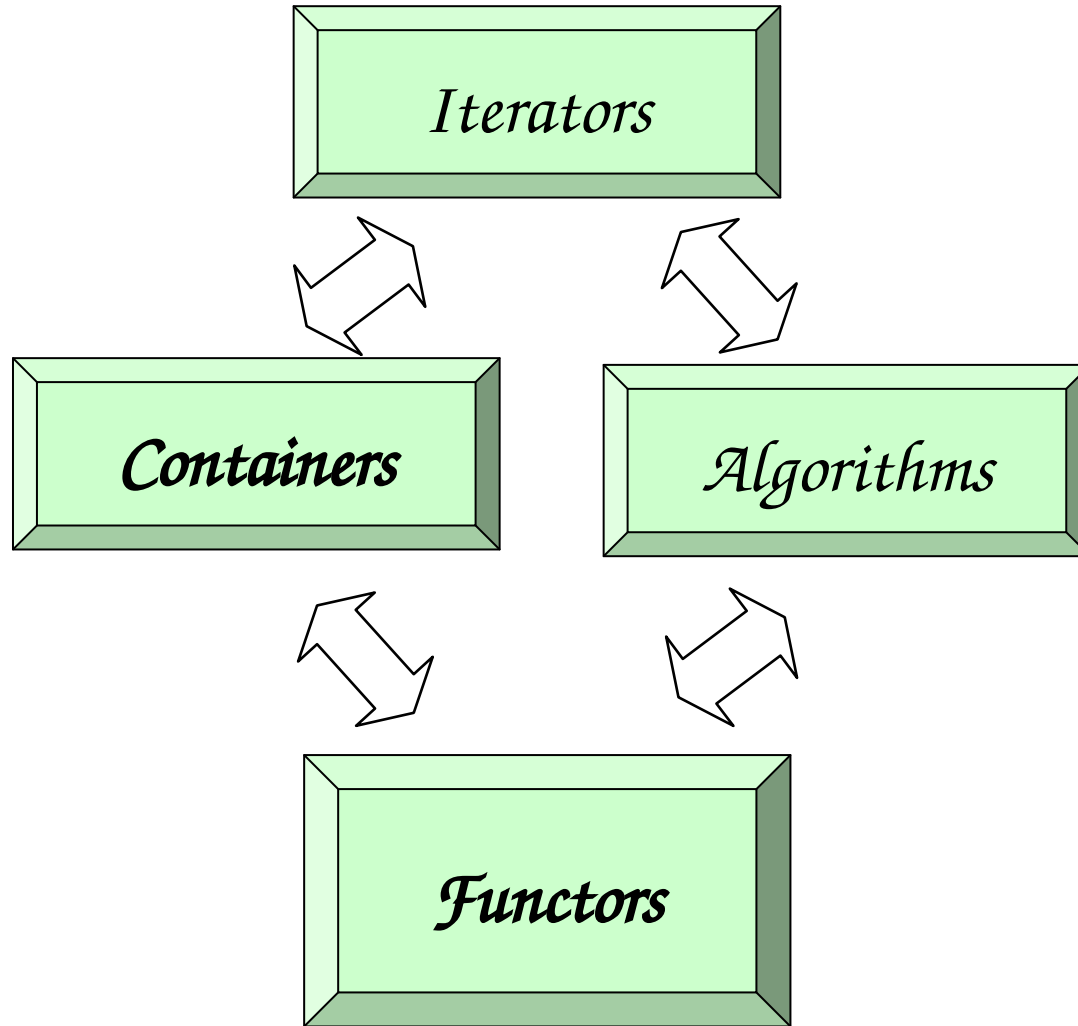


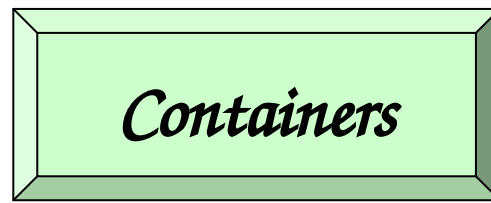
The Standard C++ Library

Version 1: Dr. Ofir Pele

Version 2: Dr. Erel Segal-Halevi

Main Components





Containers

Fixed size:

