

# C++ Inheritance II, Casting

## CSE 333

**Instructor:** Hannah C. Tang

### Teaching Assistants:

Deeksha Vatwani	Hannah Jiang	Jen Xu
Justin Tysdal	Leanna Nguyen	Sayuj Shahi
Wei Wu	Yiqing Wang	Youssef Ben Taleb

❖ Whose **Foo** () is called?

- |    | Q1                   | Q2       |
|----|----------------------|----------|
| A. | <b>B</b>             | <b>B</b> |
| B. | <b>B</b>             | <b>D</b> |
| C. | <b>C</b>             | <b>B</b> |
| D. | <b>C</b>             | <b>D</b> |
| E. | <b>We're lost...</b> |          |

```
void Bar() {
    B* b_ptr;
    C c;
    D d;

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

    // Q2:
    b_ptr = &d;
    b_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 {
};
```

# Administrivia

- ❖ Back onto our exercise-per-lecture schedule
  - Ex 12 released: file I/O with C++
  
- ❖ HW3 due in a 2.5 weeks
  - Read the spec over the weekend
  - Starter code will be released over the weekend
  - Median completion time for 24sp: 19h
    - (but stddev was substantially larger than the comparable HW2)

# Lecture Outline

## ❖ C++ Inheritance

- **Static and Mixed Dispatches**
- Abstract Classes
- Constructors, Destructors, and Assignment

## ❖ C++ Casting

- ❖ Reference: *C++ Primer*, Chapter 15

# What happens if we omit “virtual”?

- ❖ By default, without `virtual`, methods are dispatched *statically*
  - At compile time, the compiler writes in a `call` to the address of the class' method in the generated code `.text` segment
    - Based on the compile-time visible type of the called code (callee)
  - This is *different* than Java

```
class Derived : public Base { ... };  
  
int main(int argc, char** argv) {  
    Derived d;  
    Derived* dp = &d;  
    Base* bp = &d;  
    dp->foo();  
    bp->foo();  
    return 0;  
}
```

Derived::foo()  
...

Base::foo()  
...

# Static Dispatch Example

- ❖ Removed `virtual` on methods:

Stock.h

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

```
DividendStock dividend;  
DividendStock* ds = &dividend;  
Stock* s = &dividend;  
  
// Calls DividendStock::GetMarketValue()  
ds->GetMarketValue();  
  
// Calls Stock::GetMarketValue()  
s->GetMarketValue();  
  
// Calls Stock::GetProfit(), since that method is inherited.  
// Stock::GetProfit() calls Stock::GetMarketValue().  
ds->GetProfit();  
  
// Calls Stock::GetProfit().  
// Stock::GetProfit() calls Stock::GetMarketValue().  
s->GetProfit();
```

# `virtual` is “sticky”

- ❖ If `X::f()` is declared `virtual`, then a vtable will be created for class `X` and for *all* of its subclasses
  - The vtables will include function pointers for (the correct) `f`
- ❖ `f()` will be called using dynamic dispatch even if overridden in a derived class without the `virtual` keyword
  - Good style to help the reader *and avoid bugs* by using `override`
    - Style guide controversy, if you use `override` should you use `virtual` in derived classes? Recent style guides say just use `override`, but you’ll sometimes see both, particularly in older code

# Why Not Always Use `virtual`?

- ❖ Two (fairly uncommon) reasons:
  - Efficiency:
    - Non-virtual function calls are a tiny bit faster (no indirect lookup)
    - A class with no virtual functions has objects without a `vptr` field
  - Control:
    - If `f()` calls `g()` in class `X` and `g` is not virtual, we're guaranteed to call `X::g()` and not `g()` in some subclass
      - Particularly useful for framework design
- ❖ In Java, all methods are virtual, except `static` class methods, which aren't associated with objects
- ❖ In C++ and C#, you can pick what you want
  - Omitting virtual can cause obscure bugs



