C++ Programming II

C++ 11 Standard Template Library - STL Algorithms
A Walk-through

C++ Programming II
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Agenda

- **STL Algorithms**
  - Lambda Expression

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  - Lambda Expression
- **Non-Modifying Algorithms**

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- **STL Algorithms**
  - Lambda Expression
- **Non-Modifying Algorithms**
- **Modifying Algorithms**

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- **STL Algorithms**
  - Lambda Expression
- **Non-Modifying Algorithms**
- **Modifying Algorithms**
- **Sort Algorithms**

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- **STL Algorithms**
  - Lambda Expression
- **Non-Modifying Algorithms**
- **Modifying Algorithms**
- **Sort Algorithms**
- **Sorted Data Algorithms**

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- **STL Algorithms**
  - Lambda Expression
- **Non-Modifying Algorithms**
- **Modifying Algorithms**
- **Sort Algorithms**
- **Sorted Data Algorithms**
- **Numerical Algorithms**

STL Algorithms

STL - Algorithms
Intro

- Most people use STL-Containers
- But, most people don't use STL-Algorithms!
- The goal of this walk-through is to give you an overview of the existing algorithms
- Later, you may remember existing implementations in STL when facing a coding problem

STL - Algorithms
Intro

- Most people use STL-Containers
- But, most people don't use STL-Algorithms!
- The goal of this walk-through is to give you an overview of the existing algorithms
- Later, you may remember existing implementations in STL when facing a coding problem
- We'll cover 4 different types of algorithm:
    1. **Non-Modifying** Algorithms
    2. **Modifying** Algorithms
    3. **Sort** Algorithms
    4. **Sorted Data** Algorithms

Lambda Expression / Function

What is a Lambda Function

- During these slides the so called lambda-function are used often
- Lambda Functions are basically functions without a name!
- Lambda functions were introduced in C++ 11 and can help in the usage of STL algorithms, *e.g.* to sort or process data

Lambda Expression / Function

What is a Lambda Function

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```
// C++ 11 Lambda Function: Function without name
num = count_if(vec.begin(), vec.end(),
               [](int x){return x<10;} // lambda expression
);

// same as:
bool lessThan10(int x)
{
    return x<10;
}

num = count_if(vec.begin(), vec.end(),lessThan10);
```

1. `[ ]` - capture clause / lambda introducer: A lambda can introduce new variables in its body (in C++ 14), and it can also access - or capture -variables from the surrounding scope. An empty capture clause, `[]`, indicates that the body of the lambda expression accesses no variables in the enclosing scope.
2. `( )` - parameter list (comma separated parameter list)
3. `{ }` - lambda function body (same as function body)

Lambda Expression

Defining Lambda Functions on the Fly

- Defining Lambda with no parameters, returning integer constants:

```
auto just_one ( [](){ return 1; });
auto just_two ( []  { return 2; }); // () optional

cout << just_one() << ", " << just_two();
```

Lambda Expression

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```

- Defining Lambda with two input parameters, returning an integer

```
auto plus( [](auto l, auto r){ return l + r; });

cout << plus(1, 2) << '\n';
cout << plus(string{"a"}, "b");
```

Lambda Expression

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- Same Lambda, but defined in-place with parameters in `()` just behind

```
cout << [](auto l, auto r){ return l + r; }(1, 2);
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- **What's the output?**

Lambda Expression
Defining Lambda Functions on the Fly

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cout << [](auto l, auto r){ return l + r; }(1, 2);
```

- **What's the output?**

```
1, 2
3
ab
3
```

Lambda Expression

Defining Lambda Functions on the Fly

- Lambda function, carrying a counter initialized to zero with it. In order to modify its own capture, the keyword `mutable` is used:

```
auto counter( [count=0] () mutable { return ++count; });

for (size_t i{0}; i < 5; ++i)
    cout << counter() << ", ";
```

Lambda Expression
Defining Lambda Functions on the Fly

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auto counter( [count=0] () mutable { return ++count; });

for (size_t i{0}; i < 5; ++i)
    cout << counter() << ", ";
```

