

# **The Standard C++ Library – Iterators and Algorithms**

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# *Iterators*

**++,  
input**

**Input Iterator**

**++,  
output**

**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		<code>x = *i</code>	<code>x = *i</code>	<code>x = *i</code>	<code>x = *i</code>
Write	<code>*i = x</code>		<code>*i = x</code>	<code>*i = x</code>	<code>*i = x</code>
Iteration	<code>++</code>	<code>++</code>	<code>++</code>	<code>++</code> , <code>--</code>	<code>++</code> , <code>--</code> , <code>+</code> , <code>-</code> , <code>+=</code> , <code>-=</code>
Comparison		<code>==</code> , <code>!=</code>	<code>==</code> , <code>!=</code>	<code>==</code> , <code>!=</code>	<code>==</code> , <code>!=</code> , <code>&lt;</code> , <code>&gt;</code> , <code>&lt;=</code> , <code>&gt;=</code>

- 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();
```

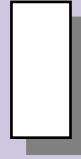
Note that the `begin()` and `end()` methods that return regular iterator are not **const** methods. i.e: if we get a container by `const` (`const ref`, ...) we can't use these methods. We have to use the methods that return **const\_iterator**

*[end of first week?]*

# IntBufferSwap example revisited

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

# Iterators & Sequence Containers

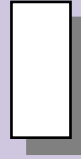


```
SeqContainerName<...> c;
```

```
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

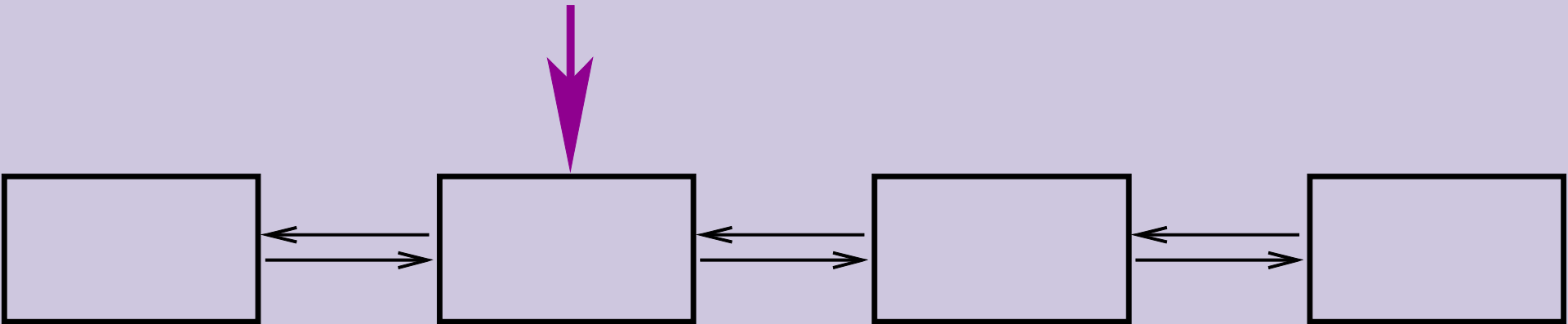
Two cases:

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

# Iterator validity

Two cases:

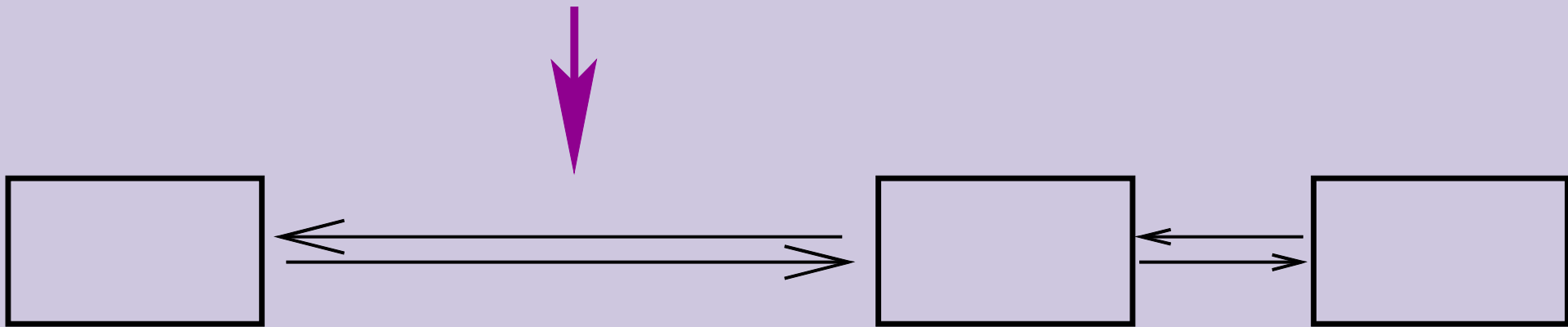
- **list**, set, map
  - `i` is not a legal iterator



