Module 28: Programming in C++

Polymorphism: Part 3: Abstract Base Class

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Slides taken from NPTEL course on Programming in Modern C++

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Module Objectives

- Understand why destructor must be `virtual` in a class hierarchy
- Learn to work with class hierarchy

Module Outline

Virtual Destructor


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

class B { int data_; public:
    B(int d) :data_(d) { cout << "B()" << endl; }
    ~B() { cout << "~B()" << endl; }
     virtual void Print() { cout << data_; }
};
class D: public B { int *ptr_; public:
    D(int d1, int d2) :B(d1), ptr_(new int(d2)) { cout << "D()" << endl; }
    ~D() { cout << "~D()" << endl; delete ptr_; }
    void Print() { B::Print();  cout << " " << *ptr_; }
};
int main() {
    B *p = new B(2);
    B *q = new D(3, 5);

    p->Print(); cout << endl;
    q->Print(); cout << endl;

    delete p;
    delete q;
}
```

```
Output:
B()
B()
D()
2
3 5
~B()
~B()

Destructor of d (type D) not called!
```

Virtual Destructor


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

class B { int data_; public:
    B(int d) :data_(d) { cout << "B()" << endl; }
    virtual ~B() { cout << "~B()" << endl; }       // Destructor made virtual
    virtual void Print() { cout << data_; }
};
class D: public B { int *ptr_; public:
    D(int d1, int d2) :B(d1), ptr_(new int(d2)) { cout << "D()" << endl; }
    ~D() { cout << "~D()" << endl; delete ptr_; }
    void Print() { B::Print();  cout << " " << *ptr_; }
};
int main() {
    B *p = new B(2);
    B *q = new D(3, 5);

    p->Print(); cout << endl;
    q->Print(); cout << endl;

    delete p;
    delete q;
}
```

```
Output:
B()
B()
D()
2
3 5
~B()
~D()
~B()

Destructor of d (type D) is called!
```

Virtual Destructor: Slicing

- Slicing is where we assign an object of a derived class to an instance of a base class, thereby losing part of the information - some of it is sliced away

```
#include <iostream>
using namespace std;
class Base { protected: int i; public:
    Base(int a)      i = a;
    virtual void display() { cout << "I am Base class object, i = " << i << endl; }
};
class Derived : public Base { int j; public:
    Derived(int a, int b) : Base(a) { j = b; }
    virtual void display() { cout<< "I am Derived class object, i = " << i << ", j = " << j <<endl; }
};
// Global method, Base class object is passed by value
void somefunc (Base obj) { obj.display(); }
int main() { Base b(33); Derived d(45, 54);
    somefunc(b);
    somefunc(d);  // Object Slicing, the member j of d is sliced off
}
```

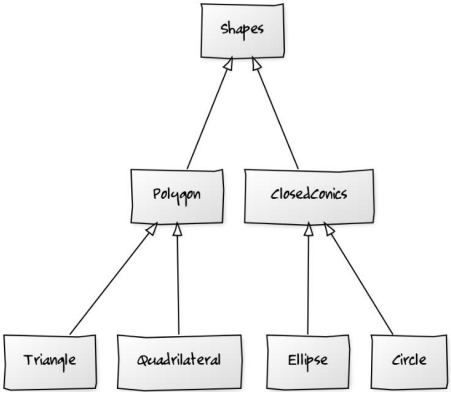
```
I am Base class object, i = 33
I am Base class object, i = 45
```

- If the destructor is not `virtual` in a polymorphic hierarchy, it leads to Slicing
- **Destructor must be declared `virtual` in the base class**

Pure Virtual Function

Pure Virtual Function

Hierarchy of Shapes



- We want to have a polymorphic `draw()` function for the hierarchy
- `draw()` will be overridden in every class based on the drawing algorithms
- What is the `draw()` function for the root `Shapes` class?

Pure Virtual Function

- For the polymorphic hierarchy of `Shapes`, we need `draw()` to be a `virtual` function
- `draw()` must be a member of `Shapes` class for polymorphic dispatch to work
- But we cannot define the body of `draw()` function for the root `Shapes` class as we do not have an algorithm to draw an arbitrary share. In fact, we cannot even have a representation for shapes in general!
- Pure Virtual Function solves the problem
- A Pure Virtual Function has a signature but no body!
- Example:

```
class Root { public:
    void f();             // Non-Virtual Function
    virtual void g();     // Virtual Function
    virtual void h() = 0; // Pure Virtual Function
};
```

