The Standard C++ Library – Iterators and Algorithms

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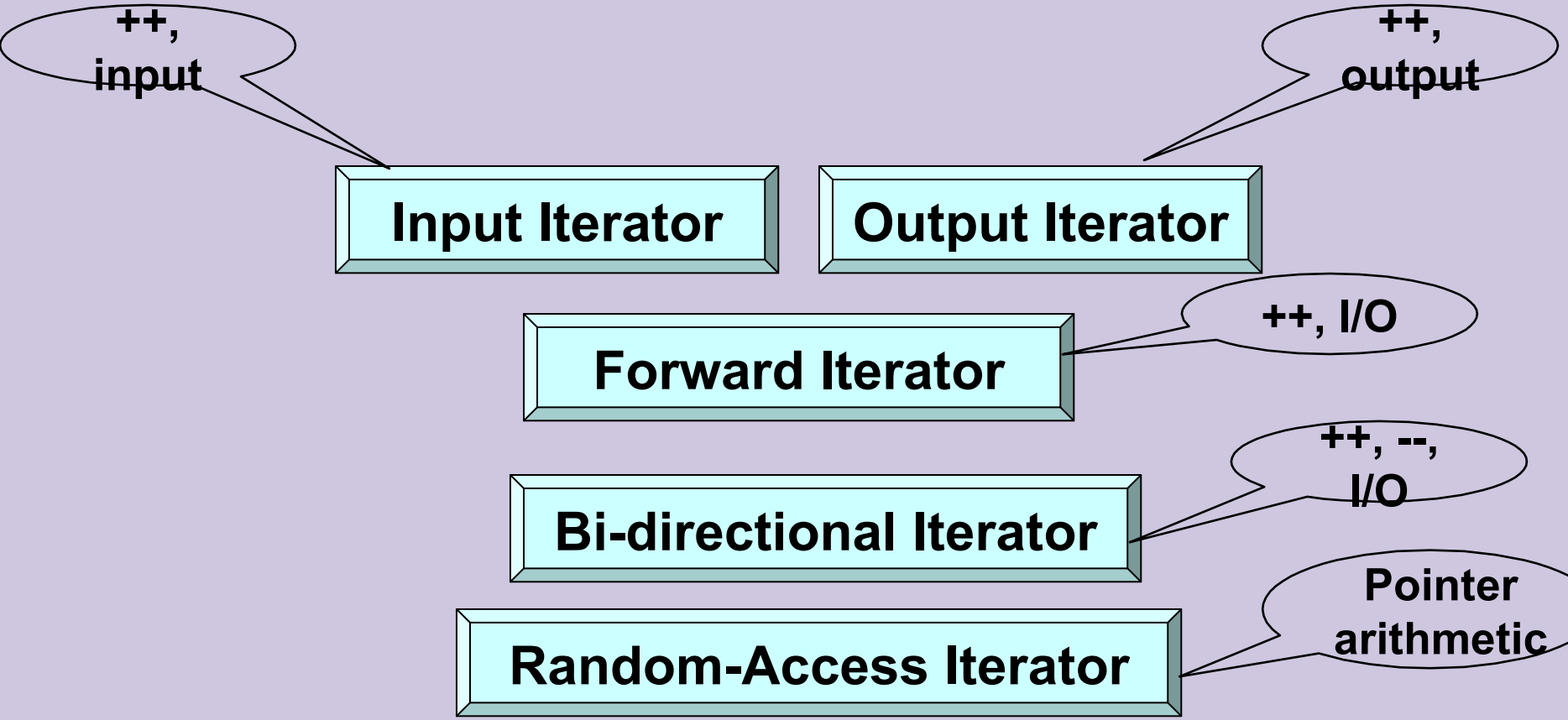
Iterators


++, input
++, output
Input Iterator
Output Iterator
Forward Iterator
++, I/O
Bi-directional Iterator
++, --, I/O
Random-Access Iterator
Pointer arithmetic

Iterator Types

	Output	Input	Forward	Bi-directional	Random
Read		`x = *i`	`x = *i`	`x = *i`	`x = *i`
Write	`*i = x`		`*i = x`	`*i = x`	`*i = x`
Iteration	`++`	`++`	`++`	`++, --`	`++, --, +, -, +=, -=`
Comparison		`==, !=`	`==, !=`	`==, !=`	`==, !=, <, >, <=, >=`

