8. Inheritance and Polymorphism

8.1. Inheritance https://isocpp.org/wiki/faq/basics-of-inheritance

- Generalization: Relationship between a more general class (base class, or superclass) and a more specialized class (subclass)
  - the specialized class is consistent with the base class, but contains additional attributes, operations and/or associations
  - an object of the subclass can be used wherever an object of the super class is permitted

- Generalization is not about just summarizing common properties and behaviors, but about generalizing in the literal sense:
  Every object of the subclass is an object of the superclass

8.1. Inheritance

```
class Person {
 private:
  std::string name;
  std::string address;
  int birthYear;
 public:
  void printBadge();   // prints name
  int getAge();   // returns age in years
};
```

```
int main() {
  Staff newStaff;
  Trainee newTrainee;
  // newStaff and newTrainee objects
  // can access Person public method
  newStaff.printBadge();
  newTrainee.getAge();
  return 0;
}
```

```
class Staff: public Person {
 private:
  double salary;
 public:
  void setSalary(double s);
};
```

```
class Trainee: public Person {
 private:
  int startDay;
 public:
  int daysInTraining();
};
```

8.2. The `protected` keyword

- Private members (attributes or methods) are only accessible within the class that has defined them
- Public members are accessible from anywhere
- Protected members are accessible in the class that defines them, and in classes that inherit from that class

8.2. The **protected** keyword: Inaccessible from outside the class..

```
class Person {
 private:
  std::string address;
  int birthYear;
 protected:
  std::string name;
 public:
  void printBadge();  // prints name
  int getAge();  // returns age in years
};
```

```
int main() {
  Staff newStaff;
  // newStaff object cannot access
  // Person protected attributes
  // or methods from outside class:
  // std::cout << newStaff.name;
  //   -> ERROR
  return 0;
}
```

```
class Staff: public Person {
 private:
  double salary;
 public:
  void setSalary(double s);
};
```

```
class Trainee: public Person {
 private:
  int startDay;
 public:
  int daysInTraining();
};
```

8.2. The **protected** keyword: .. but accessible from child classes

```
class Person {
 private:
  std::string address;
  int birthYear;
 protected:
  std::string name;
 public:
  void printBadge();  // prints name
  int getAge();  // returns age in years
};
```

```
int Trainee::daysInTraining() {
  int returnVal;
  // Trainee cannot access Person's
  // private attributes:
  // returnVal = birthYear -> ERROR
  // but Trainee can access Person's
  // protected attributes in class:
  std::cout << name << std::endl;
  return (today()-startDay);
}
```

```
class Staff: public Person {
 private:
  double salary;
 public:
  void setSalary(double s);
};
```

```
class Trainee: public Person {
 private:
  int startDay;
 public:
  int daysInTraining();
};
```

8.3. (Delegate) constructors and destructors

Remember the special syntax in constructors, to initialize attributes:

```
class Example {
 public:
  Example(int &aVar);
 private:
  const int aConst;   // a constant
  int &aRef;          // a reference
};
// This would lead to errors:
// Example::Example(int &aVar) {
//    aConst = 47; aRef = aVar;
// }
// But this works:
Example::Example(int &aVar)
  : aConst(47), aRef(aVar) {
  // here can follow more code
}
```

Passing arguments to the base class constructor is possible with:

```
class BaseClass {
 public:
  BaseClass(int var) : var(var) {}
 private:
  int var;
};

class SubClass : public BaseClass {
 public:
  SubClass(bool myBool)
   : BaseClass(7), myBool(myBool) {}
 private:
  bool myBool;
};
```

8.3. (Delegate) constructors and destructors

Passing arguments to a base class constructor is possible with:

```
class BaseClass {
 public:
  BaseClass(int var) : var(var) {}
 private:
  int var;
};

class SubClass : public BaseClass {
 public:
  SubClass(bool myBool)
   : BaseClass(7), myBool(myBool) {}
 private:
  bool myBool;
};
```

