Single & Multiple Inheritance in C++

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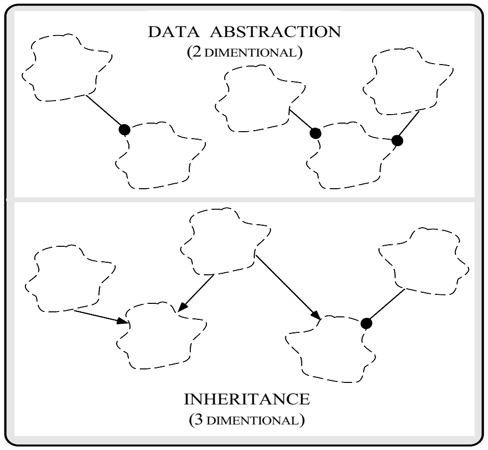
Background

- Object-oriented programming is often defined as the combination of *Abstract Data Types* (ADTs) with *Inheritance* & *Dynamic Binding*
- Each concept addresses a different aspect of system decomposition:
  1. ADTs decompose systems into *two-dimensional* grids of modules
     - Each module has *public* & *private* interfaces
  2. Inheritance decomposes systems into *three-dimensional* hierarchies of modules
     - Inheritance relationships form a *lattice*
  3. Dynamic binding enhances inheritance
     - *e.g.*, defer implementation decisions until late in the design phase or even until run-time!

Data Abstraction vs. Inheritance



Motivation for Inheritance

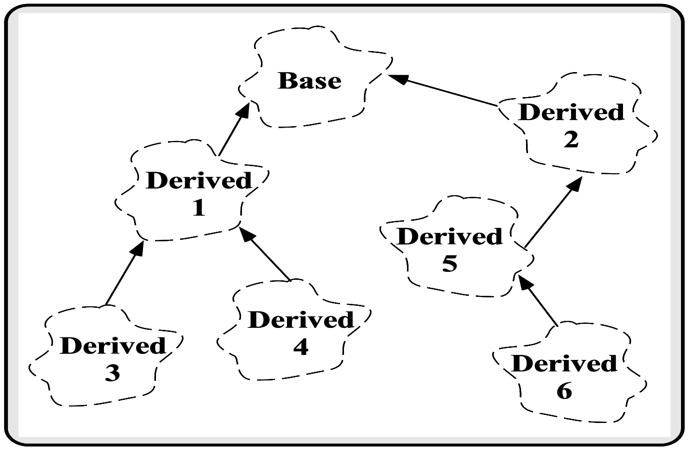
- Inheritance allows you to write code to handle certain cases & allows other developers to write code that handles more specialized cases, while your code continues to work
- Inheritance partitions a system architecture into semi-disjoint components that are related hierarchically
- Therefore, we may be able to modify and/or reuse sections of the inheritance hierarchy without disturbing existing code, *e.g.*,
  - Change sibling subtree interfaces
    - ∗ *i.e.*, a consequence of inheritance
  - Change implementation of ancestors
    - ∗ *i.e.*, a consequence of data abstraction

Inheritance Overview

- A type (called a *subclass* or *derived* type) can inherit the characteristics of another type(s) (called a *superclass* or *base type*)
  - The term *subclass* is equivalent to *derived type*
- A derived type acts just like the base type, except for an explicit list of:

1. *Specializations*
   - Change implementations *without* changing the base class interface
   - Most useful when combined with dynamic binding
2. *Generalizations/Extensions*
   - Add new operations or data to derived classes

Visualizing Inheritance

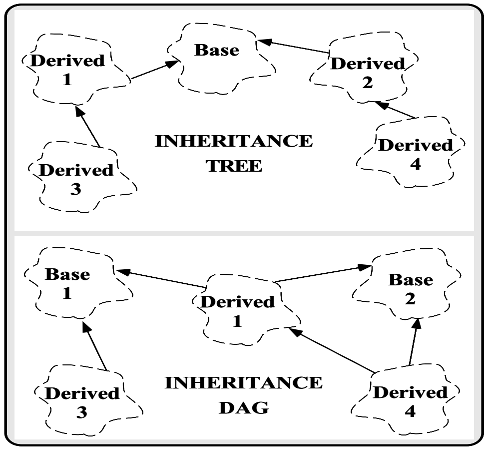


Types of Inheritance

- Inheritance comes in two forms, depending on number of *parents* a subclass has