- Output: write only and can write only once
- Input: read many times each item
- Forward supports both read and write
- Bi-directional support also decrement
- Random supports random access

(just like C pointer)

Iterators & Containers

Input/output/forward iterators:

- iostreams (folder 3)

Bidirectional iterators:

- list, map, set

Random access iterators:

- vector

Iterators & Containers

```
class NameOfContainer {
   …
   typedef … iterator; // iterator type
   iterator begin();      // first element
   iterator end();        // element after last
```

```
NameOfContainer<...> c

…

NameOfContainer<...>::iterator it;

for( it= c.begin(); it!=c.end(); ++it)

      // do something that changes *it
```

Iterators & Containers: c++11

```
class NameOfContainer {
   …
   typedef … iterator; // iterator type
   iterator begin();      // first element
   iterator end();        // element after last
```

```
NameOfContainer<...> c

…


for(auto it= c.begin(); it!=c.end(); ++it)
      // do something that changes *it
```

Iterators & Containers: c++11

```
class NameOfContainer {
   …
   typedef … iterator; // iterator type
   iterator begin();      // first element
   iterator end();        // element after last
```

```
NameOfContainer<...> c

…


for(auto& val : c)
      // do something that changes val
```

const_iterators & Containers

```
class NameOfContainer {
   …
typedef … const_iterator; // iterator type
const_iterator begin() const;      // first element
const_iterator end() const;        // element after last
```

```
NameOfContainer<...> c

…

NameOfContainer<...>::const_iterator it;

for( it= c.begin(); it!=c.end(); ++it)

      // do something that does not change *it
```

const_iterators & Containers: c++11

```
class NameOfContainer {
   …
typedef … const_iterator; // iterator type
const_iterator cbegin() const;      // first element
const_iterator cend() const;        // element after last
```

```
NameOfContainer<...> c

…


for(auto it= c.cbegin(); it!=c.cend(); ++it)
      // do something that does not change *it
```

const_iterators & Containers: c++11

```
class NameOfContainer {
   …
typedef … const_iterator; // iterator type
const_iterator cbegin() const;      // first element
const_iterator cend() const;        // element after last
```

```
NameOfContainer<...> c

…


for(const auto& val : c)
      // do something that does not change val
```

const_iterators & Containers

```
...
const_iterator cbegin() const;
const_iterator cend() const;
const_iterator begin() const;
const_iterator end() const;
```

```
...

iterator begin();
iterator end();
```

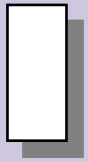
Note that the begin() and end() methods that return regular iterator are not **const** methods. i.e: if we get a container by const (const ref, ...) we can't use these methods. We have to use the methods that return **const_iterator**

[end of first week]

IntBufferSwap example revisited

- See folder 4.
- Focus on iterator and const_iterator.

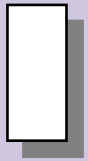
Iterators & Sequence Containers



```
SeqContainerName<...> c;
SeqContainerName<...>::iterator i,j;
```

- `c.insert(i,x)` – inserts `x` before `i`
- `c.insert(i,first,last)`
  – inserts elements in `[first,last)` before `i`
- `c.erase(i)` – erases the element that `i` points to
- `c.erase(i,j)`
  – erase elements in range `[i,j)`

Iterators & Sequence Containers c++11



```
SeqContainerName<...> c;
SeqContainerName<...>::iterator i,j;
```

- `c.emplace(i,p1,...,pn)`:

Constructs and inserts before `i` an object with a constructor that gets `p1,...,pn` parameters

Iterators & other Containers

- insert and erase has the same ideas, except they keep the invariants of the specific container.
- For example, a Sorted Associative Container will remain sorted after insertions and erases.

Iterators & other Containers

- So what does `c.insert(pos,x)` does, when c is a Unique Sorted Associative Container ?

- Inserts x into the set, using **pos** as a **hint** to where it will be inserted.

Iterators & other Containers: c++11

- So what does `c.emplace_hint(pos,x)` does, when c is a Unique Sorted Associative Container?

