Object Oriented Programming: Inheritance Polymorphism

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Today's Lecture

- Introduction to elements of object oriented programming (OOP)
  - Inheritance
  - Polymorphism

- Base and Derived Classes

- Inheritance as a mean to provide common interface

What is Inheritance?

- Powerful way to reuse software without too much re-writing

- Often several types of object are in fact special cases of a basic object
  - keyboard and files are different types of an input stream
  - screen and file are different types of output stream
  - Resistors and capacitors are different types of circuit elements
  - Circle, square, ellipse are different types of shapes
  - In StarCraft, engineers, builders, soldiers are different types of units

- Inheritance allows to define a “base” class that provides basic functionalities to “derived” classes
  - Derived classes can extend the base class by adding new data members and functions

Inheritance: Student "is a" Person

```
// example1.cpp
#include <string>
#include <iostream>
using namespace std;


class Person {
  public:
    Person(const string& name) {
      name_ = name;
      cout << "Person(" << name
           << ") called" << endl;
    }

    ~Person() {
      cout << "~Person() called for "
           << name_ << endl;
     }

    string name() const { return name_; }

    void print() {
      cout << "I am a Person. My name is "
           << name_ << endl;
    }

  private:
    string name_;
};
```

```
class Student : public Person {
  public:
    Student(const string& name, int id) :
      Person(name) {
      id_ = id;
      cout << "Student(" << name
           << ", " << id << ") called"
           << endl;
    }

    ~Student() {
      cout << "~Student() called for name:"
           << name() << " and id: " << id_
           << endl;
     }

     int id() const { return id_; }

  private:
    int id_;
};
```

Example of Inheritance in Use

```
// example1.cpp

int main() {

  Person* john = new Person("John");
  john->print();

  Student* susan = new Student("Susan", 123456);

  susan->print();
  cout << "name: " << susan->name() << " id: " << susan->id() << endl;

  delete john;
  delete susan;

  return 0;
}
```

```
$ g++ -o /tmp/app example1.cpp
$ /tmp/app
Person(John) called
I am a Person. My name is John
Person(Susan) called
Student(Susan, 123456) called
I am a Person. My name is Susan
name: Susan id: 123456
~Person() called for John
~Student() called for name:Susan and id: 123456
~Person() called for Susan
```

Student "behaves as" Person

```
Person* john = new Person("John");
john->print();

Student* susan = new Student("Susan", 123456);
susan->print();
cout << "name: " << susan->name()
     << " id: " << susan->id()
     << endl;

  delete john;
  delete susan;

  return 0;
}
```

`print()` and `name()` are methods of `Person`

`id()` is a method of `Student`

- Methods of **`Person`** can be called with an object of type **`Student`**
  - Functionalities implemented for Person available for free
  - No need to re-implement the same code over and over again
  - If a functionality changes, we need to fix it just once!

Student is an "extension" of **Person**

```
class Student : public Person {
  public:

     int id() const { return id_; }

  private:
    int id_;
};
```

id() is a method of Student

```
Person* john = new Person("John");
john->print();

Student* susan = new Student("Susan", 123456);
susan->print();
cout << "name: " << susan->name()
     << " id: " << susan->id()
     << endl;

delete john;
delete susan;

return 0;
}
```

- Student provides all functionalities of Person **and more**
- Student has additional data members and member functions
- Student is an extension of Person but not limited to be the same

Typical Error: **Person** is not **Student**!

```
// bad1.cpp

int main() {

  Person* susan = new Student("Susan", 123456);
  cout << "name: " << susan->name() << endl;
  cout << "id: " << susan->id() << endl;

  delete susan;

  return 0;
}
```

susan is a pointer to Person
but initialized by a Student ctor!