1. *Single Inheritance* (SI)
   - Only one parent per derived class
   - Form an inheritance *tree*
   - SI requires a small amount of run-time overhead when used with dynamic binding
   - *e.g.*, Smalltalk, Simula, Object Pascal
2. *Multiple Inheritance* (MI)
   - More than one parent per derived class
   - Forms an inheritance *Directed Acyclic Graph* (DAG)
   - Compared with SI, MI adds additional run-time overhead (also involving dynamic binding)
   - *e.g.*, C++, Eiffel, Flavors (a LISP dialect)

Inheritance Trees vs. Inheritance DAGs



Inheritance Benefits

1. *Increase reuse & software quality*
   - Programmers reuse the base classes instead of writing new classes
     - Integrates *black-box* & *white-box* reuse by allowing extensibility and modification without changing existing code
   - Using well-tested base classes helps reduce bugs in applications that use them
   - Reduce object code size
2. *Enhance extensibility & comprehensibility*
   - Helps support more flexible & extensible architectures (along with dynamic binding)
     - *i.e.*, supports the open/closed principle
   - Often useful for modeling & classifying hierarchically-related domains

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Inheritance Liabilities

1. May create deep and/or wide hierarchies that are hard to understand & navigate without class browser tools
2. May decrease performance slightly
   - *i.e.*, when combined with *multiple inheritance* & *dynamic binding*
3. Without dynamic binding, inheritance has limited utility, *i.e.*, can only be used for implementation inheritance
   - & dynamic binding is essentially pointless without inheritance
4. Brittle hierarchies, which may impose dependencies upon ancestor names

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Inheritance in C++

- Deriving a class involves an extension to the C++ class declaration syntax
- The class head is modified to allow a *derivation list* consisting of base classes, *e.g.*,

```
class Foo { /* . . . */ };
class Bar : public Foo { /* . . . */ };
class Baz : public Foo, public Bar { /* . . . */ };
```

Key Properties of C++ Inheritance

- The base/derived class relationship is explicitly recognized in C++ by predefined standard conversions
  - *i.e.*, a pointer to a derived class may always be assigned to a pointer to a base class that was inherited *publicly*
    - But not vice versa . . .
- When combined with dynamic binding, this special relationship between inherited class types promotes a type-secure, *polymorphic* style of programming
  - *i.e.*, the programmer need not know the actual type of a class at compile-time
  - Note, C++ is not *arbitrarily* polymorphic
    - *i.e.*, operations are not applicable to objects that don’t contain definitions of these operations at some point in their inheritance hierarchy

Simple Screen Class

```
class Screen {                              /* Base class. */
public:
  Screen (int = 8, int = 40, char = ’ ’);
  ˜Screen (void);
  short height (void) const { return this->height_; }
  short width (void) const { return this->width_; }
  void height (short h) { this->height_ = h; }
  void width (short w) { this->width_ = w; }
  Screen &forward (void);
  Screen &up (void);    Screen &down (void);
  Screen &home (void);  Screen &bottom (void);
  Screen &display (void); Screen &copy (const Screen &);
private:
  short height_, width_;
  char *screen_, *cur_pos_;
};
```

Subclassing from Screen

- **`class Screen`** can be a public base class of **`class Window`**, *e.g.*,

```
class Window : public Screen {
public:
  Window (const Point &, int rows = 24,
    int columns = 80, char default_char = ’ ’);
  void set_foreground_color (Color &);
  void set_background_color (Color &);
  void resize (int height, int width);
  // . . .
private:
  Point center_;
  Color foreground_;
  Color background_;
};
```