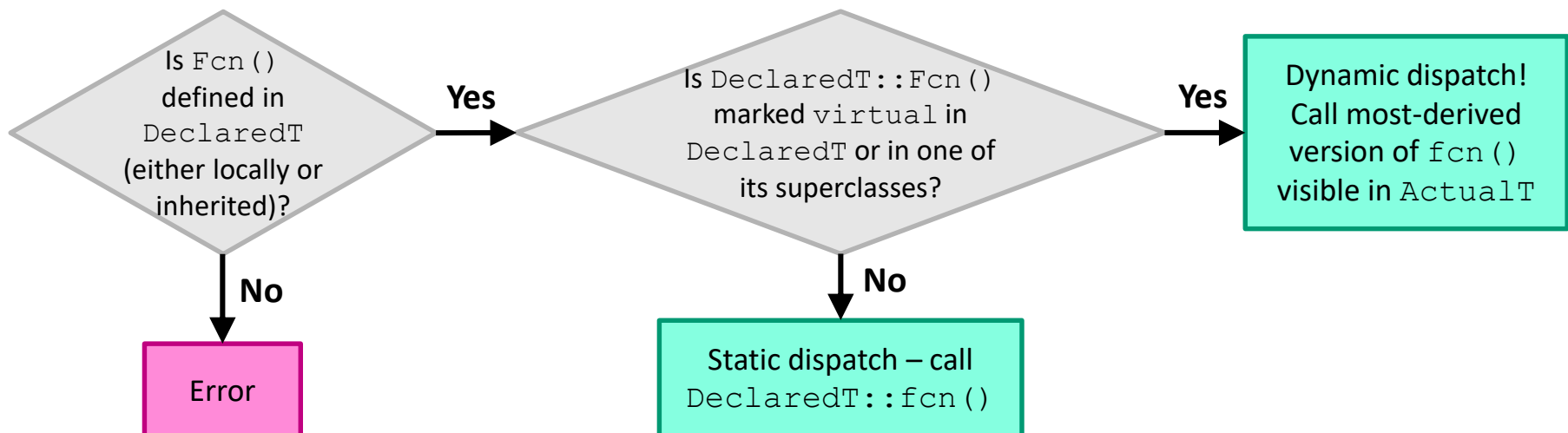
# Mixed Dispatch

- ❖ Which function is called is a mix of both compile time and runtime decisions as well as *how* you call the function

- If called on an object (e.g. `obj.Fcn()`), usually optimized into a hard-coded function call at compile time
- If called via a pointer or reference:

```
DeclaredT *ptr = new ActualT;
```

```
ptr->Fcn(); // which version is called?
```



# Mixed Dispatch Example

mixed.cc

```
class A {
public:
    void m1() { cout << "a1"; }
    virtual void m2() { cout << "a2"; }
};

class B : public A {
public:
    void m1() { cout << "b1"; }
    void m2() { cout << "b2"; }
};
```

```
void main(int argc,
           char** argv) {
    A a;
    B b;

    A* a_ptr_a = &a;
    A* a_ptr_b = &b;
B* b_ptr_a = &a;
    B* b_ptr_b = &b;

    a_ptr_a->m1(); // a1
    a_ptr_a->m2(); // a2

    a_ptr_b->m1(); // a1
    a_ptr_b->m2(); // b2

    b_ptr_b->m1(); // b1
    b_ptr_b->m2(); // b2
}
```

