CSE 307: Principles of Programming Languages

Classes and Inheritance

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Topics

Section 1

OOP Introduction

OOP (Object Oriented Programming)

- So far the languages that we encountered treat data and computation separately.
- In OOP, the data and computation are combined into an “object”.

Benefits of OOP

- more convenient: collects related information together, rather than distributing it.
  - Example: C++ iostream class collects all I/O related operations together into one central place.
  - Contrast with C I/O library, which consists of many distinct functions such as getchar, printf, scanf, sscanf, etc.
- centralizes and regulates access to data.
  - If there is an error that corrupts object data, we need to look for the error only within its class
  - Contrast with C programs, where access/modification code is distributed throughout the program

Benefits of OOP (Continued)

- Promotes reuse.
  - by separating interface from implementation.
    - We can replace the implementation of an object without changing client code.
    - Contrast with C, where the implementation of a data structure such as a linked list is integrated into the client code
  - by permitting extension of new objects via inheritance.
    - Inheritance allows a new class to reuse the features of an existing class.
    - Example: define doubly linked list class by inheriting/ reusing functions provided by a singly linked list.

Encapsulation & Information hiding

- Encapsulation
  - centralizing/regulating access to data
- Information hiding
  - separating implementation of an object from its interface
- These two terms overlap to some extent.

Classes and Objects

- Class is an (abstract) type
  - includes data
    - class variables (aka static variables)
      - shared (global) across all objects of this class
    - instance variables (aka member variables)
      - independent copy in each object
      - similar to fields of a struct
  - and operations
    - member functions
      - always take object as implicit (first) argument
    - class functions (aka static functions)
      - don't take an implicit object argument
- Object is an instance of a class
  - variable of class type

Access to Members

- Access to members of an object is regulated in C++ using three keywords
  - Private:
    - Accessibly only to member functions of the class
    - Can't be directly accessed by outside functions
  - Protected:
    - allows access from member functions of any subclass
  - Public:
    - can be called directly by any piece of code.

Member Function

- Member functions are of two types
  - statically dispatched
  - dynamically dispatched.
- The dynamically dispatched functions are declared using the keyword “virtual” in C++
  - all member function functions are virtual in Java

C++

- Developed as an *extension* to C

  by adding object oriented constructs originally found in Smalltalk (and Simula67).
- Most legal C programs are also legal C++ programs
  - "Backwards compatibility" made it easier for C++ to be accepted by the programming community
  - . . . but made certain features problematic (leading to "dirty" programs)
- Many of C++ features have been used in Java
  - Some have been "cleaned up"
  - Some useful features have been left out

Example of C++ Class

- A typical convention is C++ is to make all data members private. Most member functions are public.
- Consider a list that consists of integers. The declaration for this could be :

```
class IntList {
   private:
      int elem; // element of the list
      IntList *next ; // pointer to next element
   public:
      IntList (int first); //"constructor"
      ~IntList () ; // "destructor".
      void insert (int i); // insert element i
      int getval () ; // return the value of elem
      IntList *getNext (); // return the value of next
}
```

Example of C++ Class (Continued)

- We may define a subclass of IntList that uses doubly linked lists as follows:

```
class IntDList: IntList {
   private:
      IntList *prev;
   public:
      IntDlist(int first);
      // Constructors need to be redefined
       ~IntDlist();
      // Destructors need not be redefined, but
      // typically this is needed in practice.
      // Most operations are inherited from IntList.
      // But some operations may have to be redefined.
      insert (int);
      IntDList *prev();
 }
```

C++ and Java: The Commonalities

- Classes, instances (objects), data members (fields) and member functions (methods).
- Overloading and inheritance.
  - base class (C++) $\rightarrow$ superclass (Java)
  - derived class (C++) $\rightarrow$ subclass (Java)
- Constructors
- Protection (visibility): `private`, `protected` and `public`
- Static binding for data members (fields)

A C++ Primer for Java Programmers

Classes, fields and methods:

Java:

```java
class A extends B {
  private int x;
  protected int y;
  public int f() {
      return x;
    }
  public void print() {
      System.out.println(x);
  }
}
```

C++:

```cpp
class A : public B {
  private: int x;
  protected: int y;
  public: int f() {
      return x;
    }
  void print() {
      std::cout << x << std::endl;
  }
}
```

A C++ Primer for Java Programmers

Declaring objects:

- In Java, the declaration A va declares `va` to be a *reference* to object of class `A`.
  - Object creation is always via the `new` operator
- In C++, the declaration A va declares `va` to be an object of class `A`.
  - Object creation may be automatic (using declarations) or via new operator:

    A *va = new A;

Objects and References

- In Java, all objects are allocated on the heap; references to objects may be stored in local variables.
- In C++, objects are treated analogous to *C* `structs`: they may be allocated and stored in local variables, or may be dynamically allocated.
- Parameters to methods:
  - Java distinguishes between two sets of values: primitives (e.g. `ints`, `floats`, etc.) and objects (e.g `String`, `Vector`, etc.

