Inheritance

- Building block of Object Oriented Programming
- Captures the notion of the “is a” relationship between objects of classes
- Sub-classing or sub-typing
  - Terminology: base and derived classes or super and sub classes
- Fundamental idea of extension – the derived class “inherits” all of the properties of its base class, and adds data and methods
  - All of the methods of the base class are methods of the derived class
  - All of the data of the base class is data of the derived class
- For practical code design, allows factoring of maximum commonality
  - Promotes code reuse without duplication
- C++ allows single inheritance (like Java), but also multiple inheritance
- Examples:
  - Organizational hierarchy – Employees, Managers, Officers
    - A Manager “is a” Employee
    - An Officer “is a” Employee
  - Shapes – Shape, Circle, Rectangle, Square
    - A Circle is a shape
    - A Rectangle is a shape
    - A Square is a Rectangle

Syntax of C++ Inheritance

- Base class is named after derived class name in class definition, separated by colon (i.e., colon is used in C++ where keyword “extends” is used in Java)
- Base class is qualified by access – public is real inheritance (more about private later)
- For example:

  ```
  class Derived : public Base {
  // Think of this as “including” the class Base in the definition of Derived
  // As if the code of Base is duplicated in Derived
  // Derived may override any data or methods it inherits from Base, re-defining the inherited definitions
  // To override, signatures of methods must match exactly
  // Data or methods that are private in Base are hidden from Derived
  // I.e., deriving does not give any special access
  // Otherwise, entire access protection scheme would break down
  // This is a visibility issue – the private data and methods exist in the derived class, but just cannot be accessed by the code of the derived class
  // Some special access with protected – more later
  // No limit to inheritance chain (assume all public):
  class A { void foo(); };
  class B : public A { void bar(); };
  class C : public B { int x; void bar(); };
  class D : public C { void foo(); }
  // D has foo, bar, and x. It has re-defined foo, but inherits the rest. C has foo, bar, and x. It defines x and bar, but inherits foo. Etc.
  ```
- Note that inherited methods or data may not come from immediate ancestor
- There is no common base class implied for all classes like the Object class in Java

**Constructors and Destructors**
- Constructors and destructors are not explicitly inherited, but they are implicitly used for construction and destruction of base class
  - For any Derived object, a Base constructor is called **before** the constructor of Derived
  - For any Derived object, the Base destructor is called **after** the destructor of Derived
  - If you think of a Derived as being built upon a Base, then of course the Base must be built first, and likewise the Derived must be torn down first
- Since the base class constructors may require various arguments, we need a way to pass these values
  - The point at which the Base constructor is called is before beginning the Derived constructor, so we have Base initialization syntax:
    ```
    class A {
      A();
      A(int, double);
    };
    class B : public A {
      B() { }
      B(double d) : A(5, d) { }
    };
    ```
  - This is just like member initialization syntax
  - No such syntax is needed for destructors since no arguments are passed

**Private “Inheritance”**
- If the keyword `private` is used to modify the base class in the derived class definition, then the inheritance relationship is not part of the interface
- This is not real inheritance since the “is a” relationship is known only to the derived class itself, so is just an implementation detail
- This is useful for some implementations
  - E.g., a Stack may be privately derived from a base of Vector
  - Convenient for the implementation, but probably don’t want all of the Vector interface available to Stack users

**Protected access**
- Keyword `protected` gives special access for classes in an inheritance hierarchy
- For classes not derived from the base, `protected` is equivalent to `private`
- For classes derived from the base, `protected` is equivalent to `public`
- So `protected` reveals parts of the class to any class that may derive
- Reduces encapsulation and data hiding, but better than completely public
- Should be treated like public with regard to design since access is granted to unknown extent (any class that derives)
- Same rules apply when used on the derivation itself