# Mixed Dispatch Example

mixed.cc

```
class A {
public:
    // m1 will use static dispatch
    void m1() { cout << "a1"; }
    // m2 will use dynamic dispatch
    virtual void m2() { cout << "a2"; }
};

class B : public A {
public:
    void m1() { cout << "b1, "; }
    // m2 is still virtual by default
    void m2() { cout << "b2"; }
};
```

```
void main(int argc,
           char** argv) {
    A a;
    B b;

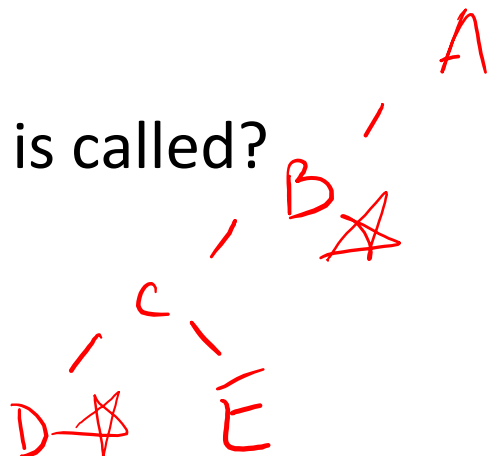
    A* a_ptr_a = &a;
    A* a_ptr_b = &b;
B* b_ptr_a = &a;
    B* b_ptr_b = &b;

    a_ptr_a->m1(); // a1
    a_ptr_a->m2(); // a2

    a_ptr_b->m1(); // a1
    a_ptr_b->m2(); // b2

    b_ptr_b->m1(); // b1
    b_ptr_b->m2(); // b2
}
```

❖ Whose **Foo** () is called?



test.cc

```

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

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

class C : public B {
};

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

class E : public C {
};
  
```

```

void Bar () {
    D d;
    E e;
    A* a_ptr = &d;
    C* c_ptr = &e;

    // Q1:
    a_ptr->Foo();

    // Q2:
    c_ptr->Foo();
}
  
```

Q1      Q2

- A      A
- A      B
- D      A
- D      B

We're lost...

# Lecture Outline

## ❖ C++ Inheritance

- Static and Mixed Dispatches
- **Abstract Classes**
- Constructors, Destructors, and Assignment

## ❖ C++ Casting

- ❖ Reference: *C++ Primer*, Chapter 15

# Abstract Classes

- ❖ Sometimes we want to include a function in a class but *only* implement it in derived classes
  - In Java, we would use an abstract method
  - In C++, we use a “pure virtual” function
    - Example: `virtual string noise() = 0;`
- ❖ A class containing *any* pure virtual methods is **abstract**
  - You can't create instances of an abstract class
  - Extend abstract classes and override methods to use them
- ❖ A class containing *only* pure virtual methods is the same as a Java interface
  - Pure type specification without implementations

# Lecture Outline

## ❖ C++ Inheritance

- Static and Mixed Dispatches
- Abstract Classes
- **Constructors, Destructors, and Assignment**

## ❖ C++ Casting

## ❖ Reference: *C++ Primer*, Chapter 15

# Derived-Class Objects

- ❖ A derived object contains “subobjects” corresponding to the data members inherited from each base class
  - No guarantees about how these are laid out in memory (not even contiguousness between subobjects)
- ❖ Conceptual structure of `DividendStock` object:

members inherited from <code>Stock</code>	<code>symbol_</code> <code>total_shares_</code> <code>total_cost_</code> <code>current_price_</code>
members defined by <code>DividendStock</code>	<code>dividends_</code>



# Constructors and Inheritance

- ❖ A derived class **does not inherit** the base class' constructor
  - The derived class must have its own constructor
  - A synthesized default constructor for the derived class first invokes the default constructor of the base class and then initializes the derived class' member variables
    - Compiler error if the base class has no default constructor
  - The base class constructor is invoked *before* the constructor of the derived class
    - You can use the initialization list of the derived class to specify which base class constructor to use

# Constructor Examples

badctor.cc

```
class Base { // no default ctor
public:
    Base(int y) : y(y) { }
    int y;
};

// Compiler error when you try to
// instantiate a Der1, as the
// synthesized default ctor needs
// to invoke Base's default ctor.
class Der1 : public Base {
public:
    int z;
};

class Der2 : public Base {
public:
    Der2(int y, int z)
        : Base(y), z(z) { }
    int z;
};
```

goodctor.cc

```
// has default ctor
class Base {
public:
    int y;
};

// works now
class Der1 : public Base {
public:
    int z;
};

// still works
class Der2 : public Base {
public:
    Der2(int z) : z(z) { }
    int z;
};
```