    Primitive parameters are passed to methods *by value* (copying the value of the argument to the formal parameter)

    Objects are passed *by reference* (copying only the reference, not the object itself).
  - C++ passes all parameters *by value* unless specially noted.

Section 2

Type & Subtype

Type

- **Apparent Type:** Type of an object as per the declaration in the program.
- **Actual Type:** Type of the object at run time.

Let `Test` be a subclass of `Base`. Consider the following Java program:

```
Base b = new Base();
Test t = new Test();
...
b = t;
```

Variable	*Apparent type of object referenced*
b	Base
t	Test

... throughout the scope of b and t's declarations

Type (Continued)

Let `Test` be a subclass of `Base`. Consider the following Java program fragment:

```
Base b = new Base();
Test t = new Test();
...
b = t;
```

Variable	*Program point*	*Actual type of object referenced*
b	**before** b=t	Base
t	**before** b=t	Test
b	**after** b=t	Test
t	**after** b=t	Test

Type (Continued)

Things are a bit different in C++, because you can have both objects and object references. Consider the case where variables are objects in C++:

```
Base b();
Test t();
...
b = t;
```

Variable	*Program point*	*Actual type of object referenced*
b	**before** b=t	Base
t	**before** b=t	Test
b	**after** b=t	Base
t	**after** b=t	Test

Type (Continued)

Things are a bit different in C++, because you can have both objects and object references. Consider the case where variables are pointers in C++:

```
Base *b = new Base();
Test *t = new Test();
...
b = t;
```

Variable	*Program point*	*Actual type of object referenced*
b	**before** b=t	Base*
t	**before** b=t	Test*
b	**after** b=t	Test*
t	**after** b=t	Test*

Subtype

- A is a subtype of B if every object of type A is also a B, i.e., every object of type A has
  - (1) all of the data members of B
  - (2) supports all of the operations supported by B, with the operations taking the same argument types and returning the same type.
  - (3) AND these operations and fields have the "same meaning" in A and B.
- It is common to view data field accesses as operations in their own right. In that case, (1) is subsumed by (2) and (3).

Subtype Principle

- A key principle :
  - "For any operation that expects an object of type T, it is acceptable to supply object of type T', where T' is subtype of T."
- The subtype principle enables OOL to support subtype polymorphism:
  - client code that accesses an object of class C can be reused with objects that belong to subclasses of C.

Subtype Principle (Continued)

- The following function will work with any object whose type is a subtype of IntList.

```
void q (IntList &i, int j) {
   ...
   i.insert(j) ;
}
```

- Subtype principle dictates that this work for IntList and IntDList.
  - This must be true even is the insert operation works differently on these two types.
  - Note that use of IntList::insert on IntDList object will likely corrupt it, since the prev pointer would not be set.

Subtype Principle (Continued)

- Hence, `i.insert` must refer to
  - IntList::insert when `i` is an IntList object, and
  - IntDList::insert function when i is an IntDList.
- Requires dynamic association between the name "insert" and the its implementation.

  - achieved in C++ by declaring a function be virtual.
  - definition of insert in IntList should be modified as follows: `virtual void insert(int i);`
  - all member functions are by default virtual in Java, while they are nonvirtual in C++
    - equivalent of "virtual" keyword is unavailable in Java.

Reuse of Code

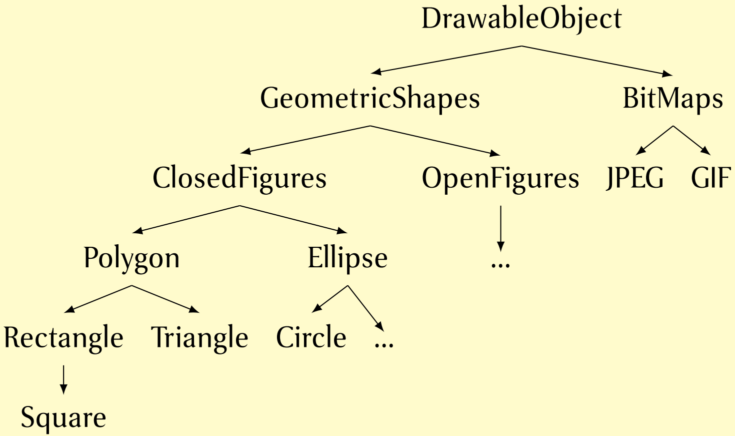
- Reuse achieved through subtype polymorphism
  - the same piece of code can operate on objects of different type, as long as:
    - Their types are derived from a common base class
    - Code assumes only the interface provided by base class.
- Polymorphism arises due to the fact that the implementation of operations may differ across subtypes.