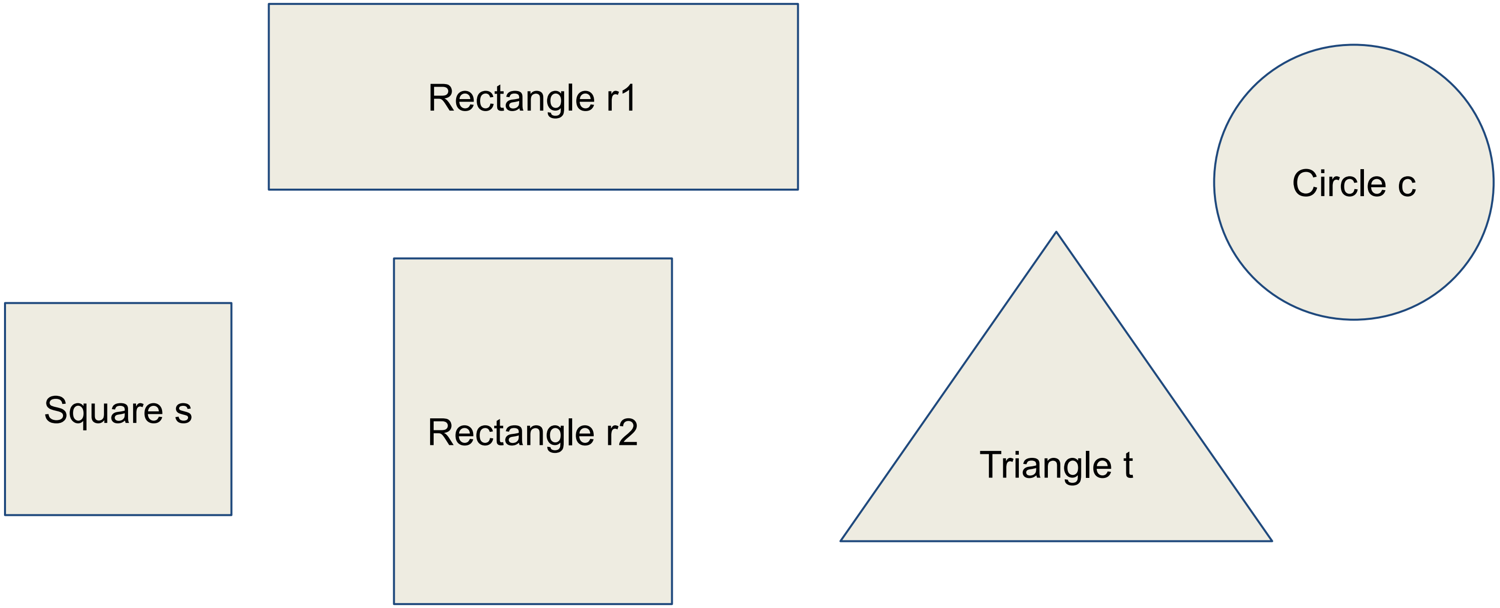
Similarly, ***delegate constructors*** call others from the same class to reduce repetitive code (from C++11):

```
class MyClass {

 public:
  MyClass(int a1, bool b1) : a(a1), b(b1) {
    // lots of initialization work
  }
  MyClass(int a1) : MyClass(a1, true) {}
  MyClass(bool b1) : MyClass(10, b1) {}

 private:
  int  a;
  bool b;
  // ...
};
```

8.3. (Delegate) constructors and destructors

Example (difficulty level: 🌶️🌶️)

Creating 2D graphics elements such as the ones below as classes' objects



8.3. (Delegate) constructors and destructors Example

```
class Element {  // class representing graphic element
 public:
  Element(double x, double y) : x(x), y(y) {}
 private:
  double x, y;  // position of graphic element
};
```

```
class Rectangle : public Element {  // class representing a rectangle
 public:
  Rectangle(double x, double y, double a, double b) : Element(x, y), a(a), b(b) {}
 private:
  double a, b;  // width and height of rectangle
};
```

```
class Square : public Rectangle {  // class representing a square
 public:
  Square(double x, double y, double a) : Rectangle(x, y, a, a) {}
};
```

🏠 Homework: Add a method to Square that prints out its location: What needs changing?

