601.220 Intermediate Programming

Summer 2023, Meeting 19 (July 17th)

Today's agenda

- Review exercises 29 and 30
- Day 31 recap questions
- Exercise 31
- Day 32 recap questions
- Exercise 32

Reminders/Announcements

- HW7 is due **Thursday, July 21st**
  - We are covering template classes today, this material is needed for the `TTrie` class
- Final project team formation
  - Submit the Google form in Piazza post 118 (pinned) by **11 am on Tuesday (July 18th)**
  - If you aren't registered as being on a team by Wednesday (July 19th) you will be assigned to a team

Exercise 29 review

cout << complex_instance << endl;

Overloading tthe output stream insertion operator for the Complex class:

```
// in complex.h (in the Complex class definition)

  friend std::ostream& operator<<(std::ostream &out,
                                  const Complex &c);

// in complex.cpp

  std::ostream& operator<<(std::ostream &out,
                           const Complex &c) {
    out << c.rel << " + " << c.img << "i";
    return out;
  }
```

Exercise 29 review

Copy constructor and assignment operator

```cpp
// in complex.cpp

Complex::Complex(const Complex &other)
  : rel(other.rel), img(other.img) {
}

Complex& Complex::operator=(const Complex &rhs) {
  if (this != &rhs) {
    rel = rhs.rel;
    img = rhs.img;
  }
  return *this;
}
```

Exercise 29 review

Overloaded operators for arithmetic, in `complex.h` (in the class
definition for the `Complex` class):

```
Complex operator+(const Complex& rhs) const;
Complex operator-(const Complex& rhs) const;
Complex operator*(const Complex& rhs) const;
Complex operator*(const float& rhs) const;
Complex operator/(const Complex& rhs) const;
```

Since these are defined as member functions, they only need one
parameter, which is the right-hand-side operand. (The left hand
`Complex` object in the expression will be the receiver object.)

Exercise 29 review

Complex1 $+$ Complex2 $=$

lhs   rhs

Implementations of arithmetic operators in `complex.cpp`:

```cpp
Complex Complex::operator+(const Complex& rhs) const {
  Complex sum(rel+rhs.rel, img+rhs.img);
  return sum;
}

Complex Complex::operator-(const Complex& rhs) const {
  return *this + (rhs * -1.0f);
}
```

Exercise 29 review

Implementation of multiplication:

```cpp
Complex Complex::operator*(const Complex& rhs) const {
  float a = rel;
  float b = img;
  float c = rhs.rel;
  float d = rhs.img;
  // (a+bi) * (c+di) = a*c + (a*d)i + (b*c)i + (b*d)(i^2)
  //                 = (a*c - b*d) + (a*d + b*c)
  return Complex(a*c - b*d, a*d + b*c);
}
```

Complex operator*(float rhs)

Complex1 * 1.2

Non-member * operator for `float` times Complex:

1.2 * Complex1

```
// in complex.h

  friend Complex operator*(float lhs, const Complex &rhs);

// in complex.cpp

  Complex operator*(float lhs, const Complex &rhs) {
    return rhs * lhs;
  }
```

This operator can't be a member function because the value on the left-hand-side is not an object. Also, this function technically doesn't need to be a friend because it invokes the public Complex times float operator.

Exercise 30 review

Goal complete functions from integer set data structure. No
repeated values allowed.

node → get_next()

```
// copy constructor ~ deep copy
int_set::int_set(const int_set& orig) : int_set() {
  for( const int_node *node=orig.head ; node ; node=node->get_ne
    add( node->get_data() );
}

// destructor
int_set::~int_set() {
  clear();
}
```

Exercise 30 review

```cpp
// += operator
int_set& int_set::operator+=(int new_value) {
  add(new_value);
  return *this;
}
```

Exercise 30 review

```
// assignment operator
int_set& int_set::operator=(const int_set &rhs) {
  if (this != &rhs) {
    clear(); // delete old linked list

    int_node *n = other.head;
    while (n != nullptr) {
      add(n->get_data());
      n = n->get_next();
    }
  }
  return *this;
}
```

Note: inefficient because add is $O(N)$. Overall running time is $O(N^2)$.