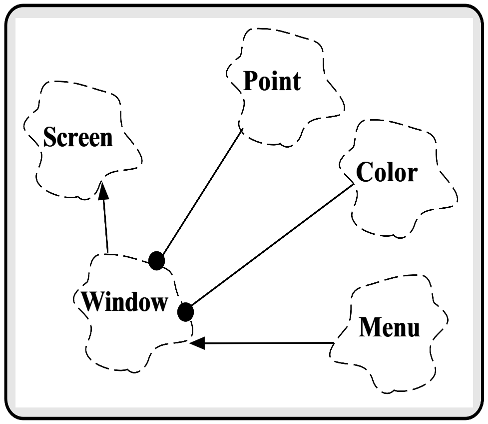
Multiple Levels of Derivation

- A derived class can itself form the basis for further derivation, *e.g.*, ls0.9

```
class Menu : public Window {
public:
  void set_label (const char *l);
  Menu (const Point &, int rows = 24,
    int columns = 80,
    char default_char = ’ ’);
  // . . .
private:
  char *label_;
};
```

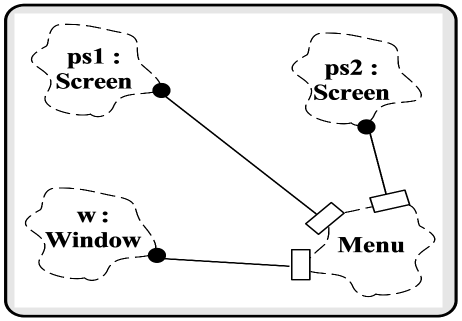
- **`class Menu`** inherits data & methods from both **`Window`** & **`Screen`**, *i.e.*, **`sizeof (Menu) >= sizeof (Window) >= sizeof (Screen)`**

The Screen Inheritance Hierarchy



Screen/Window/Menu hierarchy

Variations on a Screen . . .



- A pointer to a derived class can be assigned to a pointer to any of its *public* base classes without requiring an explicit cast:

```
Menu m; Window &w = m; Screen *ps1 = &w;
Screen *ps2 = &m;
```

Using the Screen Hierarchy

```
class Screen {
  public: virtual void dump (ostream &); };
class Window : public Screen {
  public: virtual void dump (ostream &);
};
class Menu : public Window {
  public: virtual void dump (ostream &);
};
// stand-alone function
void dump_image (Screen *s, ostream &o) {
  // Some processing omitted
  s->dump (o);
  // translates to: (*s->vptr[1]) (s, o));
}
```

Using the Screen Hierarchy, (cont’d)

```
Screen s; Window w; Menu m;
Bit_Vector bv;

// OK: Window is a kind of Screen
dump_image (&w, cout);
// OK: Menu is a kind of Screen
dump_image (&m, cout);
// OK: argument types match exactly
dump_image (&s, cout);
// Error: Bit_Vector is not a kind of Screen!
dump_image (&bv, cout);
```

Using Inheritance for Specialization

- A derived class *specializes* a base class by adding new, more specific *state variables* & *methods*
  - Method use the same interface, even though they are implemented differently
    - ∗ *i.e.*, “overridden”
  - Note, there is an important distinction between *overriding*, *hiding*, & *overloading* . . .
- A variant of this is used in the *Template Method* pattern
  - *i.e.*, behavior of the base class relies on functionality supplied by the derived class
  - This is directly supported in C++ via *abstract base classes* & *pure virtual functions*

Specialization Example

- Inheritance may be used to obtain the features of one data type in another closely related data type
- For example, we can create a class Date that represents an arbitrary date:

```
class Date {
public:
  Date (int m, int d, int y);
  virtual void print (ostream &s) const {
    s << month_ << day_ << year_ << std::endl;
  }
  // . . .
private:
  int month_, day_, year_;
};
```

Specialization Example, (cont'd)

- Class Birthday derives from Date, adding a name field, *e.g.*,

```
#include <string>

class Birthday : public Date {
public:
  Birthday (const std::string &n, int m, int d, int y)
    : Date (m, d, y),
      person_ (n) { }
  virtual void print (ostream &s) const;
  // . . .
private:
  std::string person_;
};
```

Implementation & Use-case

- `Birthday::print()` could print the person's name as well as the date, *e.g.*,

```
void Birthday::print (ostream &s) const {
  s << this->person_ << " was born on ";
  Date::print (s); s << std::endl;
}

const Date july_4th (7, 4, 1993);
july_4th.print (cout);  // july 4, 1993
Birthday igors_birthday ("Igor Stravinsky", 6, 17, 1882);
igors_birthday.print (cout);
// Igor Stravinsky was born on june 17, 1882

Date *dp = &igors_birthday;
dp->print (cout); // what gets printed ?!?!
// (*dp->vptr[1])(dp, cout);
```