8.4. **mutable**, **using**, **friend**, and **delete**

Any **mutable** data members of **const** class instances can be modified. This is useful if most of the class' members should be constant, but a few need to be modified.

```
#include <iostream>

class A {  // class A
 public:
  int x = 4;   // public attributes, default initialized (since C++11)
  mutable int y = 3;
};

int main() {
  const A a;  // constant object of class A
  a.y = 7;    // this works, a.x would result in compile error
  std::cout << a.y << "\n";
  return 0;
}
```

8.4. **mutable**, **using**, **friend**, and **delete**

The **using** keyword can be used to change the inheritance properties of class attributes or methods:

```
class A {  // class A
 protected:
  int x = 4;    // protected attribute
};

class B : A {  // class A
 public:
  using A::x;    // inherits x and exposes it as a public attribute
};

int main() {
  B b;
  b.x = 7;     // this works, b.x is public (even though A.x is protected)
  return 0;
}
```

8.4. `mutable`, `using`, `friend`, and `delete`

The **`friend`** keyword allows a class to access the private and protected attributes and methods of the class that is declared as a friend.

A **`friend`** relation is **not**:

symmetric: Class A as a friend of B does not imply class B being a friend of A

transitive: A is a friend of B and B is a friend of C does not imply A is a friend of C

inherited: Class Base as a friend of class X does not imply subclass Derived is a friend of class X; Class X as a friend of class Base does not imply class X is a friend of subclass Derived

8.4. mutable, using, friend, and delete

```
#include <iostream>

class A {  // class A declares that B is a friend
 private:
  friend class B;
  int x = 4;  // private attribute
};

class B {  // class B is a friend of A
 public:
  B() { A a; y = a.x;}          // and thus can access
  int f(A a) { return a.x; }  // A's private attribute x
 private:
  int y;
};

int main() {
  A a; B b;
  std::cout << b.f(a) << "\n";
  return 0;
}
```

8.4. **mutable**, **using**, **friend**, and **delete**

A **friend** ***method*** can access the private and protected members of a class if it is declared a friend of that class.

```
#include <iostream>

class A {  // class A declares funct as a friend method
 private:
  int x = 4;  // private attribute
  friend int funct(A a);
};

int funct(A a) { return a.x; }  // funct is not a class method

int main() {
  A a;
  std::cout << funct(a) << "\n";
  return 0;
}
```

8.4. **mutable**, **using**, **friend**, and **delete**

The **delete** keyword marks a class method as deleted. Calling that method (explicitly or implicitly) will result in a compiler error. The **delete** keyword prevents implicitly generating default copy constructors or assignments.

```
class Element {  // class representing graphic element
 public:
  Element(double x, double y) : x(x), y(y) {}  // default constructor is deleted
  Element(Element const &e) = delete;  // copying gives a compiler error
  void setX(double x) { this->x = x;}
  void setX(float x) = delete;  // calling with a float results in a compiler error
 private:
  double x, y;  // position of graphic element
};

int main() {
  Element e(2.0, 3.0);
  e.setX(5.0);  // works, but: e.setX(5.0f) would fail (due to delete above)
}
```

8.5. Polymorphism

C++ provides a way to create a base object with methods that through overriding change their behavior. At run-time, objects of the base class behave as objects of a derived class

If **Sub** is a subclass of **Super**, then the following assignments are allowed:

```
Sub sub;
Super *superPtr = &sub;
Super &superRef = sub;
```

A base class pointer or reference can also point or refer to a subclass' object.

The other way round is not allowed.