- Constructs and Inserts x into the set, using **pos** as a **hint** to where it will be inserted.

Iterator validity

- When working with iterators, we have to remember that their validity can change

What is wrong with this code?

```
Container<...> c;
...
for(auto i= c.begin(); i!=c.end(); ++i )
    if( f( *i ) ) { // some test
      c.erase(i);
    }
```

Iterator validity

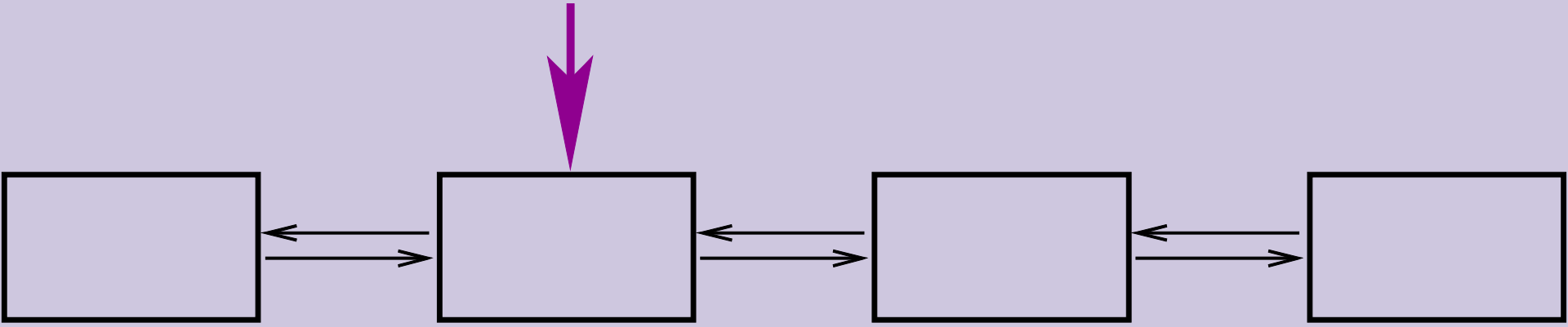
Two cases:

- list, set, map
  - `i` is not a legal iterator

Iterator validity

Two cases:

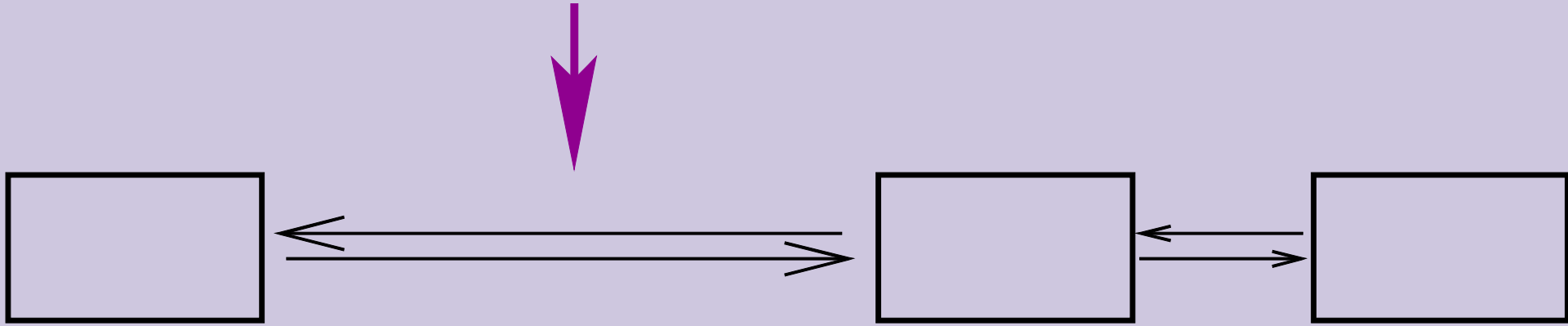
- **list**, set, map
  - `i` is not a legal iterator



Iterator validity

Two cases:

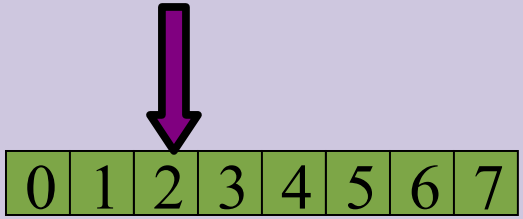
- **list**, set, map
  - `i` is not a legal iterator