- or we can capture values by reference. Like this the values are accessible from outside:

```
int a{0};
auto incrementer ( [&a] { ++a; } ); // capture by reference

incrementer();
incrementer();
incrementer();
cout << "Value of 'a' after 3 incrementer() calls: " << a;
```

- **What's the output?**

Lambda Expression

Defining Lambda Functions on the Fly

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```

- **What's the output?**

```
1, 2, 3, 4, 5,
Value of 'a' after 3 incrementer() calls: 3
```

Lambda Expression

All Parameters at Once

```
[capture list] (parameters)
        mutable                 (optional)
        constexpr               (optional)
        exception attr          (optional)
        -> return type          (optional)
{
    body
}
```

- **Capture list**:
  - If we write `[=](){...}`, we capture every variable the closure references from outside by value, *i.e.* that the values are **copied**
  - Writing `[&] () {...}` means that everything the closure references outside is only captured by reference, which does not lead to a copy

Lambda Expression
Capture List Examples

- **Capture list:**
  - `[a, &b] () {...}`: This captures `a` by copy and `b` by reference
  - `[&, a] () {...}`: This captures `a` by copy and any other used variable by reference
  - `[=, &b, i{22}, this] () {...}`: This captures `b` by reference, `this` by copy, initializes a new variable `i` with value 22 , and captures any other used variable by copy
  - If you want to capture **member variables** you have to capture `this`

Lambda Expression
Optional Parameters

- `mutual` (optional):
  - If the function object should be able to modify the variables it captures by copy (`[=]`), it must be defined mutable. This includes calling non-const methods of captured objects

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- `exception attr` (optional):
  - This is the place to specify if the function object can throw exceptions when it's called and runs into an error case.
- `return type` (optional):
  - Allows full control over the return type, we may not want the compiler to deduce it for us automatically. In such a case, we can just write `[] () -> Foo {}` , which tells the compiler that we will really always return the Foo type.

Non-Modifying Algorithms

STL - Algorithms

Non-Modifying Algorithms

- Algorithms not modifying the data
  1. count
  2. min and max
  3. compare
  4. linear search
  5. attribute

STL - Algorithms
Non-Modifying Algorithms

- The following variables are used for the examples:

```
vector<int> vec = {9,60,90,8,45,87,90,69,69,55,7};
vector<int> vec2 = {9,60,70,8,45,87};
vector<int>::iterator itr, itr2;
pair<vector<int>::iterator, vector<int>::iterator> pair_of_itr;
```

STL - Algorithms

Non-Modifying Algorithms

- Counting, min/max

```
vector<int> vec = {9,60,90,8,45,87,90,69,69,55,7};

// 1. Counting
//      Algorithm    Data                    Operation       Result
int n = count(vec.begin()+2, vec.end()-1, 69);      // 2
int m = count_if(vec.begin(), vec.end(),
                 [](int x){return x==69;});          // 2

int m = count_if(vec.begin(), vec.end(),
                 [](int x){return x<10;});           // 3

// 2.  Min and Max
itr = max_element(vec.begin()+2, vec.end());         // 90
// It returns the first max value
itr = max_element(vec.begin(), vec.end(),
                  [](int x, int y){ return (x%10)<(y%10);}); // 9


// Most algorithms have a simple form and a generalized form
// which allow to define own comparison function
itr = min_element(vec.begin(), vec.end());           // 7
// Generalized form: min_element()

pair_of_itr = minmax_element(vec.begin(), vec.end(),  // {60, 69}
                       [](int x, int y){ return (x%10)<(y%10);});
// returns a pair, which contains first of min and last of max
```

