CS100
Introduction to Programming

Lectures 17: Structuring your code

Outline

- passing by reference
- references & initializer lists
- const
- namespaces
- pre-processor directives

- More on operators
- smart/shared pointers
- friend

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Passing by reference

- In C, there have been two ways to pass a variable to a function
  - Pass-by-value:

```
void functionX( double val ) {
    val = …;
}
```

  - Pass-by-reference:

```
void functionX( double * val ) {
    *val = …; //de-referencing
}
```

Passing by reference

- In C, there have been two ways to pass a variable to a function
  - Drawback of using pointers:
    - Can be uninitialized!
    - Can be invalid

      ```
      double * val = NULL;
      ```

Passing by reference

- In C++, we can use references
  - Pass-by-value:

```
void functionX( double val ) {
    val = …;
}
```

  - Pass-by-reference:

```
void functionX( double & val ) {
    val = …; //no de-referencing!
}
```

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Passing by reference

- References are:
  - Valid types, just like pointers
  - Internally: just a pointer
  - Easier to manipulate
    - No de-referencing needed
  - Safer
    - can only be initialized from a valid instance of an object

Where do references appear?

- Example 1: Simply in the code

```
int x = 5;
if( … ) {
      int & y = x; //create reference
      y = 6;
}
//x = 6!
```

Where do references appear?

- Example 2: Through a function call

```
void functionX( double & val ) {
    val = 6; //no de-referencing!
}

int main {
    int x = 5;
    functionX(x);
    //x = 6!
    …
}
```

Where do references appear?

- Example 3: As a member of a class?

```
class Car {
public:
      Car();
private:
      Driver & driver;
};

Car::Car() {};
```

Not permitted! A reference always needs to be initialized from an existing object!

Where do references appear?

- Example 3: What about this?

```
class Car {
public:
        Car( Driver & driver );
private:
        Driver & m_driver;
};

Car::Car( Driver & driver ) {
        m_driver = driver;
}
```

- Problem 1: class members need to exist before the body of the constructor so they can be used.
- Problem 2: This syntax would not set m_driver as a reference to driver, but aim at copying the content of driver to where m_driver is referring to

Where do references appear?

- Example 3: Solution for class membership
  - Use an initializer list!

```
class Car {
public:
      Car( Driver & driver );
private:
      Driver & m_driver;
};

Car::Car( Driver & driver ) : m_driver(driver)
{}
```

Initializer lists must be used for any members that do not have a default constructor!

Facts about references

- `Driver &` does not have a default constructor
  - → needs to be initialized in initializer list
- Interesting observation:
  - Car also can no longer have simple default constructor!
  - Explains why single constructor overload makes default constructor unavailable
    - default constructor can’t work
    - overload becomes “default” constructor

Where do references appear?

- Example 3: And what about this?

```
class Car {
public:
    Car();
    Car( Driver & driver );
private:
    Driver & m_driver;
};

Car::Car()  : m_driver( *(new Driver()) ) {}
Car::Car( Driver & driver ) : m_driver(driver) {}
```

- Works, but useless!
- Composition! (Car would own driver in this case) → no reference needed!

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Using const

- Let us assume to have a class called **`MyVectorA`** with a resize function

```
class MyVectorA {
public:
    …
    void resize( MyVectorB & that );
};
```

- Goal:
  - resize only needs size of **`MyVectorB that`** to reset its own size.
  - It takes a reference as we would not want to pass a copy of the entire vector

Using const

- Let us assume to have a class called **`MyVectorA`** with a resize function

```
class MyVectorA {
public:
    …
    void resize( MyVectorB & that );
};
```

- Problem:
  - **`resize`** has a reference to **`that`**, and can therefore change the original
  - Can we formally prevent this? Can we protect **`that`** from changes?

