CS100
Introduction to Programming

Lectures 20: Structuring your code

Outline

- references
- const
- Namespaces

- pre-processor directives
- More on operators
- smart/shared pointers
- friend

Outline

- references

- const

- namespaces

- pre-processor directives

- More on operators

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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!
    }
    ```

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?

```cpp
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?

```cpp
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!

Outline

- references

- **const**

- namespaces

- pre-processor directives

- More on operators

- smart/shared pointers

- friend

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!

```cpp
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

```cpp
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!

```cpp
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?

```cpp
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?

```cpp
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?

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

Outline

- references

- const

- **namespaces**

- pre-processor directives

- More on operators

- smart/shared pointers

- friend

The name conflict problem

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

```cpp
#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

```cpp
#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:

```cpp
#include <iostream>

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

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

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

Custom namespace 1

Custom namespace 2

Introducing your own namespace

- Namespaces for classes
  - A way to create logical grouping

```cpp
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

File 2

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

```
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

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

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

Outline

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- namespaces

- **pre-processor directives**
- More on operators
- smart/shared pointers
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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

```cpp
#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`

```cpp
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> > >
        MatrixTable;
```

- Can be in global, class, or function scope
- Not really a pre-processor directive anymore

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- pre-processor directives

- **More on operators**

- smart/shared pointers

- friend

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)

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

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

- Binary comparison operator!

What are operators?

- Example of a member function

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

    // define meaning of comparison for boxes
    bool operator< (const 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

```cpp
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;
};
```
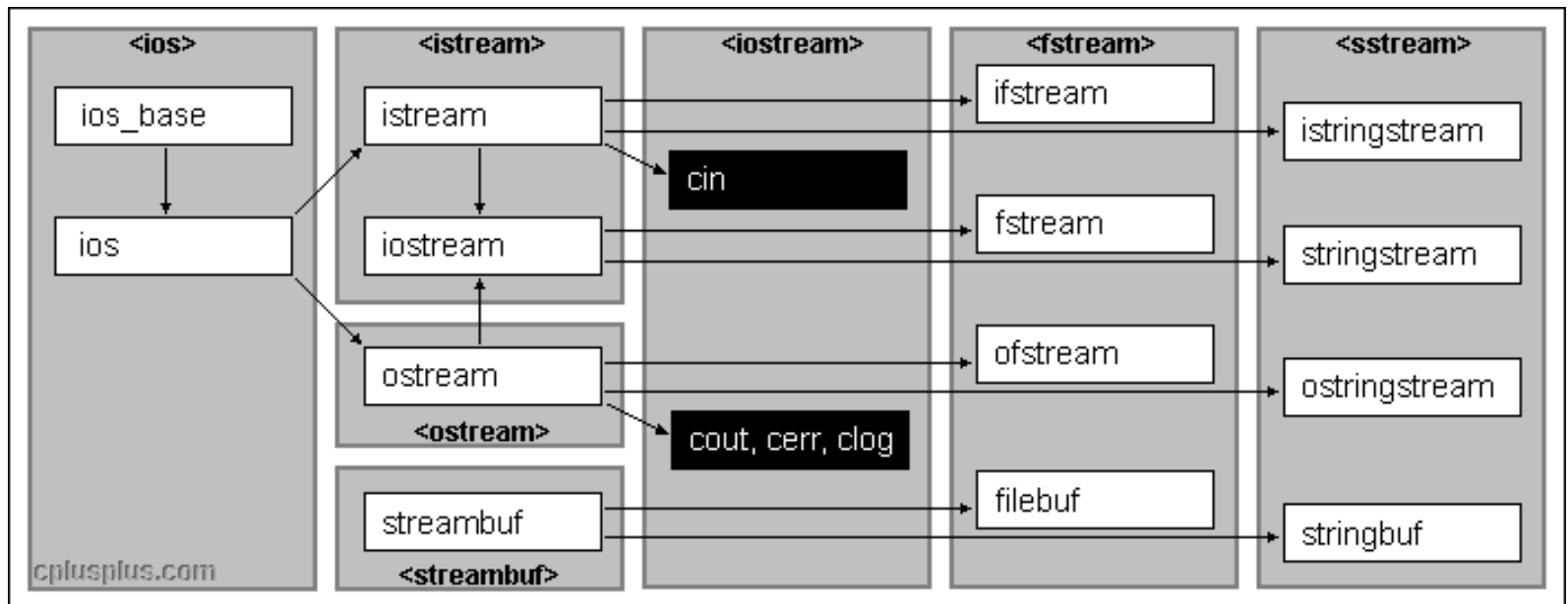
The Shift Operators

