Module 35: Programming in C++

Multiple Inheritance

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Module Objectives

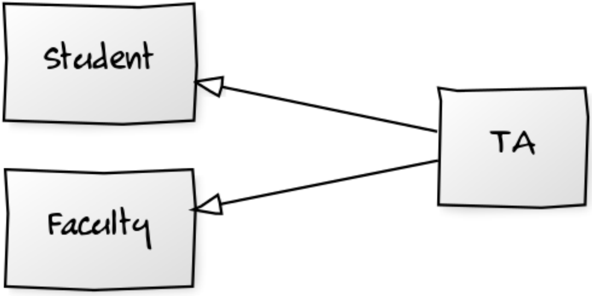
- Understand Multiple Inheritance in C++

Module Outline

- Multiple Inheritance in C++
    - Semantics
    - Data Members and Object Layout
    - Member Functions
    - `protected` Access
    - Constructor & Destructor
    - Object Lifetime
- Diamond Problem
    - Exercise
- Design Choice

Multiple Inheritance in C++: Hierarchy

- TA **ISA** Student; TA **ISA** Faculty

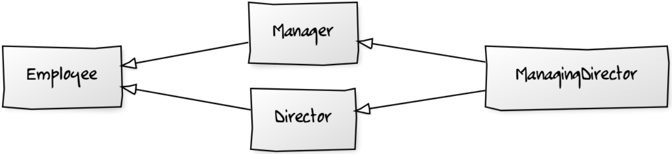


```
class Student;                           // Base Class = Student
class Faculty;                           // Base Class = Faculty
class TA: public Student, public Faculty; // Derived Class = TA
```

- TA inherits properties and operations of both Student as well as Faculty

Multiple Inheritance in C++: Hierarchy

- Manager **ISA** Employee, Director **ISA** Employee, ManagingDirector **ISA** Manager, ManagingDirector **ISA** Director

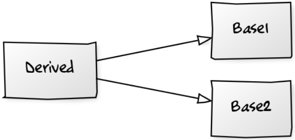


```
class Employee;                    // Base Class = Employee -- Root
class Manager: public Employee;   // Derived Class = Manager
class Director: public Employee; // Derived Class = Director
class ManagingDirector: public Manager, public Director;
                                  // Derived Class = ManagingDirector
```

- Manager inherits properties and operations of Employee
- Director inherits properties and operations of Employee
- ManagingDirector inherits properties and operations of both Manager as well as Director
- ManagingDirector, by transitivity, inherits properties and operations of Employee
- **Multiple inheritance hierarchy usually has a common base class**
- This is known as the **Diamond Hierarchy**

Multiple Inheritance in C++: Semantics

- Derived **ISA** Base1, Derived **ISA** Base2



```
class Base1;                    // Base Class = Base1
class Base2;                    // Base Class = Base2
class Derived: public Base1, public Base2;
                                // Derived Class = Derived
```

- Use keyword `public` after class name to denote inheritance
- Name of the Base class follow the keyword
- There may be more than two base classes
- `public` and `private` inheritance may be mixed

Multiple Inheritance in C++: Semantics

- Derived **ISA** Base1, Base2
- Data Members
  - Derived class *inherits* *all* data members of *all* Base classes
  - Derived class may *add* data members of its own
- Member Functions
  - Derived class *inherits* *all* member functions of *all* Base classes
  - Derived class may *override* a member function of *any* Base class by *redefining* it with the same signature
  - Derived class may *overload* a member function of *any* Base class by *redefining* it with the *same name*; but *different signature*
- Access Specification
  - Derived class *cannot access* private members of *any* Base class
  - Derived class *can access* protected members of *any* Base class
- Construction-Destruction
  - A *constructor* of the Derived class *must first* call *all constructor*s of the Base classes to construct the Base class instances of the Derived class – Base class *constructor*s are called in *listing order*
  - The *destructor* of the Derived class *must* call the *destructor*s of the Base classes to destruct the Base class instances of the Derived class

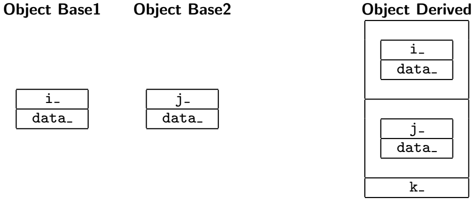
Multiple Inheritance in C++: Data Members and Object Layout

