Poll Everywhere

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

CSE 333 Winter 2023

Instructor: Justin Hsia

Teaching Assistants:

Adina Tung	Danny Agustinus	Edward Zhang
James Froelich	Lahari Nidadavolu	Mitchell Levy
Noa Ferman	Patrick Ho	Paul Han
Saket Gollapudi	Sara Deutscher	Tim Mandzyuk
Timmy Yang	Wei Wu	Yiqing Wang
Zhuochun Liu		

Relevant Course Information

- Exercise 9 released today, due Monday (holiday)
  - C++ smart pointers and inheritance
- Homework 3 is due next Thursday (2/23)
  - Suggestion: write index files to `/tmp/`, which is a local scratch disk and is very fast, but please clean up when you're done
- Mid-quarter Survey ‘due’ tonight at 11:59 pm
  - Accepting submissions for a while longer
  - Feedback greatly appreciated!

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

defined in Stock & DividendStock

```
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();
```

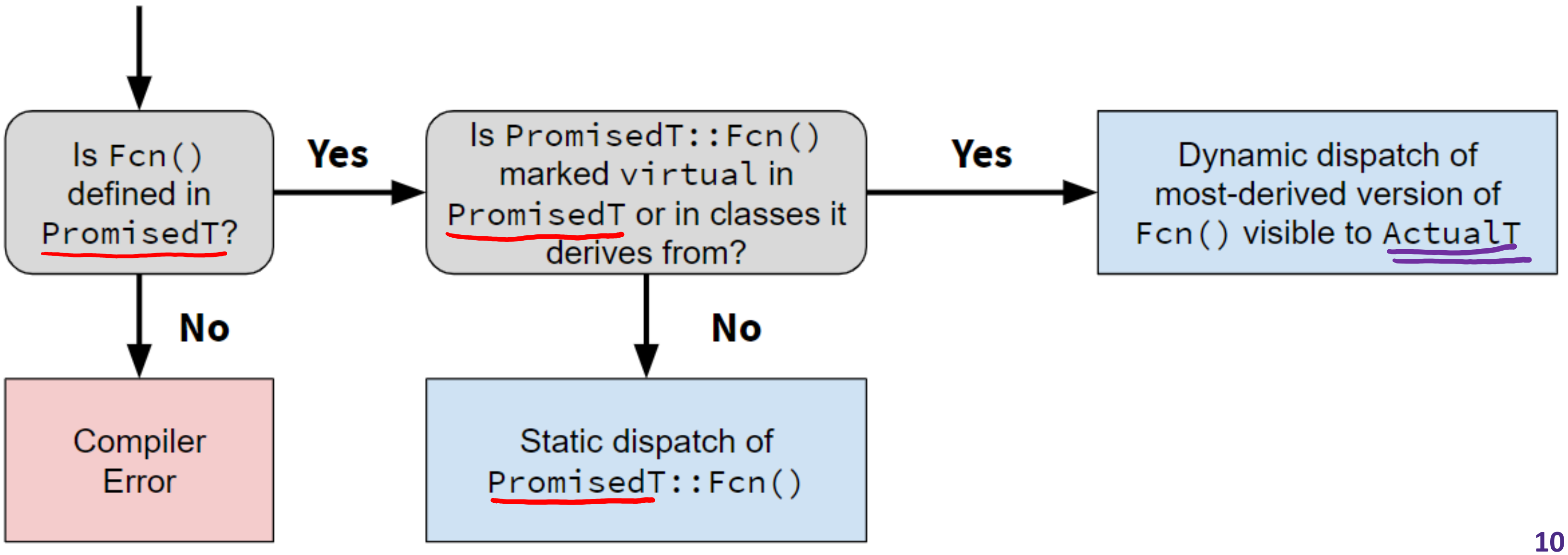
Why Not Always Use `virtual`?

- 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

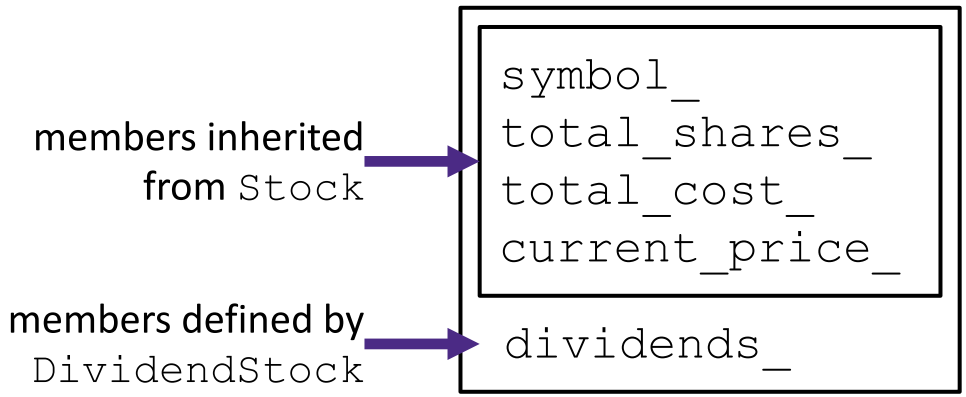
- **C++ Inheritance**
  - Abstract Classes
  - Static Dispatch
  - **Constructors and Destructors**
  - **Assignment**
- C++ Casting
- C++ Conversions

- 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;
};      b0ptr
        b1ptr
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?
}
```

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>>

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++

STYLE TIP

- 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

staticcast.cc

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

class B {
 public:
  float x;
};

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

A

B → C

- 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!

```
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);
}
```

(unrelated)

(would have been done implicitly)

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*`

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 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!