

CS100 Recitation 9

GKxx

April 18, 2022

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Inheritance and Polymorphism

- Inheritance

- Dynamic Binding

- Abstract Base Classes

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Defining a Subclass

An item for sale:

- `std::string name;`
- `double price;`
- `std::string get_name() const;`
- `double net_price(std::size_t n) const;`

A discounted item **is an** item, and has some more information:

- `std::size_t min_quantity;`
- `double discount;`

The net price for such item is $n * \text{price}$ if $n < \text{min_quantity}$,
or $n * \text{discount} * \text{price}$ otherwise.

Defining a Subclass

Things to consider:

- Does your class need a default constructor?
 - If so, what should be a reasonable behavior?
 - What will happen if not?
- Does your class need special copy-control?
 - Seems not.
 - But what if we have another thing called a Basket...?
 - What if every item has a unique id...?
- What value should `discount` have to represent '20% off'?

protected members

A **protected** member is private, except that it is accessible in subclasses.

- price is accessible in Discounted_item.
- Should name be **protected** or **private**?
 - **private** is ok if the subclass doesn't (shouldn't) modify it. It is accessible through the public get_name interface.
 - **protected** is also reasonable.

The core idea is to **separate implementation details and interfaces**.

Inheritance

By defining `Discounted_item` to be a subclass of `Item`, **every object of `Discounted_item` contains an object of `Item`.**

- Every data member and member function, except the constructors, are inherited, no matter what access level they have.
- What can we derive from this?
 - When constructing an object of a subclass, one of the ctors of the base class must be called before initializing the members that the subclass declares.
 - The dtor of the subclass must call the dtor of the base class (automatically) after the members of the subclass are destroyed.
 - `sizeof(Derived) >= sizeof(Base).`

Inheritance

Core ideas of inheritance:

- Every sub-object contains an object of the base class.
- The father has his own ways of doing things, which children cannot affect!

Inheritance and Constructors

```
class Discounted_item : public Item {  
    std::size_t min_quantity = 0;  
    double discount = 1.0;  
public:  
    Discounted_item(const std::string &s, double p,  
                    std::size_t qty, double disc)  
        : Item(s, p), min_quantity(qty), discount(disc) {}  
    // other members  
};
```

- What if we don't call the ctor of the base class explicitly?
- Can we directly initialize the members of the base class?

```
Discounted_item(const std::string &s, double p,  
                std::size_t qty, double disc)  
    : name(s), price(p), min_quantity(qty),  
      discount(disc) {}
```

Inheritance and Constructors

Constructors are not automatically inherited, but we can inherit them explicitly:

```

class Binary_node {
protected:
    Expr_node *lhs, *rhs;
    Binary_node(Expr_node *left,
                Expr_node *right)
        : lhs(left), rhs(right) {}
    // other members
};

class Plus_node
    : public Binary_node {
using Binary_node::Binary_node;
    // other members
};

```

then `Plus_node` has a constructor

```

Plus_node(Expr_node *left,
           Expr_node *right)
    : Binary_node(left, right)
{}

```

and we can call it by

```

Plus_node pn(a, b);
auto pnp
    = new Plus_node(a, b);

```

Inheritance and Constructors

- Default ctor and copy ctor won't be inherited by a `using` declaration. (Why?)
- All the ctors (except default ctor and copy ctor) are inherited by a `using` declaration. But the subclass can rewrite some.
 - If the subclass has a ctor which has the same parameters as one of the ctors of the base class, then this ctor is hiding the corresponding one of the base class.
- The access-level will be preserved. (Why?)
- The `explicit` attribute, if any, is also preserved.
- How will the inherited ctors initialize the members of the subclass?

Inheritance and friends

Friendship cannot be inherited.

- Are you getting along well with your father's friends?

Inheritance and Copy-control

We will talk about this later...

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Upcasting

A reference or pointer to base class can be bound to an object of subclass. (Why?)

```
Discounted_item di = some_value();  
Item &ir = di;    // Treat di as an Item object  
Item *ip = &di;
```

But on such references or pointers, only the members of base class are accessible. (Why?)