Using const

- Solution: Pass as a const reference!

```
class MyVectorA {
public:
    …
    void resize( const MyVectorB & that );
};
```

  - Now **`resize`** is no longer allowed to change **`that!`**

Using const

- Let us furthermore assume that MyVectorB has a function to get the size

```
class MyVectorB {
public:
    …
    int size() {
        return m_size;
    }
};
```

Using const

- MyVectorA uses this function inside its resize method

```
class MyVectorA {
public:
    …
    void resize( const MyVectorB & that ) {
            this->m_data.resize( that.size() );
    }
};
```

- Does not work!
- Class methods can change the member variables!
- Calling `size()` is not safe, it may change `that`!

Using const

- Solution:
  - Mark function as constant!

```
class MyVectorB {
 public:
        …
        int size() {
                return m_size;
        }
 };
```

Using const

- Solution:
  - Mark function as constant!

```
class MyVectorB {
 public:
        ...
        int size() const {
              return m_size;
        }
 };
```

  - Adding **`const`** behind function means this function is not allowed to change member variables!

Using const

- What about functions that are not allowed to change either member variables or parameters?

```
class MyVectorA {
public:
    …
    double innerProd( MyVectorA & that ) {
        //calculate inner product
        //…
        return result;
    }
};
```

Using const

- What about functions that are not allowed to change either member variables or parameters?

```
class MyVectorA {
public:
    …
    double innerProd( const MyVectorA & that ) {
        //calculate inner product
        //…
        return result;
    }
};
```

Using const

- What about functions that are not allowed to change either member variables or parameters?

```
class MyVectorA {
public:
    …
    double innerProd( const MyVectorA & that ) const {
        //calculate inner product
        //…
        return result;
    }
};
```

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The name conflict problem

- Imagine we want to define our own class **vector**

```
#include <vector>

template<class T>
class vector {
public:
    …
private:
    std::vector<T> m_data;
};
```

- STL vector lives in namespace std
- namespace has to be resolved

The name conflict problem

- For convenience, we want to resolve the namespace **`std`** generally

```
#include <vector>

using namespace std;

template<class T>
class vector {
public:
    …
private:
    vector<T> m_data;
};
```

- Name conflict!
- Compiler can’t decide which vector to use
- Compiler won’t allow the name **`vector`** for a class

The name conflict problem

- Other sources of name conflicts:
  - Variable name used more than once

```
#include <stdlib.h>

int lengthParameter;
int lengthParameter;

//...
```

Global namespace

The name conflict problem

- Other sources of name conflicts:
  - Function name/signature used more than once

```
#include <stdlib.h>

int computeLength();
int computeLength();

//...
```

Global namespace

Introducing your own namespace

- Example:

```
#include <iostream>
```

Custom namespace 1

```
namespace VarSet1 {
     int lengthParameter;
     int computeLength();
}
```

Custom namespace 2

```
namespace VarSet2 {
     int lengthParameter;
     int computeLength();
}
```

```
int main() {
     std::cout << VarSet1::lengthParameter << “\n”;
}
```

Introducing your own namespace

- Namespaces for classes
  - A way to create logical grouping

```
namespace MyMathLibrary {
    template<class T>
    class Vector {
          //…
    };

    template<class T>
    class Matrix {
          //…
    };
}
```

Introducing your own namespace

- Namespaces for classes
  - A way to create logical grouping
  - Namespace additions can be in different files

File 1

```
namespace MyMathLibrary {
    template<class T>
    class Vector {
          //…
    };
}
```

File 2

```
namespace MyMathLibrary {
    template<class T>
    class Matrix {
          //…
    };
}
```

  - Custom namespaces can be generally included, too:
    `using namespace MyMathLibrary;`

Nested namespaces

- Namespaces can be nested
  - Creates a hierarchy of the functionality

```
namespace MyMathLibrary {
    namespace Linear {
        //…
    }
    namespace Nonlinear {
        namespace ClosedForm {
            //…
        }
        namespace Iterative {
            //…
        }
    }
}
```