Reuse of Code (Continued)

- Example:
  - Define a base class called DrawableObject
    - supports draw() and erase().
  - DrawableObject just defines an interface
    - no implementations for the methods are provided.
    - this is an abstract class — a class with one or more abstract methods (declared but not implemented).
    - also an interface class — contains only abstract methods subtypes.

Reuse of Code: example (Continued)

- The hierarchy of DrawableObject may look as follows:



Reuse of Code: example (Continued)

- The subclasses support the draw() and erase() operation supported by the base class.
- Given this setting, we can implement the redraw routine using the following code fragment:

```
void redraw(DrawableObject* objList[], int size){
   for (int i = 0; i < size; i++)
   objList[i]->draw();
}
```

Reuse of Code: example (Continued)

- objList[i].draw will call the appropriate method:
  - for a square object, Square::draw
  - for a circle object, Circle:draw
- The code need not be changed even if we modify the inheritance hierarchy by adding new subtypes.

Reuse of Code: example (Continued)

- Compare with implementation in C:

```
void redraw(DrawableObject *objList[], int size) {
   for (int i = 0; i < size; i++){
      switch (objList[i]->type){
         case SQUARE: square_draw((struct Square *)objList[i]);
            break;
         case CIRCLE: circle_draw((struct Circle *)objList[i]);
            break;
         ........
         default: ....
      }
   }
}
```

- Differences:
  - no reuse across types (e.g., Circle and Square)
  - need to explicitly check type, and perform casts
  - will break when new type (e.g., Hexagon) added

Reuse of Code (Continued)

- Reuse achieved through subtype polymorphism
  - the same piece of code can operate on objects of different type, as long as:
    - Their types are derived from a common base class
    - Code assumes only the interface provided by base class.
- Polymorphism arises due to the fact that the implementation of operations may differ across subtypes.

Dynamic Binding

- Dynamic binding provides overloading rather than parametric polymorphism.
  - the draw function implementation is not being shared across subtypes of DrawableObject, but its name is shared.
- Enables client code to be reused
- To see dynamic binding more clearly as overloading:
  - Instead of a.draw(),
  - view as draw(a)

Reuse of Code (Continued)

- Subtype polymorphism = function overloading
- Implemented using dynamic binding
  - i.e., function name is resolved at runtime, rather than at compile time.
- Conclusion: just as overloading enables reuse of client code, subtype polymorphism enables reuse of client code.

Section 3

Inheritance

Inheritance

- language mechanism in OO languages that can be used to implement subtypes.
- The notion of interface inheritance corresponds conditions (1), (2) and (3) in the definition of Subtype
- but provision (3) is not checked or enforced by a compiler.

Subtyping & interface inheritance

- The notion of subtyping and interface inheritance coincide in OO languages.

  OR

- Another way to phrase this is to say that “interface inheritance captures an ’is-a’ relationship”

  OR

- If A inherits B’s interface, then it must be the case that every A is a B.

Implementation Inheritance

- If A is implemented using B, then there is an implementation inheritance relationship between A and B.
  - However A need not support any of the operations supported by B

    OR
  - There is no `is-a` relationship between the two classes.
- Implementation inheritance is thus “irrelevant” from the point of view of client code.
- Private inheritance in C++ corresponds to implementation-only inheritance, while public inheritance provides both implementation and interface inheritance.

Implementation Inheritance (Continued)

- Implementation-only inheritance is invisible outside a class
  - not as useful as interface inheritance.
  - can be simulated using composition.

```
class B{
   op1(...)
   op2(...)
}
class A: private class B {
   op1(...) /* Some operations supported by B may also be supported in
               A (e.g., op1), while others (e.g., op2) may not be */
   op3(...) /* New operations supported by A */
}
```

Implementation Inheritance (Continued)

- The implementation of op1 in A has to explicitly invoke the implementation of op1 in B:

```
A::op1(...){
   B::op1(...)
}
```

- So, we might as well use composition:

```
class A{
   B b;
   op1(...) {  b.op1(...) }
   op3(...)...
}
```

Polymorphism

"*The ablilty to assume different forms*"

- A function/method is polymorphic if it can be applied to values of many types.
- Class hierarchy and inheritance provide a form of polymorphism called *subtype polymorphism*.
- As dicussed earlier, it is a form of overloading.
  - Overloading based on the first argument alone.
  - Overloading resolved dynamically rather than statically.
- Polymorphic functions increase code reuse.