STL - Algorithms

Non-Modifying Algorithms

- Linear Searching (used when data is not sorted)

```
vector<int> vec = {9,60,90,8,45,87,90,69,69,55,7};

// Returns the first match
itr = find(vec.begin(), vec.end(), 55);

itr = find_if(vec.begin(), vec.end(), [](int x){ return x>80; });

itr = find_if_not(vec.begin(), vec.end(), [](int x){ return x>80; });

itr = search_n(vec.begin(), vec.end(), 2, 69);  // Consecutive 2 items of 69
// Generalized form: search_n()

// Search subrange
vector<int> sub = {45, 87, 90};
itr = search( vec.begin(), vec.end(), sub.begin(), sub.end());
// search first subrange
itr = find_end( vec.begin(), vec.end(), sub.begin(), sub.end());
// search last subrange
// Generalized form: search(), find_end()
```

STL - Algorithms

Non-Modifying Algorithms

- Linear Searching (used when data is not sorted)

```
vector<int> vec = {9,60,90,8,45,87,90,69,69,55,7};

// Search any_of
vector<int> items  = {87, 69};
itr = find_first_of(vec.begin(), vec.end(),
                    items.begin(), items.end());

// Search any one of the item in items
itr = find_first_of(vec.begin(), vec.end(),
                    items.begin(), items.end(),
                    [](int x, int y) { return x==y*4;});
// Search any one of the item in items that satisfy: x==y*4;

// // find two adjacent items that
itr = adjacent_find(vec.begin(), vec.end());
// are same
itr = adjacent_find(vec.begin(), vec.end(),
                    [](int x, int y){ return x==y*4;});
// find two adjacent items that satisfy: x==y*4;
```

STL - Algorithms

Non-Modifying Algorithms

- Comparing Ranges

```
// 4. Comparing Ranges
if (equal(vec.begin(), vec.end(), vec2.begin()))
{
    cout << "vec and vec2 are same.\n";
}

if (is_permutation(vec.begin(), vec.end(), vec2.begin()))
{
    cout << "vec and vec2 have same items, but reversed.\n";
}

pair_of_itr = mismatch(vec.begin(), vec.end(), vec2.begin());
// find first difference
// pair_of_itr.first is an iterator of vec
// pair_of_itr.second is an iterator of vec2

//Lexicographical Comparison: one-by-one comparison with "less
    than"
lexicographical_compare(vec.begin(), vec.end(),
                        vec2.begin(), vec2.end());
// {1,2,3,5} < {1,2,4,5}
// {1,2}     < {1,2,3}

// Generalized forms:
// equal(), is_permutation(), mismatch(),
    lexicographical_compare()
```

STL - Algorithms
Non-Modifying Algorithms

- Check Attributes

```
is_sorted(vec.begin(), vec.end());  // Check if vec is sorted

itr = is_sorted_until(vec.begin(), vec.end());
// itr points to first place to where elements are no longer sorted
// Generalized forms: is_sorted(), is_sorted_until()

is_partitioned(vec.begin(), vec.end(), [](int x){return x>80;} );
// Check if vec is partitioned according to condition of (x>80)

is_heap(vec.begin(), vec.end());  // Check if vec is a heap
itr = is_heap_until(vec.begin(), vec.end());
// find the first place where it is no longer a heap
// Generalized forms: is_heap(), is_heap_until()
```

STL - Algorithms

Non-Modifying Algorithms

- Check Attributes

```
// All, any, none
all_of(vec.begin(), vec.end(), [](int x) {return x>80} );
// If all of vec is bigger than 80

any_of(vec.begin(), vec.end(), [](int x) {return x>80} );
// If any of vec is bigger than 80

none_of(vec.begin(), vec.end(), [](int x) {return x>80} );
// If none of vec is bigger than 80
```

Modifying Algorithms

STL - Algorithms

Modifying Algorithms I

- Value changing algorithms
  1. copy
  2. move
  3. transform
  4. swap
  5. replace
  6. fill
  7. remove

STL - Algorithms
Modifying Algorithms I

- The following variables are used for the examples:

```
vector<int> vec = {9,60,70,8,45,87,90};      // 7 items
vector<int> vec2 = {0,0,0,0,0,0,0,0,0,0,0}; // 11 items
vector<int>::iterator itr, itr2;
pair<vector<int>::iterator, vector<int>::iterator> pair_of_itr;
```

