

C++ Inheritance I

CSE 333 Spring 2022

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Administrivia

- ❖ Next exercise (ex 12), was out Fri., due Wed. morning
 - wordcount! (and stl map makes it very short!!)

- ❖ HW3 starter code pushed to repos Friday
 - Not due for a couple of weeks, but start now!

- ❖ Midterm exam this(!) Friday 5/6
 - Topic list and old exams on website now
 - Closed book, slides, etc., but you may have one 5x8 notecard with whatever handwritten notes you want on both sides
 - Free blank cards available in class this week
 - Review in sections this week – bring questions!!

Lecture Outline

❖ C++ Inheritance

- Review of basic idea
- Dynamic Dispatch
- vtables and vptr

❖ Reference: *C++ Primer*, Chapter 15

Overview of Next Two Lectures

❖ C++ inheritance

- Review of basic idea (pretty much the same as in Java)
- What's different in C++ (compared to Java)
 - *Static vs dynamic dispatch - virtual functions and vtables (i.e., dynamic dispatch) are optional*
 - *Pure virtual functions, abstract classes, why no Java "interfaces"*
 - *Assignment slicing, using class hierarchies with STL*
- Casts in C++
- Reference: C++ Primer, ch. 15
 - (read it! a lot of how C++ does this looks like Java, but details differ)

Stock Portfolio Example

- ❖ A portfolio represents a person's financial investments
 - Each *asset* has a cost (*i.e.* how much was paid for it) and a market value (*i.e.* how much it is worth)
 - The difference between the cost and market value is the *profit* (or loss)
 - Different assets compute market value in different ways
 - A **stock** that you own has a ticker symbol (*e.g.* "GOOG"), a number of shares, share price paid, and current share price
 - A **dividend stock** is a stock that also has dividend payments
 - **Cash** is an asset that never incurs a profit or loss

(Credit: thanks to Marty Stepp for this example)

Design Without Inheritance

❖ One class per asset type:

Stock
symbol_ total_shares_ total_cost_ current_price_
GetMarketValue() GetProfit() GetCost()

DividendStock
symbol_ total_shares_ total_cost_ current_price_ dividends_
GetMarketValue() GetProfit() GetCost()

Cash
amount_
GetMarketValue()

- Redundant!
- Cannot treat multiple investments together
 - *e.g.* can't have an array or `vector` of different assets