Polymorphism (Continued)

- Consider the following code fragment: (x < y)? x : y
- "Finds the minimum of two values".
- The same code fragment can be used regardless of whether x and y are:
  - integers
  - floating point numbers
  - objects whose class implements operator "<".
- *Templates* lift the above form of polymorphism (called *parametric* polymorphism) to functions and classes.

Parametric polymorphism Vs Interface Inheritance

- In C++,
  - template classes support parametric polymorphism
  - public inheritance support interface + implementation inheritance.
- Parametric polymorphism is more flexible in many cases.

```
template class List<class ElemType>{
   private:
      ElemType *first; List<ElemType> *next;
   public:
      ElemType *get(); void insert(ElemType *e);
}
```

- Now, one can use the List class with any element type:

```
void f(List<A> alist, List<B> blist){
   A a = alist.get();
   B b = blist.get();
}
```

Parametric polymorphism Vs Inheritance (Continued)

- If we wanted to write a List class using only subtype polymorphism:
  - We need to have a common base class for A and B
  - e.g., in Java, all objects derived from base class "Object"

```
class AltList{
   private:
      Object first; AltList next;
   public:
      Object get(); void insert(Object o);
}

void f(AltList alist, AltList blist) {
   A a = (A)alist.get();
   B b = (B)blist.get();
}
```

Parametric polymorphism Vs Interface Inheritance (Continued)

- Note: get() returns an object of type Object, not A.
- Need to explicitly perform runtime casts.
  - type-checking needs to be done at runtime, and type info maintained at runtime
  - potential errors, as in the following code, cannot be caught at compile time

```
List alist, blist;
A a; A b;//Note b is of type A, not B
alist.insert(a);
blist.insert(b);
f(alist, blist);//f expects second arg to be list of B's, but we are giving a list of A's.
```

Section 4

Overloading and Overriding

Overloading, Overriding, and Virtual Functions

- Overloading is the ability to use the same function NAME with different arguments to denote DIFFERENT functions.
- In C++
  - void add(int a, int b, int& c);
  - void add(float a, float b, float& c);
- Overriding refers to the fact that an implementation of a method in a subclass supersedes the implementation of the same method in the base class.

Overloading, Overriding, and Virtual Functions (Continued)

- Overriding of non-virtual functions in C++:

```
class B {
   public:
      void op1(int i) { /* B's implementation of op1 */ }
}
class A: public class B {
   public:
      void op1(int i) { /* A's implementation of op1 */ }
}
main() {
   B b; A a;
   int i = 5; b.op1(i); // B's implementation of op1 is used
   a.op1(i); // Although every A is a B, and hence B's implementation of
             // op1 is available to A, A's definition supercedes B's defn,
             // so we are using A's implementation of op1.
   ((B)a).op1(); // Now that a has been cast into a B, B's op1 applies.
   a.B::op1(); // Explicitly calling B's implementation of op1
}
```

Overloading, Overriding, and Virtual Functions (Continued)

- In the above example the choice of B's or A's version of op1 to use is based on compile-time type of a variable or expression. The runtime type is not used.
- Overloaded (non-member) functions are also resolved using compile-time type information.

Overriding In The Presence Of Virtual Function

```
class B {
   public:
      virtual void op1(inti){/* B's implementation of op1 */ }
}
class A: public class B {
   public:
      void op1(int i) {// op1 is virtual in base class, so it is virtual here too
      /* A's implementation of op1 */ }
}
main() {
   B b; A a;
   int i = 5;
   b.op1(i); // B's implementation of op1 is used
   a.op1(i); // A's implementation of op1 is used.
   ((B)a).op1(); // Still A's implementation is used
   a.B::op1(); // Explicitly requesting B's definition of op1
}
```

Overriding In The Presence Of Virtual Function (Continued)

```
void f(B x, int i) {
  x.op1(i);
}
```

- which may be invoked as follows:

```
B b;
A a;
f(b, 1); // f uses B's op1
f(a, 1); // f still uses B's op1, not A's
```

```
void f(B& x, int i) {
  x.op1(i);
}
```

- which may be invoked as follows:

```
B b;
A a;
f(b, 1); // f uses B's op1
f(a, 1); // f uses A's op1
```