Alternatives to Specialization

- Note that we could also use *object composition* (*containment*) instead of *inheritance* for this example, *e.g.*,

```
class Birthday {
public:
  Birthday (const std::string &n, int m, int d, int y):
    date_ (m, d, y), person_ (n) {}
  // same as before
private:
  Date date_;
  std::string person_;
};
```

Alternatives to Specialization, (cont'd)

- However, in this case we would not be able to utilize the dynamic binding facilities for base classes & derived classes, *e.g.*,

```
Date *dp = &igors_birthday;
// ERROR, Birthday is not a subclass of date!
```

- While this does not necessarily affect reusability, it does affect extensibility . . .

Another View of Inheritance

- Inheritance can also be viewed as a way to construct a hierarchy of types that are "incomplete" except for the leaves of the hierarchy
  - *e.g.*, you may wish to represent animals with an inheritance hierarchy. Lets call the root class of this hierarchy "Animal"
  - Two classes derive from Animal: Vertebrate and Invertebrate
  - Vertebrate can be derived to Mammal, Reptile, Bird, Fish, *etc.*.
  - Mammals can be derived into Rodents, Primates, Pachyderms, *etc.*.
  - Primates can be derived into Apes, Sloths, Humans, *etc.*.
  - Humans can be derived into Males & Females
    - ∗ We can then declare objects to represent specific males & females, *e.g.*, Bob, Ted, Carol, & Alice

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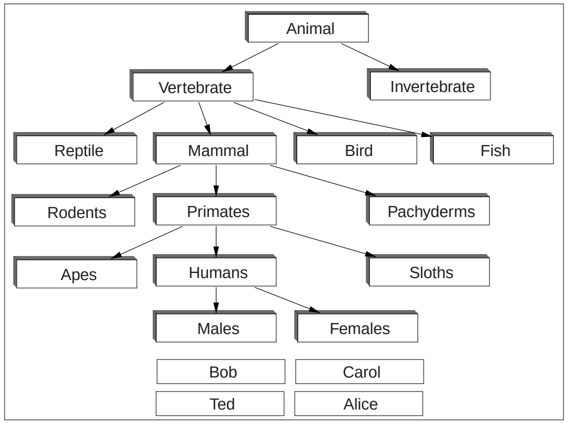
Another View of Inheritance



- Advantages
  - Share code & set-up dynamic binding
  - Model & classify external objects with design & implementation

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Using Inheritance for Extension/Generalization

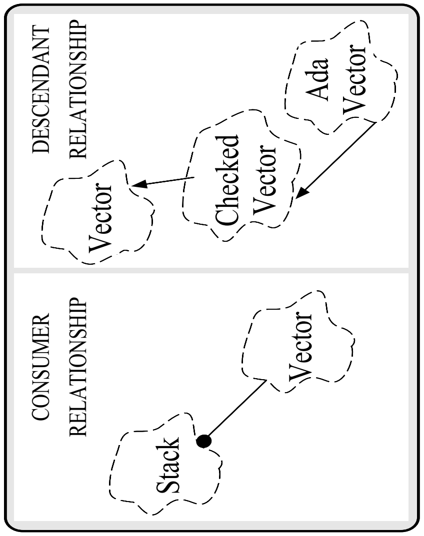
- Derived classes add *state variables* and/or *operations* to the *properties* and *operations* associated with the base class
  - Note, the interface is generally widened!
  - Data member & method access privileges may also be modified
- Extension/generalization is often used to faciliate reuse of *implementations*, rather than *interface*
  - However, it is not always necessary or correct to export interfaces from a base class to derived classes

Extension/Generalization Example

- Using **`class Vector`** as a private base class for derived **`class Stack`**:
  - **`class Stack : private Vector { /* . . . */ };`**
- In this case, Vector's **`operator[]`** may be reused as an implementation for the Stack **push** & **pop** methods
  - Note that using private inheritance ensures that **`operator[]`** does not appear in **`class Stack`**'s interface!

