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.

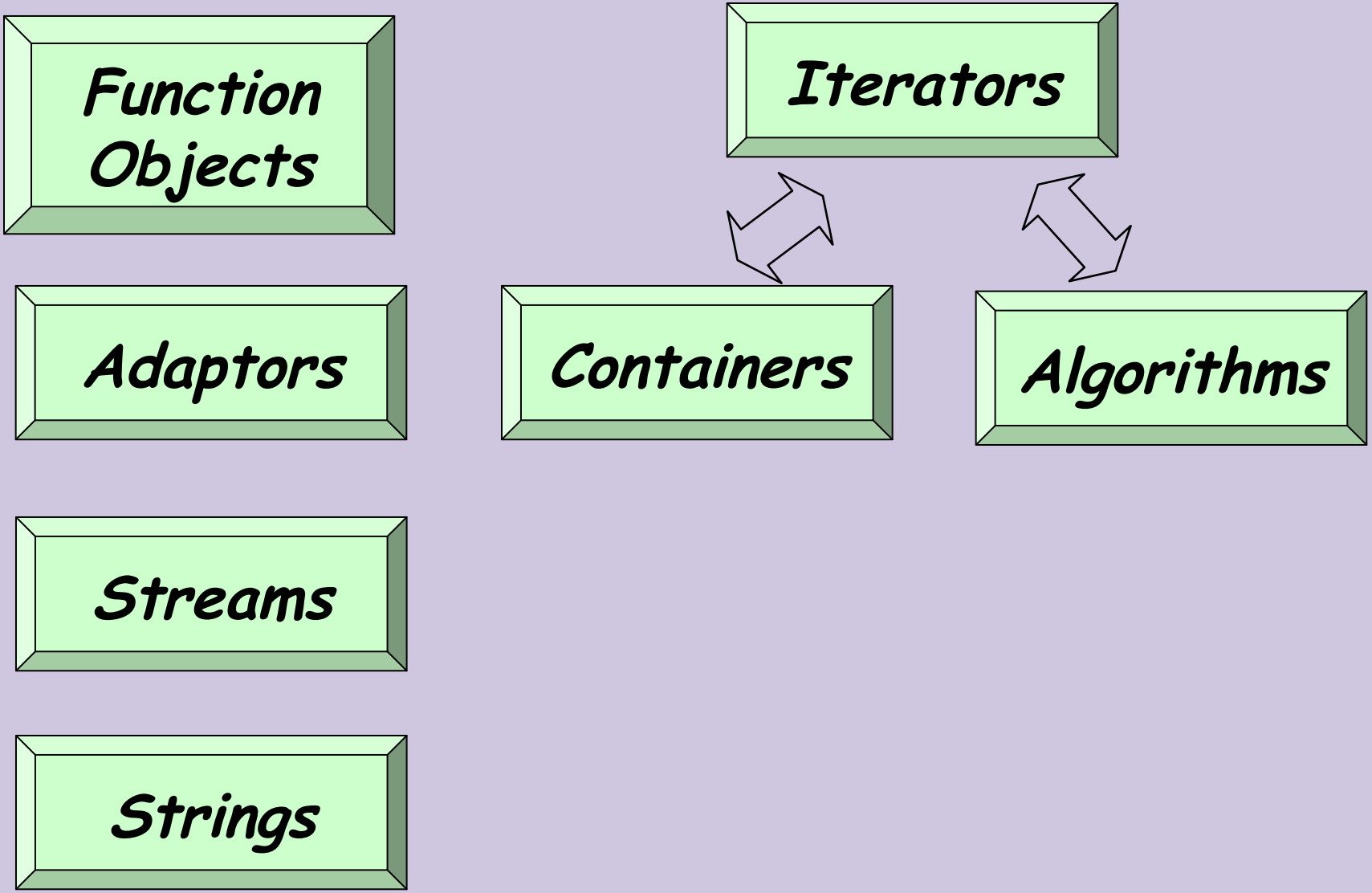
Concepts - Example

- 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(200);
v[0]= 45;
v[100]= 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
```

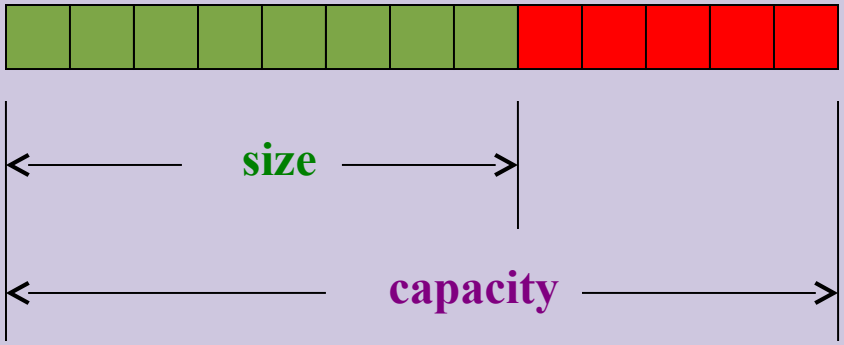
3)Initializing a vector like an array (calls ctor):

```
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:

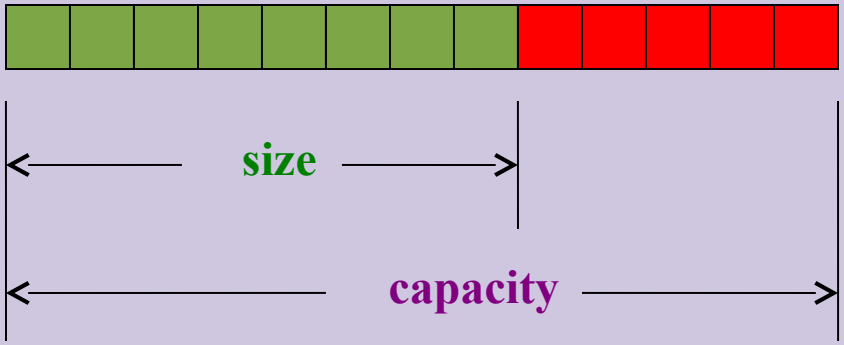
1+**2**+1+**4**+1+1+1+**8**+…+**n** =

O(n) + **1**+**2**+**4**+…+**n** =

O(n)

On average an each insertion cost O(1)

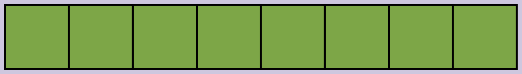
size and capacity methods



- `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**.

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**