STL - Algorithms

Modifying Algorithms I

- copy, copy_if, copy_n, copy_backward

```
vector<int> vec = {9,60,70,8,45,87,90};      // 7 items
vector<int> vec2 = {0,0,0,0,0,0,0,0,0,0,0}; // 11 items

// Copy
copy(vec.begin(), vec.end(), // Source
     vec2.begin());          // Destination

copy_if(vec.begin(), vec.end(),        // Source
        vec2.begin(),                  // Destination
        [](int x){ return x>80;});     // Condition
// vec2: {87, 90, 0, 0, 0, 0, 0, 0, 0, 0, 0}

copy_n(vec.begin(),  4, vec2.begin());
// vec2: {9, 60, 70, 8, 0, 0, 0, 0, 0, 0, 0}

copy_backward(vec.begin(),  vec.end(),   // Source
              vec2.end());               // Destination
// vec2: {0, 0, 0, 0, 9, 60, 70, 8, 45, 87, 90}
```

STL - Algorithms
Modifying Algorithms I

- move, move_backward

```
// Move
vector<string> vec = {"apple","orange","pear","grape"};// 4 items
vector<string> vec2 = {"", "", "", "", "", ""};       // 6 items

move(vec.begin(), vec.end(), vec2.begin());
// vec:  {"", "", "", ""}  // Undefined
// vec2: {"apple", "orange", "pear", "grape", "", ""};
//
// If move semantics are defined for the element type, elements
// are moved over, otherwise they are copied over with copy
// constructor, just like copy().

move_backward(vec.begin(), vec.end(), vec2.end());
// vec2: {"", "", "apple", "orange", "pear", "grape"};
```

STL - Algorithms

Modifying Algorithms I

- transform, swap

```
// Transform
transform(vec.begin(), vec.end(),      // Source
          vec3.begin(),                // Destination
          [](int x){ return x-1;});    // Operation

transform(vec.begin(), vec.end(),              // Source #1
          vec2.begin(),                        // Source #2
          vec3.begin(),                        // Destination
          [](int x, int y){ return x+y;});     // Operation

// Add items from vec and vec2 and save in vec3
// vec3[0] = vec[0] + vec2[0]
// vec3[1] = vec[1] + vec2[1]
// ...

// Swap - two way copying
swap_ranges(vec.begin(), vec.end(), vec2.begin());
```

STL - Algorithms
Modifying Algorithms I

- `fill`

```
// Fill
vector<int> vec = {0, 0, 0, 0, 0};

fill(vec.begin(), vec.end(), 9); // vec: {9, 9, 9, 9, 9}

fill_n(vec.begin(), 3, 9);       // vec: {9, 9, 9, 0, 0}

generate(vec.begin(), vec.end(), rand);

generate_n(vec.begin(), 3, rand);
```

STL - Algorithms
Modifying Algorithms I

- `replace`

```cpp
// 6. Replace
replace(vec.begin(), vec.end(),   // Data Range
        6,                        // Old value condi
        9);                       // new value

replace_if(vec.begin(), vec.end(),      // Data Range
           [](int x){return x>80;},     // Old value condition
           9);                          // new value

replace_copy(vec.begin(), vec.end(),   // Source
             vec2.begin(),               // Destination
             6,                          // Old value condition
             9);                         // new value
// Generalized form: replace_copy_if()
```

STL - Algorithms

Modifying Algorithms I

- `remove`, `remove_if`, `remove_copy`, `unique`, `unique_copy`

```
// Remove
remove(vec.begin(), vec.end(), 3);    // Remove all 3's
remove_if(vec.begin(), vec.end(), [](int x){return x>80;});
// Remove items bigger than 80

remove_copy(vec.begin(), vec.end(),   // Source
            vec2.begin(),             // Destination
            6);                       // Condition
// Remove all 6's, and copy the remain items to vec2
// Generalized form: remove_copy_if()

unique(vec.begin(), vec.end()); // Remove consecutive equal elems

unique(vec.begin(), vec.end(), less<int>());
// Remove elements whose previous element is less than itself

unique_copy(vec.begin(), vec.end(), vec2.begin());
// Remove consecutive equal elements, and then copy the
// items to vec2
// Generalized form: unique_copy()
```