Extension/Generalization Example, (cont'd)

- Often, a better approach in this case is to use a composition/Has-A rather than a descendant/Is-A relationship . . .



Vector Interface

- Using **`class Vector`** as a base class for a derived class such as class **`Checked_Vector`** or class **`Ada_Vector`**

```
/* Bare-bones Vector implementation, fast but not safe:
   the array of elements is uninitialized, & ranges are
   not checked.  Also, assignment is not supported. */
template <class T> class Vector {
public:
  Vector (size_t s);
  ~Vector (void);
  size_t size (void) const;
  T &operator[] (size_t index);
private:
  T *buf_;
  size_t size_;
};
```

Vector Implementation

```
template <class T>
Vector<T>::Vector (size_t s): size_ (s), buf_ (new T[s])
{}

template <class T>
Vector<T>::~Vector (void) { delete [] this->buf_; }

template <class T> size_t
Vector<T>::size (void) const { return this->size_; }

template <class T> T &
Vector<T>::operator[] (size_t i)
{
  return this->buf_[i];
}
```

Vector Use-case

```
int
main (int, char *[])
{
  Vector<int> v (10);

  v[6] = v[5] + 4; // oops, no initial values

  int i = v[v.size ()]; // oops, out of range!

  // destructor automatically called
}
```

Benefits of Inheritance

- Inheritance enables modification and/or extension of ADTs *without changing the original source code*
  - *e.g.*, someone may want a variation on the basic Vector abstraction:
    1. A vector whose bounds are checked on every reference
    2. Allow vectors to have lower bounds other than 0
    3. Other vector variants are possible too . . .
       - *e.g.*, automatically-resizing vectors, initialized vectors, *etc.*
- This is done by defining new derived classes that inherit the characteristics of the `Vector` base class
  - Note that inheritance also allows code to be shared

Checked_Vector Interface

- The following allows run-time range checking:

```
/* File Checked-Vector.h (incomplete wrt
   initialization & assignment) */
struct Range_Error { Range_Error (size_t index); /* ... */ };

template <class T>
class Checked_Vector : public Vector<T> {
public:
  Checked_Vector (size_t s);
  T &operator[] (size_t i) throw (Range_Error);
  // Vector::size () inherited from base class Vector.
protected:
  int in_range (size_t i) const;
private:
  typedef Vector<T> inherited;
};
```

Implementation of Checked_Vector

```
template <class T> int
Checked_Vector<T>::in_range (size_t i) const {
  return i < this->size (); }

template <class T>
Checked_Vector<T>::Checked_Vector (size_t s)
: inherited (s) {}

template <class T> T &
Checked_Vector<T>::operator[] (size_t i)
  throw (Range_Error) {
  if (this->in_range (i))
    return (*(inherited *) this)[i];
    // equivalent to:  return inherited::operator[](i);
  else throw Range_Error (i); }
```

Checked_Vector Use-case

```
#include Checked_Vector.h
typedef Checked_Vector<int> CV_int;

int foo (int size)
{
  try
  {
    CV_int cv (size);
    int i = cv[cv.size ()]; // Error detected!
      // exception raised . . .
      // Call base class destructor
  }
  catch (Range_Error)
  { /* . . . */ }
}
```

Describing Relationships Between Classes

- *Consumer/Composition/Aggregation*
  - A class is a consumer of another class when it makes use of the other class's services, as defined in its interface
    - For example, our Bounded_Stack implementation relies on Array for its implementation, & thus is consumer of the Array class
  - Consumers are used to describe a *Has-A* relationship
- *Descendant/Inheritance/Specialization*
  - A class is a descendant of one or more other classes when it is designed as an extension or specialization of these classes. This is the notion of inheritance
  - Descendants are used to describe an *Is-A* relationship

Interface vs. Implementation Inheritance

- Class inheritance can be used in two primary ways:
  1. *Interface inheritance*: a method of creating a subtype of an existing class for purposes of setting up dynamic binding, *e.g.*,
     - Circle is a subclass of Shape (*i.e.*, *Is-A* relation)
     - A Birthday is a subclass of Date
  2. *Implementation inheritance*: a method of reusing an implementation to create a new class type
     - *e.g.*, a class Stack that inherits from class Vector. A Stack is not really a subtype or specialization of Vector
     - In this case, inheritance makes implementation easier, because there is no need to rewrite & debug existing code.
     - This is called *using inheritance for reuse*
     - *i.e.*, a pseudo-*Has-A* relation