**Pointers and References**
- The B “is a” A relationship means that a B object can be used wherever an A object is expected
- This holds for pointers and references
  ```
  class A { }
  class B : public A { }
  A a; B b;
  A *pa = & a;   // Legal – always has been
  A *pa = & b;   // Also legal – a B is an A
  B *pb = & a;   // Illegal – we don’t have a whole B
  void foo(A *); foo(&a); foo(&b);  // Legal
  void bar(A &); bar(a); bar(b);  // Legal
  ```
- Allowing addresses of derived objects to be treated as addresses of base objects appears to lose information
- Okay if all we need to know is the base characteristics of the object, but what if the derived object has overridden function definitions?
  - Could result in surprises – if compiler sees whole object definition, it “knows” what the object is – static binding
  - But if it sees only the address, maybe the object there is really a derived type and then we would be missing information
  - Solution is to bind member functions dynamically

**Virtual Functions**
- Dynamically bound functions are called virtual functions
- Default behavior is static binding, to get dynamic binding you must have the `virtual` keyword on the function declaration in base class
  - Only required on earliest base class where we want dynamic binding
- This is the way all methods are resolved in Java (dynamic binding is default, keyword `final` is used for static binding in Java)
- Cost of dynamic binding is fairly trivial, but still too expensive if not needed (e.g., an inline’d length function)
- Dynamic binding means the compiler arranges that the “right thing” is done at runtime, even if static analysis doesn’t show true type of object
- Allows for polymorphic treatment
  - A manager class can maintain a list of pointers, where pointer type is pointer to base.
  - Pointers may really be addresses of various derived objects
  - When methods are called, the correct method for the actual object is invoked if it is a virtual method
Example: window manager has Window pointers or references. Calls draw() for each one, and the correct draw() method is invoked for each object
- Replaces need for carrying around type fields and using switches on type
  - Compiler does this for us, and efficiently
- Typical implementation uses a virtual function table
  - Table has slots for each function declared virtual
  - Populated with addresses of the right functions
  - Only need one table for each class, not for each object of the class
  - Object only needs to associate with correct table
  - Overhead is one table per class, one pointer per object, extra level of indirection to call a function

Virtual Destructors
- Destructors can be virtual, too
- Always a good idea if any virtual functions (or if polymorphic treatment with pointers or references is expected)
- Remember that destructor calls begin with derived, and work back to base destructor (like unwinding of stack)
- If destructor is not virtual, and compiler only has a pointer or reference, it can only start this chain at the destructor for the type that it knows
  - This skips the calling of any destructors further down subclass chain
  - …which could be catastrophic
- A best practice: always define empty virtual destructor in base class

Pure Virtual Functions
- A member function may be declared pure virtual
- This means that no definition can or will be given – the function is a declaration only, so is a placeholder (like an abstract method in Java)
- Rather than a keyword, the syntax is to “initialize” the function with the null pointer, i.e., the value zero
  
```c++
class A {
  virtual void foo() = 0;
};
```
- A class containing (or inheriting without redefining) a pure virtual is called an abstract class
- No object of an abstract class can be instantiated
  - It’s abstract, and we can’t have a concrete instance
  - If we could, and attempted to call the pure virtual function…
- A pure virtual holds a place in the virtual function table
- Abstract characteristic of class continues down inheritance until all pure virtuals are defined
- Useful for factoring out common abstractions, where objects are too incomplete to function on their own
- Useful for abstraction of objects kept by container classes
- Similar to Java interface
Copy Constructors and Assignment
- Copy constructors and assignment not inherited
- However, default copy constructor and assignment do **member-wise** initialization and assignment
  - This applies to the base class as well
  - So derived class only has to take care of itself (the part not in the base)
- Consistent with object oriented philosophy of self containment

Multiple Inheritance
- A class can be derived from multiple base classes
- Expresses several “is a” relationships
- Syntax is to list base classes, separated by commas (and each qualified with public, private)
  - Similar to Java multiple interfaces
- Difficulty comes if two of the bases are in turn derived from a common base
  - Do we want multiple copies of the common base or do we want one copy of the common base?
  - If only one copy desired, base inheritance should be declared virtual
  - For example,
    ```cpp
class B : virtual public A { };
class C : virtual public A { };
class D : public B, public C;
```
    Then objects of type D have a single A part
- Multiple inheritance results in a lattice diagram of inheritance
- Ambiguities may result
  - Can usually be resolved with scoping operator
  - Sometimes we want redefinition to invoke overridden functions from each super class (sum of parts)
- Can be argued that multiple inheritance is unnecessary
  - In any case, should be used sparingly as it complicates design