❖ See sample code in `initial_design/`

Inheritance

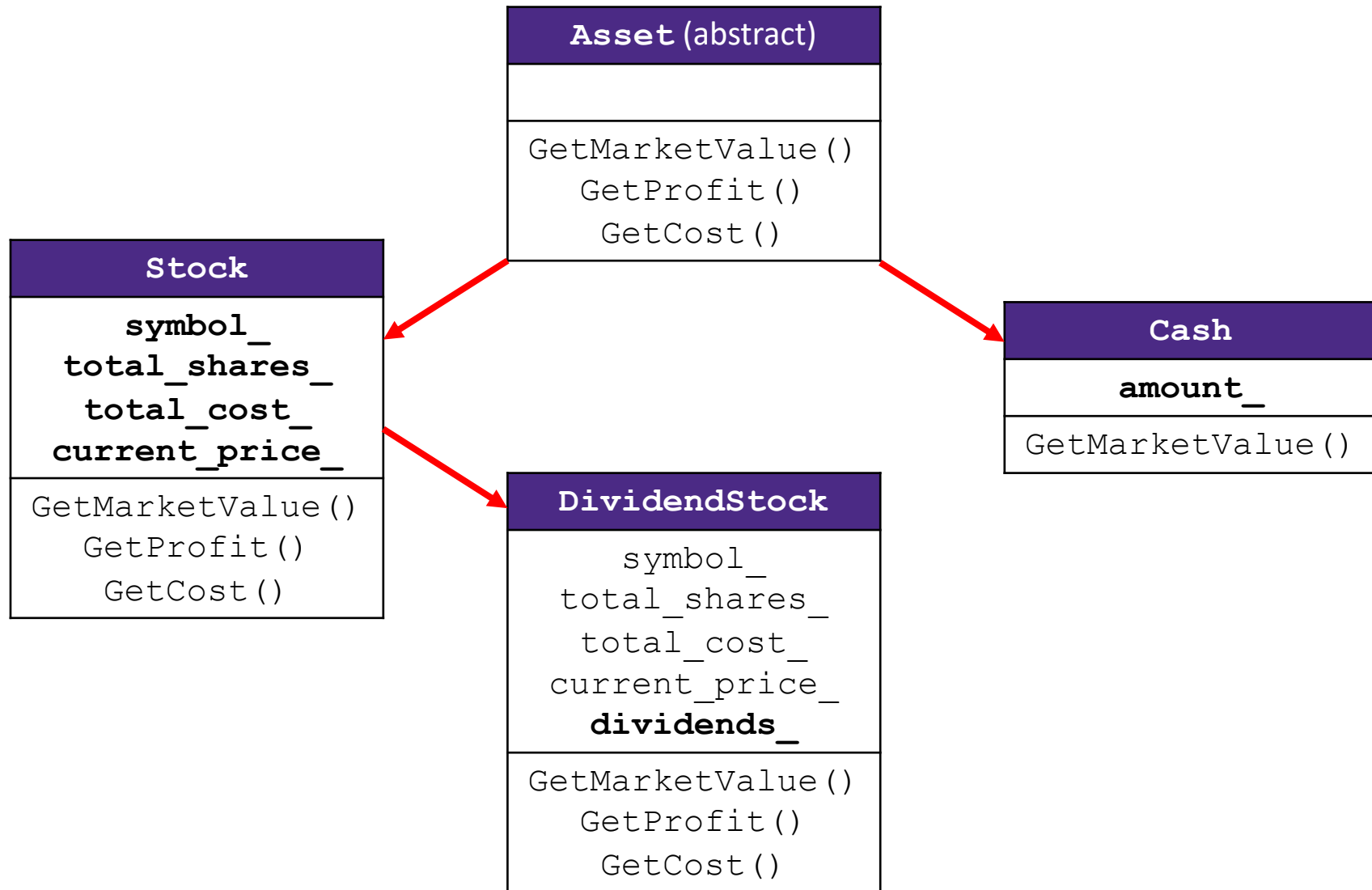
- ❖ A parent-child “is-a” relationship between classes
 - A child (**derived class**) extends a parent (**base class**)
- ❖ Benefits:
 - Code reuse
 - Children can automatically inherit code from parents
 - Polymorphism
 - Ability to redefine existing behavior but preserve the interface
 - Children can override the behavior of the parent
 - Others can make calls on objects without knowing which part of the inheritance tree it is in
 - Extensibility
 - Children can add behavior

Terminology

Java	C++
Superclass	Base Class
Subclass	Derived Class

- ❖ Mean the same things. You'll hear both.

Design With Inheritance



Like Java: Access Modifiers

- ❖ `public`: visible to all other classes
- ❖ `protected`: visible to current class and its *derived* classes
- ❖ `private`: visible only to the current class

- ❖ Use `protected` for class members only when
 - Class is designed to be extended by subclasses
 - Subclasses must have access but clients should not be allowed

Class derivation List

- ❖ Comma-separated list of classes to inherit from:

```
#include "BaseClass.h"

class Name : public BaseClass {
    ...
};
```

- Focus on **single inheritance**, but *multiple inheritance* possible
- ❖ Almost always you will want **public inheritance**
 - Acts like `extends` does in Java
 - Any member that is non-private in the base class is the same in the derived class; both *interface and implementation inheritance*
 - Except that constructors, destructors, copy constructor, and assignment operator are *never* inherited