Iterator validity

Two cases:

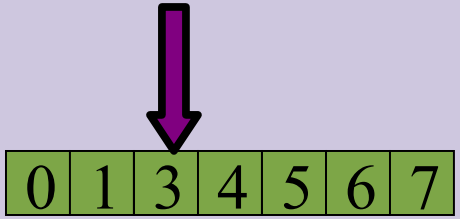
- list, set, map
  - `i` is not a legal iterator
- **vector**
  - `i` points to the element after



Iterator validity

Two cases:

- list, set, map
  - `i` is not a legal iterator
- **vector**
  - `i` points to the element after



Iterator validity

Two cases:

- list, set, map
  - `i` is not a legal iterator
- **vector**
  - `i` points to the element after

In either case,

this is not what we want…

Erasing during iteration (folder 5)

```
Container<...> c;
...
for(auto i= c.begin(); i!=c.end();/*no ++i*/ )
  if( f( *i ) ) { // some test
    i = c.erase(i);
  } else {
    ++i;
  }
```

Iterators & Map

Suppose we work with:

```
map<string,int> dictionary;
map<string,int>::iterator it;
…
it = dictionary.begin();
```

What is the type of `*it` ?

Iterators & Map

Every STL container type Container defines

`Container::value_type`

Type of elements stored in container

- This is the type returned by an iterator

```
Container::value_type operator*();
```

Iterators & Map

- Ok, so what type of elements does a map return?

- `map<KeyType,ValueType>` keeps pairs
  - `KeyType key` – "key" of entry
  - `ValueType value` – "value" of entry

Pairs

```
template< typename T1, typename T2>
struct pair {
  typedef T1 first_type;
  typedef T2 second_type;

  T1 first;
  T2 second;

  pair( const T1& x, const T2& y )
     : first(x), second(y)
  {}
};
```

Map value_type

```
template< typename Key, typename T,
          typename Cmp = less<Key> >
class map {
public:
  typedef pair<const Key, T> value_type;

  typedef Key key_type;
  typedef T mapped_type;
  typedef Cmp key_compare;
};
```

Using map iterator

```
map<string,int> dict;
…

for( auto i = dict.cbegin();
     i != dict.cend();
     ++i )
{
   cout << i->first << " "
        << i->second << "\n";
}
```

Using map iterator

```
  map<string,int> dict;
  …

  for( const auto& val : dict) {
     cout << val.first << " "
          << val.second << "\n";
}
```

Iterators and Assoc. Containers (folder 6)

Additional set of operations:

- **`iterator C::find(key_type const& key)`**

Return iterator to first element with **`key`**.

Return **`end()`** if not found

- **`iterator C::lower_bound(key_type const& key)`**

Return iterator to first element greater or equal to **`key`**

- **`iterator C::upper_bound(key_type const& key)`**

Return iterator to first element greater than **`key`**

Adaptors

- Good functionality, wrong interface
- For example, adaptors of basic containers

with limited interface:

stack<T,SequentialContainer>

queue<T,SequentialContainer>

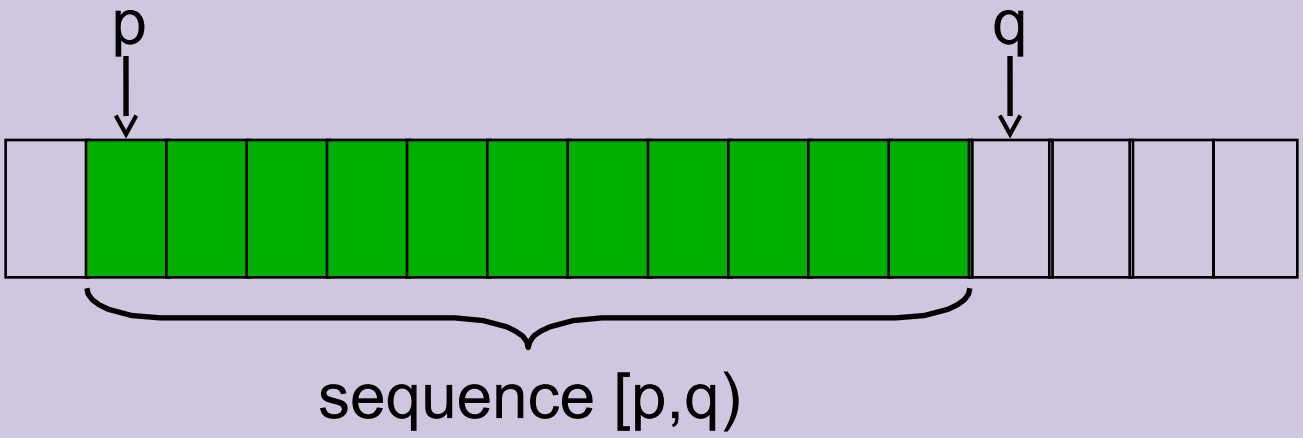
stack<T,SequentialContainer>

- provides `emplace, push, pop, top, size, empty,...`
- Notice that unlike java, `pop` , is not returning a value. i.e: it's a void function.
- The reason (historic with c++-11?):

  to make pop return a value it would be either inefficient or wrong: http://www.sgi.com/tech/stl/stack.html#3

Algorithms

- Most STL algorithms works on sequences
- Sequences are passed as two iterators:
  - beginning element
  - element one after last



- Algorithms depend on iterator type

  not on container type

Example – merge documentation

copy

```
template< typename In, typename Out>
Out copy(In first, In last, Out res)
{
  while (first != last)
    *res++ = *first++;
  return res;
}
```

copy

```
template< typename In, typename Out>
Out copy(In first, In last, Out res)
{
  while (first != last)
    *res++ = *first++;
  return res;
}
```

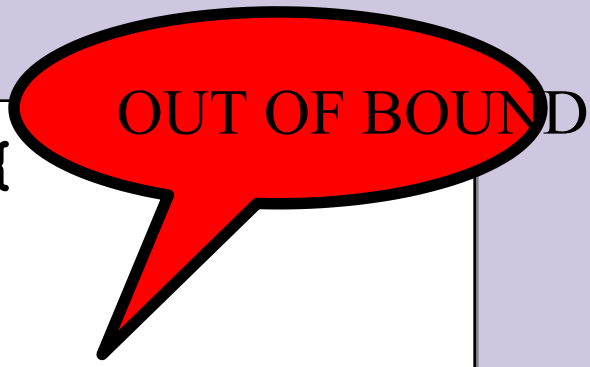
What's wrong with this ?

```
void foo(const vector<char>& v) {
   vector<char> v2;
   ...
   copy(v.begin(),v.end(), v2.begin());
```

copy

```
template< typename In, typename Out>
Out copy(In first, In last, Out res)
{
  while (first != last)
    *res++ = *first++;
  return res;
}
```

What's wrong with this ?




```
void foo(const vector<char>& v) {
   vector<char> v2;
   ...
   copy(v.begin(),v.end(), v2.begin());
```

So how can we copy and insert ?

Solution #1: Use insert explicitly

```
void foo(const vector<char>& v) {
   vector<char> v2;
   ...
   v2.insert(v2.end(),v.begin(),v.end());
```

So how can we copy and insert ?

Solution #2: Use back_inserter, which returns an iterator that knows to “push_back”. See folder 6.

```
void foo(const vector<char>& v) {
   vector<char> v2;
   ...
   copy(v.begin(),v.end(), back_inserter(v2));
```

sort – using operator <

```
template <class RandomAccessIterator>
void sort(RandomAccessIterator first,
          RandomAccessIterator last);
```

Example usage(the hard way):

```
sort< vector<int>::iterator >
                    (vec.begin(), vec.end());
```

sort – using operator <

```
template <class RandomAccessIterator>
void sort(RandomAccessIterator first,
          RandomAccessIterator last);
```

Example usage:

```
sort(vec.begin(), vec.end());
```

sort – using operator <

```
template <class RandomAccessIterator>
void sort(RandomAccessIterator first,
          RandomAccessIterator last);
```

Example usage with primitive arrays:

```
int arr[5];
...
sort(arr, arr+5);
```

sort – using operator <

```
template <class RandomAccessIterator>
void sort(RandomAccessIterator first,
          RandomAccessIterator last);
```