  - Use: `using namespace MyMathLibrary::Nonlinear::Iterative::…;`

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Preprocessor directives

- Preprocessor directives are lines in the code preceded by a hash-tag (#)
- They are processed by the ”pre-processor”
  - Resolved before actual compilation starts
  - They will be replaced by something else
  - They define code to be replaced by something else
- Example: include-guards!

```
#ifndef MYCLASS_HPP_
#define MYCLASS_HPP_
//…
#endif
```

Defines

- `#define`
- Can be used to define constants
  - Example:

```
#define PI 3.1415

//…

int main() {
//…
        float circum = 2.0f * radius * PI;
//…
}
```

Defines

- `#define`
- Does not need a value
  - Can simply mark a variable as defined

```
#define DEBUG_MODE

//…

int main() {
#ifdef DEBUG_MODE
        if( !(index < vec.size()) )
                cout << "Access out of bounds\n";
#endif
}
```

Defines

- `#define`
- Can be set through the console
  - Example: `g++ -DDEBUG_MODE problem1.cpp -o main`

```
int main() {
#ifdef DEBUG_MODE
        if( !(index < vec.size()) )
                cout << "Access out of bounds\n";
#endif
}
```

Defines

- `#define` vs `static const`
  - **`#define`** consumes no memory
  - **`#define`** has no type, so can be assigned flexibly
  - **`static const`** can be scoped
  - **`static const`** has a single, clearly defined type, which may also be an advantage
  - **`static const`** enables pointers

Macros

- `#define` can be used to define functions
- Syntax:

```
#define fctName(param1,param2) ([fct using params])
```

- Example:

```
#define getrandom(min, max) ((rand()%(int)(((max) + 1)-(min)))+ (min))
```

typedef

- Sometimes we may have long type-names
- Example:

```
std::vector< std::vector< MyMathLibrary::Types::Matrix<double> > >
```

- We can introduce an alias for this type:

```
typdef std::vector< std::vector< MyMathLibrary::Types::Matrix<double> > >
     newtype;
```

- Can be in global, class, or function scope

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What are operators?

+			-	*	/	%
^		&	|	~	!	&&
||		++	--	<<	>>	,
<		<=	==	!=	>	>=
=		+=	-=	*=	/=	%=
&=	|=	^=	<<=		>>=	
[]		()	->	new		delete

What are operators?

- Almost all operators in C++ can be overloaded with new meanings
- Operators may not look like functions but can hide function invocations
- You cannot overload the meaning of operators if all arguments are primitive data types, nor can you change the precedence or associativity of operators
- Operators can be defined as either functions or member functions

What are operators?

- Example of an operator (global operator)

```
class Box {
public:
      Box (int v) : value(v) {}
      int value;
};

// define meaning of comparison for boxes
bool operator< (Box & left, Box & right) {
      return left.value < right.value;
}
```

- Binary comparison operator!

What are operators?

- Example of a member function

```
class Box {
public:
      Box (int v) : value(v) {}

      // define meaning of comparison for boxes
      bool operator< (Box & right) {
            return value < right.value;
      }
private:
      int value;
};
```

The Increment and Decrement Operators

- … `operator++`
  … `operator--`
- If the increment operator is overloaded, you should define both the prefix and postfix forms (`++it`, `it++`)
- Whenever you have a choice, always invoke the prefix form of the increment operator as it is usually simpler

The Increment and Decrement Operators

```
class Box {
   public:
      Box (int v) : value(v) { }

      // prefix versions (++someBox)
      int operator++ () { value++; return value; }
      int operator-- () { value--; return value; }

      int operator++ (int) // postfix versions (someBox++)
      {
            int result = value; // step 1, save old value
            value++;            // step 2, update value
            return result;      // step 3, return original
      }
      int operator -- (int) {
            int result = value;
            value--;
            return result;
      }
   private:
      int value;
};
```

