Reuse

- One of the most important keywords in OO programming is **code reuse**
- If you have a piece of code that works correctly, you want to reuse it as much as you can:
  - because it has been tested and used, so there is more probability that it contains less bugs
  - because you do not need to redo the same thing again (so you save time and production cost)
- We have already seen that reusing software is far from being trivial (see the LSP section in the 04.inher.pdf).
- However, it is the *lapis philosophorum* (Philosopher’s Stone) of all programmers
In the previous slides, we have seen one particular OO technique for reusing code: inheritance
- It achieves reuse through abstraction
- A concept is abstracted, and then a hierarchy of concepts are linked together through inheritance
- However, inheritance may not be the best approach to reuse!

Consider the problem of providing a generic container of objects

Example
- We designed and developed a Stack class container
- It is an object that contains other objects, and provides operations for inserting, extracting, finding object, and visiting them in a certain order
- Our stack class contains integers
- However, the code is generic enough and depends only in minimal part from the fact that it contains integers

Problem:
- How to extend it to contains other types of objects?
- For example, Shapes
Cut & Paste

- In the early days of programming the solution would have been:
  - Copy and paste the code
  - modify it to use Shape instead of int
- Can you enumerate the problems with this approach?

Use inheritance

- OO languages that do not have templates, use inheritance for implementing such containers
  - For example, in Smalltalk (and in Java), all classes derive from a common ancestor: Object
  - The containers will contain pointers to Object
  - however, the type is lost when you insert an object in a container
  - The user has to perform an appropriate downcast to get back to the original type
- We can do something similar in C++, by using multiple interface inheritance
Using interfaces

- The following interface specifies that an object can be cloned

```cpp
class Clonable {
public:
  virtual Clonable * clone() = 0;
  virtual ~Clonable();
};
```

Using interfaces with Stack

- Stack now contains pointers to Clonable objects (i.e. objects that possess the Clonable interface)

```cpp
class Clonable {
public:
  virtual Clonable * clone() = 0;
  virtual ~Clonable();
};

class Stack {
  class Elem {...};
public:
  class Iterator {...};

  Stack();
  ~Stack();

  void push(Clonable *d);
  Clonable * pop();
  int size();
  ...
};
```
Exercise

1. Extend the previous Stack class by providing a copy constructor that actually copies all elements (using the clone() virtual function)
   - To show that they are actually different, first implement a static id counter in the Shape class, so that every object has its own id

2. Now, write a “OrderedList” class that contains objects with Interface Comparable
   - The objects in the list must be inserted according to an order decided by a function lessThan() that returns true if the object is “less” than the object passed as argument:

```cpp
class Comparable {
public:
    virtual bool lessThan(Comparable *obj) = 0;
    virtual ~Comparable() {};
};
```

   - Extend class hierarchy shapes to also derive from Comparable, and shapes must be ordered by their x position

Problems with this approach

The problems with this approach are the following:

- It is necessary to modify the code for the objects (they must derive from the appropriate interfaces)
  - A possible solution is to write a wrapper object that derives from the contained object and from the interface

- It is necessary to downcast at least once
  - Type safety is lost, the compiler cannot check anything meaningful during compilation time
  - For example, it is not possible to avoid that different types of objects are inserted in the same container by mistake
Templates

- Templates are used for generic programming
- The general idea is: what we want to reuse is not only the abstract concept, but the code itself
- we templates we reuse algorithms by making them general
- As an example, consider the code needed to swap two objects of the same type (i.e. two pointers)

```cpp
void swap(int &a, int &b)
{
    int tmp;
    tmp = a;
    a = b;
    b = tmp;
}
...
int x=5, y=8;
swap(x, y);
```

- Can we make it generic?

Solution

- By using templates, we can write

```cpp
template<class T>
void swap(T &a, T &b)
{
    T tmp;
    tmp = a;
    a = b;
    b = tmp;
}
...
int x=5, y=8;
swap<int>(x, y);
```

- Apart from the first line, we have just substituted the type int with a generic type T
How it works

- The template mechanism resembles the macro mechanism in C
  - We can do the same in C by using pre-processing macros:

```c
#define swap(type, a, b) { type tmp; tmp=a; a=b; b=tmp; }
...
int x = 5; int y = 8;
swap(int, x, y);
```

- in this case, the C preprocessor substitutes the code
  - it works only if the programmer knows what he is doing
- The template mechanism does something similar
  - but the compiler performs all necessary type checking