Back to Stocks

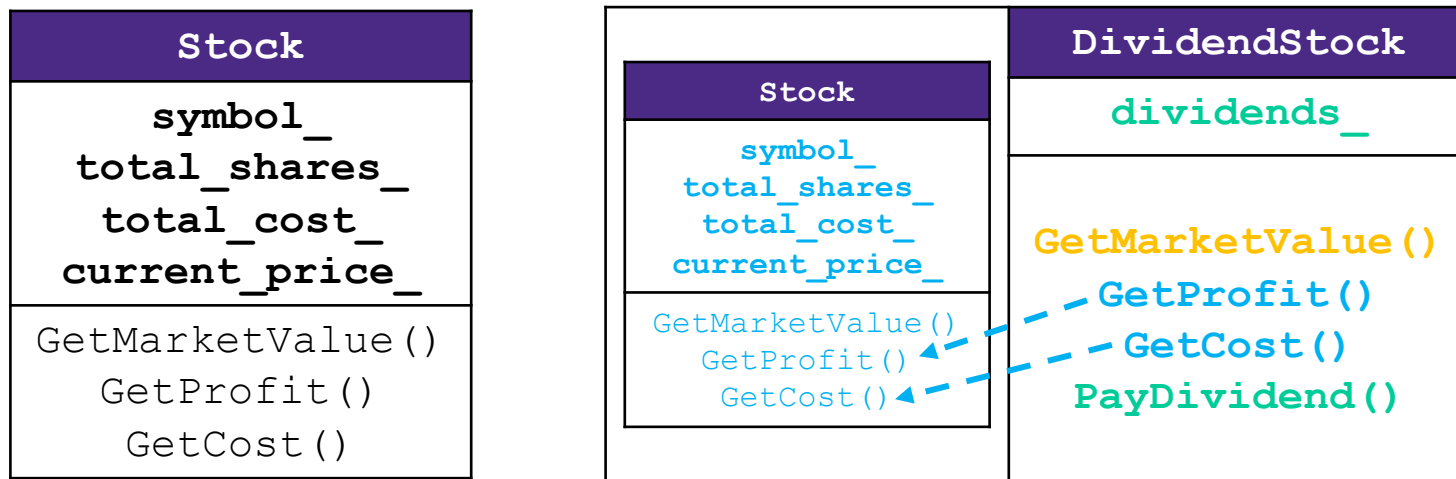
Stock
symbol_ total_shares_ total_cost_ current_price_
GetMarketValue() GetProfit() GetCost()

BASE

DividendStock
symbol_ total_shares_ total_cost_ current_price_ dividends_
GetMarketValue() GetProfit() GetCost()

DERIVED

Back to Stocks



- ❖ A derived class:
 - **Inherits** the behavior and state (specification) of the base class
 - **Overrides** some of the base class' member functions (opt.)
 - **Extends** the base class with new member functions, variables (opt.)

Like Java: Dynamic Dispatch

- ❖ Usually, when a derived function is available for an object, we want the derived function to be invoked
 - This requires a *run time* decision of what code to invoke
 - This is similar to Java
- ❖ A member function invoked on an object should be the *most-derived function* accessible to the object's visible type
 - Can determine what to invoke from the *object* itself
- ❖ Example: `PrintStock(Stock *s) { s->Print() }`
 - Calls `Print()` function appropriate to `Stock`, `DividendStock`, etc. without knowing the exact class of `*s`, other than it is some sort of `Stock`
 - So the `Stock` (`DividendStock`, etc.) object *itself* has to carry some sort of information that can be used to decide which `Print()` to call
 - (see inherit-design/useassets.cc)

Requesting Dynamic Dispatch

- ❖ Prefix the member function declaration with the `virtual` keyword
 - Derived/child functions don't need to repeat `virtual`, but was traditionally good style to do so
 - This is how method calls work in Java (no virtual keyword needed)
 - You almost always want functions to be virtual
- ❖ `override` keyword (C++11)
 - Tells compiler this method should be overriding an inherited virtual function – *always* use if available
 - Prevents overloading vs. overriding bugs
- ❖ Both of these are technically *optional* in derived classes
 - A virtual function is virtual in all subclasses as well
 - Be consistent and follow local conventions

