# Part VIII

## More classes

# Outline

# Inheritance

- In OOP, we may have objects which are of some general type, but are also of some specialised type
- For example, we may have a Vehicle class with various member functions:

```
Vehicle v;
v.setNumberPassengers(4);
v.startEngine();
```

- However, there are types of vehicle with features not shared by all other vehicles:

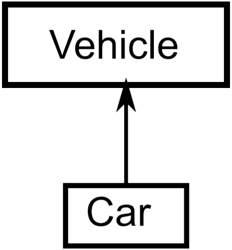
```
car.openBoot();
```

  doesn't apply to a ferry, for example

# Inheritance

- We would like to have a **Car** be a specialized type of **Vehicle**:

```
class Car : public Vehicle
{
public:
  void openBoot();
};
```




- Now **Car** inherits the member functions and data of **Vehicle**, and can be regarded as being of type **Vehicle**:

```
Car car;
car.openBoot();
car.startEngine();
Vehicle v;
v.openBoot(); // Compile-time error
```

# Protected inheritance for data

When `Car` derives from `Vehicle`, we may want it to have access to some of `Vehicle`'s data:

```
class Vehicle{
public:
  void setNumPassengers(int);
  int getNumPassengers()const;
protected:
  int numPassengers;
private:
  int vehicleData;
};
```

Now, a member-function of `Car` can access `numPassengers`, but not `vehicleData`.

# Protected inheritance for functions

- The same applies to member-functions of a parent class:

```
class Vehicle{
protected:
  void runStarterMotor();
};
```

- This is then not accessible from outside `Vehicle` (only called through a public function such as `turnIgnitionOn`).
- However, it is accessible from member functions of `Car` because `Car` inherits `Vehicle` as a public class

# Inheritance rules

Suppose we have a classes `X` and `Y`:

```
class X{
  public:
    int pub;
    int m();
  protected:
    int pro;
  private:
    int pri;
};
```

```
class Y : public X {
  public:
    int f();
};
```

```
int main(){
X x;
x.pub=0;// OK
x.pro=0;// Error
x.pri=0;// Error
}
```

```
int X::m(){
pub = 0;// OK
pro = 0;// OK
pri = 0;// OK
}
```

```
int Y::f(){
pub = 0;// OK
pro = 0;// OK
pri = 0;// Error
}
```

# Constructing base classes

- In order to initialize members of a base class in a constructor, you can either initialize them directly:

```
Child::Child(int a, int b){
  m_parentData = a;
  m_childData = b;
}
```

or by calling the base class constructor:

```
Child::Child(int a, int b) : Parent(a) {
  m_childData = b;
}
```

# Outline

# Virtual functions

- What happens if we want a **Car** to have a maximum number of passengers, but most **Vehicles** do not have this restriction?
- We could introduce a new data-member, **maximumPassengers**, to the **Vehicle** class:

```
void Vehicle::setNumberPassengers(int p){
if( p > maximumPassengers){
  std::cout << "Crowded" << std::endl;
}
}
```

- However, this represents a leakage of information into the base class
- Anyway, we would potentially have to do this every time we wanted to add extra information to a **Car**

# Virtual functions

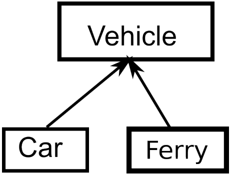
- Virtual functions allow definitions of functions in a base-class to be re-implemented by a derived class

```
class Vehicle{
public:
  virtual void setNumberPassengers(int);
};
void Vehicle::setNumberPassengers(int p){
  passengers = p;
}
class Car : public Vehicle{
  void setNumberPassengers(int) override;
};
void Car::setNumberPassengers(int p){
  if( p > 6 ){
    std::cout << "Crowded" << std::endl;
  }
  passengers = p;
}
```

# Virtual functions ctd.

- If `setNumberPassengers()` is called on a `Vehicle`, then the first version is called.
- If `setNumberPassengers()` is called in a `Car`, then the second version is called.

```
Ferry f;
f.setNumberPassengers(10); //
    Will not print error message
Car c;
c.setNumberPassengers(10); //
    Will print error message
```