The Shift Operators

```
cout << "m " << m << " n " << n
     << " average " << (n+m)/2.0 << '\n';
```

- The shift operators are overloaded in exactly the same fashion as the binary arithmetic operators

```
ostream & operator<<
        (ostream & out, const RationalNumber & value)
{
   // print rational number on an output stream
   out << value.numerator() << '/' << value.denominator();
   return out;
}
```

The Assignment Operator

- … `operator=( … )`
- The assignment, comma, and address-of operators will be constructed automatically if the programmer does not specify an alternative.

```
class Box {
public:
      Box () { value = 0; }
      Box (int i) { value = i; }
      int value;
};

Box a(7);
Box b;
b = a;
```

The Assignment Operator

- Note 1:
  - Always redefine the assignment operator in classes that include a pointer value
    - Similar to copy constructor: needs deep copy to prevent dangling pointers
  - Example: Box contains vector-pointer

```
const Box & operator= (Box & left, const Box & right) {
       left.m_ptr = new std::vector(*(right.m_ptr));
       return left;
}

Box a, c;
//… fill box a with elements
c = a;
```

The Assignment Operator

- Note 2:
  - Despite the use of the assignment symbol, constructors do not use the assignment operator

```
Box d = c; // uses copy constructor
```

- Note 3:
  - If addition and assignment are both overloaded, then += should be overloaded as well

The Compound Assignment Operators

- Whenever possible, define one operator in terms of another

```
AnObject operator+ ( const AnObject & left, const AnObject & right) {
   AnObject clone(left); // copy the left argument
   clone += right;       // combine with right
   return clone;         // return updated value
}
```

```
const AnObject & operator+= (AnObject & left, const AnObject & right) {
   AnObject sum = left + right;
   left = sum;
   return left;
}
```

The Subscript Operator

- Subscript operator is often defined for classes that represent a container abstraction

```
class MyArray {
public:
	MyArray(int s) {
		size = s;
		values = new int[size];
	}
	int & operator[] (unsigned int i) {
		assert(i < size);
		return values[i];
	}
private:
	unsigned int size;
	int * values;
};
```

The Parenthesis Operator

- Function Object: an object that can be used as though it were a function

```
class LargerThan {
public:
	// constructor
	LargerThan (int v) {
		val = v;
	}

	// the function call operator
	bool operator() (int test) {
		return test > val;
	}
private:
	int val;
};
```

The Parenthesis Operator

- Example use:

```
LargerThan tester(12);

int i = ... ;

if(tester(i)) // true if i is larger than 12
```

- Use inside STL algorithms:

```
list<int>::iterator found =
      find_if( aList.begin(), aList.end(),
      LargerThan(12));
```

The Arrow Operator

- Overloading the arrow operator is useful in objects that have a ‘pointer-like’ behavior
  - Example: iterators, smart pointers
- The arrow operator can only be defined as a member function
- The return type must either be a pointer to a class type or an object for which the member access arrow is defined

The Arrow Operator

- Example:

Returns pointer!

```
class CountPointer {
public:
   CountPointer(Window * w) {
       count = 0; win = w;
   }
   Window * operator->() {
       count++; return win;
   }
private:
   Window * win;
   int count;
};

Window * x = new Window(...);// create the underlying value
CountPointer p(x);           // create a counting pointer value
p->setSize(300, 400);        // invoke method in class window
```

Conversion Operators

- For conversions from user types
  - Conversions to user types are defined by constructors

```
operator double( const Rational & val ) {
      return val.numerator() / (double) val.denominator();
}

Rational r(2, 3);
double d;
d = 3.14 * double(r); // cast converts fraction to double
```

- In-class definition

```
class Rational {
  //…
  operator double() const {
      return numerator() / (double) denominator();
  }
  //…
};
```

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Raw pointers

- Raw pointers are used to handle memory that was allocated dynamically using **`new`**
- Raw pointers are unsafe
  - Missing delete causes memory leak

```
if( var == 1 ) {
  Person* p = new Person("John", 25);
  p->call();
  //no assignment, no delete
}
```