OK… because a Student is also a Person!
elements of polymorphism

```
$ g++ -o /tmp/app bad1.cpp
bad1.cpp:53:28: error: no member named 'id' in 'Person'
  cout << "id: " << susan->id() << endl;
                  ~~~~~  ^
1 error generated.
```

- You can not use methods of Student on a Person object
  - Inheritance is a one-way relation
  - Student knows to be derived from Person
  - Person does not know who could be derived from it

- You can treat a Student object (*susan) as a Person object

Public Inheritance

```
class Person {
  public:
    Person(const string& name) {
      name_ = name;
      cout << "Person(" << name
           << ") called" << endl;
    }

    ~Person() {
      cout << "~Person() called for "
           << name_ << endl;
     }

    string name() const { return name_; }

    void print() {
      cout << "I am a Person. My name is "
           << name_ << endl;
    }

  private:
    string name_;
};
```

```
class Student : public Person {
  public:
    Student(const string& name, int id) :
      Person(name) {
      id_ = id;
      cout << "Student(" << name
           << ", " << id << ") called"
           << endl;
    }

    ~Student() {
      cout << "~Student() called for
name:"
           << name() << " and id: " << id_
           << endl;
      }

      int id() const { return id_; }

  private:
    int id_;
};
```

Student can use only public methods and data of Person
like anyone else (public inheritance)

No special access privilege… as usual access can be granted not taken

public and **private** in public inheritance

- Student is derived from Person through public inheritance

```
class Student : public Person {
  public:

  private:
};
```

private and protected inheritance are also possible but will not be discussed here

- All public members of Person become public members of Student as well
  - Both data and functions

- Private members of Person **remain** private and not accessible directly by Student
  - Access provided only through public methods (getters)
- You don't need to access source code of a class to inherit from it!
  - *Use public inheritance and add new data members and functions*

protected members

- protected members become protected members of derived classes
  - Protected is somehow between public and private

```
// example2.cpp
class Person {
  public:
    Person(const string& name, int age) {
      name_ = name;
      age_ = age;
      cout << "Person(" << name << ", "
           << age << ") called" << endl;
    }
    ~Person() {
      cout << "~Person() called for "
           << name_ << endl;
     }

    string name() const { return name_; }
    int age() const { return age_; }
    void print() {
      cout << "I am a Person. name: " << name_
           << " age: " << age_ << endl;
    }

  private:
    string name_;

  protected:
    int age_;

};
```

```
class Student : public Person {
  public:
    Student(const string& name, int age,
            int id) :
                        Person(name,age) {
      id_ = id;
      cout << "Student(" << name << ", "
           << age  << ", " << id
           << ") called"
           << endl;
    }

    ~Student() {
      cout << "~Student() called for name:"
           << name()
           << " age: " << age_ << " and id: "
           << id_ << endl;
    }

    int id() const { return id_; }

  private:
    int id_;
};
```

protected members can be used by derived classes

Constructors of Derived Classes

- Compiler calls default constructor of base class in constructors of derived class ***unless*** you call explicitly a specific constructor
  - NB: constructors are not inherited by constructed by compiler
- Necessary to insure data members of the base class **always** initialised when creating instance of derived class

```
class Student : public Person {
  public:
    Student(const string& name, int id) {
      id_ = id;
      cout << "Student(" << name << ", "
           << id << ") called" << endl;
    }

private:
    int id_;
};
```

Bad Programming!

Constructor of Student does not call constructor of Person

Compiler is forced to call Person() to make sure name_ is intialised correctly

Bad: we rely on default constructor to do the right thing

Common Error with Missing Constructors

```
class Person {
  public:
    Person(const string& name) {
      name_ = name;
      cout << "Person(" << name
           << ") called" << endl;
    }
    ~Person() {
      cout << "~Person() called for "
          << name_  << endl;
     }

private:
    string name_;
};
```

```
class Student : public Person {
  public:
    Student(const string& name, int id) {
      id_ = id;
      cout << "Student(" << name << ", "
           << id << ") called" << endl;
    }

  private:
    int id_;
};
```

```
$ g++ -o /tmp/app bad2.cpp
bad2.cpp:32:5: error: constructor for 'Student' must explicitly initialize
the base class 'Person' which does not
      have a default constructor
    Student(const string& name, int id) {
    ^
bad2.cpp:7:7: note: 'Person' declared here
class Person {
      ^
1 error generated.
```

```
// bad2.cpp

int main() {

  Person anna("Anna");

  Student* susan =
        new Student("Susan", 123456);
  susan->print();
  delete susan;

  return 0;
}
```

No default constructor implemented for Person

Compiler can use a default one to make anna

But gives error dealing with derived classes.