STL - Algorithms
Modifying Algorithms II

- Order changing algorithms
  1. reverse
  2. rotate
  3. permute
  4. shuffle

STL - Algorithms
Modifying Algorithms II

- The following variables are used for the examples:

```
vector<int> vec =  {9,60,70,8,45,87,90};      // 7 items
vector<int> vec2 = {0,0,0,0,0,0,0};           // 7 items
```

STL - Algorithms

Modifying Algorithms II

- reverse, reverse_copy, rotate, copy_backward

```
vector<int> vec =  {9,60,70,8,45,87,90};      // 7 items
vector<int> vec2 = {0,0,0,0,0,0,0};           // 7 items

// Reverse
reverse(vec.begin()+1, vec.end()-1);
// vec: {9,87,45,8,70,60,90};     // 7 items

reverse_copy(vec.begin()+1, vec.end()-1, vec2.begin());
// vec2: {87,45,8,70,60,0,0};

// Rotate
rotate(vec.begin(), vec.begin()+3, vec.end());
// vec: {8,45,87,90,9,60,70};     // 7 items

rotate_copy(vec.begin(), vec.begin()+3, vec.end(), // Source
            vec2.begin());                          // Destination
// Copy vec to vec2 in rotated order
// vec is unchanged
```

STL - Algorithms
Modifying Algorithms II

- `permute`

```
vector<int> vec =  {9,60,70,8,45,87,90};     // 7 items
vector<int> vec2 = {0,0,0,0,0,0,0};          // 7 items

next_permutation(vec.begin(), vec.end());
// Lexicographically next greater permutation
prev_permutation(vec.begin(), vec.end());
// Lexicographically next smaller permutation
// Exmaple with 1, 2 and 3
// 3 2 1
// 3 1 2
// 2 3 1
// 2 1 3
// 1 3 2
// 1 2 3
```

STL - Algorithms
Modifying Algorithms II

- shuffle

```cpp
// Shuffle
// Rearrange the elements randomly
// (swap each element with a randomly selected element)
random_shuffle(vec.begin(), vec.end());
random_shuffle(vec.begin(), vec.end(), rand);

// C++ 11
shuffle(vec.begin(), vec.end(), default_random_engine());
// Better random number generation
```

Sort Algorithms

STL - Algorithms
Modifying Algorithms II

- Sorting algorithms requires random access iterators!
- Sorting is limited to:
  `vector`, `deque`, `container array`, `native array`
- Sorting algorithms
  1. sort, partial_sort
  2. nth_element
  3. partition, stable_partition

STL - Algorithms
Modifying Algorithms II

- sort

```
vector<int> vec = {9,1,10,2,45,3,90,4,9,5,8};

sort(vec.begin(), vec.end());  // sort with operator <
// vec:  1 2 3 4 5 8 9 9 10 45 90



bool lsb_less(int x, int y) {
    return (x%10)<(y%10);
}
sort(vec.begin(), vec.end(), lsb_less);  // sort with lsb_less()
// vec: 10 90 1 2 3 4 45 5 8 9 9
```

STL - Algorithms

Modifying Algorithms II

- `partial_sort`

```
// Sometime we don't need complete sorting.

// Problem #1:
// Finding top 5 students according to their test scores.
//  -  partial sort
vector<int> vec = {9,60,70,8,45,87,90,69,69,55,7};

partial_sort(vec.begin(), vec.begin()+5, vec.end(),
     greater<int>());
// vec: 90 87 70 69 69 8 9 45 60 55 7

// Overloaded:
partial_sort(vec.begin(), vec.begin()+5, vec.end());
// vec: 7 8 9 45 55 90 60 87 70 69 69
```

