

# C++ Inheritance II, Casts

## CSE 333 Autumn 2021

**Instructor:** Chris Thachuk

**Teaching Assistants:**

Arpad (John) Depaszthory

Ian Hsiao

Logan Gnanapragasam

Mengqi (Frank) Chen

Angela Xu

Khang Vinh Phan

Maruchi Kim

Cosmo Wang

# Administrivia

- ❖ Virtual section on Thursday (materials will be posted)
  
- ❖ Exercise 12 due Monday
  - C++ smart pointers and inheritance
  - New exercise, expect to be on the longer side
  - New tests added: see Ed announcement
  
- ❖ hw3 is out, due Wednesday, November 24
  - Review spec and linked videos / slides asap
  - Make use of office hours early (late days overlap Thanksgiving)
  - Suggestion: write index files to `/tmp/`, which is a local scratch disk and is very fast, but please clean up when you're done



# Reminder: `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

# 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 `.text` segment
    - Based on the compile-time visible type of the 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 EXIT_SUCCESS;  
}
```

Derived::foo()  
...

Base::foo()  
...

# Static Dispatch Example

- ❖ Removed `virtual` on methods:

Defined in `Stock & DividendStock` `Stock.h`

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

Only defined in `Stock`, `DividendStock` inherits. Calls `GetMarketValue`

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

# Why Not Always Use `virtual`?

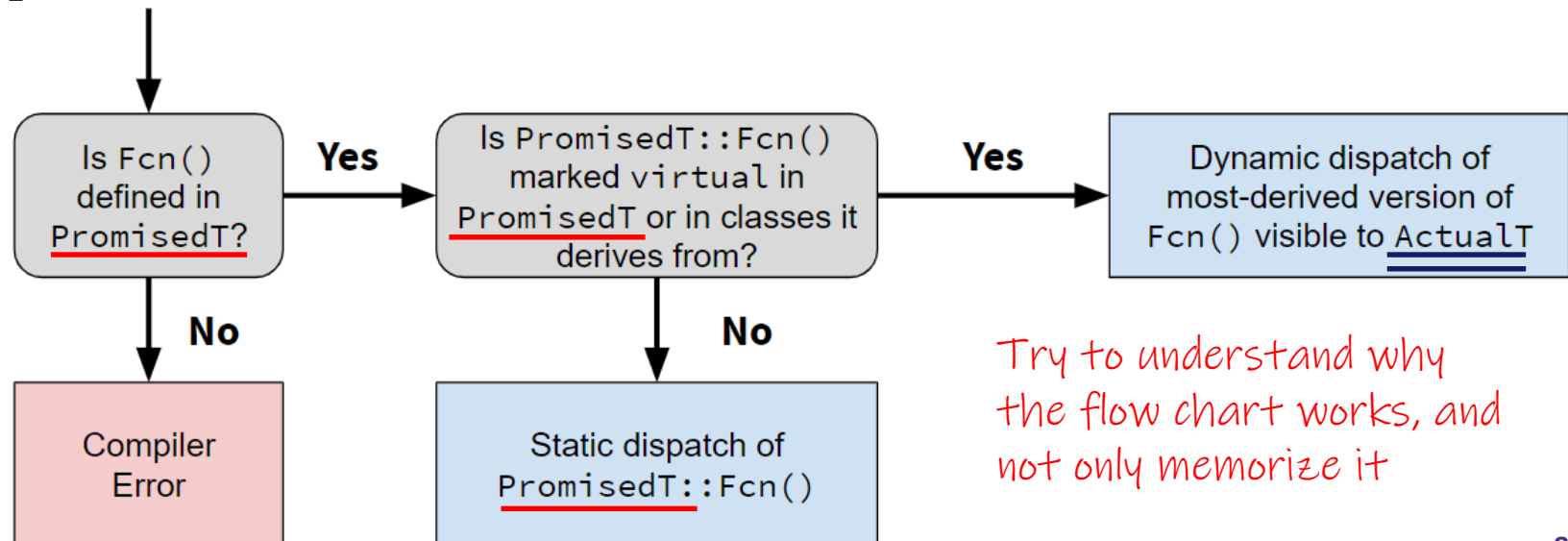
- ❖ Two (fairly uncommon) reasons:
  - Efficiency:
    - Non-virtual function calls are a tiny bit faster (no indirect lookup)
    - A class with no virtual functions has objects without a `vptr` field
  - Control:
    - If `f()` calls `g()` in class `X` and `g` is not virtual, we're guaranteed to call `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
  - (Most of the time, you want member function to be `virtual`)

# Mixed Dispatch Decision Tree

- ❖ 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:

```
PromisedT* ptr = new ActualT;  
ptr->Fcn(); // which version is called?
```



Try to understand why the flow chart works, and not only memorize it

# 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
    virtual void m2() { cout << "b2"; }
};
```



virtual void m2() { cout << "b2"; }

(remember, virtual is "sticky")

Key:

Static dispatch

Dynamic dispatch

```
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; // Compiler error
    B* b_ptr_b = &b;

    a_ptr_a->m1(); // A::m1
    a_ptr_a->m2(); // A::m2

    a_ptr_b->m1(); // A::m1
    a_ptr_b->m2(); // B::m2

    b_ptr_b->m1(); // B::m1
    b_ptr_b->m2(); // B::m2
}
```

promisedType

actualType

Compiler error

 **Poll Everywhere**[pollev.com/cse333](https://pollev.com/cse333)

- ❖ Apply what you've learned to a more complex example!
- ❖ What is printed?

