



Outline

- 1 Standard library algorithms
 - Algorithms
 - Insert iterators
- 2 Iterators
 - Different kinds of iterators
 - stream iterators
- 3 Algorithms and function objects

Algorithms

Standard library algorithms

```
#include <algorithm>
```

Numeric algorithms:

```
#include <numeric>
```

Random number generation

```
#include <random>
```

Appendix A.2 in Lippman gives an overview

Standard algorithms

Main categories of algorithms

- 1 Search, count
- 2 Compare, iterate
- 3 Generate new data
- 4 Copying and moving elements
- 5 Changing and reordering elements
- 6 Sorting
- 7 Operations on sorted sequences
- 8 Operations on sets
- 9 Numeric algorithms

Standard algorithms

Algorithm limitations

- ▶ Algorithms may *modify container elements*. E.g.,
 - ▶ `std::sort`
 - ▶ `std::replace`
 - ▶ `std::copy`
 - ▶ `std::remove` (sic!)
- ▶ No algorithm *inserts or removes container elements*.
 - ▶ That requires operating on the actual container object
 - ▶ or using an *insert iterator* that knows about the container (cf. `std::back_inserter`)

Algorithms

Exempel: `find`

```
template <class InputIterator, class T>  
InputIterator find (InputIterator first, InputIterator last,  
                  const T& val);
```

Exempel:

```
vector<std::string> s{"Kalle", "Pelle", "Lisa", "Kim"};  
  
auto it = std::find(s.begin(), s.end(), "Pelle");  
  
if(it != s.end())  
    cout << "Found " << *it << endl;  
else  
    cout << "Not found" << endl;  
  
Found Pelle
```

Algorithms

Example: find_if

```
template <class InputIterator, class UnaryPredicate>
InputIterator find_if (InputIterator first, InputIterator last,
                     UnaryPredicate pred);
```

Exempel:

```
bool is_odd(int i) { return i % 2 == 1; }

void test_find_if()
{
    vector<int> v{2,4,6,5,3};

    auto it = std::find_if(v.begin(), v.end(), is_odd);

    if(it != v.end())
        cout << "Found " << *it << endl;
    else
        cout << "Not found" << endl;
}
```

Found 5

Function pointer

Algorithms

count och count_if

Count elements, in a data structure, that satisfy some predicate

- ▶ `std::count(first, last, value)`
 - ▶ elements equal to value
- ▶ `std::count_if(first, last, predicate)`
 - ▶ elements for which predicate is true

Algorithms

Example: copy and copy_if

```
template <class InputIterator, class OutputIterator>
OutputIterator copy (InputIterator first, InputIterator last,
                   OutputIterator result);
```

Example:

```
vector<int> a(8,1);

print_seq(a);           length = 8: [1][1][1][1][1][1][1][1]

vector<int> b{5,4,3,2};

std::copy(b.begin(), b.end(), a.begin()+2);
print_seq(a);           length = 8: [1][1][5][4][3][2][1][1]
```

copy_if with predicate, as previous slide

Algorithms

remove / remove_if

Remove elements equal to a value or matching a predicate.

- ▶ `std::remove` et al. do not actually remove anything. They
 - ▶ move the "retained" elements to the front
 - ▶ return an iterator to the first "removed" element
- ▶ To actually remove from a container, use the `erase` member function, e.g `std::vector::erase()`

The erase-remove idiom

```
auto new_end = std::remove_if(c.begin(), c.end(), pred);
c.erase(new_end, c.end());
```

or

```
c.erase(std::remove_if(c.begin(), c.end(), pred), c.end());
```

Algorithms

Insert iterators (in <iterator>)

Example:

```
vector<int> v{1, 2, 3, 4};

vector<int> e;
std::copy(v.begin(), v.end(), std::back_inserter(e));
print_seq(e);           length = 4: [1][2][3][4]

deque<int> e2;
std::copy(v.begin(), v.end(), std::front_inserter(e2));
print_seq(e2);          length = 4: [4][3][2][1]

std::copy(v.begin(), v.end(), std::inserter(e2, e2.end()));
print_seq(e2);          length = 8: [4][3][2][1][1][2][3][4]
```

Requirements on iterators

The standard library algorithms put requirements on iterators. For instance, `std::find` requires its arguments to be

CopyConstructible (and Destructible) as it is passed by value
EqualityComparable to have `operator!=`
Dereferencable to have `operator*` (for reading)
Incrementable to have `operator++`

The requirements are often specified using iterator concepts.