The Dangers of Implementation Inheritance

- Using inheritance for reuse may sometimes be a dangerous misuse of the technique
  - Operations that are valid for the base type may not apply to the derived type at all
    - *e.g.*, performing an subscript operation on a stack is a meaningless & potentially harmful operation

```
class Stack : public Vector { /* . . . */ };
Stack s;
s[10] = 20; // could be big trouble!
```

  - In C++, the use of a private base class minimizes the dangers
    - *i.e.*, if a class is derived "private," it is illegal to assign the address of a derived object to a pointer to a base object
  - On the other hand, a consumer/Has-A relation might be more appropriate . . .

Private vs Public vs Protected Derivation

- Access control specifiers (*i.e.*, public, private, protected) are also meaningful in the context of inheritance
- In the following examples:
  - `<. . . .>` represents actual (omitted) code
  - `[. . . .]` is implicit
- Note, all the examples work for both data members & methods

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Public Derivation

```
class A {
public:
  <public A>
protected:
  <protected A>
private:
  <private A>
};
```

```
class B : public A {
public:
  [public A]
  <public B>
protected:
  [protected A]
  <protected B>
private:
  <private B>
};
```

Protected Derivation

```
class A {
public:
  <public A>
protected:
  <protected A>
private:
  <private A>
};
```

```
class B : protected A {
public:
  <public B>
protected:
  [protected A]
  [public A]
  <protected B>
private:
  <private B>
};
```

Private Derivation

```
class A {
public:
  <public A>
private:
  <private A>
protected:
  <protected A>
};
```

```
class B : private A {
// same as class B : A
public:
  <public B>
protected:
  <protected B>
private:
  [public A]
  [protected A]
  <private B>
};
```

Derived Class Access to Base Class Members

Base Class Access Control	Inheritance mode		
	public	**protected**	**private**
public	**public**	**protected**	**private**
protected	**protected**	**protected**	**private**
private	**none**	**none**	**none**

- The vertical axis represents the access rights specified in the base class
- The horizontal access represents the mode of inheritance used by the derived class
- Note that the resulting access is always the most restrictive of the two

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Other Uses of Access Control Specifiers

- Selectively redefine visibility of individual methods inherited from base classes. NOTE: the redifinition can only be to the visibility of the base class. Selective redefinition can only override the additional control imposed by inheritance.

```
class A {
public:
  int f (void);
  int g_;
  . . .
private:
  int p_;
};
```

```
class B : private A {
public:
  A::f; // Make public
protected:
  A::g_; // Make protected
};
```

Common Issues with Access Control Specifiers

- It is an error to *increase* the access of an inherited method above the level given in the base class
- Deriving *publicly* & then selectively decreasing the visibility of base class methods in the derived class should be used with caution: *removes* methods from the public interface at lower scopes in the inheritance hierarchy.

```
// Error if p_ is
// protected in A!
class B : private A {
public:
  A::p_;
};
```

```
class B : public A {
private:
  A::f; // hides A::f
};
```

General Rules for Access Control Specifiers

- Private methods of the base class are not accessible to a derived class (unless the derived class is a friend of the base class)
- If the subclass is derived *publicly* then:
  1. Public methods of the base class are accessible to the derived class
  2. Protected methods of the base class are accessible to derived classes & friends only

Caveats

- Using protected methods weakens the data hiding mechanism because changes to the base class implementation might affect all derived classes.
- However, performance & design reasons may dictate use of the protected access control specifier
  - Note, inlining functions often reduces the need for these efficiency hacks.