You need to provide a default constructor or call one of the implemented constructors

Bad Working Example

```
class Person {
  public:
    Person() { } // default constructor
    Person(const string& name) {
      name_ = name;
      cout << "Person(" << name << ") called"
           << endl;
    }

};
```

```
class Student : public Person {
  public:
    Student(const string& name, int id) {
      id_ = id;
      cout << "Student(" << name << ", "
           << id << ") called" << endl;
    }

};
```

```
// bad3.cpp

int main() {

  Student* susan =
       new Student("Susan", 123456);
  susan->print();

  delete susan;

  return 0;
}
```

```
$ g++ -o /tmp/app bad3.cpp
$ /tmp/app
Student(Susan, 123456) called
I am a Person. My name is
~Student() called for name: and id: 123456
~Person() called for
```

- Default constructor is called by compiler
- No name assigned to student by default
  - Ask yourself: why name is not used in the constructor?
- Code compiles, links, and runs but bad behavior

Destructors

- Similar to constructors
- Compiler calls the default destructor of base class in destructor of derived class
- No compilation error if destructor of base class not implemented
  - Default will be used but… bad things can happen!
- Extremely important to implement correctly the destructors to avoid memory leaks!

Member Functions of Derived Classes

- Derived classes can also overload functions provided by the base class
  - Same signature but different implementation

```
class Person {
  public:
    void print() {
      cout << "I am a Person. My name is " << name_ << endl;
    }

  private:
    string name_;
};
```

```
class Student : public Person {
  public:
    void print() {
      cout << "I am Student "
           <<  name()
           << " with id " << id_
           << endl;
    }

  private:
    int id_;
};
```

Overloading Methods from Base Class

```
// example3.cpp
#include <string>
#include <iostream>
using namespace std;

int main() {

  Person* john = new Person("John");
  john->print();  // Person::print()

  Student* susan = new Student("Susan", 123456);
  susan->print(); // Student::print()
  susan->Person::print(); // Person::print()

  Person* p2 = susan;
  p2->print(); // Person::print()

  delete john;
  delete susan;

  return 0;
}
```

Compiler calls the correct version of print() for Person and Student

We can use Person::print() implementation for a Student object by specifying its scope

Remember: a function is uniquely identified by its namespace and class scope

```
$ g++ -o example3 example3.cpp
$ ./example3
Person(John) called
I am a Person. My name is John

Person(Susan) called
Student(Susan, 123456) called
I am Student Susan with id 123456
I am a Person. My name is Susan

I am a Person. My name is Susan

~Person() called for John
~Student() called for name:Susan and id: 123456
~Person() called for Susan
```

Undesired limitation

```
// example3.cpp
int main() {

  Person john("John");
  john.print();  // Person::print()

  Student susan("Susan", 123456);
  susan.print(); // calls Student::print()
  susan.Person::print(); // explicitly call Person::print()

  // using base class pointer
  cout << "-- using base class pointer" << endl;
  Person* p2 = &susan;
  p2->print(); // calls Person::print()

  //using derived class pointer
  cout << "-- using derived class pointer" << endl;
  Student* sp = &susan;
  sp->print(); // calls Student::print()

  // using base class reference
  cout << "-- base class reference" << endl;
  Person& p3 = susan;
  p3.print(); // calls Person::print()

  // behavior of print() depends on the type
  // of pointer determined at compilation time

  return 0;
}
```

```
$ g++ -o /tmp/app example4.cpp
$ /tmp/app
Person(John) called
I am a Person. My name is John
Person(Susan) called
Student(Susan, 123456) called
I am Student Susan with id 123456
I am a Person. My name is Susan
-- using base class pointer
I am a Person. My name is Susan
-- using derived class pointer
I am Student Susan with id 123456
-- base class reference
I am a Person. My name is Susan
~Student() called for name:Susan and id: 123456
~Person() called for Susan
~Person() called for John
```

Polymorphism

Polymorphism

- Polymorphism with inheritance hierarchy
- virtual and pure virtual methods
  - When and why use virtual or/and pure virtual functions
- virtual destructors
- Abstract and Pure Abstract classes
  - Providing common interface and behavior

Polymorphism

- Ability to treat objects of an inheritance hierarchy as belonging to the base class
  - Focus on common general aspects of objects instead of specifics

- Polymorphism allows programs to be general and extensible with little or no re-writing
  - resolve **different objects** of same inheritance hierarchy **at runtime**
  - Recall videogame with polymorphic objects Soldier, Engineer, Technician of same base class Unit
  - Can add new 'types' of Unit without rewriting application

- Base class provides interface common to all types in the hierarchy
- Application uses base class and can deal with new types not yet written when writing your application!