Dynamic Dispatch Example

- ❖ When a member function is invoked on an object:
 - The *most-derived function* accessible to the object's visible type is invoked (decided at run time based on actual type of the object)

```
double DividendStock::GetMarketValue() const {  
    return get_shares() * get_share_price() + dividends_;  
}  
  
double "DividendStock"::GetProfit() const { // inherited  
    return GetMarketValue() - GetCost();  
} // really Stock::GetProfit() DividendStock.cc
```

```
double Stock::GetMarketValue() const {  
    return get_shares() * get_share_price();  
}  
  
double Stock::GetProfit() const {  
    return GetMarketValue() - GetCost();  
} Stock.cc
```


Dynamic Dispatch Example

```
#include "Stock.h"
#include "DividendStock.h"

DividendStock dividend();
DividendStock* ds = &dividend;
Stock* s = &dividend;    // why is this allowed?

// Invokes DividendStock::GetMarketValue()
ds->GetMarketValue();

// Invokes DividendStock::GetMarketValue()
s->GetMarketValue();

// invokes Stock::GetProfit(), since that method is inherited.
// Stock::GetProfit() invokes DividendStock::GetMarketValue(),
// since that is the most-derived accessible function.
s->GetProfit();
```

Most-Derived

```
class A {
public:
    // Foo will use dynamic dispatch
    virtual void Foo();
};

class B : public A {
public:
    // B::Foo overrides A::Foo
    virtual void Foo();
};

class C : public B {
    // C inherits B::Foo()
};
```

```
void Bar() {
    A* a_ptr;
    C c;

    a_ptr = &c;

    // Whose Foo() is called?
    a_ptr->Foo();
}
```

Your Turn!

❖ Which **Foo** () is called?

Q1

A

B

D

?

Q2

A

B

D

?

```
void Bar () {
    A* a_ptr;
    C c;
    E e;

    // Q1:
    a_ptr = &c;
    a_ptr->Foo();

    // Q2:
    a_ptr = &e;
    a_ptr->Foo();
}
```

```
class A {
public:
    virtual void Foo();
};

class B : public A {
public:
    virtual void Foo();
};

class C : public B {
};

class D : public C {
public:
    virtual void Foo();
};

class E : public C {
};
```

How Can This Possibly Work?

- ❖ The compiler produces `Stock.o` from *just* `Stock.cc`
 - It doesn't know that `DividendStock` exists during this process
 - So then how does the emitted code know to call `Stock::GetMarketValue()` or `DividendStock::GetMarketValue()` or something else that might not exist yet?

- **Function pointers**

Stock.h

```
virtual double Stock::GetMarketValue() const;  
virtual double Stock::GetProfit() const;
```

```
double Stock::GetMarketValue() const {  
    return get_shares() * get_share_price();  
}
```

```
double Stock::GetProfit() const {  
    return GetMarketValue() - GetCost();  
}
```

Stock.cc

vtables and the vptr

- ❖ If a class contains *any* virtual methods, the compiler emits:
 - A (single) virtual function table (**vtable**) for *the class*
 - Contains a function pointer for each virtual method in the class
 - The pointers in the vtable point to the most-derived function for that class
 - A virtual table pointer (**vptr**) for *each object instance*
 - A pointer to a virtual table as a “hidden” member variable
 - When the object’s constructor is invoked, the vptr is initialized to point to the vtable for the newly constructed object’s class
 - Thus, the vptr “remembers” what class the object is