Caveats, example

```
class Vector {
public:
  // . . .
protected:
  // allow derived classes direct access
  T *buf_;
  size_t size_;
};
class Ada_Vector : public Vector {
public:
  T &operator() (size_t i) {
    return this->buf_[i];
  } // Note the strong dependency on the buf_
};
```

Overview of Multiple Inheritance in C++

- C++ allows *multiple inheritance*
  - *i.e.*, a class can be simultaneously derived from two or more base classes, *e.g.*,

```
class X { /* . . . */ };
class Y : public X { /* . . . */ };
class Z : public X { /* . . . */ };
class YZ : public Y, public Z { /* . . . */ };
```

  - Derived classes **Y**, **Z**, & **YZ** inherit the data members & methods from their respective base classes

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Liabilities of Multiple Inheritance

- A base class may legally appear only once in a derivation list, *e.g.*,

```
class Two_Vect : public Vect, public Vect // ERROR!
```

- However, a base class may appear multiple times within a derivation hierarchy
  - *e.g.*, `class YZ` contains two instances of `class X`
- This leads to two problems with multiple inheritance:
  1. It gives rise to a form of method & data member ambiguity
     - Explicitly qualified names & additional methods are used to resolve this
  2. It also may cause unnecessary duplication of storage
     - *Virtual base classes* are used to resolve this

Motivation for Virtual Base Classes

- Consider a user who wants an **`Init_Checked_Vector`**:

```
class Checked_Vector : public virtual Vector
{ /* . . . */ };
class Init_Vector : public virtual Vector
{ /* . . . */ };
class Init_Checked_Vector :
  public Checked_Vector, public Init_Vector
{ /* . . . */ };
```

- In this example, the virtual keyword, when applied to a base class, causes **`Init_Checked_Vector`** to get one **`Vector`** base class instead of two

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Overview of Virtual Base Classes

- Virtual base classes allow class designers to specify that a base class will be shared among derived classes
  - No matter how often a virtual base class may occur in a derivation hierarchy, only *one* shared instance is generated when an object is instantiated
    - Under the hood, pointers are used in derived classes that contain virtual base classes
- Understanding & using virtual base classes correctly is a non-trivial task because you must plan in advance
  - Also, you must be aware when initializing subclasses objects . . .
- However, virtual base classes are used to implement the client & server side of many implementations of CORBA distributed objects

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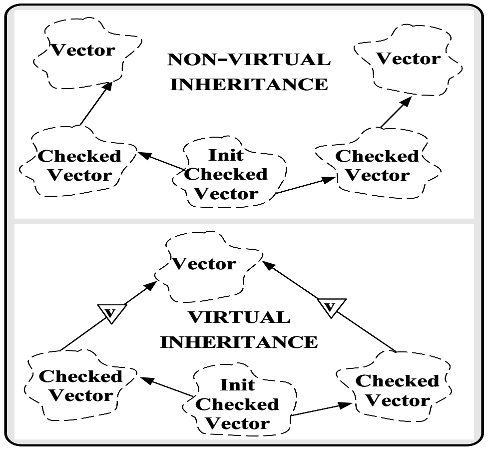
Virtual Base Classes Illustrated



Initializing Virtual Base Classes

- With C++ you must chose one of two methods to make constructors work correctly for virtual base classes:

1. You need to either supply a constructor in a virtual base class that takes no arguments (or has default arguments), *e.g.*,
   `Vector::Vector (size_t size = 100); // not clean!`
2. Or, you must make sure the *most derived class* calls the constructor for the virtual base class in its *base initialization section*, *e.g.*,

```
Init_Checked_Vector (size_t size, const T &init):
    Vector (size), Check_Vector (size),
    Init_Vector (size, init)
```

Virtual Base Class Initialization Example

```
#include <iostream.h>
class Base {
public:
  Base (int i) { cout << "Base::Base (" << i << ")" << endl; }
};

class Derived1 : public virtual Base {
public:
  Derived1 (void) : Base (1) { cout << "Derived1 (void)" << endl; }
};

class Derived2 : public virtual Base {
public:
  Derived2 (void) : Base (2) { cout << "Derived2 (void)" << endl; }
};
```

Virtual Base Class Initialization Example, (cont'd)

```
class Derived : public Derived1, public Derived2 {
public:
  // The Derived constructor _must_ call the Base
  // constructor explicitly, because Base doesn't
  // have a default constructor.
  Derived (void) : Base (3) {
    cout << "Derived (void)" << endl;
  }
};
```