Raw pointers

- Raw pointers are used to handle memory that was allocated dynamically using **`new`**
- Raw pointers are unsafe
  - Calling delete more than once -> undefined behavior

```
if( var == 1 ) {
  Person* p = new Person("John", 25);
  p->call();
  delete p;
  delete p;
}
```

Raw pointers

- Raw pointers are used to handle memory that was allocated dynamically using **`new`**
- Raw pointers are unsafe
  - Dangling pointers can cause segmentation faults

```
Person* p = new Person[10];
delete[] p;    // p still points to the same memory
p[0]->call(); // undefined behavior!
p = NULL;      // ok, now p is not dangling any more
```

Smart pointers

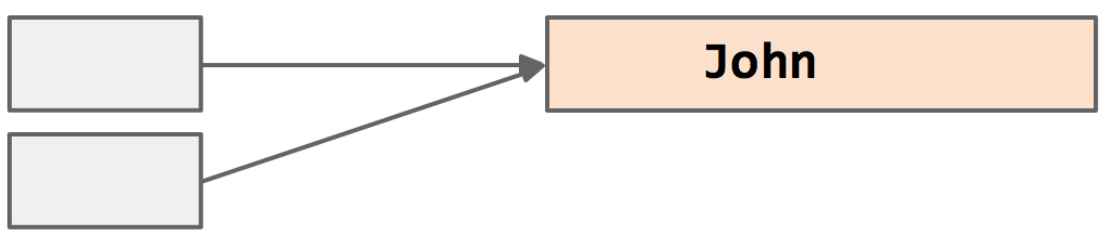
- Smart pointers can avoid these drawbacks
- A smart pointer is a wrapper of a raw pointer providing same functionalities with more safety
  - Same syntax as raw pointers for dereferencing
    - *p, p->val, and p[idx]
  - Automatic management of dynamically allocated memory lifetime
  - Exception-safe destruction
  - Automatically set to NULL, thus avoiding dangling pointers
- RAII – Resource Acquisition Is Initialization
  - A smart pointer takes ownership of the underlying object

Smart pointers

- 4 kinds (all available from `#include <memory>`)
  - **`std::auto_ptr`** (from C++98)
    - First naïve attempt to implement a smart pointer with exclusive ownership.
      (Deprecated since C++11, and removed from STL in C++14)
  - **`std::unique_ptr`** (from C++11)
    - Smart pointer used for exclusive ownership that can be copied only with move semantics
  - **`std::shared_ptr`** (from C++11)
    - Smart pointer used for shared ownership with automatic garbage collection based on a reference count
  - **`std::weak_ptr`** (from C++11)
    - Smart pointer used for observing without owning. Similar to **`shared_ptr`**, but does not contribute to the reference count