Abstract Base Class

Abstract Base Class

- A class containing at least one Pure Virtual Function is called an Abstract Base Class
- Pure Virtual Functions may be inherited or defined in the class
- No instance can be created for an Abstract Base Class
- Naturally it may not have a constructor or a `virtual` destructor
- An Abstract Base Class, however, may have other `virtual` (non-pure) and non-`virtual` member functions as well as data members
- Data members in an Abstract Base Class should be protected. Of course, private and public data are also allowed
- Member functions in an Abstract Base Class should be public. Of course, private and protected methods are also allowed
- A Concrete Class must override and implement all Pure Virtual Functions so that it can be instantiated

Shape Hierarchy


```
#include <iostream>  // Abstract Base Class shown in red
using namespace std; // Concrete Class shown in green

class Shapes { public:                                    // Abstract Base Class
    virtual void draw() = 0; // Pure Virtual Function
};
class Polygon: public Shapes { public: void draw() { cout<< "Polygon: Draw by Triangulation" <<endl; } };
class ClosedConics: public Shapes { public:               // Abstract Base Class
    // draw() inherited - Pure Virtual
};
class Triangle: public Polygon { public: void draw() { cout << "Triangle: Draw by Lines" << endl; } };
class Quadrilateral: public Polygon { public:
    void draw() { cout << "Quadrilateral: Draw by Lines" << endl; }
};
class Circle: public ClosedConics { public:
    void draw() { cout << "Circle: Draw by Breshenham Algorithm" << endl; }
};
class Ellipse: public ClosedConics { public: void draw() { cout << "Ellipse: Draw by ..." << endl; } };
int main() {
    Shapes *arr[] = { new Triangle, new Quadrilateral, new Circle, new Ellipse };

    for (int i = 0; i < sizeof(arr) / sizeof(Shapes *); ++i)
        arr[i]->draw();
    // ...
}
```

Shape Hierarchy


```
int main() {
    Shapes *arr[] = { new Triangle, new Quadrilateral, new Circle, new Ellipse };

    for (int i = 0; i < sizeof(arr) / sizeof(Shapes *); ++i)
        arr[i]->draw();
    // ...
    return 0;
}
```

```
Triangle: Draw by Lines
Quadrilateral: Draw by Lines
Circle: Draw by Breshenham Algorithm
Ellipse: Draw by ...
```

- Instances for `class Shapes` and `class ClosedConics` cannot be created

Shape Hierarchy: A Pure Virtual Function may have a body!


```
#include <iostream>
using namespace std;
class Shapes { public:                                  // Abstract Base Class
    virtual void draw() = 0 // Pure Virtual Function
    { cout << "Shapes: Init Brush" << endl; }
};
class Polygon: public Shapes { public:                  // Concrete Class
    void draw() { Shapes::draw(); cout << "Polygon: Draw by Triangulation" << endl; }
};
class ClosedConics: public Shapes { public:             // Abstract Base Class
    // draw() inherited - Pure Virtual
};
class Triangle: public Polygon { public:                // Concrete Class
    void draw() { Shapes::draw(); cout << "Triangle: Draw by Lines" << endl; }
};
class Quadrilateral: public Polygon { public:           // Concrete Class
    void draw() { Shapes::draw(); cout << "Quadrilateral: Draw by Lines" << endl; }
};
class Circle: public ClosedConics { public:             // Concrete Class
    void draw() { Shapes::draw(); cout << "Circle: Draw by Breshenham Algorithm" << endl; }
};
class Ellipse: public ClosedConics { public:            // Concrete Class
    void draw() { Shapes::draw(); cout << "Ellipse: Draw by ..." << endl; }
};
```

Shape Hierarchy


```
int main() {
    Shapes *arr[] = { new Triangle, new Quadrilateral, new Circle, new Ellipse };

    for (int i = 0; i < sizeof(arr) / sizeof(Shapes *); ++i)
        arr[i]->draw();
}
```

```
Shapes: Init Brush
Triangle: Draw by Lines
Shapes: Init Brush
Quadrilateral: Draw by Lines
Shapes: Init Brush
Circle: Draw by Breshenham Algorithm
Shapes: Init Brush
Ellipse: Draw by ...
```

- Instances for `class Shapes` and `class ClosedConics` cannot be created
- Some compilers do not allow to inline the function body for a pure `virtual` function

```
class Shapes { public: virtual void draw() = 0 { cout << "Shapes: Init Brush" << endl; } };
```

Outline the function body:

```
class Shapes { public: virtual void draw() = 0; };
void Shapes::draw() { cout << "Shapes: Init Brush" << endl; }
```

Module Summary

- Discussed why destructors must be `virtual` in a polymorphic hierarchy
- Introduced Pure Virtual Functions
- Introduced Abstract Base Class