Exercise 30 review

```cpp
// output stream insertion operator
std::ostream& operator<<(std::ostream& os, const int_set& s){
  int_node *n = s.head;
  os << "{";
  while (n != nullptr) {
    os << n->get_data();
    if (n->get_next() != nullptr) { os << ", "; }
    n = n->get_next();
  }
  os << "}";
  return os;
}
```

Day 31 recap questions

   1 How do we declare a template function?
   2 Under what conditions would you consider making a function templated?
   3 What is template instantiation?
   4 Can we separate declaration and definition when using templates?
   5 Why shouldn't template definitions be in .cpp files?

1. How do we declare a template function?

```cpp
// Example
template<typename T>
T get_max(const T &left, const T &right) {
  if (left > right) { return left; }
  else              { return right; }
}
```

not
excutable
code

Type parameter inference

T is a "type parameter". In a call to get_max, T is inferred from the argument type. E.g.

```cpp
int a = get_max(3, 4);          // T is int
double b = get_max(5.0, 6.0);   // T is double

std::string s1 = "hi", s2 = "hello";
std::string c = get_max(s1, s2); // T is std::string
```

2. Under what conditions would you consider making a function templated?

Template functions are usueful when you want to allow the function to work with a variety of different data types.

The data types that will be substituted for the type parameter(s) must have common operations that will be used by the template function.

For example, the `get_max` function (shown previously) requires the data type `T` to have a `>` operator, and also a copy constructor.

All of the built-in types (`int`, `double`, etc.) have these a `>` operator, assignment operator, and copy constuctor. (A.k.a. "value semantics".)

3. What is template instantiation?

Template instantiation is the substitution of actual data types for type parameters. For example, in

```
int a = get_max(3, 4);
```

the type `int` is substituted for T. So:

```cpp
template<typename T>
T get_max(const T &left, const T &right) {
  if (left > right) { return left; }
  else              { return right; }
}
```
}   ← template

```cpp
// instantiated with T=int
int get_max(const int &left, const int &right) {
  if (left > right) { return left; }
  else              { return right; }
}
```
}   ← generated func based on template

4. Can we separate declaration and definition when using templates?

It is possible to separate the declaration and definition of template functions and classes.

However, this is more complicated and less flexible than just putting the definition of the template function or class in a header file.

The compiler doesn't normally instantiate a teemplate function or class until the function or class is actually used. To instantiate the function or class, the compiler needs the definition.

So, we generally put the definitions for template functions and classes directly in a header file.

5. Why shouldn't template definitions be in .cpp files?

Template functions (including member functions of template classes) can't be compiled into machine code and put into an object (.o) file.

The basic problem is that there are an infinite number of possible ways a template function or class could be instantiated. For example, vector<int>, vector<string>, vector<YourClass>, etc. The compiler doesn't know which instantiations your program will need until it actually sees the code that uses vector, and knows which types will be substituted for vector's type parameter.

".inc" files

One way to allow template function definitions to be separated from a template class declaration, but still be available from a header file, is to use an ".inc" file. The .inc file contains the definitions of member functions of the template class. The header file would look like this:

```cpp
#ifndef MY_SET_H
#define MY_SET_H

template<typename T>
class my_set {
  // declarations of member functions of my_set<T>
};

#include "my_set.inc"

#endif // MY_SET_H
```
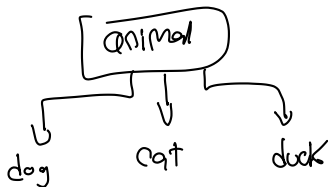
Exercise 31

- Convert your `int_set` class from Exercise 30 to a template class
- Note that ex30-sol (Exercise 30 reference solution) has been added to the public repo, `git pull` to get it
- Breakout rooms 1–10 are "social"
- Use Slack to let us know if you have questions!

Day 32 recap questions

1. Do derived classes inherit constructors?
2. What does `protected` imply for a class field?
3. What is polymorphism?
4. What is the purpose of the `virtual` keyword?
5. Can a child class have multiple parents?