```cpp
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

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

ios

- Class hierarchy for input/output functionality in STL

The Assignment Operator

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

```cpp
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 **m_ptr**

```cpp
const Box & operator= (Box & left, const Box & right) {
        if( left.m_ptr != null )
                delete left.m_ptr;
        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

```cpp
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
}
```

```cpp
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

```cpp
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

```cpp
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 (for conditional filtering):

```
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!

```cpp
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

```cpp
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

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

Outline

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- Namespaces

- pre-processor directives

- More on operators

- **smart/shared pointers**

- friend

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

```cpp
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

```cpp
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
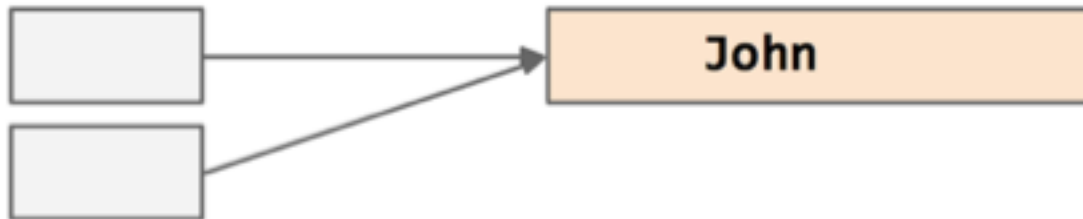
std::shared_ptr

- 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
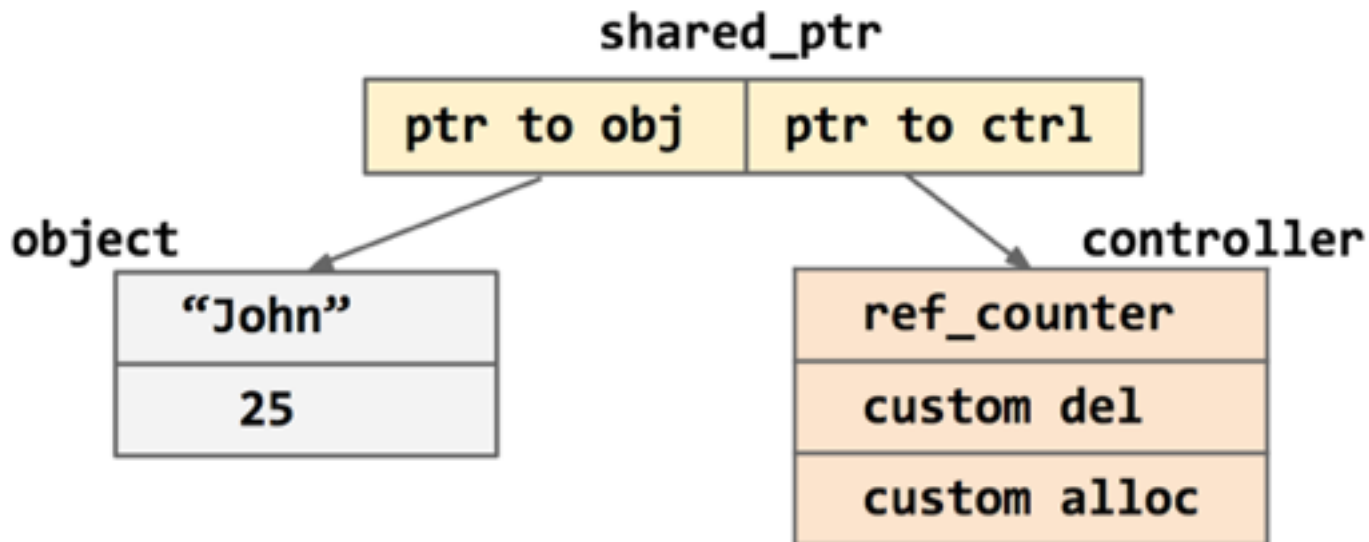
std::shared_ptr

- 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 at 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-C++11)
  - When passing arguments by address to modify their content

Outline

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- smart/shared pointers

- **friend**

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:

```cpp
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

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