

The Standard C++ Library

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Concepts

- A concept is a list of requirements on a type.
- STL defines a hierarchy of concepts for containers, iterators, and element types.
- Concepts for element types include:

Equality Comparable -
types with operator== ,...

LessThan Comparable -
types with operator< ,...

Assignable -
types with operator=
and copy Ctor

- Currently, concepts appear in documentation only.
- Maybe in C++20 they will be part of the code.

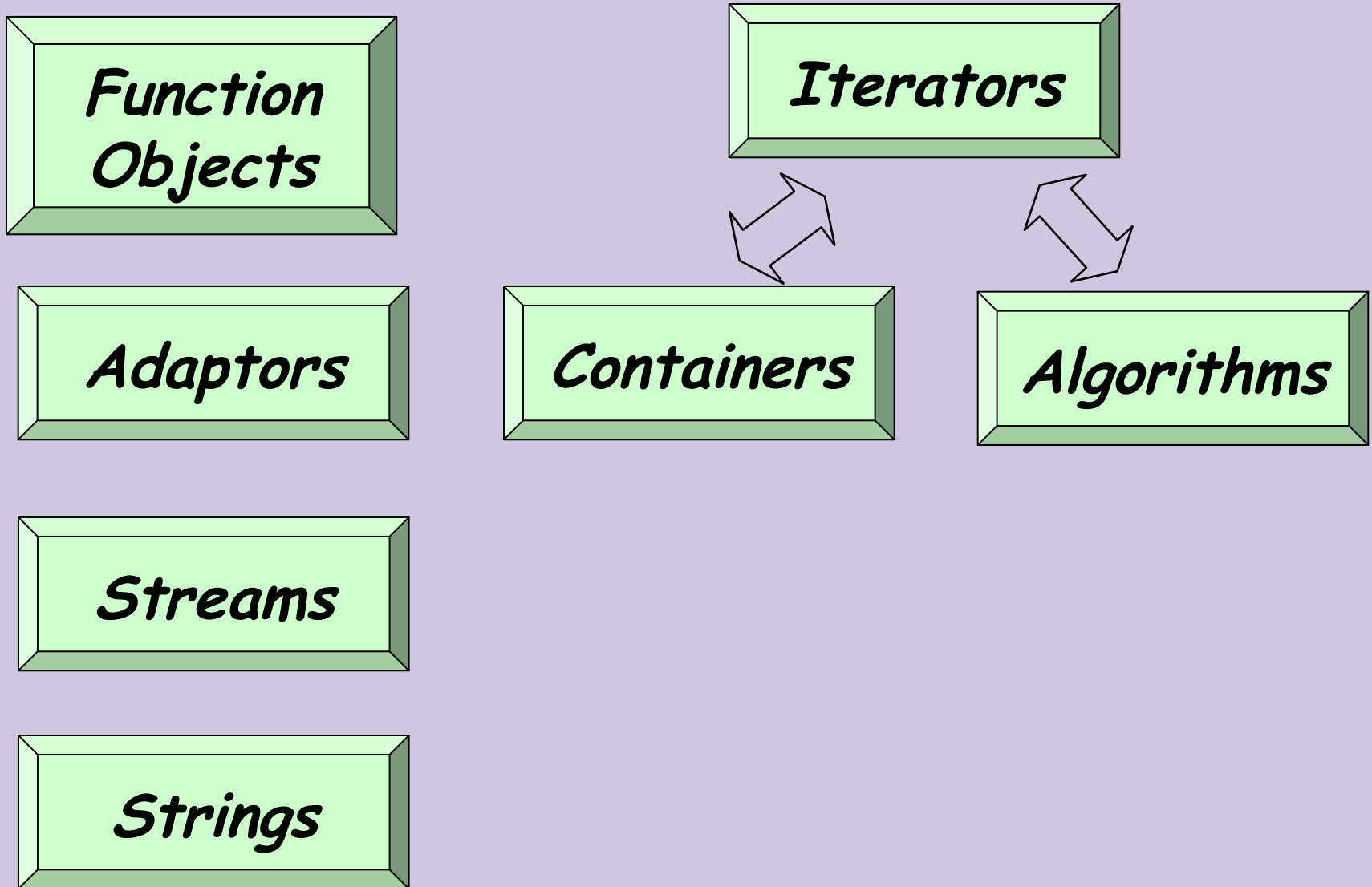
Concepts - Example

- Consider:

```
template<typename T> const T& min(const T& x,  
                                const T& y)  
{  
    return x < y? x : y;  
}
```

- The user must provide a type that has a less-than operator (<) to compare two values of type T, the result of which must be convertible to a Boolean value.
- – In short: T must be **LessThan Comparable**

Main Components



Containers

- Holds **copies** of elements.
- **Assumes** elements have:
Copy Ctor & operator =
- The standard defines the **interface**.
- Two main classes
 - **Sequential containers:**
list, vector,
 - **Associative containers:**
map, set ...