# Abstract classes

- Consider the function `addPassenger`:
- There may be no sensible way of defining the function `addPassenger` for a generic `Vehicle`, but all `Vehicle`s must implement this function.
- This can be expressed as follows:

```
class Vehicle{
public:
  virtual void addPassenger() = 0;
};
```

# Abstract classes ctd

- `assPassenger` is now a pure virtual function
- `Vehicle` is an abstract class
- No object of type `Vehicle` can now exist
- All classes derived from `Vehicle` must implement `addPassenger`
- Trying to create an object of type `Vehicle` will fail.

```
class Car : public Vehicle{
public:
  void addPassenger() override;
};
void Car::addPassenger(){
  // Code here
}

Vehicle v; // Compile-time failure
Car c; // OK
Vehicle* c2 = new Car; // OK
c2->addPassenger(); // Calls Car's version.
```

# Abstract classes ctd

- It is an error to specify `override` for a function that is not overriding another one.
- The main reason for this syntax is clarity for the developer about the intent of the class/function.

# Final functions

- Sometimes we want to prevent virtual functions from being overridden.

```
class Car : public Vehicle{
public:
  void turnIgnition(bool)const final;
};
class FordPrefect : public Car{
public:
  void turnIgnition(bool)const override; // Error
};
```

# Final functions

- We have prevented any further derived classes from `Car` from overriding the `turnIgnition` function.
- This *may* provide some performance improvement, because the compiler knows that `car->turnIgnition(true)` always calls `Car::turnIgnition`, never any overridden version.
- This improvement is unlikely to be important in practice, though; measure if you think it is important.

# Outline

# Polymorphism

- Polymorphism allows objects of one type to be referred to as objects of another type, if their inheritance allows:

```
Vehicle* v = new Car;
v->setNumberPassengers(4);
```

- will call `Vehicle`'s version of `setNumberPassengers`
- or `Car`'s, if `Car` overrides `setNumberPassengers` as a virtual function

```
std::array<Vehicle*,4> queue;
v[0] = new Car;
v[1] = new Bus;
v[0]->setNumberPassengers(4); // Calls Car's version
v[1]->setNumberPassengers(10); // Calls Bus's version
```

# Polymorphism ctd.

- The function that will be called is only determined at run-time.
- This does not contradict static type-checking
- Assigning an object of type `Car` to a `Vehicle` pointer causes the compiler to check that `Car` derives from `Vehicle`.
- For a class with virtual functions, the compiler will generate a "v-table", which allows it, for a given derived class, to determine which function it should jump to.
- This could be thought of as a class containing a set of function pointers for each of its virtual functions
- Calling a virtual function therefore requires a very tiny amount of extra overhead compared to a simple member function call.

# Losing polymorphism (Slicing)

- Object slicing occurs when a derived object is assigned to a variable of base-class type:

  ```
  DerivedClass d;
  BaseClass b = d;
  ```

  will compile.
- However, the assignment only copies data relevant to `BaseClass` from `d` to `b` (the rest has been sliced off).
- The same problem would occur in the following:

  ```
  DerivedClass *d = new DerivedClass;
  BaseClass b = *d;
  ```

- Here, `b` is only of type `BaseClass`
- This behaviour is nearly always undesirable.

# Downcasting

- So far, we have seen examples of up-casting, where a derived class pointer is converted to a base-class pointer
- Consider the following:

  ```
  void maintain(Vehicle* v){
    v->checkChain();
  }
  ```

  and we want to call this function for a collection of `Vehicles`
- However, only a `Bicycle` has a chain, so this will fail to compile!
- (Here, `maintain` should probably be a member function of `Vehicle`, but ignore this for the purposes of argument.)
- How can we check at run-time whether `v` is a `Bicycle`?