8.5. Polymorphism

For example: **`Dog`** and **`Fish`** are classes that inherit from **`Animal`**. We want any objects from these classes to have a **`print()`** method, which displays the values of the classes' attributes. Then an **`Animal`** object pointer could be used to flexibly point to a **`Dog`** or **`Fish`** object and access the right **`print()`** method:

```
Animal *animal;
animal = new Dog("Scooby");
animal->print();  // prints out: I am Scooby. Bark!
animal = new Fish("Salmon");
animal->print();  // prints out: I'm Salmon (fish)
```

For polymorphism to work in C++, the base class must declare the methods in question as being [**`virtual`**]

8.5. Polymorphism: Example (1/2)

polyDemo.cpp

```
#include <iostream>
#include <cstdlib>

class Animal {  // Animal class stores the species and prints this in print()
 protected:
  std::string _species;
 public:
  Animal(std::string species) { _species = species; }
  virtual void print() { std::cout << "I'm " +  _species << std::endl; }
};

class Dog : public Animal {  // Dogs inherit species from Animal and have a name
 protected:
  std::string _name;
 public:
  Dog(std::string name) : Animal("dog"), _name(name) {}
  void print() { std::cout << "I am " << _name << ". Bark!" << std::endl; }
};
```

8.5. Polymorphism: Example (2/2)

polyDemo.cpp

```
class Fish : public Animal {  // Fishes have species and subspecies
 protected:
  std::string _subspecies;
 public:
  Fish(std::string subspecies) : Animal("fish"), _subspecies(subspecies) {}
  void print() { std::cout << "I'm " << _subspecies << " (fish)" << std::endl; }
};

int main() {
  Animal *animals[4];
  animals[0] = new Dog("Snowy");      // animals[] has pointers
  animals[1] = new Fish("Salmon");    // to objects of different
  animals[2] = new Dog("Scooby");     // subclasses (Dog, Fish, etc.)
  animals[3] = new Animal("some animal");  // or the animal base class
  for (int i=0; i<15; i++) {
   Animal *a = animals[rand() % 4];   // a is a polymorph variable: its
   a->print();                        // print's behavior depends on the
  }                                   // object that a points to
  return 0;
}
```

8.5. Polymorphism: Example

- Note that animals is an array of pointers to the base class (Animal)
- Yet, we can let the pointers point to a subclass of Animal (Dog, Fish, …)
- And when we call print() from Animal pointer a, the right method executes

```
Animal *animals[4];
animals[0] = new Dog("Snowy");
animals[1] = new Fish("Salmon");
…
  Animal *a = animals[rand()%4];
  a->print();
```

```
~\> g++ polyDemo.cpp -o polymorph_demo
~\> ./polymorph_demo
I'm Salmon (fish)
I am Scooby. Bark!
I'm Salmon (fish)
I am Scooby. Bark!
I am Snowy. Bark!
I'm some animal
I am Scooby. Bark!
I'm Salmon (fish)
I am Snowy. Bark!
I am Scooby. Bark!
I am Snowy. Bark!
I am Scooby. Bark!
I'm some animal
I am Scooby. Bark!
I'm Salmon (fish)
~\>
```

8.5. Polymorphism: `virtual` and late binding

Connecting the function call to the function body is called ***Binding***

Early / static / compile-time binding is done by the compiler through object type, letting the program jump to the function's address

Late / dynamic / run-time binding uses the object type while the executable is running and then matches the function call with the correct function definition: The program has to read the address held in the pointer and then jump to that address. This extra jump makes it less efficient.

C++ achieves late binding by declaring a virtual function

8.5. Polymorphism: `virtual` and late binding

C++ achieves late binding by declaring a virtual function:

```
#include <iostream>
class A {  // class A has a virtual function funct:
 public:
  virtual void funct() { std::cout << "A \n"; };
};
class B : A {  // class B inherits from A and overrides funct:
 public:
  virtual void funct() { std::cout << "B \n"; };
};

void g( A &a ) { a.funct(); }  // g accepts A and B as parameter

int main() {
  A a; B b;
  g(a); g(b);  // outputs first "A", and then "B"
  return 0;
}
```