# Destructors and Inheritance

baddtor.cc

- ❖ Destructor of a derived class:
  - *First* runs body of the dtor
  - *Then* invokes of the dtor of the base class
- ❖ Static dispatch of destructors is almost always a mistake!
  - Good habit to always define a dtor as virtual
    - Empty body if there's no work to do

```
class Base {
public:
    Base() { x = new int; }
    ~Base() { delete x; }
    int* x;
};

class Der1 : public Base {
public:
    Der1() { y = new int; }
    ~Der1() { delete y; }
    int* y;
};

void foo() {
    Base* b0ptr = new Base;
    Base* b1ptr = new Der1;

    delete b0ptr; // OK
    delete b1ptr; // leaks Der1::y
}
```

# Assignment and Inheritance

- ❖ C++ allows you to assign the value of a derived class to an instance of a base class
  - Known as **object slicing**
    - It's legal since `b=d` passes type checking rules
    - But `b` doesn't have space for any extra fields in `d`

[slicing.cc](#)

```
class Base {
public:
    Base(int x) : x_(x) { }
    int x_;
};

class Der1 : public Base {
public:
    Der1(int y) : Base(16), y_(y) { }
    int y_;
};

void foo() {
    Base b(1);
    Der1 d(2);

    d = b;    // compiler error
    b = d;    // what happens to y_?
}
```

# STL and Inheritance

- ❖ Recall: STL containers store **copies of values**
  - What happens when we want to store mixes of object types in a single container? (e.g. `Stock` and `DividendStock`)
  - You get sliced 😞

```
#include <list>
#include "Stock.h"
#include "DividendStock.h"

int main(int argc, char** argv) {
    Stock s;
    DividendStock ds;
    list<Stock> li;

    li.push_back(s);    // OK
    li.push_back(ds);  // OUCH!

    return 0;
}
```

# STL and Inheritance

- ❖ Instead, store **pointers to heap-allocated objects** in STL containers
  - No slicing! 😊
  - `sort()` does the wrong thing 😞
  - You have to remember to `delete` your objects before destroying the container 😞
    - Smart pointers!

# Lecture Outline

- ❖ C++ Inheritance
  - Static and Mixed Dispatches
  - Abstract Classes
  - Constructors, Destructors, and Assignment
- ❖ **C++ Casting**
- ❖ Reference: *C++ Primer* §4.11.3, 19.2.1

# Explicit Casting in C

- ❖ Simple syntax: `lhs = (new_type) rhs;`
- ❖ Used to:
  - Convert between pointers of arbitrary type
    - Don't change the data, but treat differently
  - Forcibly convert a primitive type to another
    - Actually changes the representation
- ❖ You *can* still use C-style casting in C++, but that uses one notation for different purposes



# Casting in C++

- ❖ C++ provides an alternative casting style that is more informative:
  - `static_cast<to_type>(expression)`
  - `dynamic_cast<to_type>(expression)`
  - `const_cast<to_type>(expression)`
  - `reinterpret_cast<to_type>(expression)`
- ❖ Always use these in C++ code
  - Intent is clearer
  - Easier to find in code via searching

# static\_cast

- ❖ `static_cast` can convert:
  - Pointers to classes **of related type**
    - Compiler error if classes are not related
    - Dangerous to cast *down* a class hierarchy
  - Non-pointer conversion
    - e.g. `float` to `int`
- ❖ `static_cast` is checked at compile time

staticcast.cc

```
class A {
public:
    int x;
};

class B {
public:
    float x;
};

class C : public B {
public:
    char x;
};
```

```
void foo() {
    B b; C c;

    // compiler error
    A* aptr = static_cast<A*>(&b);
    // OK
    B* bptr = static_cast<B*>(&c);
    // compiles, but dangerous
    C* cptr = static_cast<C*>(&b);
}
```