- Derived **ISA** Base1, Base2
- Data Members
  - Derived class *inherits all* data members of *all* Base classes
  - Derived class may *add* data members of its own
- Object Layout
  - Derived class *layout* contains instances of *each* Base class
  - Further, Derived class layout will have data members of its own
  - C++ does not guarantee the relative position of the Base class instances and Derived class members

Multiple Inheritance in C++: Data Members and Object Layout

```
class Base1 { protected:
    int i_;
    int data_;
public: // ...
};
class Base2 { protected:
    int j_;
    int data_;
public: // ...
};
class Derived : public Base1, public Base2 {
    int k_;
public: // ...
};
```

Object Layout



Object Derived has two data_ member!

Ambiguity to be resolved with base class name: `Base1::data_` & `Base2::data_`

Multiple Inheritance in C++: Member Functions – Overrides and Overloads

- Derived **ISA** Base1, Base2
- Member Functions
  - Derived class *inherits all* member functions of *all* Base classes
  - Derived class may *override* a member function of *any* Base class by *redefining* it with the same signature
  - Derived class may *overload* a member function of *any* Base class by *redefining* it with the *same name*; but *different signature*
- Static Member Functions
  - Derived class *does not inherit* the static member functions of *any* Base class
- Friend Functions
  - Derived class *does not inherit* the friend functions of *any* Base class

Multiple Inheritance in C++: Member Functions – Overrides and Overloads

```
class Base1 { protected:
    int i_;
    int data_;
public: Base1(int a, int b) : i_(a), data_(b);
    void f(int) { cout << "Base1::f(int) "; }
    void g() { cout << "Base1::g() "; }
};
class Base2 { protected:
    int j_;
    int data_;
public: Base2(int a, int b) : j_(a), data_(b);
    void h(int) { cout << "Base2::h(int) "; }
};
class Derived : public Base1, public Base2 {
    int k_;
public: Derived(int x, int y, int u, int v, int z);
    void f(int) { cout << "Derived::f(int) "; }       // -- Overridden Base1::f(int)
    // -- Inherited Base1::g()
    void h(string) { cout << "Derived::h(string) "; } // -- Overloaded Base2:: h(int)
    void e(char) { cout << "Derived::e(char) "; }     // -- Added Derived::e(char)
};

    Derived c(1, 2, 3, 4, 5);

    c.f(5);      // Derived::f(int)    -- Overridden Base1::f(int)
    c.g();       // Base1::g()         -- Inherited Base1::g()
    c.h("ppd");  // Derived::h(string) -- Overloaded Base2:: h(int)
    c.e(’a’);    // Derived::e(char)   -- Added Derived::e(char)
```

Inheritance in C++:
Member Functions – using for Name Resolution

Ambiguous Calls

```
class Base1 { public:
    Base1(int a, int b) : i_(a), data_(b);
    void f(int) { cout << "Base1::f(int) "; }
    void g() { cout << "Base1::g() "; }
};
class Base2 { public:
    Base2(int a, int b) : j_(a), data_(b);
    void f(int) { cout << "Base2::f(int) "; }
    void g(int) { cout << "Base2::g(int) "; }
};
class Derived : public Base1, public Base2 {
public: Derived(int x, int y, int u,
                int v, int z);


};

    Derived c(1, 2, 3, 4, 5);

    c.f(5); // Base1::f(int) or Base2::f(int)?
    c.g(5); // Base1::g() or Base2::g(int)?
    c.f(3); // Base1::f(int) or Base2::f(int)?
    c.g();  // Base1::g() or Base2::g(int)?
```

Unambiguous Calls

```
class Base1 { public:
    Base1(int a, int b) : i_(a), data_(b);
    void f(int) { cout << "Base1::f(int) "; }
    void g() { cout << "Base1::g() "; }
};
class Base2 { public:
    Base2(int a, int b) : j_(a), data_(b);
    void f(int) { cout << "Base2::f(int) "; }
    void g(int) { cout << "Base2::g(int) "; }
};
class Derived : public Base1, public Base2 {
public: Derived(int x, int y, int u,
                int v, int z);
    using Base1::f; // Hides Base2::f
    using Base2::g; // Hides Base1::g
};

    Derived c(1, 2, 3, 4, 5);

    c.f(5);         // Base1::f(int)
    c.g(5);         // Base2::g(int)
    c.Base2::f(3);  // Base2::f(int)
    c.Base1::g();   // Base1::g()
```