Iterator concepts

- ▶ Input Iterator ($++$ $==$ $!=$) (dereference as *rvalue*: $*a$, $a->$)
- ▶ Output Iterator ($++$) (dereference as *lvalue*: $*a=t$)
- ▶ Forward Iterator (Input- and Output Iterator, reusable)
- ▶ Bidirectional Iterator (as Forward Iterator with $--$)
- ▶ Random-access Iterator ($+=$, $-=$, $a[n]$, $<$, $<=$, $>$, $>=$)

Different iterators for a container type (con is one of the containers vektor, deque, or list with the element type T)

```
con<T>::iterator           runs forward
con<T>::const_iterator    runs forward, only for reading
con<T>::reverse_iterator  runs backwards
con<T>::const_reverse_iterator runs backwards, only for reading
```

Iterator validity

In general, if the structure an iterator is referring to is changed *the iterator is invalidated*. Example:

- ▶ insertion
 - ▶ sequences
 - ▶ vector, deque*: all iterators are invalidated
 - ▶ list : iterators are unaffected
 - ▶ associative containers (set, map)
 - ▶ iterators are unaffected
- ▶ removal
 - ▶ sequences
 - ▶ vector : iterators *after* the removed elements are invalidated
 - ▶ deque : all iterators invalidated (in principle*)
 - ▶ list : iterators to the removed elements are invalidated
 - ▶ associative containers (set, map)
 - ▶ iterators are unaffected
- ▶ resize: as insertion/removal

istream_iterator<T>

istream_iterator<T> : constructors

```
istream_iterator(); // gives an end-of-stream istream iterator
istream_iterator (istream_type& s);
```

```
#include <iterator>
```

```
stringstream ss{"1 2 12 123 1234\n17\n42"};
```

```
istream_iterator<int> iit(ss);
istream_iterator<int> iit_end;
```

```
while(iit != iit_end) {
    cout << *iit++ << endl;
}
```

```
1
2
12
123
1234
17
42
```

istream_iterator<T>

Example: use to initialize a vector<int>:

```
stringstream ss{"1 2 12 123 1234\n17\n42"};
```

```
istream_iterator<int> iit(ss);
istream_iterator<int> iit_end;
```

```
vector<int> v(iit, iit_end);
```

```
for(auto a : v) {
    cout << a << " ";
}
cout << endl;
```

```
1 2 12 123 1234 17 42
```

istream_iterator<T>

Example: counting words in a string s:

Straight-forward counting

```
istringstream ss{s};
int words{0};
string tmp;
while(ss >> tmp) ++words;
```

Using the standard library

```
istringstream ss{s};
int words = distance(istream_iterator<string>{ss},
                    istream_iterator<string>{});
```

std::distance gives the distance (in number of elements) between two iterators. (UB if the second argument cannot be reached by incrementing the first.)

istream_iterator Handling errors

```
stringstream ss{"1 17 kalle 2 nisse 3 pelle\n"};
istream_iterator<int> iit2{ss};
istream_iterator<int> iit_end;
while(!ss.eof()) {
    while(iit2 != iit_end) { cout << *iit2++ << endl; }
    if(ss.fail()){
        ss.clear();
        string s;
        ss >> s;
        cout << "ss2: not an int: " << s << endl;
        iit2 = istream_iterator<int>(ss2); // create new iterator
    }
}
cout << boolalpha << "ss2.eof(): " << ss2.eof() << endl;
```

```
1
ss2: not an int: kalle
2
ss2: not an int: nisse
3
ss2: not an int: pelle
ss2.eof(): true
```

- ▶ on failure, the fail-bit is set in the stream
- ▶ the iterator is set to end
- ▶ if the stream is changed, a new iterator must be created

ostream_iterator and the algorithm copy

ostream_iterator

```
ostream_iterator (ostream_type& s);
ostream_iterator (ostream_type& s, const char_type* delimiter);

stringstream ss{"1 2 12 1234\n17\n\r42"};
istream_iterator<double> iit{ss};
istream_iterator<double> iit_end;

cout << fixed << setprecision(2);
ostream_iterator<double> oit{cout, " <-> "};

std::copy(iit, iit_end, oit);

1.00 <-> 2.00 <-> 12.00 <-> 1234.00 <-> 17.00 <-> 42.00 <->
```

transform and function objects

Iterate over a sequence, apply a function to each element and write the result to a sequence (cf. "map" in functional programming languages)

```
template < class InputIt, class OutputIt, class UnaryOperation >
OutputIt transform( InputIt first, InputIt last, OutputIt d_first,
    UnaryOperation unary_op );
```

```
template < class InputIt1, class InputIt2, class OutputIt,
    class BinaryOperation >
OutputIt transform( InputIt1 first1, InputIt1 last1, InputIt2 first2,
    OutputIt d_first, BinaryOperation binary_op );
```

A function object is an object that can be called as a function.,

- ▶ function pointers
- ▶ function objects ("functor")

The algorithm transform can handle both function pointers and functors.

Function objects and transform

Example with function pointer

```
int square(int x) {
    return x*x;
}

vector<int> v{1, 2, 3, 5, 8};
vector<int> w; // w is empty!

transform(v.begin(), v.end(), inserter(w, w.begin()), square);

// w = {1, 4, 9, 25, 64}
```

Function objects

A function object is an object that has operator()

Previous example with a function object

```
struct {
    int operator() (int x) const {
        return x*x;
    }
} sq;

vector<int> v{1, 2, 3, 5, 8};
vector<int> ww; // ww empty!

transform(v.begin(), v.end(), inserter(ww, ww.begin()), sq);

// ww = {1, 4, 9, 25, 64}
```

Anonymous struct – the type has no name, only the object.