STL - Algorithms

Modifying Algorithms II

- `nth_element`

```
// Problem #2:
// Finding top 5 students according to their score, but order is
// not important

vector<int> vec = {9,60,70,8,45,87,90,69,69,55,7};

nth_element(vec.begin(), vec.begin()+5, vec.end(),
     greater<int>());
// vec: 69 87 70 90 69 60 55 45 9 8 7
```

STL - Algorithms
Modifying Algorithms II

- `partition`, `stable_partition`

```
// Problem #3:
// Move the students whose score is less than 10 to the front
vector<int> vec = {9,60,70,8,45,87,90,69,69,55,7};

bool lessThan10(int i) {
    return (i<10);
}
partition(vec.begin(), vec.end(), lessThan10);
// vec: 8 7 9 90 69 60 55 45 70 87 69

// To preserve the original order within each partition:
stable_partition(vec.begin(), vec.end(), lessThan10);
// vec: 9 8 7 60 70 45 87 90 69 69 55
```

Sorted Data Algorithms

STL - Algorithms
Sorted Data Algorithms

- Algorithms that require data being pre-sorted
- Algorithms
  1. binary_search
  2. merge
  3. set operations

STL - Algorithms
Sorted Data Algorithms

- binary_search, includes, lower_bound, upper_bound, equal_range

```
vector<int> vec = {8,9,9,9,45,87,90};       // 7 items

// Binary Search

// Search Elements
bool found = binary_search(vec.begin(), vec.end(), 9);
// check if 9 is in vec

vector<int> s = {9, 45, 66};
bool found = includes(vec.begin(), vec.end(),      // Range #1
                      s.begin(), s.end());         // Range #2

// Return true if all elements of s is included in vec
// Both vec and s must be sorted

// Search Position
itr = lower_bound(vec.begin(), vec.end(), 9);  // vec[1]
// Find the first position where 9 could be inserted and
// keep the sorting.

itr = upper_bound(vec.begin(), vec.end(), 9);  // vec[4]
// Find the last position where 9 could be inserted and
// keep the sorting.

pair_of_itr = equal_range(vec.begin(), vec.end(), 9);
// Returns both first and last position
```

STL - Algorithms

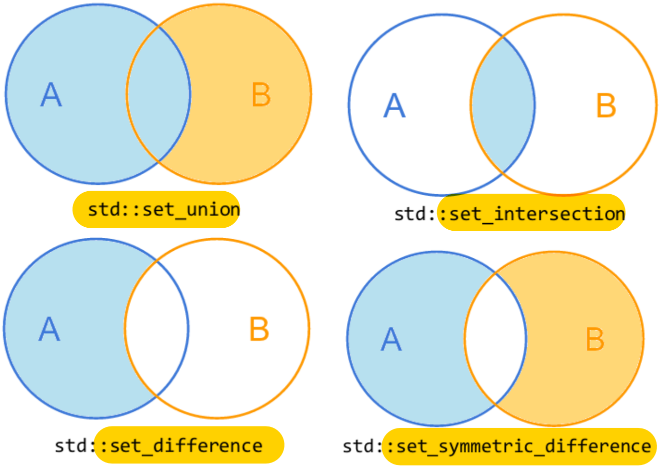
Sorted Data Algorithms

- merge, inplace_merge

```cpp
// Merge
vector<int> vec = {8,9,9,10};
vector<int> vec2 = {7,9,10};

merge(vec.begin(), vec.end(),        // Input Range #1
      vec2.begin(), vec2.end(),      // input Range #2
      vec_out.begin());              // Output

// Both vec and vec2 should be sorted (same for the set operation)
// Nothing is dropped, all duplicates are kept.
// vec_out: {7,8,9,9,9,10,10}

// Both parts of vec are already sorted, i.e. 0-3, 4-8 are two
// sorted groups of data in vec
vector<int> vec = {1,2,3,4,1,2,3,4,5};
inplace_merge(vec.begin(), vec.begin()+4, vec.end());
// vec: {1,1,2,2,3,3,4,4,5}  - One step of merge sort
```