Examples of Polymorphism

- Application for graphic rendering
  - Base class **`Shape`** with **`draw()`** and **`move()`** methods
  - Application expects all shapes to have such functionality

- **`Function`** in Physics
  - We'll study this example in detail
  - **`Guassian`**, **`Breit-Wigner`**, **`polynomials`**, **`exponential`** are all functions
  - A **`Function`** must have
    - **`value(x)`**
    - **`integral(x1,x2)`**
    - **`primitive(x)`**
    - **`derivative(x)`**
  - Can write a fit application that can handle existing or not-yet implemented functions using a base class Function

Reminders about Inheritance

- Inheritance is a is-a relationship
  - Object of derived class ‘is a’ base class object as well

- Can treat a derived class object as a base class object
  - call methods of base class on derived class
  - can point to derived class object with pointer of type base class

- Base class does not know about its derived classes
  - Can not treat a base class object as a derived object

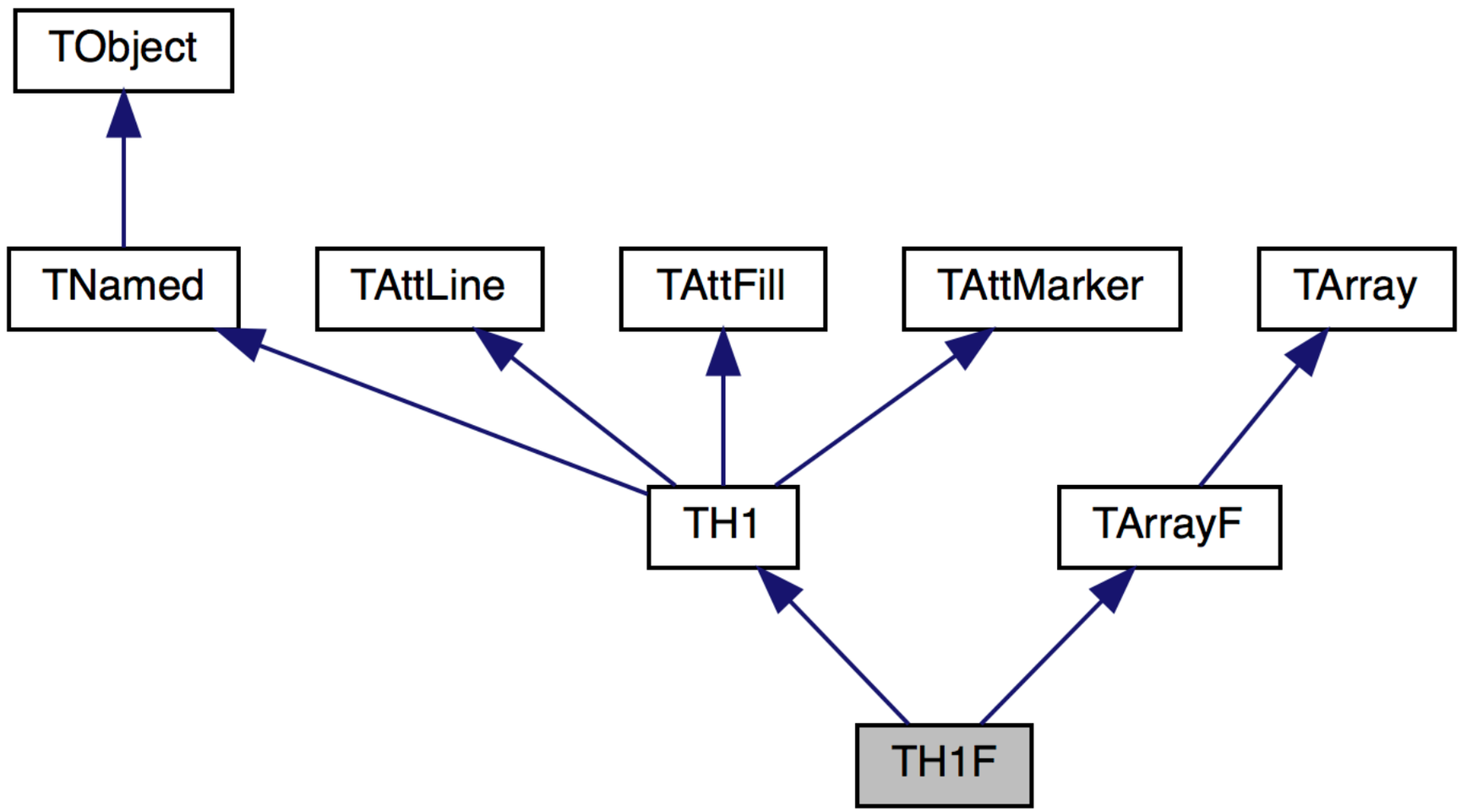
- Methods of base class can be redefined in derived classes
  - Same interface but different implementation for different types of object in the same hierarchy