- Overload resolution does not work between Base1::g(int) and Base2::g()
- using hides other candidates
- Explicit use of base class name can resolve (weak solution)

Multiple Inheritance in C++: Access Members of Base: protected Access

- Access Specification
  - Derived class *cannot access* private members of *any* Base class
  - Derived class *can access* protected members of *any* Base class

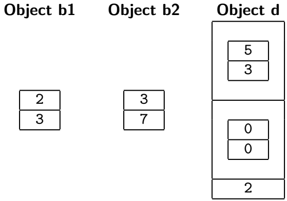
Multiple Inheritance in C++: Constructor & Destructor

- Constructor-Destructor
  - Derived class *inherits all* Constructors and Destructor of Base classes (but in a different semantics)
  - Derived class *cannot override* or *overload* a Constructor or the Destructor of *any* Base class
- Construction-Destruction
  - A *constructor* of the Derived class *must first* call *all constructor*s of the Base classes to construct the Base class instances of the Derived class
  - Base class *constructor*s are called in *listing order*
  - The *destructor* of the Derived class *must* call the *destructor*s of the Base classes to destruct the Base class instances of the Derived class

Multiple Inheritance in C++: Constructor & Destructor

```
class Base1 { protected: int i_; int data_;
public: Base1(int a, int b) : i_(a), data_(b) { cout << "Base1::Base1() "; }
    ~Base1() { cout << "Base1::~Base1() "; }
};
class Base2 { protected: int j_; int data_;
public: Base2(int a = 0, int b = 0) : j_(a), data_(b) { cout << "Base2::Base2() "; }
    ~Base2() { cout << "Base2::~Base2() "; }
};
class Derived : public Base1, public Base2 { int k_;
public: Derived(int x, int y, int z) :
            Base1(x, y), k_(z) { cout << "Derived::Derived() "; }
            // Base1::Base1 explicit, Base2::Base2 default
    ~Derived() { cout << "Derived::~Derived() "; }
};
Base1 b1(2, 3);
Base2 b2(3, 7);
Derived d(5, 3, 2);
```

Object Layout



Multiple Inheritance in C++: Object Lifetime

```
class Base1 { protected: int i_; int data_;
public: Base1(int a, int b) : i_(a), data_(b) { cout << "Base1::Base1() "; }
    ~Base1() { cout << "Base1::~Base1() "; }
};
class Base2 { protected: int j_; int data_;
public:
    Base2(int a = 0, int b = 0) : j_(a), data_(b) { cout << "Base2::Base2() "; }
    ~Base2() { cout << "Base2::~Base2() "; }
};
class Derived : public Base1, public Base2 { int k_;
public:
    Derived(int x, int y, int z) :
        Base1(x, y), k_(z) { cout << "Derived::Derived() "; }
        // Base1::Base1 explicit, Base2::Base2 default
    ~Derived() { cout << "Derived::~Derived() "; }
};

Derived d(5, 3, 2);
```

Construction O/P

```
Base1::Base1(): 5, 3  // Obj. d.Base1
Base2::Base2(): 0, 0  // Obj. d.Base2
Derived::Derived(): 2 // Obj. d
```

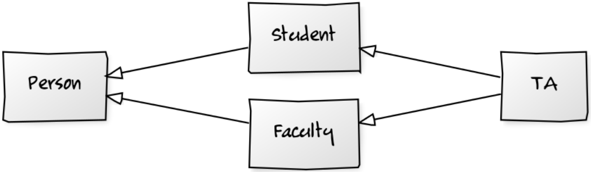
Destruction O/P

```
Derived::~Derived(): 2 // Obj. d
Base2::~Base2(): 0, 0  // Obj. d.Base2
Base1::~Base1(): 3, 5  // Obj. d.Base1
```

- First construct base class objects, then derived class object
- First destruct derived class object, then base class objects