Random numbers

<cstdlib>

Example: dice with the C standard lib

```
#include <iostream>
#include <cstdlib>
#include <ctime>

using std::cout;
using std::endl;

int main()
{
    unsigned int seed = time(0);
    srand(seed);
    int n{20};
    for (int i=0; i<n; i++) {
        cout << rand()%6+1 << " ";
    }
    cout << endl;
}
```

Random numbers

Better C++: encapsulate in an object – "function with state"

Assume that we have a class Rand_int giving random numbers in the interval [min, max].

with RandInt object

```
int main()
{
    unsigned long seed = time(0);
    Rand_int dice(1,6, seed);
    int n{20};
    for(int i = 0; i != n; ++i) {
        cout << dice() << " ";
    }
    cout << endl;
}
```

The C version

```
int main( )
{
    unsigned int seed = time(0);
    srand(seed);
    int n{20};
    for (int i=0; i<n; i++) {
        cout << rand()%6+1 << " ";
    }
    cout << endl;
}
```

Random numbers

Example of a random integer class

Example: Rand_int

```
#include <random>

class Rand_int {
public:
    Rand_int(int low, int high) :dist{low,high} {}
    Rand_int(int low, int high, unsigned long seed)
        :re{seed}, dist{low,high} {}
    int operator()() {return dist(re);}
private:
    std::default_random_engine re;
    std::uniform_int_distribution<> dist;
};
```

Function objects

lambda expressions

syntax:

```
[capture] (parameters) -> return type {statements}
```

where

capture specifies by value ([=]) or by reference ([&]), default or for each named variable

parameters are like normal function parameter declaration

return type can be inferred from return statements if unambiguous

Example

```
auto plus = [](int a, int b) {return a + b;};

int x = 10;
auto plus_x = [=](int a) {return a + x;}; // x is captured
```

Function objects

Predefined function objects: <functional>

Functions:

plus, minus, multiplies, divides, modulus, negate, equal_to, not_equal_to, greater, less, greater_equal, less_equal, logical_and, logical_or, logical_not

Predefined function object creation

operation<type>()

E.g.,

```
auto f = std::plus<int>();
```

Function objects

Example: std::plus from <functional>

transform with binary function

```
vector<int> v1{1,2,3,4,5};
vector<int> v2{10,10};

vector<int> res2;
auto it = std::back_inserter(res2);
auto f = std::plus<int>();
std::transform(v1.begin(), v1.end(), v2.begin(), it, f);

print_seq(res2);
length = 5: [11][12][13][14][15]
```

Example with accumulate <numeric>

```
auto mul = std::multiplies<int>();
int prod = std::accumulate(v1.begin(), v1.end(), 1, mul);

cout << "product(v1) = " << prod << endl;
product(v1) = 120
```

Function objects

functions with state

Function objects can be used to create functions with state (more flexible than static local variables).

Example

```
struct {
    int operator()(int x) {return val+=x;}
    int get_sum() const {return val;}
    void reset() {val=0;}
    int val=0;
} accum;

std::vector<int> v{1,2,3,4,5};

for(auto x : v) {
    accum(x);
    cout << "sum is " << accum.get_sum() << endl;
}
```

Function objects

Example: a function object class template

```
template<typename T>
class Less_than {
public:
    const T val;
public:
    Less_than(const T& v) :val{v} {}
    bool operator()(const T& x) {return x < val;}
};

void use_less_than()
{
    Less_than<int> lt5{5};
    Vector<int> v{1,7,6,2,8};

    for(auto x : v) {
        cout << x << " < 5:" << boolalpha << lt5(x) << endl;
    }
}
```

Custom comparator for std::set

```
#include <set>

struct Longest_Str{
    bool operator()(const string& l, const string &r) const {
        return l.size() > r.size();
    };
};

bool short_str(const string& l, const string& r)
{
    return l.size() < r.size();
}

std::set<string, Longest_Str> s{"a", "bb"};
std::set<string, Longest_Str> s2;

using StrComp = bool (*)(const string&, const string&);
std::set<string, StrComp> t1{"x", "yy"}, short_str;
std::set<string, StrComp> t2(short_str);
```

Suggested reading

References to sections in Lippman

[Function templates](#) 16.1.1

[Algorithms](#) 10 – 10.3.1, 10.5

[Iterators](#) 10.4

[Function objects](#) 14.8

[Random numbers](#) 17.4.1

Next lecture

Resource management

References to sections in Lippman

[Dynamic memory and smart pointers](#) 12.1

[Dynamically allocated arrays](#) 12.2.1

[Classes, resource management](#) 13.1, 13.2

[Type casts](#) 4.11