



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

## About how long did Exercise 8 take you?

- A. [0, 2) hours
- B. [2, 4) hours
- C. [4, 6) hours
- D. [6, 8) hours
- E. 8+ Hours
- F. I didn't submit / I prefer not to say

# C++ Inheritance II, Casts (Wrap-up)

## CSE 333 Fall 2023

**Instructor:** Chris Thachuk

**Teaching Assistants:**

Ann Baturytski

Yuquan Deng

Noa Ferman

James Froelich

Hannah Jiang

Yegor Kuznetsov

Humza Lala

Alan Li

Leanna Mi Nguyen

Chanh Truong

Jennifer Xu

# Relevant Course Information

- ❖ Exercise 9 is due Wednesday (11/15)
- ❖ Homework 3 is due next Thursday (11/23)
  - Suggestion: write index files to `/tmp/`, which is a local scratch disk and is very fast, but please clean up when you're done
  - Late submission deadline (no penalty): **11/26 before 10pm**
- ❖ Lecture on “Intro to Networking” recording posted this evening
  - We'll start on IP/DNS/Client-side networking on Wednesday

# Lecture Outline

- ❖ **C++ Inheritance**
  - **Abstract Classes**
  - **Static Dispatch**
  - Constructors and Destructors
  - Assignment
- ❖ C++ Casting
- ❖ C++ Conversions
  
- ❖ 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

# 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:

Stock.h

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

↙ defined in Stock & DividendStock

↖ defined in Stock, inherited by DividendStock, 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();
```



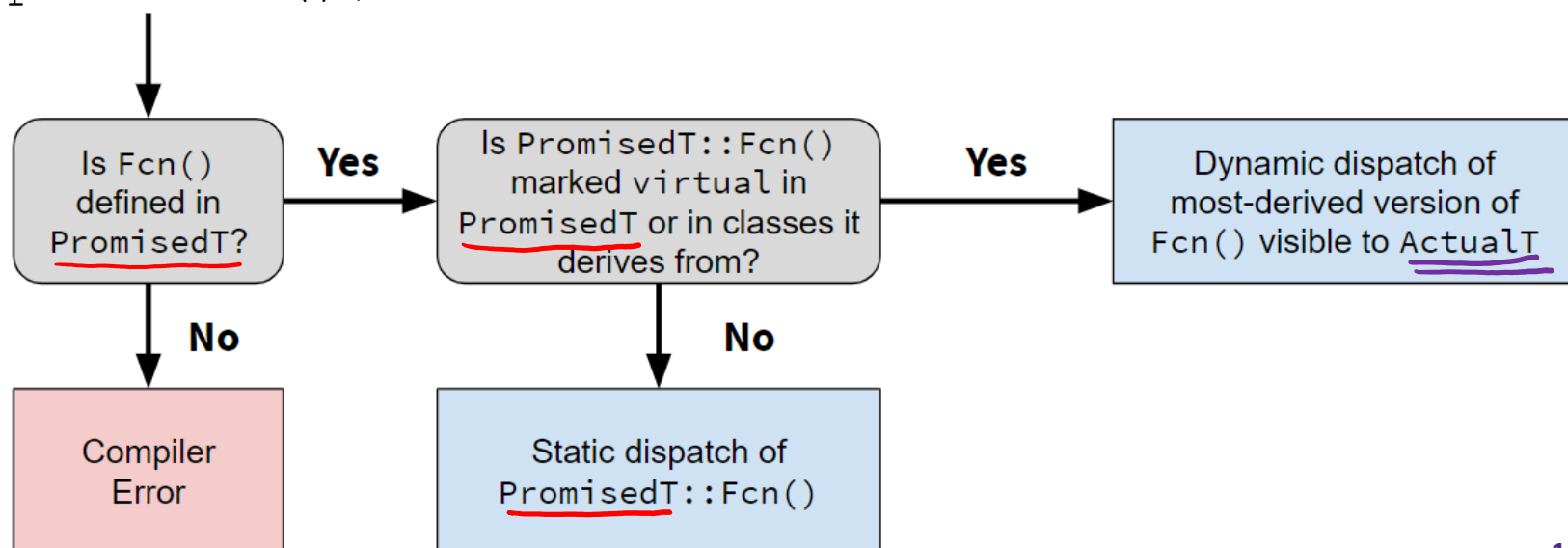
# Why Not Always Use `virtual`?

- ❖ 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

- ❖ 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?
```



# 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"; }
};
```



static dispatch based on promised type  
dynamic dispatch based on actual type

