroyed, should we destroy the object that `b` points to?

We want both!

Contents

Reference-counting

We define a new kind of ‘surrogate’, named a **handle**.

- Allow an object to be shared by many handles, and **set a counter on it**.
- Increase the counter when a new handle is pointing to it.
- Decrease the counter when a handle no longer points to it.
- **When the counter is decreased to zero, delete the object!**
  - “*A man is dead when he is forgotten.*”

Reference-counting

```cpp
class Shape_base {
  friend class Shape;
  int use{1};
  virtual double perimeter() const = 0;
  virtual double area() const = 0;
 protected:
  virtual ~Shape_base() = default;
  Shape_base() = default;
};
```

A Reference-counting Handle

```
class Shape {
  Shape_base *bp;
 public:
  double perimeter() const {
    return bp->perimeter();
  }
  double area() const {
    return bp->area();
  }
  bool is_null() const { return !bp; }
 private:
  Shape(Shape_base *p) : bp(p) {}
};
```

Copy Control

Copy ctor and dtor: (Be careful with null pointers!)

```
class Shape {
 public:
  Shape(const Shape &other) : bp(other.bp) {
    if (bp)
      ++bp->use;
  }
  ~Shape() {
    if (bp && !--bp->use)
      delete bp;
  }
};
```

Copy Control

Copy-assignment operator: Self-assignment-safe!!!

```
class Shape {
 public:
  Shape &operator=(const Shape &other) {
    if (other.bp)
      ++other.bp->use;
    if (bp && !--bp->use)
      delete bp;
    bp = other.bp;
    return *this;
  }
};
```

Copy Control

This is **not** self-assignment-safe:

```
Shape &operator=(const Shape &other) {
  if (bp && !--bp->use)
    delete bp;
  bp = other.bp;
  if (other.bp)
    ++other.bp->use;
  return *this;
}
```

Where is Copy?

It seems that we don't need the virtual `clone` functions at all!

But...

Where is Copy?

It seems that we don't need the virtual `clone` functions at all!

But... What if we allow some form of modification?

```
class Shape {
 public:
  void stretch(double m) {
    if (bp)
      bp->stretch(m);
  }
};
```

Where is Copy?

It seems that we don't need the virtual `clone` functions at all!
But... What if we allow some form of modification?

```
class Shape {
 public:
  void stretch(double m) {
    if (bp)
      bp->stretch(m);
  }
};
```

Suppose `Shape a = b;`. After modification on `a`, what if we still want `b` to hold the original object?

```
a.stretch(2);
```

Copy on Write

Solution: We don't copy the object **until modification happens**.

- *Laziness is a virtue!*

```
class Shape {
 public:
  void stretch(double m) {
    if (bp) {
      if (bp->use > 1) {
        --bp->use;
        bp = bp->clone();
      }
      bp->stretch(m);
    }
  }
};
```

Standard Library Support

Since C++11, the ideas of **surrogates** and **reference-counting handles** are supported in the standard library `<memory>` as **smart pointers**.

- `std::shared_ptr` is a reference-counting smart pointer.
- `std::unique_ptr` is a surrogate that keeps unique ownership of an object.
- `std::weak_ptr` might be used for some special purposes.

Reading Materials

- The ideas in this slides are from *Ruminations on C++* Chapter 5 - 7. Chapter 8 is related to Problem 3 in HW5. An interesting example is in Chapter 9 - 10.
- *Effective C++* Item 15, 17 talks about something else related.
- *C++ Primer* Chapter 12 (section 12.1) introduces smart pointers.
- To know about how to use smart pointers properly, see *Effective Modern C++* Item 18 - 22.