Upcasting: Example

```
inline void print_info(const Item &item) {  
    std::cout << "Name: " << item.get_name()  
               << ", price: " << item.net_price(1)  
               << std::endl;  
}  
  
// in main  
Discounted_item di = some_value();  
Item i = some_other_value();  
print_info(di);  
print_info(i);
```


Static Type and Dynamic Type

- **static type** of an expression: The type known at compile-time.
- **dynamic type** of an expression: The real type of the object that the expression or variable is representing. **Known at runtime.**

```
Discounted_item di = some_value();  
Item &ir = di; // ir has static type Item &,  
               // but dynamic type Discounted_item.
```

Static Type and Dynamic Type

```
inline void print_info(const Item &item) {  
    std::cout << "Name: " << item.get_name()  
               << ", price: " << item.net_price(1)  
               << std::endl;  
}
```

The static type of `item` is `const Item &`, but the dynamic type is unknown.

virtual Functions

```
inline void print_info(const Item &item) {  
    std::cout << "Name: " << item.get_name()  
               << ", price: " << item.net_price(1)  
               << std::endl;  
}
```

Which net_price is called?

virtual Functions

```
class Item {  
    public:  
        virtual double net_price(std::size_t n) const;  
        // other members  
};  
class Discounted_item : public Item {  
    public:  
        virtual double net_price(std::size_t n) const override;  
        // other members  
};
```

virtual Functions

- The dynamic type of parameter `item` is runtime-determined.
- Since `net_price` is a **virtual** function, which one is called is determined at **runtime**, so that the correct version is called.
- **late-binding**, or **dynamic-binding**.

Overriding a virtual Function

To **override** a **virtual** function,

- The function must have parameters the same as the function in the base class has.
- The return-type of the function should be either **identical to** or **covariant with** (What's this?) that of the corresponding function in the base class.
- Don't forget the **const** qualifier!

To make sure that your function overrides the one in the base class, use the **override** keyword.

Overriding a virtual Function

- An overriding function is still **virtual**, even if not explicitly declared.
- The best practice is to explicitly write '**virtual**' and '**override**'.
 - The **override** keyword lets the compiler check and report if the function is not actually overriding.
- Distinguish between **overriding**, **overloading** and '**hiding**'.
 - Avoid confusing cases in your program! Don't invite troubles for yourself.

virtual Destructors

```
Base *bp = some_value();  
delete bp;
```

which destructor should be called by 'delete bp'?

virtual Destructors

```
Base *bp = some_value();  
delete bp;
```

which destructor should be called by 'delete bp'?

- To make dynamic binding work correctly, the destructors must be **virtual**!
- The synthesized destructor is **non-virtual**, but we can:

```
virtual ~Base() = default;
```

- If the dtor of the base class is **virtual**, the synthesized destructor is also **virtual**.

Inheritance and Copy-control

Remember to copy the base part correctly! One possible way:

```
class Derived : public Base {
public:
    Derived(const Derived &d)
        : Base(d), /* members of Derived */ {}
    Derived &operator=(const Derived &d) {
        Base::operator=(d);
        // copy members of Derived
        return *this;
    }
};
```

Synthesized Copy-control Functions

- When will the compiler synthesize a copy-control function?
- What's the behavior of them?
- When will the compiler mark them as **deleted**?
- What about default ctors?

Slicing

Suppose Base and Derived have a **virtual** function foo.

```
Derived d = some_value();
```

```
Base b = d;
```

```
b.foo();    // Base::foo or Derived::foo?
```

When using an object of a subclass to initialize or assign to an object of the base class, the copy-ctor or copy-assignment operator **of the base class** is called.

- Therefore, the sub-part of the object is ignored, or **sliced down**.
- Dynamic binding won't happen.

Downcasting

```
Base *bp = new Derived{};
```

We cannot access the members of the subclass through a pointer to the base class. We need a **downcasting**.