# dynamic\_cast

- ❖ `dynamic_cast` can convert:
  - Pointers to classes **of related type**
  - References to classes **of related type**
- ❖ `dynamic_cast` is checked at both compile time and run time

- Casts between unrelated classes fail at compile time
- Casts from base to derived fail at run time if the pointed-to object is not the derived type

```
class Base {
public:
    virtual void foo() { }
    float x;
};

class Der1 : public Base {
public:
    char x;
};
```

```
void bar() {
    Base b; Der1 d;

    // OK (run-time check passes)
    Base* bptr = dynamic_cast<Base*>(&d);
    assert(bptr != nullptr);

    // OK (run-time check passes)
    Der1* dptr = dynamic_cast<Der1*>(bptr);
    assert(dptr != nullptr);

    // Run-time check fails, returns nullptr
    bptr = &b;
    dptr = dynamic_cast<Der1*>(bptr);
    assert(dptr != nullptr);
}
```

# const\_cast

- ❖ `const_cast` adds or strips const-ness
  - Dangerous (!)

```
void foo(int* x) {
    *x++;
}

void bar(const int* x) {
    foo(x); // compiler error
    foo(const_cast<int*>(x)); // succeeds
}

int main(int argc, char** argv) {
    int x = 7;
    bar(&x);
    return 0;
}
```

# reinterpret\_cast

- ❖ `reinterpret_cast` casts between *incompatible* types
  - Low-level reinterpretation of the bit pattern
  - e.g. storing a pointer in an `int`, or vice-versa
    - Works as long as the integral type is “wide” enough
  - Converting between incompatible pointers
    - Dangerous (!)
    - This is used (carefully) in hw3

# Implicit Conversion

- ❖ The compiler tries to infer some kinds of conversions
  - When types are not equal and you don't specify an explicit cast, the compiler looks for an acceptable implicit conversion

```
void bar(std::string x);

void foo() {
    int x = 5.7;    // conversion, float -> int
    bar("hi");     // conversion, (const char*) -> string
    char c = x;    // conversion, int -> char
}
```

# Sneaky Implicit Conversions

- ❖ (`const char*`) to `string` conversion?
  - If a class has a constructor with a single parameter, the compiler will exploit it to perform implicit conversions
  - At most, one user-defined implicit conversion will happen
    - Can do `int` → `Foo`, but not `int` → `Foo` → `Baz`

```
class Foo {
public:
    Foo(int x) : x(x) { }
    int x;
};

int Bar(Foo f) {
    return f.x;
}

int main(int argc, char** argv) {
    return Bar(5); // equivalent to return Bar(Foo(5));
}
```

# Avoiding Sneaky Implicit

- ❖ Declare one-argument constructors as `explicit` if you want to disable them from being used as an implicit conversion path
  - Usually a good idea

```
class Foo {
public:
    explicit Foo(int x) : x(x) { }
    int x;
};

int Bar(Foo f) {
    return f.x;
}

int main(int argc, char** argv) {
    return Bar(5); // compiler error
}
```



# Extra Exercise #1

- ❖ Design a class hierarchy to represent shapes
  - *e.g.* Circle, Triangle, Square
- ❖ Implement methods that:
  - Construct shapes
  - Move a shape (*i.e.* add (x,y) to the shape position)
  - Returns the centroid of the shape
  - Returns the area of the shape
  - **Print** ( ) , which prints out the details of a shape

# Extra Exercise #2

- ❖ Implement a program that uses Extra Exercise #1 (shapes class hierarchy):
  - Constructs a vector of shapes
  - Sorts the vector according to the area of the shape
  - Prints out each member of the vector
  
- ❖ Notes:
  - Avoid slicing!
  - Make sure the sorting works properly!