Example from ROOT: TH1F

https://root.cern.ch/doc/master/classTH1F.html

```
#include <TH1.h>
```

Inheritance diagram for TH1F:



TObject and TNamed

ROOT » CORE » BASE » TObject

https://root.cern.ch/root/html526/TObject.html

class TObject

TObject

Mother of all ROOT objects.

The TObject class provides default behaviour and protocol for all objects in the ROOT system. It provides protocol for object I/O, error handling, sorting, inspection, printing, drawing, etc. Every object which inherits from TObject can be stored in the ROOT collection classes.

ROOT » CORE » BASE » TNamed

https://root.cern.ch/root/html526/TNamed.html

class TNamed: public TObject

TNamed

The TNamed class is the base class for all named ROOT classes
A TNamed contains the essential elements (name, title)
to identify a derived object in containers, directories and files.
Most member functions defined in this base class are in general
overridden by the derived classes.

TH1

https://root.cern.ch/root/html526/TH1.html

class TH1: public TNamed, public TAttLine, public TAttFill, public TAttMarker

The Histogram classes

ROOT supports the following histogram types:

- 1-D histograms:
  - TH1C : histograms with one byte per channel. Maximum bin content = 127
  - TH1S : histograms with one short per channel. Maximum bin content = 32767
  - TH1I : histograms with one int per channel. Maximum bin content = 2147483647
  - TH1F : histograms with one float per channel. Maximum precision 7 digits
  - TH1D : histograms with one double per channel. Maximum precision 14 digits
- 2-D histograms:
  - TH2C : histograms with one byte per channel. Maximum bin content = 127
  - TH2S : histograms with one short per channel. Maximum bin content = 32767
  - TH2I : histograms with one int per channel. Maximum bin content = 2147483647
  - TH2F : histograms with one float per channel. Maximum precision 7 digits
  - TH2D : histograms with one double per channel. Maximum precision 14 digits
- 3-D histograms:
  - TH3C : histograms with one byte per channel. Maximum bin content = 127
  - TH3S : histograms with one short per channel. Maximum bin content = 32767
  - TH3I : histograms with one int per channel. Maximum bin content = 2147483647
  - TH3F : histograms with one float per channel. Maximum precision 7 digits
  - TH3D : histograms with one double per channel. Maximum precision 14 digits
- Profile histograms: See classes TProfile, TProfile2D and TProfile3D. Profile histograms are used to display the mean value of Y and its RMS for each bin in X. Profile histograms are in many cases an elegant replacement of two-dimensional histograms : the inter-relation of two measured quantities X and Y can always be visualized by a two-dimensional histogram or scatter-plot; If Y is an unknown (but single-valued) approximate function of X, this function is displayed by a profile histogram with much better precision than by a scatter-plot.

All histogram classes are derived from the base class TH1