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

CSE 333 Spring 2023

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Relevant Course Information

- Exercise 9 is due Wednesday (5/17)
- Homework 3 is due Thursday (5/18)
  - Suggestion: write index files to `/tmp/`, which is a local scratch disk and is very fast, but please clean up when you're done
- 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 <u>compile time</u>, 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;
```

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();
```

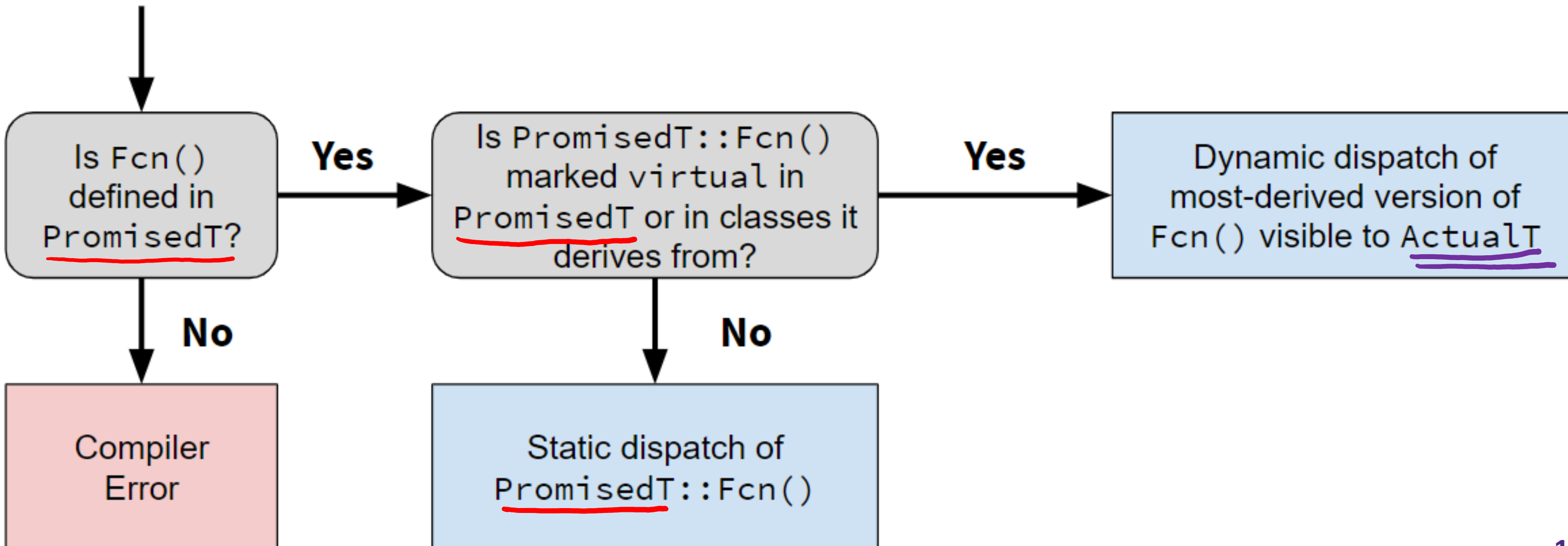
Why Not Always Use `virtual`?

- 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"; }
};
```

A → B

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

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

Lecture Outline

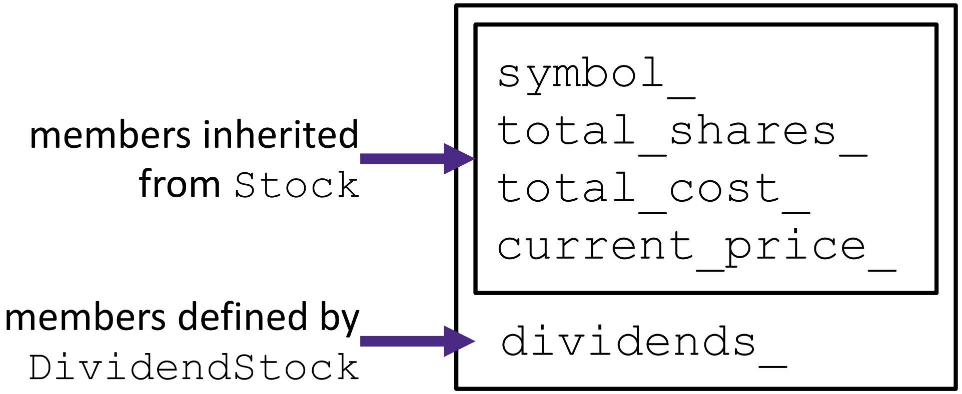
- **C++ Inheritance**
  - Abstract Classes
  - Static Dispatch
  - **Constructors and Destructors**
  - **Assignment**
- C++ Casting
- C++ Conversions

- 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

STYLE TIP

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!
             ↑ 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?
}
```

b x 1

d x 16 y 2

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 vector<Stock*>
  Stock DividendStock
  - 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! e.g., vector<shared_ptr<Stock>>

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- C++ Inheritance
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  - 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

staticcast.cc

static_cast

- static_cast can convert: any well-defined conversion
  - 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!

```
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);
}
```

dynamiccast.cc

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

return nullptr

```
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

STYLE TIP

- 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*`

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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 Implicits

STYLE TIP

- 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!