Assignable -
types with operator=
and copy Ctor

Containers documentation

see

<http://www.cplusplus.com/reference/stl/>

STL: Sequential Containers

Sequential Containers

Maintain a linear sequence of objects.

forward_list - a singly-linked list.

list - a doubly-linked list.

- Efficient insertion/deletion in front/end/middle

vector - an extendable sequence of objects

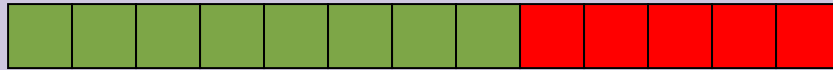
- Efficient insertion at end, and random access

deque – double-ended queue

- Efficient insertion/deletion at front/end
- Random access

array – fixed size, on the stack.

vector<T>



- Contiguous array of elements of type T
- Random access
- Can grow on as needed basis

```
std::vector<int> v(2);  
v[0]= 45;  
v[1]= 32;  
v.emplace_back(60); //C++11
```

Vectors of ints

1) Creating an empty vector and filling it:

```
std::vector<int> vec;  
vec.push_back(42);  
vec.emplace_back(42); // equivalent
```

2) Creating a vector with 10 ints with value 42:

```
std::vector<int> vec(10,42);  
std::vector<int> vec(10); // default is 0
```

3) Initializing a vector like an array:

```
std::vector<int> vec { 42, 52, 62 };
```

4) Initializing a vector from iterators:

```
std::vector<int> v2(vec.begin(), vec.end());
```

Vectors of objects (folder 1)

1) Creating an empty vector and filling it:

```
std::vector<MyClass> vec;  
vec.push_back(MyClass{42});  
vec.emplace_back(42); // more efficient
```

2) Creating a vector with 10 objs:

```
std::vector<MyClass> vec(10, MyClass{42});  
std::vector<MyClass> vec(10); // default ctor
```

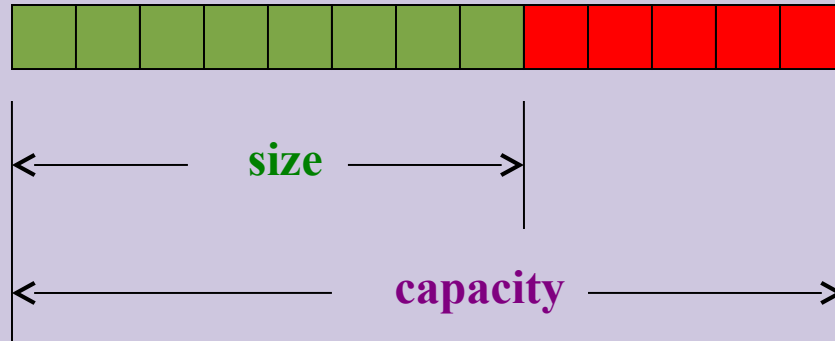
3) Initializing a vector like an array (calls ctor):

```
std::vector<MyClass> vec { {42}, {52}, {62} };
```

4) Initializing a vector from iterators:

```
std::vector<MyClass> v2(vec.begin(), vec.end());
```

size and capacity



- The first “size” elements are constructed (initialized)
- The last “capacity - size” elements are uninitialized
- `push_back` / `emplace_back` use the uninitialized elements until they are full; then, they **multiply the vector size by 2**.

emplace_back / push_back

Average Time Complexity

If we inserted n elements we paid:

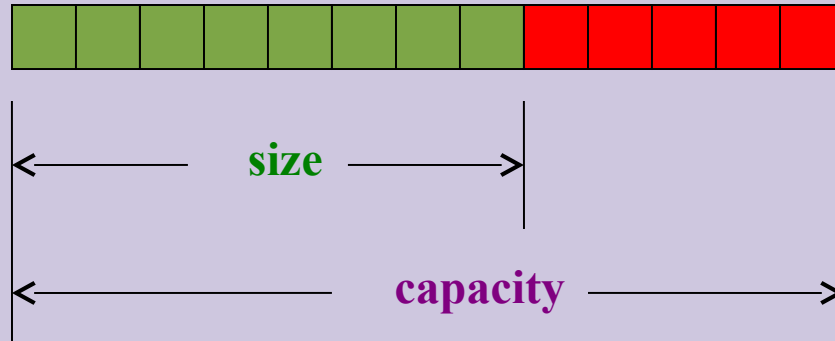
$$1 + 2 + 1 + 4 + 1 + 1 + 1 + 8 + \dots + n =$$

$$O(n) + 1 + 2 + 4 + \dots + n =$$

$$O(n)$$

On average an each insertion cost $O(1)$

size and capacity methods

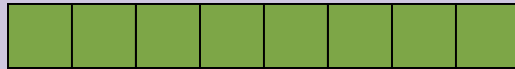


- `uint size() const;`
- `uint capacity() const;`
- `void reserve(uint new_capacity);`
 `// ensure that the capacity is`
 `// at least "new_capacity".`

vector<T> v



v.shrink_to_fit() // c++11



Accessing elements

Without boundary checking:

- `reference operator[](size_type n)`
- `const_reference operator[](size_type n) const`

With boundary checking:

- `reference at(size_type n)`
- `const_reference at(size_type n) const`

Associated types in vector

`vector<typename T>::`

- `value_type` - The type of object, T, stored
- `reference` - Reference to T
- `const_reference` - const Reference to T
- `iterator` - Iterator used to iterate through a vector (*how would you write it?*)
- ...

vectors: C++ vs. Java

- Look at **cplusplus** documentation of vector.
- Look at **Java** documentation of Vector.
- Differences:
 - **Simple class** vs. **interface and vtable**.
 - **Simple elements** vs. **class elements**.
 - **Two accessors** (with and without range check) vs. a **single accessor**

deque

- More efficient insertion at start and middle;
- Less efficient deallocation.
- How do we know? - performance tests:
- <https://www.codeproject.com/Articles/5425/An-In-Depth-Study-of-the-STL-Deque-Container>
- Implementation – non contiguous blocks:
<https://stackoverflow.com/a/6292437/827927>

STL: Associative Containers

Associative Containers

Supports efficient retrieval of elements (values) based on keys.

(Typical) Implementation:

- red-black binary trees
- hash-table

Sorted Associative Containers

set

- A set of unique keys ordered by <

map

- Associate a value to key (associative array)
- Unique value of each key, ordered by <

multiset, multimap

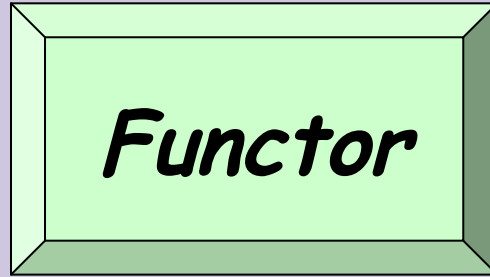
- Same, but allow multiple values

unordered_set, unordered_map

- Same, but without order (faster).

Sorted Associative Containers & Order

- Sorted associative containers assume that their elements are *LessThanComparable*.
- They use operator< as default order.
- We can control order using our own comparison function.
- We need to use a **functor**.



A functor in C++ is an object with an **operator()**. Examples:

- Pointer to function (like in C);
- A class that implements `operator()` ;
- Lambda expressions.

Example (see also folder 2)

```
class c_str_less {  
public:  
    bool operator() (const char* s1,  
                     const char* s2) {  
        return (strcmp(s1,s2) < 0);  
    }  
};
```

```
c_str_less cmp; // declare an object
```

```
if (cmp("aa","ab"))
```

```
...
```

```
if( c_str_less() ("a","b") )
```

Creates temporary objects, and then call operator()

Template comparator example

```
template<typename T>
class less {
public:
    bool operator()(const T& lhs, const T& rhs)
    { return lhs < rhs; }
};
```

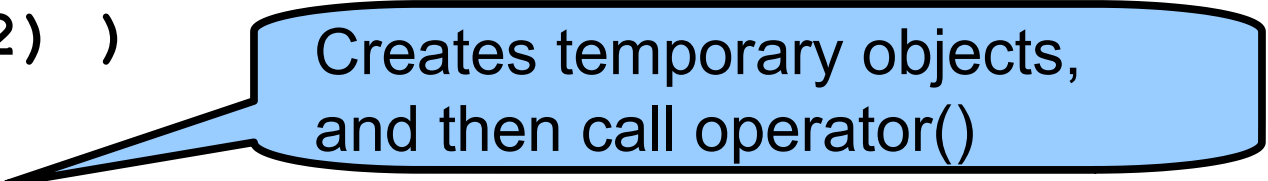
```
less<int> cmp;    // declare an object
```

```
if( cmp(1,2) )
```

```
...
```

```
if( less<int>()(1,2) )
```

```
...
```



Creates temporary objects,
and then call operator()

Using Comparators

```
// ascending order
// uses operator < for comparison
set<int> s1;
set<int, less<int>> s1; // same

// descending order
// uses operator > for comparison
set<int, greater<int>> s2;
```

Using Comparators

```
set<int, MyComp> s3;
```

Creates a default constructed MyComp object.

```
MyComp cmp(42);
```

```
set<int, MyComp> s4(cmp);
```

Use given MyComp object.

Why should we use classes as functors?

So that we get the “power” of classes:

- Inheritance.
- Parameterize our functions in run time.
(folder 2).
- Accumulate information.

Tuples

(folder 0)

- Can hold a fixed number of elements of various types.
- Particularly useful in a **return** statement, to let your function return several values.
- Shortest (most automated) version:

```
auto f () {  
    return std::make_tuple(5, 'a', "hello");  
}
```

```
// in main:
```

```
auto [ii, cc, ss] = f();
```

- Longer versions in folder 0.

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>

Strings

- A string is just a typedef for **basic_string<char>**
- The **basic_string** class represents a Sequence of characters.
- It contains:
 - all the usual operations of a sequential container.
 - useful 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