Example usage with primitive arrays (C++11):

```
int arr[5];
...
sort(begin(arr), end(arr));
```

sort – using comparator

```
template <class RandomAccessIterator,
          class StrictWeakOrdering>
void sort(RandomAccessIterator first,
          RandomAccessIterator last,
          StrictWeakOrdering comp);
```

Example usage:

```
sort(vec.begin(), vec.end(), greater<int>());
```

sort – compile error

```
list<int> l(nums, nums+SIZE);
sort(l.begin(), l.end());
```

sort – compile error

```
list<int> l(nums, nums+SIZE);
sort(l.begin(), l.end());
```

list iterators are bidirectional and not random a

g++

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h: In function ‘void std::sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator = std::_List_iterator<int>]’:

Main.cpp:17: instantiated from here

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h:2713: error: no match for ‘operator-’ in ‘__last - __first’

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_bvector.h:182: note: candidates are: ptrdiff_t std::operator-(const std::_Bit_iterator_base&, const std::_Bit_iterator_base&)

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h: In function ‘void std::__final_insertion_sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator = std::_List_iterator<int>]’:

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h:2714: instantiated from ‘void std::sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator = std::_List_iterator<int>]’

Main.cpp:17: instantiated from here

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h:2357: error: no match for ‘operator-’ in ‘__last - __first’

. . .

g++

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h: In function ‘void std::sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator = std::_List_iterator<int>]’:

Main.cpp:17: instantiated from here

/usr/lib/gcc/i486-linux-g... 3: error: no match for ‘operator-’ in ‘__last

/usr/lib/gcc/i486-linux-g... 82: note: candidates are: ptrdiff_t std::operato... ator_base&)

/usr/lib/gcc/i486-linux-g... unction ‘void std::__final_insertior... ator) [with _RandomAccessIter...

???

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h:2714: instantiated from ‘void std::sort(_RandomAccessIterator, _RandomAccessIterator) [with _RandomAccessIterator = std::_List_iterator<int>]’

Main.cpp:17: instantiated from here

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h:2357: error: no match for ‘operator-’ in ‘__last - __first’

. . .

g++

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h: In function ‘void std::sort(_RandomAccessIterator, _RandomAccessIterator) [with **_RandomAccessIterator = std::_List_iterator<int>**]’:

Main.cpp:17: instantiated from here

/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h:2713: error: no match for ‘operator-’ in ‘__last - __first’

...

g++ -D_GLIBCXX_CONCEPT_CHECKS and STLFilt

```
BD Software STL Message Decryptor v2.47a for gcc
stl_algo.h: In function ‘void sort(_List_iterator<int>,
_List_iterator<
          int>)’:
Main.cpp:17:   instantiated from here
stl_algo.h:2713: error: no match for ‘operator-’ in ‘__last - __first’
stl_algo.h: In function ‘void __final_insertion_sort(
       _List_iterator<int>, _List_iterator<int>)’:
stl_algo.h:2714:   instantiated from ‘void sort(
       _List_iterator<int>, _List_iterator<int>)’
Main.cpp:17:   instantiated from here
```

• • •

g++ -D_GLIBCXX_CONCEPT_CHECKS and STLFilt

…
Main.cpp:17: instantiated from here
boost_concept_check.h:223: error: **conversion from ‘**
bidirectional_iterator_tag’ to non-scalar type ‘
random_access_iterator_tag’ requested

Cryptic error messages

STLFilt:

An STL Error Message Decryptor for C++:

http://www.bdsoft.com/tools/stlfilt.html

Cryptic error messages

Different compilers:

- clang++ (free)
- intel c++ (not free)

Strings

What is a string ?

- a typedef for basic_string<char>
- The basic_string class represents a Sequence of characters.
- It contains:
  - all the usual operations of a Sequence.
  - standard string operations such as search and concatenation.

How to convert something to a string?

- c++11: to_string for primitives

- Using std::ostringstream
- We can encapsulate the string conversion and format into stringify functions – **stringify example**

More?

- Lots of other features, especially in c++11 (threads,…)

- Other libraries:
  - Boost
  - opencv, dlib, armadillo, zlib, …