

# The Standard Template Library

EECS 211

Winter 2019

## Problem: finding a vector's maximum element

A simple fixed-size vector struct:

```
struct Int_vec
{
    int* data;
    size_t size;
};
```

## Solution: max\_int\_vec

```
// Finds the index of the maximum element in vec.  
// - If vec is empty returns 0.  
// - If the maximum element repeats, returns the  
//   first occurrence.  
size_t max_int_vec(const Int_vec& vec)  
{  
    size_t best = 0;  
  
    for (size_t i = 1; i < vec.size; ++i)  
        if (vec.data[best] < vec.data[i])  
            best = i;  
  
    return best;  
}
```

## Testing max\_int\_vec

```
TEST_CASE("max_int_vec")
{
    int data[] = { 2, 0, 5, 3, 9, 5, 1 };
    Int_vec v{data, 7};

    CHECK( max_int_vec(v) == 4 );
}
```

## Problem: finding a link list's maximum element

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    int data;
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    int data;
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};
```

```
using Int_list = std::shared_ptr<Int_node>;
```

```
Int_list cons(int data, Int_list next)
{
    return std::make_shared<Int_node>({data, next});
}
```

## Solution: max\_int\_list

```
// Finds the link to the node containing the  
// maximum element.  
// - If empty, returns the null pointer.  
// - If the maximum repeats, returns the first  
// occurrence.  
Int_list max_int_list(Int_list lst)  
{  
    Int_list best = lst;  
  
    for (Int_list i = lst; i; i = i->next)  
        if (best->data < i->data)  
            best = i;  
  
    return best;  
}
```



## Testing max\_int\_list

```
TEST_CASE("max_int_list")
{
    Int_list exp =
        cons(9, cons(5, cons(1, nullptr)));
    Int_list lst =
        cons(2, cons(0, cons(5, cons(3, exp))));

    CHECK( max_int_list(lst) == exp );
}
```

# Making our code more general

To make our code more general (and thus more reusable):

- Make the data structures generic over the element types
- Make the algorithm generic over the data structures

## Generic fixed-size vector

```
template <typename T>
struct Vec
{
    T* data;
    size_t size;
};
```

## Generic max\_vec

```
template <typename T>
size_t max_vec(const Vec<T>& vec)
{
    size_t best = 0;

    for (size_t i = 1; i < vec.size; ++i)
        if (vec.data[best] < vec.data[i])
            best = i;

    return best;
}
```

## Generic linked list

```
template <typename T>
struct Node
{
    T data;
    std::shared_ptr<Node<T>> next;
};
```

## Generic linked list

```
template <typename T>
struct Node
{
    T data;
    std::shared_ptr<Node<T>> next;
};
```

```
template <typename T>
using List = std::shared_ptr<Node<T>>;
```

```
template <typename T>
List<T> cons(const T& data, List<T> next)
{
    return std::make_shared<Node<T>>({data, next});
}
```

## Generic max\_list

```
template <typename T>
List<T> max_list(const List<T>& lst)
{
    List<T> best = lst;

    for (List<T> i = lst; i; i = i->next)
        if (best->data < i->data)
            best = i;

    return best;
}
```

# Introducing the Standard Template Library

- Includes containers like `std::vector<T>`, `std::list<T>` (a doubly-linked list), and more
- Containers have *iterators* for traversing them
- An iterator is like a pointer to one element of a container



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- `++i` advances an iterator `i` to the next element
- (and more...)

## max\_vec using std::vector iterators

```
#include <vector>
```

```
using iter = typename std::vector<int>::iterator;
```

```
iter max_vec(std::vector<int>& vec)
```

```
{  
    iter best = vec.begin();  
  
    for (iter i = vec.begin(); i != vec.end(); ++i)  
        if (*best < *i)  
            best = i;  
  
    return best;  
}
```

## max\_vec using auto

```
#include <vector>
```

```
typename std::vector<int>::iterator
```

```
max_vec(std::vector<int>& vec)
```

```
{  
    auto best = vec.begin();  
  
    for (auto i = vec.begin(); i != vec.end(); ++i)  
        if (*best < *i)  
            best = i;  
  
    return best;  
}
```

## max\_list using std::list iterators

```
#include <list>
```

```
typename std::list<int>::iterator
```

```
max_list(std::list<int>& lst)
```

```
{
```

```
    auto best = lst.begin();
```

```
    for (auto i = lst.begin(); i != lst.end(); ++i)
```

```
        if (*best < *i)
```

```
            best = i;
```

```
    return best;
```

```
}
```

## Making the algorithm generic

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We can use a template to abstract over the iterator type

We'll make the function take an iterator range to search through

## Generic maximum element algorithm