Virtual Base Class Initialization Example, (cont'd)

```
int
main (int, char *[])
{
  Base b (0);    // Direct instantiation of Base:
                 //   Base::Base (0)
  Derived1 d1;   // Instantiates Base via Derived1 ctor:
                 //   Base::Base (1)
  Derived2 d2;   // Instantiates Base via Derived2 ctor:
                 //   Base::Base (2)
  Derived d;     // Instantiates Base via Derived ctor:
                 //   Base::Base (3)
  return 0;
}
```

Vector Interface Revised

- The following example illustrates templates, multiple inheritance, and virtual base classes in C++:

```
#include <iostream.h>
// A simple-minded Vector base class,
// no range checking, no initialization.
template <class T> class Vector
{
public:
  Vector (size_t s): size_ (s), buf_ (new T[s]) {}
  T &operator[] (size_t i) { return this->buf_[i]; }
  size_t size (void) const { return this->size_; }
private:
  size_t size_;
  T *buf_;
};
```

Init_Vector Interface

- A simple extension to the Vector base class, that enables automagical vector initialization

```
template <class T>
class Init_Vector : public virtual Vector<T>
{
public:
  Init_Vector (size_t size, const T &init)
    : Vector<T> (size)
  {
    for (size_t i = 0; i < this->size (); i++)
      (*this)[i] = init;
  }
  // Inherits subscripting operator \& size().
};
```

Checked_Vector Interface

- Extend Vector to provide checked subscripting

```
template <class T>
class Checked_Vector : public virtual Vector<T> {
public:
  Checked_Vector (size_t size): Vector<T> (size) {}
  T &operator[] (size_t i) throw (Range_Error) {
    if (this->in_range (i)) return (*(inherited *) this)
    else throw Range_Error (i);
  }
  // Inherits inherited::size.
private:
  typedef Vector<T> inherited;
  int in_range (size_t i) const
   { return i < this->size (); }
};
```

Init_Checked_Vector Interface

- A simple multiple inheritance example that provides for both an initialized *and* range checked Vector

```
template <class T>
class Init_Checked_Vector :
  public Checked_Vector<T>, public Init_Vector<T> {
public:
  Init_Checked_Vector (size_t size, const T &init):
    Vector<T> (size),
    Init_Vector<T> (size, init),
    Checked_Vector<T> (size) {}
  // Inherits Checked_Vector::operator[]
};
```

Init_Checked_Vector Driver

```
int main (int argc, char *argv[]) {
  try {
    size_t size = ::atoi (argv[1]);
    size_t init = ::atoi (argv[2]);
    Init_Checked_Vector<int> v (size, init);
    cout << "vector size = " << v.size ()
         << ", vector contents = ";

    for (size_t i = 0; i < v.size (); i++)
      cout << v[i];

    cout << "\n" << ++v[v.size () - 1] << "\n";
  }
  catch (Range_Error) { /* . . . */ }
}
```

Multiple Inheritance Ambiguity

- Consider the following:

```
struct Base_1 { int foo (void); /* . . . */ };
struct Base_2 { int foo (void); /* . . . */ };
struct Derived : Base_1, Base_2 { /* . . . */ };
int main (int, char *[]) {
  Derived d;
  d.foo (); // Error, ambiguous call to foo ()
}
```

Multiple Inheritance Ambiguity, (cont'd)

- There are two ways to fix this problem:

1. Explicitly qualify the call, by prefixing it with the name of the intended base class using the scope resolution operator, *e.g.*,

```
  d.Base_1::foo (); // or d.Base_2::foo ()
```

2. Add a new method **foo** to class Derived (similar to Eiffel's renaming concept) *e.g.*,

```
struct Derived : Base_1, Base_2 {
    int foo (void) {
      Base_1::foo (); // either, both
      Base_2::foo (); // or neither
    }
  };
```

Summary

- Inheritance supports evolutionary, incremental development of reusable components by specializing and/or extending a general interface/implementation
- Inheritance adds a new dimension to data abstraction, *e.g.*,
  - Classes (ADTs) support the expression of *commonality* where the *general* aspects of an application are encapsulated in a few *base classes*
  - Inheritance supports the development of the application by *extension* and *specialization* without affecting existing code . . .
- Without browser support, navigating through complex inheritance hierarchies is difficult . . . tools can help.