- As long as the following conditions are satisfied, you can make a downcasting:
 - The pointer or reference to the base class is **indeed** bound to an object of the subclass.
 - The base class and the subclass are polymorphic, which means that there is at least one **virtual** function.
- You can make a downcasting by **dynamic_cast**:

```
Derived *dp = dynamic_cast<Derived *>(bp);  
Derived &dr = dynamic_cast<Derived &>(*bp);
```

Downcasting

- `dynamic_cast` may have a significant runtime cost.
- Several common ways to avoid `dynamic_cast`, like writing a group of `virtual` functions.
- *Effective C++* Item 27 talks about type-casting.
- *More Effective C++* Item 31 talks about some more complicated cases: Making functions virtual with respect to more than one object.

Notice

Avoid `dynamic_cast`, especially in performance-sensitive code.

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Pure virtual Functions

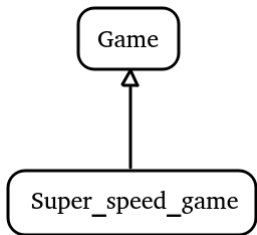
By defining a function to be =0, it is defined as a **pure virtual** function.

- A class with at least one pure virtual function is an **abstract class**.
- A pure virtual function can be overridden in a subclass. But if it is not overridden, the subclass is still abstract.
- Creating objects of a type that is an abstract class is **not allowed**.

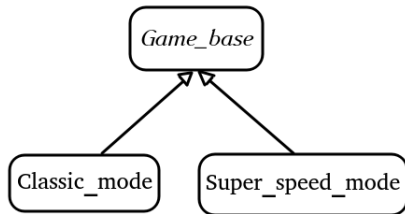
Generally, virtual functions in the base class that do not have a reasonable behavior should be pure virtual, and such class should be abstract.

Example: Greedy Snake

“A super-speed game is a game.”

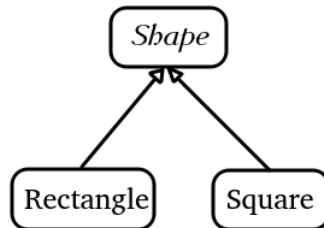
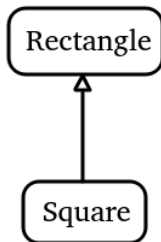


“A classic-mode game is a game.
A super-speed game is also a game.”



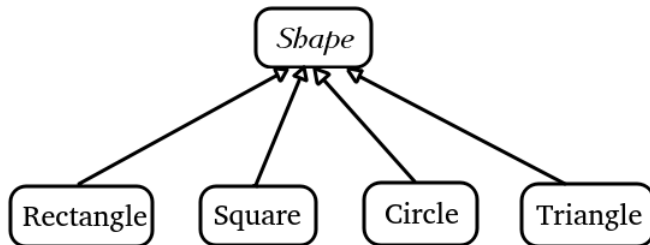
It turns out that the super-speed mode has too many differences from the classic-mode, so I **refactored** the program according to the diagram on the right.

Which One is Better?



Which One is Better?

- “A square **is** a rectangle” is correct, but sometimes this is deceptive. (*Effective C++* Item 32, very important)
- The structure on the right can be extended easily: (**reusability**)



A Pure virtual Destructor

Sometimes a class should be abstract, but there seems to be no reasonable choice over which function should be pure virtual.

A Pure virtual Destructor

Sometimes a class should be abstract, but there seems to be no reasonable choice over which function should be pure virtual.

- Define the destructor to be pure virtual, and provide another definition.

```
class Base {  
    public:  
        virtual ~Base() = 0;  
};  
Base::~~Base() {}
```

In fact, we can provide definitions for pure virtual functions.

More on Inheritance...

- There is still one thing that is magic to us: the ‘**public**’ keyword:

```
class Discounted_item : public Item {};
```

- **public** inheritance models ‘is-a’, while **private** inheritance models ‘is-implemented-in-terms-of’. What’s that?

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Default Arguments

```
void create_window(std::size_t height = 24,  
                  std::size_t width = 80) {  
    // create a window with given height and width  
}
```

If the caller omit the 'width' argument

```
create_window(30);
```

then width will be set to default value 80. If both arguments are omitted

```
create_window();
```

then height is set to 24 and width 80.