Code duplicates

- the compiler will instantiate a version of swap() with integer as a internal type
- if you call swap() with a different type, the compiler will generate a new version of swap
  - Only when a template is instantiated, the code is generated
    - If we do not use swap(), the code is never generated, even if we include it!
    - if there is some error in swap(), the compiler will never find it until it tries to generate the code
- Looking from a different point of view:
  - the template mechanism is like cut&paste done by the compiler at compiling time
Swap for other types

• What happens if we call swap for a different type:

```cpp
class A { ... };
A x;
A y;
...
swap<A>(x, y);
```

• A new version of swap is automatically generated
  • Of course, the class A must support the assignment operator, otherwise the generation fails to compile
  • see template/swap/swap.cpp

• Parameters can be automatically implied by the compiler

```cpp
int a = 5, b = 8;
swap(a, b); // equivalent to swap<int>(a, b);
```

• Sometimes, this is not so straightforward ...
Generalizing Stack

Now, let’s go back to our Stack class, and generalize it to contain any type of object

```cpp
template<class T>
class Stack {
    class Elem {
        public:
            T data_;
        ...
    };
    public:
        class Iterator {
            friend class Stack<T>;
            ...
        public:
            inline T operator*() const { ... }
        ...
    };
    Stack() : head_(0), size_(0) {}
    ~Stack() {...}

    void push(const T &a) {...}
    T pop() {...}
    ...
}
```

Exercises

1. Write a program that inserts pointers to shapes into the stack
   - You will only need to modify the main!

2. Write a program that inserts only rectangles into a stack

3. Write a OrderedList container that makes use of operator<() to compare elements. Insert shapes into it, and order by increasing x coordinate
Advantages of this solution

- We do not need to modify the original code (i.e. the Shape hierarchy should not be modified)
- The code is polymorphic to the right level (no extra downcast is necessary)
- Can be applied not only to containers but also to any function

Inlines

- It is possible to define the members of a template class later on
  - Must be preceded by keyword template

```
template<class T>
class Array {
    enum { size = 100 };  
    T A[size];

    public:
    T& operator[](int index);
};

template<class T>
T& Array<T>::operator[](int index) {
    require(index >= 0 && index < size,
        "Index out of range");
    return A[index];
}

int main() {
    Array<float> fa;
    fa[0] = 1.414;
} ///:~
Template instantiation

- The code for the template is not instantiated until the template is used
  - It works similarly to in-lines
  - The template code should go in the header file
- It is possible to have the template code in a separate cpp file
  - through the export keyword
  - not supported by gcc and by Visual C++
  - it is a candidate for deletion from the standard

Parameters

- A template can have any number of parameters
- A parameter can be:
  - a class, or any predefined type
  - a function
  - a constant value (a number, a pointer, etc.)

```cpp
template<T, int sz>
class Buffer {
    T v[sz];
    int size_;
public:
    Buffer() : size_(i) {} 
};

Buffer<char, 127> cbuf;
Buffer<Record, 8> rbuf;
int x = 16;
Buffer<char, x> ebuf; // error!
```
Default values

- Some parameter can have default value

```cpp
template<class T, class Allocator = allocator<T> >
class vector;
```

Templates of templates

- The third type of parameter a template can accept is another class template

```cpp
template<class T>
class Array {
...
};

template<class T, template<class> class Seq>
class Container {
    Seq<T> seq;
public:
    void append(const T& t) { seq.push_back(t); }   
    T* begin() { return seq.begin(); }            
    T* end() { return seq.end(); }                
};

int main() {
    Container<int, Array> container;
    container.append(1);
    container.append(2);
    int* p = container.begin();
    while(p != container.end())
        cout << *p++ << endl;
} ///:~
Using standard containers

- If the container class is well-written, it is possible to use any container inside

```cpp
template<class T, template<class U, class = allocator<U> > class Seq>
class Container {
    Seq<T> seq; // Default of allocator<T> applied implicitly

public:
    void push_back(const T& t) { seq.push_back(t); }
    typename Seq<T>::iterator begin() { return seq.begin(); }
    typename Seq<T>::iterator end() { return seq.end(); }
};

int main() {
    // Use a vector
    Container<int, vector> vContainer;
    vContainer.push_back(1);
    vContainer.push_back(2);
    for(vector<int>::iterator p = vContainer.begin(); p != vContainer.end(); ++p) {
        cout << *p << endl;
    }
    // Use a list
    Container<int, list> lContainer;
    lContainer.push_back(3);
    lContainer.push_back(4);
    for(list<int>::iterator p2 = lContainer.begin(); p2 != lContainer.end(); ++p2) {
        cout << *p2 << endl;
    }
} ///:~
```

The typename keyword

- The typename keyword is needed when we want to specify that an identifier is a type

```cpp
template<class T> class X {
    typename T::id i; // Without typename, it is an error:

public:
    void f() { i.g(); }
};

class Y {
public:
    class id {
        public:
            void g() {}
        };
};

int main() {
    X<Y> xy;
    xy.f();
} ///:~
```
General rule

- If a type referred to inside template code is qualified by a template type parameter, you must use the typename keyword as a prefix,
- Unless it appears in a base class specification or initializer list in the same scope (in which case you must not).