# Dynamic-casting

- The following is valid:

```
Bicycle* b = dynamic_cast<Bicycle*>(v);
```

  and will convert `v` to be of type `Bicycle` if possible.
- If not possible, then the `dynamic_cast` returns `nullptr`:

```
if( b ){
  b->checkChain();
}
```

  is perfectly valid.
- Almost all uses of `dynamic_cast` are the result of bad design and are better replaced by a member function:

```
bool Vehicle::isBicycle()const;
```

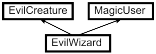
  (or just making `maintain` a virtual member function of `Vehicle`)
- However, there are cases where it is needed

# Multiple inheritance

- It is also possible for a class to derive from multiple classes

```
class EvilWizard : public EvilCreature,
    public MagicUser{};
```

since not all **EvilCreature**s can wield magic, and not all **MagicUser**s are evil.




- An **EvilWizard** can therefore be used as an **EvilCreature** or as a **MagicUser**
- We can now use

```
EvilCreature* e = new EvilWizard;
if( dynamic_cast<MagicUser*>(e) )
```

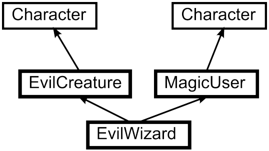
to determine whether an **EvilCreature** is also a **MagicUser**.

# Virtual inheritance

- What happens in the previous example if we have a general `Character` class?
- Obviously every `EvilCreature` is a `Character` and so is every `MagicUser`:

```
class MagicUser : public
    Character{};
class EvilCreature : public
    Character{};
```

- But now `EvilWizard` has two `Character` bases
- Anything stored in `Character` will be duplicated, and refering to the `Character` base of `EvilWizard` is ambiguous.



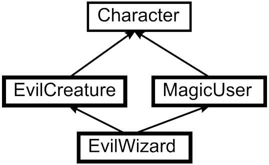
# Virtual inheritance

- We can correct this by using **virtual** inheritance

```
class MagicUser : public
    virtual Character{};
class EvilCreature : public
    virtual Character{};
```

- Now **EvilWizard** has a unique **Character** base
- It can be consistently cast to something of type **Character**
- Further, the following is now valid:

```
Character* c = new EvilWizard;
```



# Outline

# Static in member functions

- Recall that `static` variables are local to a function, but are initialized only once and persist throughout the program's run
- The same applies to `static` variables in a class's member-function
- These are not unique to each class instance:

```
int A::f(int x){
  static int firstVal = x;
  return firstVal;
}

A a,b;
int x = a.f(5); // x == 5
int y = b.f(6); // y == 5
```

# Static member data

- It is permissable to have `static` member data within a class
- This data is then available to all instances of the class, similar to global variables, but with class access-permissions
- Ordinary member data has space allocated when an instance of the class is allocated
- Static member data must be allocated exactly once per program
- This is done outside the class definition:

```
class A{
  static double myData;
};

double A::myData = 9.80665;
```

- For constant static variables of integer or enumeration type only, the initialization can be done inside the class definition:

```
class A{
  static const int myVal = 9;
};
```

# Static member functions

- Class member functions may also be static.
- This means that they do not need a class object on which to be called:

```
class A{
  static int f();
};

int A::f(){
  return 9;
}

int x = A::f();
```

- Static member functions may not have `const` or virtual qualifiers

# Use of static

- One use for `static` functions is the following:
- Suppose we have a class which must only be instantiated once in a program
- We could use a global variable, but this fails to prevent other functions from creating new instances, and means that the initialization of the variable is situated away from the class
- This is known as a Singleton, and can be implemented as:

```
class SimlParams{
public:
  static const SimlParams* inst(){
    static SimlParams* s = new SimlParams;
    return s;
  }
private:
  SimlParams();
};
```

# Use of the Singleton

- Since the constructor is private, this prevents other functions from creating a different instance of `SimlParams`.
- Since `s` is static, only a single instance of `SimlParams` is created, and this is returned every time `inst` is called.
- This construct is used as:

```
const SimlParams* params = SimlParams::inst();
```

- Note that we do not require an object of type `SimlParams` to call `inst`.
- This construct can be used anywhere in the code to reference the unique instance of `SimlParams`
- Any misuse of the class, such as multiple instantiations, is prevented.