- pair, tuple, array

Sequence containers:

- forward_list, list, vector, deque, [basic_string]

Associative containers:

- set, multiset, map, multimap
- *unordered_set*, multiset, map, multimap

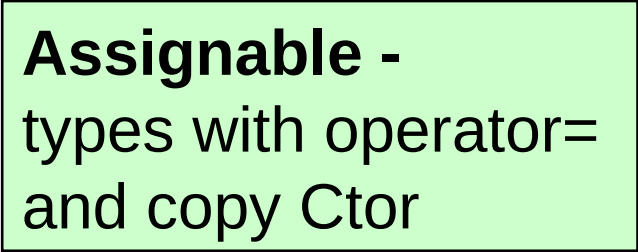
Container adaptors:

- stack, queue, priority_queue



Containers – General Rules

- Holds **copies** of elements.
- **Assumes** elements have:
Copy Ctor & operator =



Assignable -
types with operator=
and copy Ctor

Pairs, 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 tuple(5, 'a', "hello");  
}
```

```
// in main:
```

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

- Longer versions in folder 0.

STL: Sequential Containers

Sequential Containers

Objects are ordered by the user

	insert first	insert middle	insert last	random access	iterate forward	iterate back	<i>find</i>	storage
forward_ list	fast	fast	fast	slow	fast	slow	<i>slow</i>	heap
list	fast	fast	fast	slow	fast	fast	<i>slow</i>	heap
deque	fast	~slow	fast	~fast	fast	fast	<i>slow</i>	heap
vector	slow	slow	~fast	fast	fast	fast	<i>slow</i>	heap
basic_ string	slow	slow	~fast	fast	fast	fast	<i>slow</i>	heap
array	-	-	-	fast	fast	fast	<i>slow</i>	stack

vector<T>



- Contiguous array of elements of type T
- Random access
- Can grow on as needed basis
- Most useful in practice

```
std::vector<int> v(200);  
v[0]= 45;  
v[100]= 32;  
v.emplace_back(60);
```


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

1) Creating an empty vector and filling it:

```
std::vector<MyClass> vec;  
vec.push_back(MyClass{42,43});  
vec.emplace_back(42,43); // more efficient
```

2) Creating a vector with 10 objs:

```
std::vector<MyClass> vec(10,MyClass{42,43});  
std::vector<MyClass> vec(10); // default ctor
```

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

```
std::vector<MyClass> vec { {42,43}, {52}, {62,72} };
```

4) Initializing a vector from iterators:

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

push vs. emplace

- Inserts a new element at the end:

```
void push_back(const T&)
```

- **a.push_back(t)**

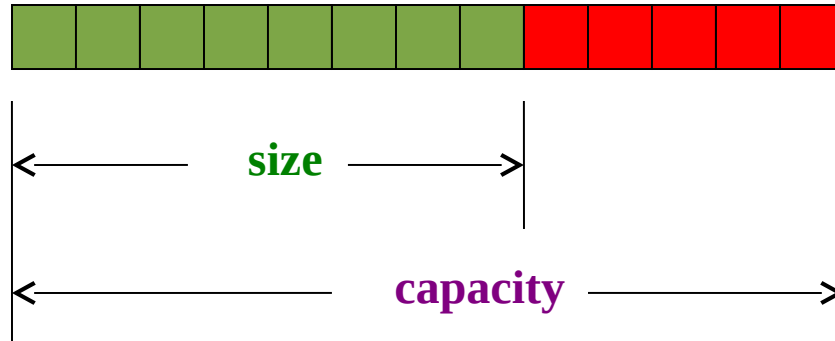
- Construct and insert a new element at end:

```
template<typename... Args>
```

```
void emplace_back(Args&&... args)
```

- **a.emplace_back(t)**

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 capacity by 2**.

emplace_back / push_back

Average Time Complexity

If we inserted n elements we paid:

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

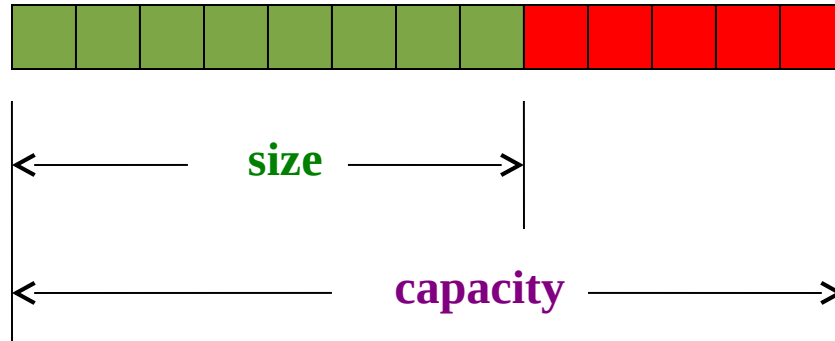
$$O(n) + 1 + 2 + 4 + \dots + n =$$

$$O(n)$$

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

size and capacity methods

(see folder 1)



- `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`

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>

basic_strings

- The well-known **string** is just a typedef for **basic_string<char>**.
- **basic_string** can be used with any char-like type (folder 1).

	String operations (e.g. substr, replace, stol)	Non-trivial classes (e.g. with vptr, heap usage)
vector	No	Yes
basic_ string	Yes	No

STL: Associative Containers

Associative Containers

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

(Typical) Implementation:

- red-black binary trees
- hash-table

Associative Containers

Ordered: Objects are ordered by "<".

Insertion, deletion, find: $O(\log n)$.

set: Unique keys.

map: Associate unique keys to values.

multiset: Allows multiple keys.

multimap: Associate keys to multiple values.

Unordered: Insertion, deletion, find: $O(1)$.

unordered_set: Unique keys.

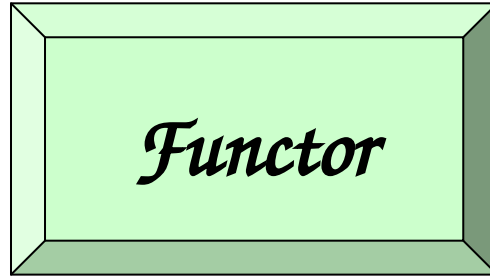
unordered_map: Associate keys to values.

unordered_multiset: Allows multiple keys.

unordered_multimap: Associate keys to multiple values.

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.

Functor in the STL

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

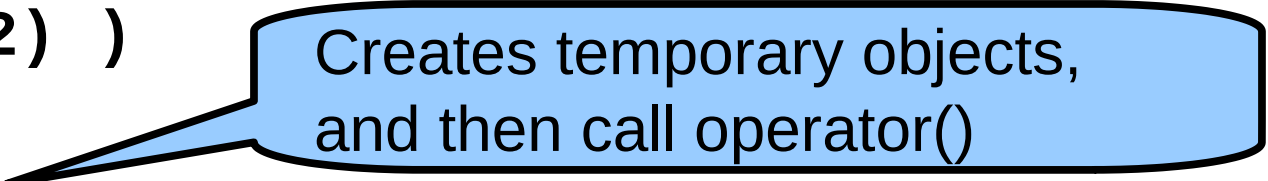
```
less<int> cmp;    // declare an object
```

```
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;
```

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.

Container Adaptors

Take any sequential container;
return a container with a given interface:

- **stack**: last in – first out;
- **queue**: first in – first out;
- **priority_queue**: best in – first out.

How to choose a container?