Default Arguments

- Only the last few parameters can have default arguments.

```
void fun(int a = 42, int b); // Error
```

- Functions that have default arguments will be treated as **overloading functions**. For the `create_window` function, it is the same as

```
void create_window();  
void create_window(std::size_t height);  
void create_window(std::size_t height,  
                  std::size_t width);
```

Default Arguments

Member functions can also have default arguments:

```
class Vector {  
    public:  
        Vector(std::size_t n, int val = 0)  
            : m_size(n), m_capacity(n),  
              m_data(new int[n]{})) {  
            for (std::size_t i = 0; i < n; ++i)  
                m_data[i] = val;  
        }  
        // other members  
};
```

It will be treated as if there are two constructors

```
Vector::Vector(std::size_t);  
Vector::Vector(std::size_t, int);
```

Default Argument Declaration

A function may be declared multiple times, but default arguments should **not** be redeclared.

```
class Vector {  
    public:  
        Vector(std::size_t n, int val = 0);  
};  
Vector::Vector(std::size_t n, int val = 0) // Error.  
    : m_size(n), m_capacity(n), m_data(new int[n]{} ) {  
    std::fill_n(m_data, n, val);  
}
```

Default Argument Declaration

A function may be declared multiple times, but default arguments should **not** be redeclared. (Why?)

```
class Vector {  
    public:  
        Vector(std::size_t n, int val = 0);  
};  
Vector::Vector(std::size_t n, int val) // Correct.  
    : m_size(n), m_capacity(n), m_data(new int[n]{} ) {  
    std::fill_n(m_data, n, val);  
}
```

Default Argument Declaration

Although it seems weird, subsequent declarations can have additional default arguments.

```
void create_window(std::size_t height,  
                  std::size_t width = 80);  
void craete_window(std::size_t height = 24, // OK.  
                  std::size_t width) {  
    // ...  
}
```

Defaults can be specified only when all parameters to the right already have defaults.

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Command-Line Arguments

Suppose you are the author of `g++`. When the user type `g++ -o hello hello.cpp` in the terminal, there should be a way to let your program get this command.

Command-Line Arguments

Suppose you are the author of g++. When the user type
`g++ -o hello hello.cpp`
in the terminal, there should be a way to let your program get this command.

```
int main(int argc, char **argv) {  
    // ...  
}
```

- `argv` is an array of strings. In this example, `argv = {"g++", "-o", "hello", "hello.cpp"}`.
- `argc` is the number of strings in the array `argv`.
- `char *argv[]` is the same as `char **argv`.

Command-Line Arguments

The only two correct versions of the main function:

```
int main();  
int main(int argc, char **argv);
```

Assertion

```
#include <cassert>
int main() {
    int a, b;
    std::cin >> a >> b;
    assert(b != 0);
    int c = a / b;
    // ...
}
```

C++11 also provides compile-time assertion `static_assert`, but it's too early for you now... (We used this in Problem 2 to detect whether your `Shape` class is abstract.)

Some Helpful Macros

To disable assertions, we can `#define` the `NDEBUG` macro textbfat the very beginning.

```
#define NDEBUG
#include <cassert>
#include <iostream>
int main() {
    int a, b;
    std::cin >> a >> b;
    assert(b != 0); // This assertion will not be performed.
    // ...
}
```

Some Helpful Macros

- `__LINE__`: `int`, the line number.
- `__func__`: `const char []`, the name of the current function.
- `__FILE__`: `const char []`, the name of the current file.
- `__TIME__`: `const char []`, the current time.

New-style Alias Declaration

```
using LL = long long;
```

The new-style type alias declaration is more clear:

```
typedef int arr_t[10];  
using arr_t = int[10];
```

The `using` type alias declaration can also be a template, but `typedef` cannot.

Type Alias Member

```

class Vector {
public:
    using size_type = std::size_t;
    using value_type = int;
    using pointer = int *;
    using reference = int &;
    // other members
};

int main() {
    Vector v = some_value();
    for (Vector::size_type i = 0;
         i < v.size(); ++i)
        // do something
}

```

- Access modifiers also apply to type alias members.
- To access a type alias member, use *class-name::type-member*.