Multiple Inheritance in C++: Diamond Problem

- Student **ISA** Person
- Faculty **ISA** Person
- TA **ISA** Student; TA **ISA** Faculty



```
class Person;                            // Base Class = Person -- Root
class Student: public Person;            // Base / Derived Class = Student
class Faculty: public Person;            // Base / Derived Class = Faculty
class TA: public Student, public Faculty; // Derived Class = TA
```

- Student inherits properties and operations of Person
- Faculty inherits properties and operations of Person
- TA inherits properties and operations of both Student as well as Faculty
- TA, by transitivity, inherits properties and operations of Person

Multiple Inheritance in C++: Diamond Problem

```
#include<iostream>
using namespace std;

class Person { // Data members of person
public: Person(int x)  { cout << "Person::Person(int)" << endl; }
};
class Faculty : public Person { // data members of Faculty
public: Faculty(int x) :Person(x) { cout << "Faculty::Faculty(int)" << endl; }
};
class Student : public Person { // data members of Student
public: Student(int x) :Person(x) { cout << "Student::Student(int)" << endl; }
};
class TA : public Faculty, public Student  {
public: TA(int x) :Student(x), Faculty(x) { cout << "TA::TA(int)" << endl; }
};
int main()  {
    TA ta(30);

    return 0;
}
-----
Person::Person(int)
Faculty::Faculty(int)
Person::Person(int)
Student::Student(int)
TA::TA(int)
```

- **Two instances of base class object (`Person`) in a `TA` object!**

Multiple Inheritance in C++: virtual Inheritance – virtual Base Class

```
#include<iostream>
using namespace std;

class Person { // Data members of person
public: Person(int x)  { cout << "Person::Person(int)" << endl; }
    Person()  { cout << "Person::Person()" << endl; } // Default ctor for virtual inheritance
};
class Faculty : virtual public Person { // data members of Faculty
public: Faculty(int x) :Person(x) { cout << "Faculty::Faculty(int)" << endl; }
};
class Student : virtual public Person { // data members of Student
public: Student(int x) :Person(x) { cout << "Student::Student(int)" << endl; }
};
class TA : public Faculty, public Student  {
public: TA(int x) :Student(x), Faculty(x)   { cout << "TA::TA(int)" << endl; }
};
int main()  {
    TA ta(30);

    return 0;
}
-----
Person::Person()
Faculty::Faculty(int)
Student::Student(int)
TA::TA(int)
```

- Introduce a default constructor for root base class Person
- Prefix every inheritance of Person with virtual
- **Only one instance of base class object (Person) in a TA object!**

Multiple Inheritance in C++: `virtual` Inheritance with Parameterized Ctor

```
#include<iostream>
using namespace std;
class Person {
public: Person(int x) { cout << "Person::Person(int)" << endl; }
    Person() { cout << "Person::Person()" << endl; }
};
class Faculty : virtual public Person {
public: Faculty(int x) :Person(x) { cout << "Faculty::Faculty(int)" << endl; }
};
class Student : virtual public Person {
public: Student(int x) :Person(x) { cout << "Student::Student(int)" << endl; }
};
class TA : public Faculty, public Student  {
public:
    TA(int x):Student(x), Faculty(x), Person(x) { cout << "TA::TA(int)" << endl;     }
};
int main()  {
    TA ta(30);

    return 0;
}
-----
Person::Person(int)
Faculty::Faculty(int)
Student::Student(int)
TA::TA(int )
```

- **Call parameterized constructor of root base class `Person` from constructor of `TA` class**

Multiple Inheritance in C++: Ambiguity

```
#include<iostream>
using namespace std;
class Person {
public: Person(int x) { cout << "Person::Person(int)" << endl; }
    Person() { cout << "Person::Person()" << endl; }
    virtual ˜Person();
    virtual void teach() = 0;
};
class Faculty : virtual public Person {
public: Faculty(int x) :Person(x) { cout << "Faculty::Faculty(int)" << endl; }
    virtual void teach();
};
class Student : virtual public Person {
public: Student(int x) :Person(x) { cout << "Student::Student(int)" << endl; }
    virtual void teach();
};
class TA : public Faculty, public Student  {
public:
    TA(int x):Student(x), Faculty(x) { cout << "TA::TA(int)" << endl; }
    virtual void teach();
};
```

