CS100 Recitation 10

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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.
- Inefficiency 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?

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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

```cpp
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.

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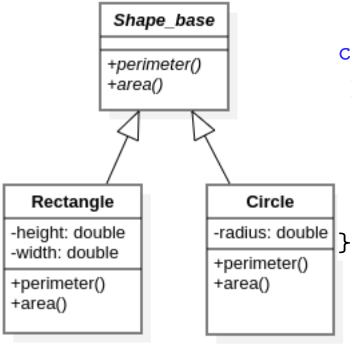
Shape




```cpp
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?

```
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 them.
- 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 them.
- 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.

Use the Surrogate

Now we can use the shapes smoothly.

```
std::vector<Shape> shapeVec;
for (int i = 0; i < n; ++i) {
  if (some_condition(i))
    shapeVec.push_back(make_rectangle(f(), g()));
  else
    shapeVec.push_back(make_circle(h()));
}
for (auto shape : shapeVec) {
  std::cout << "perimeter == " << shape.perimeter()
            << ", area == " << shape.area() << std::endl;
}
```

The annoying pointers suddenly disappear!

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.
- Reference semantics: avoid copying.
    - But if `b` is destroyed, should we destroy the object that `b` points to?

We want both!

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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

```
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->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 some_modification(Type params) {
    if (bp)
      bp->some_modification(params);
  }
};
```

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 some_modification(Type params) {
    if (bp)
      bp->some_modification(params);
  }
};
```

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

```
a.some_modification(/* ... */);
```

Copy on Write

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

- *Laziness is a virtue!*

```
class Shape {
 public:
  void some_modification(Type params) {
    if (bp) {
      auto original = bp;
      bp = original->clone();
      if (!--original->use)
        delete original;
      bp->some_modification(params);
    }
  }
};
```

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, 6, 7. Chapter 8 is related to Problem 3 in HW5. Chapter 9 and 10 talks about an interesting example.
- *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.