```
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
}
```

# Lecture Outline

## ❖ C++ Inheritance

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

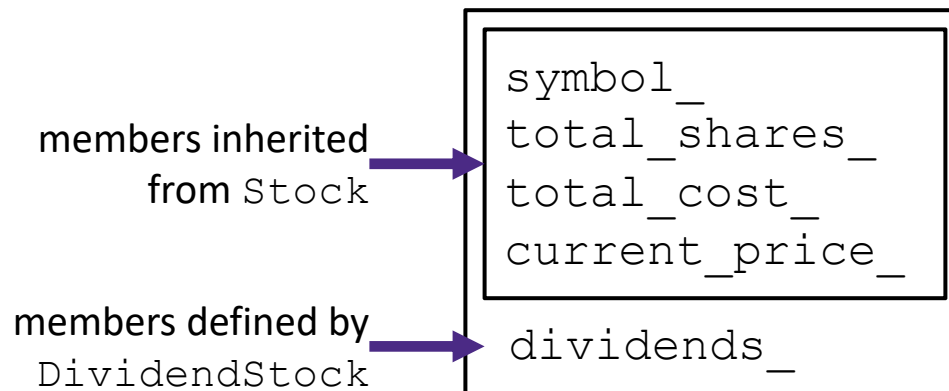
## ❖ C++ Casting

## ❖ C++ Conversions

## ❖ 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; invokes a specific constructor
};
```

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;
};
```

# 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; } // static dispatch
    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; // deletes x
    delete b1ptr; // only deletes x - leaks y!
}

```

Diagram illustrating static dispatch of destructors:

- `b0ptr` points to a `Base` object containing `x`. A red arrow points from `b0ptr` to the `Base` object, and another red arrow points from the `Base` object to a box containing `x`. A blue arrow points from the `x` box to a box containing a blue arrow pointing up and right.
- `b1ptr` points to a `Der1` object containing `x` and `y`. A red arrow points from `b1ptr` to the `Der1` object, and another red arrow points from the `Der1` object to a box containing `x` and `y`. A yellow arrow points from the `y` box to a box containing a yellow arrow pointing up and right. A red arrow points from the `x` box to a box containing a red arrow pointing up and right.

Handwritten notes:

- `delete b0ptr;` // deletes `x`
- `delete b1ptr;` // only deletes `x` - leaks `y`!
- ↑ invokes `~Base()`



# 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, but what happens to y?
}
  
```

Handwritten annotations in red:

- A box around `x` in the `Base` class definition, with `b` written to its left.
- A box around `x` and `y` in the `Der1` class definition, with `d` written to its left.

# 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;

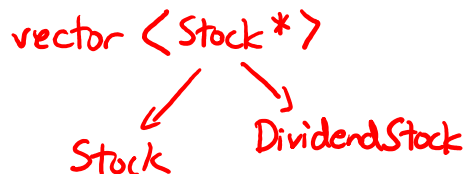
    li.push_back(s);    // OK
    li.push_back(ds);  // OUCH!

    return EXIT_SUCCESS;
}
```

# STL and Inheritance

❖ Instead, store **pointers to heap-allocated objects** in STL containers

■ No slicing! 😊



■ `sort()` does the wrong thing 😞 — sorts on addresses by default

■ You have to remember to `delete` your objects before destroying the container 😞

- Unless you use smart pointers! *eg.*, `vector<shared_ptr<Stock>>`

# Lecture Outline

- ❖ C++ Inheritance
  - Abstract Classes
  - Static Dispatch
  - Constructors and Destructors
  - Assignment
- ❖ **C++ Casting**
- ❖ C++ Conversions
  
- ❖ 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 *(void \*) my\_ptr*
    - Doesn't change the data, but treats it differently
  - Forcibly convert a primitive type to another *(float) 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` <sup>any well-defined conversion</sup> can convert:
  - Pointers to classes **of related type**
    - Compiler error if classes are not related
    - Dangerous to cast *down* a class hierarchy
  - Casting between `void*` and `T*`
  - Non-pointer conversion
    - e.g., `float` to `int`
- ❖ `static_cast` is checked at compile time

*static\_cast can change the data representation!*

staticcast.cc

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

class B {
public:
    float x;
};

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

*(A)*

*(B)* → *(C)*

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

    // compiler error (unrelated)
    A* aptr = static_cast<A*>(&b);
    // OK (would have been done implicitly)
    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 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!

*reinterpret\_cast  
cannot change  
the data representation*



# Casting Style Considerations

- ❖ From the “Casting” and “Run-Time Type Information (RTTI)” sections of the Google C++ Style Guide:
  - When the logic of a program guarantees that a given instance of a base class is, in fact, an instance of a particular derived class, then a `dynamic_cast` may be used freely on the object.
    - Usually one can use a `static_cast` as an alternative in such situations
  - Only use `reinterpret_cast` if you know what you are doing and you understand the aliasing issues
    - For *unsafe conversions* of pointer types to and from integer and other pointer types, including `void*`

# Lecture Outline

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

# 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
    char c = x;    // conversion, int -> char
    Bar("hi");     // conversion, (const char*) -> string
}
```

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

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

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

*constructor implicitly invoked*



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

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

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

*// compiler error - no longer allowed, but could still do Bar(Foo(5)) instead*

# 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!