- **In the absence of `TA::teach()`, which of `Student::teach()` or `Faculty::teach()` should be inherited?**

Multiple Inheritance in C++: Exercise

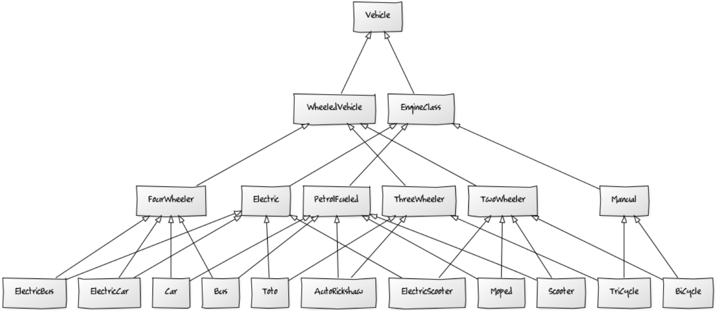
```
class A {
public:
    virtual ~A() { cout << "A::~A()" << endl; }
    virtual void foo() { cout << "A::foo()" << endl; }
};
class B : public virtual A {
public:
    virtual ~B() { cout << "B::~B()" << endl; }
    virtual void foo() { cout << "B::foo()" << endl; }
};
class C { // : public virtual A {
public:
    virtual ~C() { cout << "C::~C()" << endl; }
    virtual void foobar() { cout << "C::foobar()" << endl; }
};

class D : public B, public C {
public:
    virtual ~D() { cout << "D::~D()" << endl; }
    virtual void foo() { cout << "D::foo()" << endl; }
    virtual void foobar() { cout << "D::foobar()" << endl; }
};
```

- **Consider the effect of calling `foo` and `foobar` for various objects and various pointers**

Design Choice: Inheritance or Composition

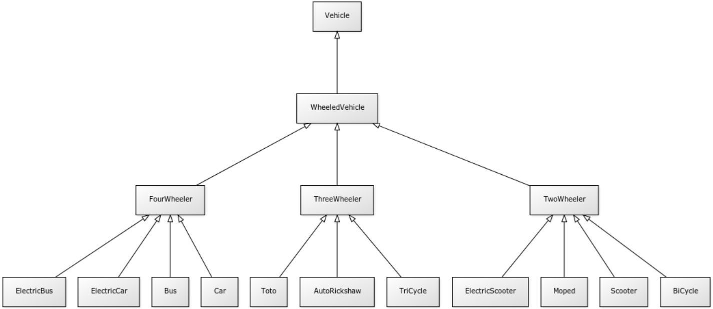
- Vehicle Hierarchy



- Wheeled Hierarchy and Engine Hierarchy interact
- Large number of cross links!
- Multiplicative options make modeling difficult

Design Choice: Inheritance or Composition

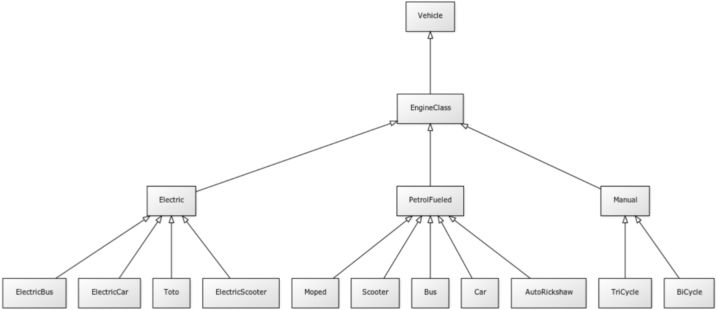
- Vehicle Hierarchy



- Wheeled Hierarchy use Engine as Component
- Linear options to simplify models
- Is this dominant?

Design Choice: Inheritance or Composition

- Vehicle Hierarchy



- Engine Hierarchy use Wheeled as Component
- Linear options to simplify models
- Is this dominant?

Module Summary

- Introduced the Semantics of Multiple Inheritance in C++
- Discussed the Diamond Problem and solution approaches
- Illustrated the design choice between inheritance and composition

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