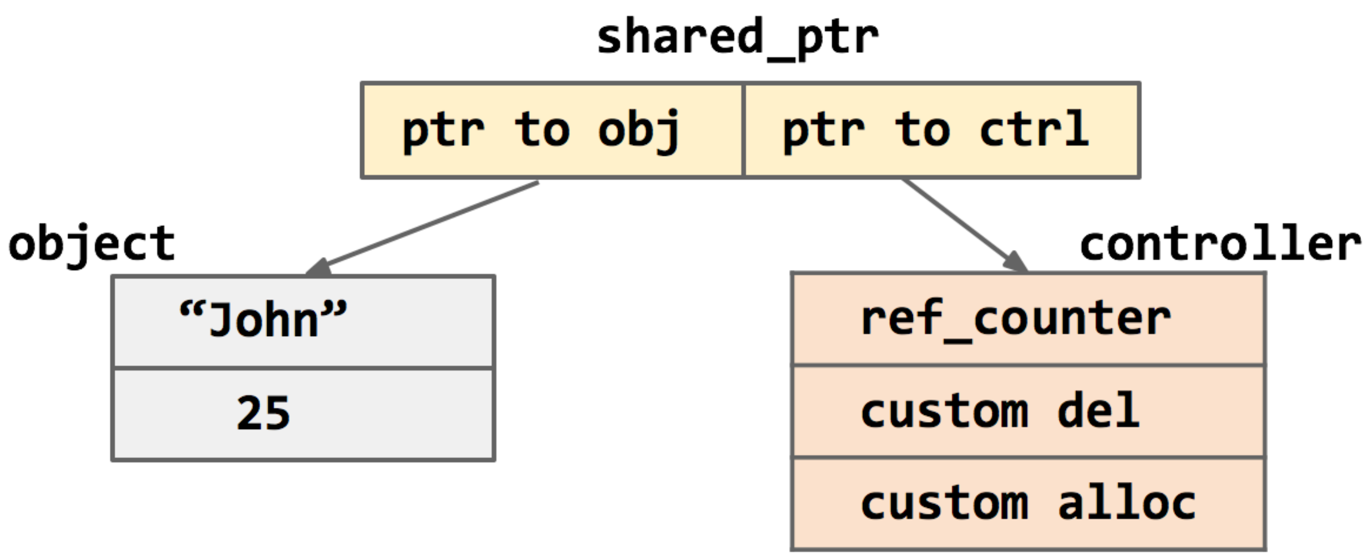
std::shared_ptr

- Shared pointers:
  - Provide shared ownership
  - Many pointers may own the same object
  - The last one to survive is responsible of its disposal through the deleter



std::shared_ptr

- Shared pointers have a garbage collection mechanism based on a reference counter contained in a control block
- Each new shared owner copies the pointer to the control block and increases the count by 1



std::shared_ptr

- Example:

```
std::shared_ptr p(new Person(“John”,25)); //ref-count = 1
std::shared_ptr q = p;                    //ref-count = 2
p.reset( new Person(“Alice”,23) );        //ref-count = 1
q = NULL;                                 //ref-count = 0
                                          //call delete!
```

- Important properties:
  - Copy-constructible and copy-assignable, so it can work inside STL containers
  - Non-trivial implementation and memory overhead (2 pointers:object itself, and control block)
  - Operations require atomic update of ref_counter (thread safety!), which may be slow

std::shared_ptr

- Useful methods:

```
T* get() const;           //returns stored pointer
long use_count() const;   //returns the reference count
bool unique() const;      //returns whether ref count == 1

template<class Y> void reset( Y * ptr );
                          //replaces the managed object
                          //with the one pointed ay by ptr.
                          //disposes off the previously
                          //owned object by reducing the
                          //ref-count and evtl. calling delete
```

Do we still need raw pointers?

- Smart pointers implement automatic management of dynamically allocated memory. This comes with very little overhead!
- However, raw pointers are still needed
  - When the pointer really just means an address, not ownership of an object
  - To implement iterators
  - To handle an array decaying into a pointer
  - When working with legacy code (e.g. pre-C11++)
  - When passing arguments by address to modify their content

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friend

- Occasionally, we may want to allow a function that is not member of a given class to access its private fields/methods
- Can specify that a given external function gets full access by
  - Placing the signature of the external function inside the class
  - Preceding this signature copy by the keyword `friend`

friend

- Example:

```
class USCurrency {
        friend ostream& operator<<( ostream &o, const USCurrency &c);
public:
        USCurrency( const int d, const int c) : dollars(d), cents(c) {}
private:
        int dollars, cents;
};

ostream& operator<<( ostream &o, const USCurrency &c) {
        o << '$' << c.dollars << '.' << c.cents;
        return o;
}
```

friend

- Can do the same with classes
  - Declaring other class as “friend” lets this class directly access private members of the other class

```
class A {
      friend class B;
      // More code ...
};
```