Usage

- The typical example of usage is for iterators

```cpp
#include <vector>
#include <list>
#include <iostream>

template<class T, template<class U, class = allocator<U> > class Seq>
void printSeq(Seq<T>& seq) {
    for(typename Seq<T>::iterator b = seq.begin();
        b != seq.end();)
        cout << *b++ << endl;
}

int main() {
    // Process a vector
    vector<int> v;
    v.push_back(1);
    v.push_back(2);
    printSeq(v);
    // Process a list
    list<int> lst;
    lst.push_back(3);
    lst.push_back(4);
    printSeq(lst);
} ///:~
```
Making a member template

- An example for the complex class

```cpp
template<typename T> class complex {
public:
    template<class X> complex(const complex<X>&);
    ...
};
complex<float> z(1, 2);
complex<double> w(z);
```

- In the declaration of w, the complex template parameter T is double and X is float. Member templates make this kind of flexible conversion easy.

Another example

```cpp
int data[5] = { 1, 2, 3, 4, 5 };  
vector<int> v1(data, data+5);  
vector<double> v2(v1.begin(), v1.end());
```

- As long as the elements in v1 are assignment-compatible with the elements in v2 (as double and int are here), all is well.
- The vector class template has the following member template constructor:

```cpp
template<class InputIterator>
vector(InputIterator first, InputIterator last,  
const Allocator& = Allocator());
```

- InputIterator is interpreted as `vector<int>::iterator`
Another example

```cpp
template<class T> class Outer {
public:
    template<class R> class Inner {
public:
        void f();
    };
};

template<class T> template<class R>
void Outer<T>::Inner<R>::f() {
    cout << "Outer == " << typeid(T).name() << endl;
    cout << "Inner == " << typeid(R).name() << endl;
    cout << "Full Inner == " << typeid(*this).name() << endl;
}

int main() {
    Outer<int>::Inner<bool> inner;
    inner.f();
} ///:~
```

Restrictions

- Member template functions cannot be declared virtual.
  - Current compiler technology expects to be able to determine the size of a class’s virtual function table when the class is parsed.
  - Allowing virtual member template functions would require knowing all calls to such member functions everywhere in the program ahead of time.
  - This is not feasible, especially for multi-file projects.
Function templates

- The standard template library defines many function templates in algorithm
  - sort, find, accumulate, fill, binary_search, copy, etc.
- An example:

```cpp
#include <algorithm>
...
int i, j;
...
int z = min<int>(i, j);
```

Deduction

- Type can be deducted by the compiler
- But the compiler is smart until a certain point...

```cpp
int z = min(x, j); // x is a double, error, not the same types
int z = min<double>(x, j); // this one works fine
```
Return type

```cpp
template<typename T, typename U>
const T& min(const T& a, const U& b) {
    return (a < b) ? a : b;
}
```

- The problem is: which return value is the most correct? T or U?
- If the return type of a function template is an independent template parameter, you must always specify its type explicitly when you call it, since there is no argument from which to deduce it.

Example

```cpp
template<typename T> T fromString(const std::string& s) {
    std::istringstream is(s);
    T t;
    is >> t;
    return t;
}

template<typename T> std::string toString(const T& t) {
    std::ostringstream s;
    s << t;
    return s.str();
}

int main() {
    int i = 1234;
    cout << "i == " << toString(i) << "\n" << endl;
    float x = 567.89;
    cout << "x == " << toString(x) << "\n" << endl;
    complex<float> c(1.0, 2.0);
    cout << "c == " << toString(c) << "\n" << endl;
    cout << endl;
    i = fromString<int>(string("1234"));
    cout << "i == " << i << endl;
    x = fromString<float>(string("567.89"));
    cout << "x == " << x << endl;
    c = fromString<complex<float>>(string("(1.0,2.0)"));
    cout << "c == " << c << endl;
    // /~/