- A. HI
- B. HA
- C. Compiler Error
- D. Segmentation fault
- E. We're lost...

```
int main() {  
    B b;  
    B* b_ptr = &b;  
  
    // Q:  
    b_ptr->Foo();  
}
```

poll.cc

```
class A {  
public:  
    virtual void Foo() {  
        cout << "H";  
        this->Bar();  
    }  
  
    void Bar() {  
        cout << "A";  
    }  
};  
  
class B : public A {  
public:  
    virtual void Bar() {  
        cout << "I";  
    }  
};
```



# Poll Everywhere

[pollev.com/cse333](https://pollev.com/cse333)

- ❖ Apply what you've learned to a more complex example!
- ❖ What is printed?

*"this"  
is of type A\*  
in this context  
So, static dispatch*

A. HI

**B. HA**

C. Compiler Error

D. Segmentation  
fault

E. We're lost...

*If we removed "this->"  
we would get same behaviour*

```
int main() {
    B b;
    B* b_ptr = &b;

    // Q:
    b_ptr->Foo();
}
```

poll.cc

```
class A {
public:
    virtual void Foo() {
        cout << "H";
        this->Bar();
    }

    void Bar() {
        cout << "A";
    }
};

class B : public A {
public:
    virtual void Bar() {
        cout << "I";
    }
};
```

# 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

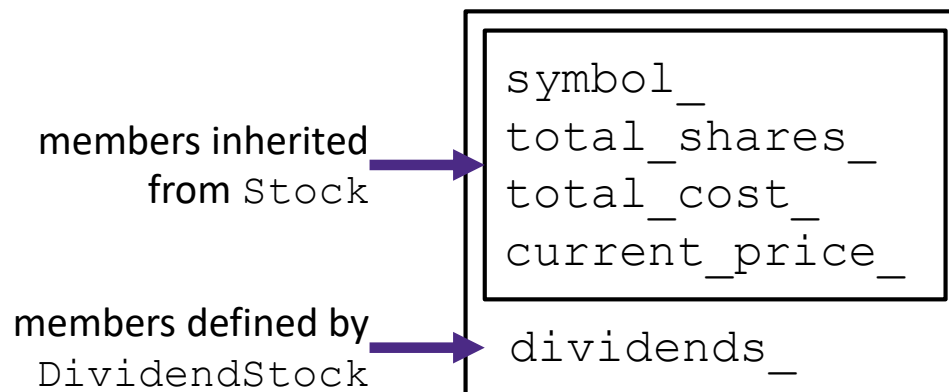
- Static Dispatch
- Abstract Classes
- **Constructors and Destructors**
- **Assignment**

## ❖ 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:



# 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 initialize 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 yi) : y(yi) { }
    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 yi, int zi)
        : Base(yi), z(zi) { }
    int z;
};
```

Compiler error ☹️  
No default ctor

Invokes a specific ctor

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 zi) : z(zi) { }
    int z;
};
```

Because base has default ctor

# 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; // delete's x
    delete b1ptr; // delete's x, but not y
}

```

*Not virtual, Static dispatch*

*Both invoke Base dtor!!!!*

# 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 xi) : x(xi) { }
    int x;
};

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

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

    d = b; // Compiler error - not enough info
    b = d; // ok, what happens to y?
}
// Y is not copied over.
```

# 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 EXIT_SUCCESS;
}
```

# STL and Inheritance

- ❖ Instead, store **pointers to heap-allocated objects** in STL containers
  - No slicing! 😊 `vector<Stock*>`
  - `sort()` does the wrong thing 😞 *Sorts by address value on default*
  - You have to remember to `delete` your objects before destroying the container 😞
    - Unless you use Smart pointers! `vector<shared_ptr<Stock>>`



# Explicit Casting in C

- ❖ Simple syntax: `lhs = (new_type) rhs;`
- ❖ Used to:
  - Convert between pointers of arbitrary type `(void*) my_ptr`
    - Doesn't change the data, but treats it differently
  - Forcibly convert a primitive type to another `(double) my_int`
    - Actually changes the representation
- ❖ You *can* still use C-style casting in C++, but sometimes the intent is not clear
  - You *should not* use C-style casting in C++.

# 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` *Any well-defined conversion* can convert:

- Pointers to classes **of related type**
  - Compiler error if classes are not related
  - Dangerous to cast *down* a class hierarchy
- casting `void*` to `T*`
- 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 y;
};

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

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

    // compiler error Unrelated types
    A* aptr = static_cast<A*>(&b);
    // OK Would have worked without cast
    B* bptr = static_cast<B*>(&c);
    // compiles, but dangerous
    C* cptr = static_cast<C*>(&b);
    // What happens when you do cptr->z?
}
```

# 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
- ❖ Can be used like `instanceof` from java

```
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 EXIT_SUCCESS;
}
```

# 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
  - Use any other C++ cast if you can.

# 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!