1. Do derived classes inherit constructors?

No. Each derived class must define its own constructors. These will call one of the base class's constructors in its initializer list.

```cpp
// example base class
class Point2D {
private:
  double x, y;

public:
  Point2D() : x(0.0), y(0.0) { }
  Point2D(double x, double y)
    : x(x), y(y) { }
  double get_x() const { return x; }
  double get_y() const { return y; }
};
```

is a

Derived class, constructors

```cpp
// derived class
class Point3D : public Point2D {
private:
  double z;

public:
  Point3D() : Point2D(), z(0.0) { }
  Point3D(double x, double y, double z)
    : Point2D(x, y)
    , z(z) { }

  double get_z() const { return z; }
};
```
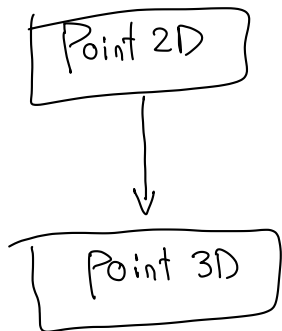
→ Base class constructor

Picture of `Point2D` and `Point3D` objects

2. What does `protected` imply for a class field?

A `protected` member may be directly accessed by code in derived classes, but may not be accessed by code in "unrelated" classes or functions.

Opinion: It is never really necessary to make a member function protected. Derived classes can (and should) use public getter and setter functions to access private data values in the base class.

3. What is polymorphism?

Polymorphism is the phenomenon that anywhere in a program that there is either a pointer to a base class type or a reference to a base class type, that pointer or reference could really refer to an object that is an instance of a class derived from the base class type.

E.g.:

```
public class Dog : public Animal { ... };
public class Cat : public Animal { ... };
public class Owl : public Animal { ... };

void do_stuff(Animal &a) {
  // the reference could refer to a Dog, Cat, or Owl object,
  // or an instance of any class deriving from Animal
}
```

4. What is the purpose of the `virtual` keyword?

The `virtual` keyword marks a member function that can be overridded by a derived class. This allows the derived class to provide its own behavior for that member function.

A base class will *usually* have at least one virtual member function. The idea is that virtual member functions in the base class define *common operations* which can be implemented by derived classes with *varying behavior*.

Example base class with a virtual member function

```cpp
// base class with a virtual member function representing
// a common operation
class Animal {
public:
  virtual void vocalize() { cout << "?\n"; }
  // ...
};
```

Example derived classes overriding a virtual member
function

Animal

dog   Cat

```cpp
class Dog : public Animal {
public:
  virtual void vocalize() { cout << "woof\n"; }
  // ...
};

class Cat : public Animal {
  virtual void vocalize() { cout << "meow\n"; }
  // ...
};
```
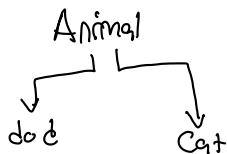
Polymorphism!

```
void stuff(Animal &a) {
  a.vocalize();
}

int main() {
  Dog leo;
  Cat ingo;

  stuff(leo);  // prints "woof"
  stuff(ingo); // prints "meow"
}
```

5. Can a child class have multiple parents?

Yes. However, this is a feature that is not used very widely.

One example: the `iostream` type inherits from both `istream` and `ostream`.

Since `stringstream` inherits from `iostream`, this explains why you can both read data from a `stringstream` and also write data to a `stringstream`.
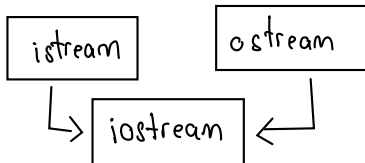
Exercise 32

- Practice with examples of classes using inheritance and `virtual` member functions
- Breakout rooms 1–10 are "social"
- Use Slack to let us know if you have questions!

Notes

* Stream & operator << (stream , inset)

  Inset &

(cout << "Hello") << inset 1 << end;

(cout << inset 1) << end;

(cout << end;)

cout.

Notes

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