```
template <typename Fwd_iter>
Fwd_iter max_gen(Fwd_iter start, Fwd_iter limit)
{
    Fwd_iter best = start;

    for (Fwd_iter i = start; i != limit; ++i)
        if (*best < *i)
            best = i;

    return best;
}
```

## max\_generic is very generic

It doesn't care about:

- the shape of the data structure
- the element type of the data structure
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It doesn't care about:

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- the element type of the data structure
- whether the iterator is const or not

What it does care about:

- `Fwd_iterator` is copyable (`best = i`), pre-incrementable (`++i`), and dereferenceable (`*i`)
- The results of dereferencing `Fwd_iterator` are comparable with `operator<`

## Using max\_generic

```
TEST_CASE("max_gen(vector<int>)")
{
    std::vector<int> vec{ 2, 0, 5, 3, 9, 5, 1 };
    auto exp = vec.begin() + 4;
    CHECK( max_gen(vec.begin(), vec.end()) == exp );
}
```

```
TEST_CASE("max_gen(list<double>)")
{
    std::list<double> lst{ 2, 0, 5, 3, 9, 5, 1 };
    auto exp = lst.begin();
    advance(exp, 4);
    CHECK( max_gen(lst.begin(), lst.end()) == exp );
}
```

It's in <algorithm>

```
#include <algorithm>
```

```
TEST_CASE("max_element(vector<int>)")
```

```
{
    std::vector<int> v{ 2, 0, 5, 3, 9, 5, 1 };
    auto i = v.begin() + 4;
    CHECK(std::max_element(v.begin(), v.end()) == i);
}
```

```
TEST_CASE("max_element(list<double>)")
```

```
{
    std::list<double> w{ 2, 0, 5, 3, 9, 5, 1 };
    auto i = w.begin();
    advance(i, 4);
    CHECK(std::max_element(w.begin(), w.end()) == i);
}
```

# STL algorithms

The STL `<algorithm>` header contains many algorithms:  
<http://en.cppreference.com/w/cpp/algorithm>



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Let's try using it for counting...

## Counting occurrences

```
#include <algorithm>

using namespace std;

const vector<int> v{ 2, 0, 5, 3, 9, 5, 1 };

TEST_CASE("count")
{
    CHECK( count(v.begin(), v.end(), 4) == 0 );
    CHECK( count(v.begin(), v.end(), 3) == 1 );
    CHECK( count(v.begin(), v.end(), 5) == 2 );
}
```

## Counting with a predicate

```
bool lt6(int x) { return x < 6; }
```

```
const vector<int> v{ 2, 0, 5, 3, 9, 5, 1 };
```

```
TEST_CASE("count_if<lt6>")
```

```
{  
    CHECK( count_if(v.begin(), v.end(), lt6) == 6 );  
}
```

## Counting with a function object

```
struct Less_than
{
    int value;

    bool operator()(int x) const
    {
        return x < value;
    }
};
```

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struct Less_than
{
    int value;

    bool operator()(int x) const
    {
        return x < value;
    }
};
```

```
TEST_CASE("Less_than")
{
    Less_than lt{5};
    CHECK( lt(4) );
    CHECK_FALSE( lt(5) );
}
```

## Counting with a function object

```
struct Less_than
{
    int value;

    bool operator()(int x) const
        { return x < value; }
};

const vector<int> v{ 2, 0, 5, 3, 9, 5, 1 };

CHECK( count_if(v.begin(), v.end(), Less_than{6})
        == 6 );
CHECK( count_if(v.begin(), v.end(), Less_than{5})
        == 4 );
```

## Constructing a function object using `std::bind`

```
using namespace std;
using namespace std::placeholders;

const vector<int> v{ 2, 0, 5, 3, 9, 5, 1 };

CHECK( count_if(v.begin(), v.end(),
               bind(<less<int>(), _1, 6))
       == 6 );
```

## The slickest way: lambda

```
const vector<int> v{ 2, 0, 5, 3, 9, 5, 1 };
```

```
CHECK( count_if(v.begin(), v.end(),  
               [](auto x) { return x < 6; })  
      == 6 );
```



## The slickest way: lambda

```
const vector<int> v{ 2, 0, 5, 3, 9, 5, 1 };
```

```
CHECK( count_if(v.begin(), v.end(),  
               [](auto x) { return x < 6; })  
       == 6 );
```

```
int y = 5;
```

```
CHECK( count_if(v.begin(), v.end(),  
               [&](auto x) { return x < y; })  
       == 4 );
```

## The slickest way: lambda

```
const vector<int> v{ 2, 0, 5, 3, 9, 5, 1 };
```

```
CHECK( count_if(v.begin(), v.end(),  
               [](auto x) { return x < 6; })  
       == 6 );
```

```
int y = 5;
```

```
CHECK( count_if(v.begin(), v.end(),  
               [&](auto x) { return x < y; })  
       == 4 );
```

```
int z = 4;
```

```
CHECK( count_if(v.begin(), v.end(),  
               [=](auto x) { return x < z; })  
       == 4 );
```

– *Fin* –