vtable/vptr Example

```
class Base {
public:
    virtual void f1();
    virtual void f2();
};

class Der1 : public Base {
public:
    virtual void f1();
};

class Der2 : public Base {
public:
    virtual void f2();
};
```

```
Base b;
Der1 d1;
Der2 d2;

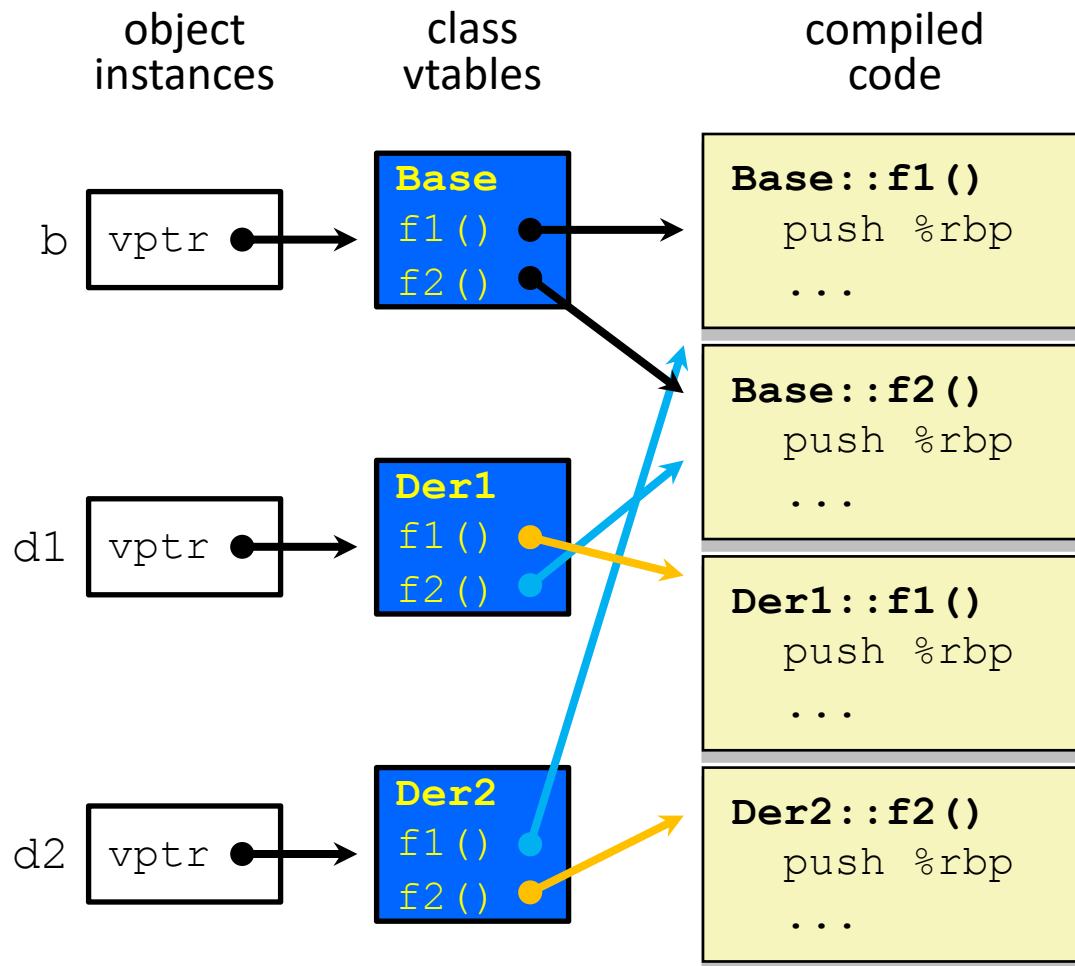
Base* b0ptr = &b;
Base* b1ptr = &d1;
Base* b2ptr = &d2;

b0ptr->f1(); // Base::f1()
b0ptr->f2(); // Base::f2()

b1ptr->f1(); // Der1::f1()
b1ptr->f2(); // Base::f2()

d2.f1(); // Base::f1()
b2ptr->f1(); // Base::f1()
b2ptr->f2(); // Der2::f2()
```

vtable/vptr Example



```

Base b;
Der1 d1;
Der2 d2;

Base* bptr = &d1;

bptr->f1();
// bptr -->
// d1.vptr -->
// Der1.vtable.f1 -->
// Der1::f1()

bptr = &d2;

bptr->f1();
// bptr -->
// d2.vptr -->
// Der2.vtable.f1 -->
// Base::f1()
    
```

Let's Look at Some Actual Code

❖ Let's examine the following code using `objdump`

■ `g++ -g -o vtable vtable.cc`

■ `objdump -CDS vtable > vtable.d`

`vtable.cc`

```
class Base {
public:
    virtual void f1();
    virtual void f2();
};

class Der1 : public Base {
public:
    virtual void f1();
};

int main(int argc, char** argv) {
    Der1 d1;
    d1.f1();
    Base* bptr = &d1;
    bptr->f1();
}
```


More to Come...

Next time...