# Iterator validity

Two cases:

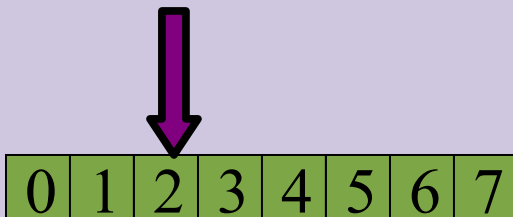
- **list**, set, map
  - `i` is not a legal iterator



# Iterator validity

Two cases:

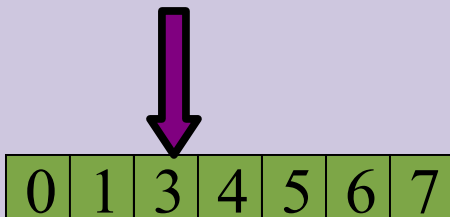
- list, set, map
  - $i$  is not a legal iterator
- **vector**
  - $i$  points to the element after



# 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>

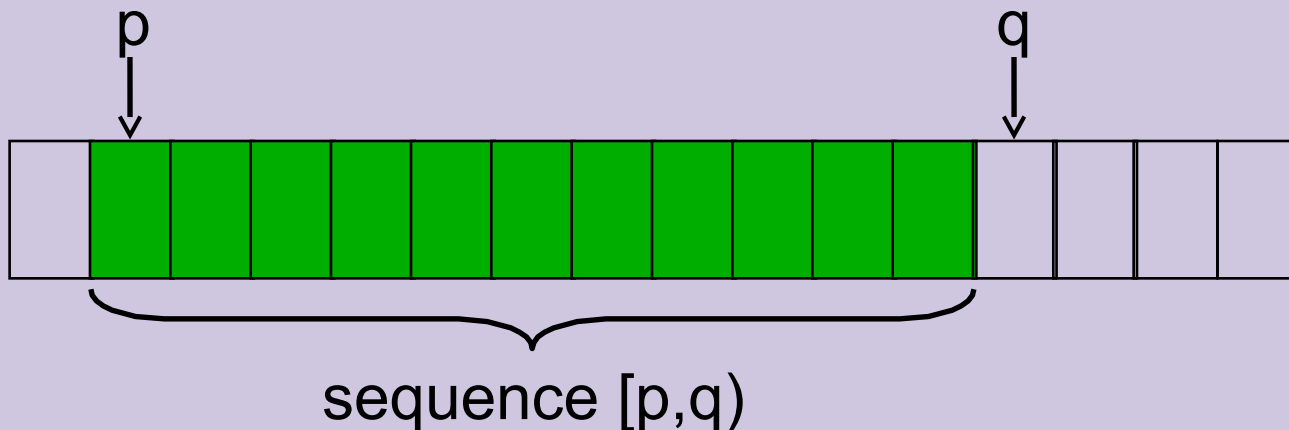
**queue**<T, SequentialContainer>

# **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 work 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());
}
```



OUT OF BOUND



# 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

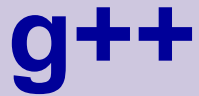
```
list<int> l(nums, nums+SIZE);  
sort(l.begin(), l.end());
```



## sort – compile error

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

list iterators are bidirectional and not random access



```
/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-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h:2713: error: no match for  
'operator-' in '___last
```

```
/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h:2713: error: no match for  
ptrdiff_t std::operator
```

```
/usr/lib/gcc/i486-linux-gnu/4.1.2/../../../../include/c++/4.1.2/bits/stl_algo.h:2713: error: no match for  
std::__final_insertion  
_RandomAccessIter
```

???

```
82: note: candidates are:  
ator_base&)
```

```
unction 'void  
ator) [with
```

```
/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 STL Filt

...

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.

# Rope: non standard!

- Scalable string implementation.
- Efficient operation that involve the string as a whole.
- A rope is a reasonable representation for very long strings such as edit buffers or mail messages.

# Rope: non standard!

- Scalable string implementation.
- Efficient operation that involve the string as a whole.
- A rope is a reasonable representation for very long strings such as edit buffers or mail messages.

# 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, ...