STL - Algorithms
Sorted Data Algorithms

- Algorithms on set



STL - Algorithms

Sorted Data Algorithms

- set_union, set_intersection

```
// Set operations
// – Both vec and vec3 should be sorted
// – The resulted data is also sorted
vector<int> vec = {8,9,9,10};
vector<int> vec2 = {7,9,10};
vector<int> vec_out[5];
set_union(vec.begin(), vec.end(),                // Input Range #1
          vec2.begin(), vec2.end(),              // input Range #2
          vec_out.begin());                      // Output
// if X is in both vec and vec2, only one X is kept in vec_out
// vec_out: {7,8,9,9,10}

set_intersection(vec.begin(), vec.end(),         // Input Range #1
                 vec2.begin(), vec2.end(),       // input Range #2
                 vec_out.begin());               // Output
// Only the items that are in both vec and vec2 are saved
// in vec_out
// vec_out: {9,10,0,0,0}
```

STL - Algorithms
Sorted Data Algorithms

- set_difference, set_symmetric_difference

```
vector<int> vec = {8,9,9,10};
vector<int> vec2 = {7,9,10};
vector<int> vec_out[5];
set_difference(vec.begin(), vec.end(),              // In Range #1
               vec2.begin(), vec2.end(),            // In Range #2
               vec_out.begin());                    // Output
// Only the items that are in vec but not in vec2 are saved
// in vec_out
// vec_out: {8,9,0,0,0}

set_symmetric_difference(vec.begin(), vec.end(),   // In Range #1
                         vec2.begin(), vec2.end(),// In Range #2
                         vec_out.begin());         // Output
// vec_out has items from either vec or vec2, but not from both
// vec_out: {7,8,9,0,0}
```

Numerical Algorithms

STL - Algorithms
Numerical Algorithms

- Numerical Algorithms are in `<numeric>`
- Algorithms
  1. Accumulate
  2. Inner product
  3. Partial sum
  4. Adjacent difference

STL - Algorithms
Numerical Algorithms

- `accumulate`

```
// Accumulate

int x = accumulate(vec.begin(), vec.end(), 10);
// 10 + vec[0] + vec[1] + vec[2] + ...
// 10 is initial value

x = accumulate(vec.begin(), vec.end(), 10, multiplies<int>());
// 10 * vec[0] * vec[1] * vec[2] * ...
```

STL - Algorithms
Numerical Algorithms

- `inner_product`

```
// Inner Product

vector<int> vec = {9,60,70,8,45,87,90};          // 7 items

int x = inner_product(vec.begin(), vec.begin()+3,   // Range #1
                      vec.end()-3,                  // Range #2
                      10);                          // Init Value
// 10 + vec[0]*vec[4] + vec[2]*vec[5] + vec[3]*vec[6]

int x = inner_product(vec.begin(), vec.begin()+3,   // Range #1
                      vec.end()-3,                  // Range #2
                      10,                           // Init Value
                      multiplies<int>(),
                      plus<int>());
// 10 * (vec[0]+vec[4]) * (vec[2]+vec[5]) * (vec[3]+vec[6])
```

STL - Algorithms
Numerical Algorithms

- `partial_sum`, `adjacent_difference`

```
// Partial Sum
partial_sum(vec.begin(), vec.end(), vec2.begin());
// vec2[0] = vec[0]
// vec2[1] = vec[0] + vec[1];
// vec2[2] = vec[0] + vec[1] + vec[2];
// vec2[3] = vec[0] + vec[1] + vec[2] + vec[3];
// ...

partial_sum(vec.begin(), vec.end(),
            vec2.begin(), multiplies<int>());


// Adjacent Difference
adjacent_difference(vec.begin(), vec.end(), vec2.begin());
// vec2[0] = vec[0]
// vec2[1] = vec[1] - vec[0];
// vec2[2] = vec[2] - vec[1];
// vec2[3] = vec[3] - vec[2];
// ...

adjacent_difference(vec.begin(), vec.end(),
                    vec2.begin(), plus<int>());
```

Thank You

Questions

???