Poll Everywhere

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

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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 std::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: \textit{virtual} is “sticky”

- If \texttt{X::F()} is declared virtual, then a vtable will be created for class \texttt{X} and for \textit{all} of its subclasses
  - The vtables will include function pointers for (the correct) \texttt{F}

- \texttt{F()} will be called using dynamic dispatch even if overridden in a derived class without the \textit{virtual} keyword
  - Good style to help the reader \textit{and avoid bugs} by using \texttt{override}
    - Style guide controversy, if you use \texttt{override} should you use \texttt{virtual} in derived classes? Recent style guides say just use \texttt{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

```cpp
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;
}
```
Static Dispatch Example

- Removed `virtual` on methods:

```cpp
// defined in Stock & DividendStock
double Stock::GetMarketValue() const;
double Stock::GetProfit() const;
```

```cpp
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:
    ```cpp
    PromisedT* ptr = new ActualT;
    ptr-> Fcn(); // which version is called?
    ```
Mixed Dispatch Example

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();  // 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
}

mixed.cc
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

```cpp
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

```cpp
// 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

- 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

```cpp
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; // deletes x
  delete b1ptr; // only deletes x - leaks 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 \( d \)

```cpp
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?
}
```
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 😞

```cpp
#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!  
      
      ```cpp
      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:**
  \[
  \text{lhs} = (\text{new\_type}) \text{rhs};
  \]

- **Used to:**
  - Convert between pointers of arbitrary type
    - Doesn’t change the data, but treats it differently
  - Forcibly convert a primitive type to another
    - 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** 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

```
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

```cpp
dynamiccast.cc

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 (!)

```cpp
class Base { public: int x; }
class Derived : public Base { public: void modify(int& x) { x = 42; } };

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!
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*`
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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

```cpp
void Bar(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`

```cpp
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));
}
```
Avoiding Sneaky Implicits

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

```cpp
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!