EDAF50 – C++ Programming

9. More about resource management and the standard library.

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Outline

1. Classes, copy and move
   - copy and swap
2. The standard library
   - Sequences
   - Insertion
   - Container adapters
3. std::tie
   - tuples and std::tie()

Resource management

copy assignment: **operator=**

Declaration (in the class definition of Vector)

```
const Vector& operator=(const Vector& v);
```

Definition (outside the class definition)

```
Vector& Vector::operator=(const Vector& v)
{
  if (this != &v) {
      auto tmp = new int[sz];
      for (int i=0; i<sz; i++)
          tmp[i] = v.elem[i];
      sz = v.sz;
      delete[] elem;
      elem = tmp;
  }
  return *this;
}
```

1. check "self assignment"
2. Allocate new resources
3. Copy values
4. Free old resources

For error handling, better to allocate and copy first and only **delete** *if copying succeded.*

Copy control: (Move semantics – C++11)
Example: Vector

Move assignment

```
Vector& Vector::operator=(Vector&& v) {
    if(this != &v) {
        delete[] elem;      // delete current array
        elem = v.elem;      // "move" the array from v
        v.elem = nullptr;   // mark v as an "empty hulk"
        sz = v.sz;
        v.sz = 0;
    }
    return *this;
}
```

Copy/move assignment
We can (often) do better

- Code complexity
  - Both copy and move assignment operators
  - Code duplication
  - Brittle, manual code
    - self-assignment check
    - copying
    - memory management

alternative: The copy-and-swap idiom.

Copy assignment
The copy and swap idiom

Copy and move assignment

```
Vector& Vector::operator=(Vector v) {
    swap(*this, v);
    return *this;
}
```

- Call by value
  - let the compiler do the copy
  - works for both copy assign and move assign
    - called with *lvalue* ⇒ copy construction
    - called with *rvalue* ⇒ move construction
- No code duplication
- Less error-prone
- May need an overloaded `swap()`
- Slightly less efficient (one additional assignment)

Swapping – std::swap

The standard library defines a function (template) for swapping the values of two variables:

Example implementation (C++11)

```
template <typename T>
void swap(T& a, T& b)
{
  T tmp = a;
  a = b;
  b = tmp;
}
```

```
template <typename T>
void swap(T& a, T& b)
{
   T tmp = std::move(a);
   a = std::move(b);
   b = std::move(tmp);
}
```

The generic version may do unnecessary copying (especially pre move semantics, or if members cannot be moved), for `Vector` we can simply swap the members.

Overload for Vector (needs to be **friend**)

```
void swap(Vector& a, Vector& b) noexcept
{
  using std::swap;
  swap(a.sz, b.sz);
  swap(a.elem, b.elem);
}
```

common idiom:

- use **using** to make std::swap visible
- call swap unqualified to allow ADL to find an overloaded swap for the argument type

Swapping – `std::swap`

- The swap function can be both declared as a friend and *defined inside the class definition*.
- Still a free function
- In the same namespace as the class
  - Good for ADL

Overload for Vector ("inline" **friend**)

```
class Vector {
  // declarations of members ...

  friend void swap(Vector& a, Vector& b) noexcept
  {
    using std::swap;
    swap(a.sz, b.sz);
    swap(a.elem, b.elem);
  }
};
```

Standard container iterators and swap

23.2.1 General container requirements includes

> *The expression a.swap(b), for containers a and b of a standard container type other than array, shall exchange the values of a and b without invoking any move, copy, or swap operations on the individual container elements.*

and

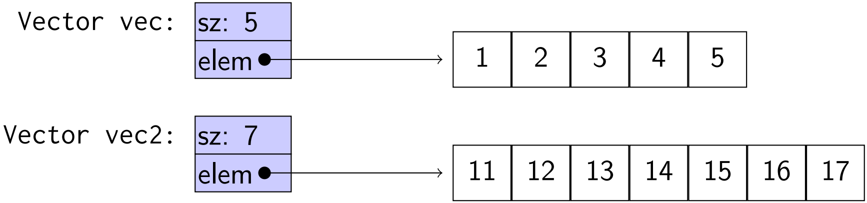
> *no swap() function invalidates any references, pointers, or iterators referring to the elements of the containers being swapped. [Note: The end() iterator does not refer to any element, so it may be invalidated. — end note]*

C++-14 clarifies:

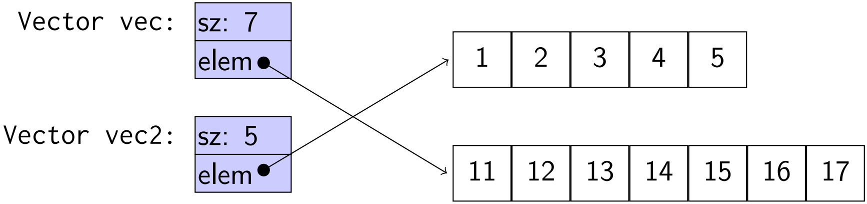
> *Every iterator referring to an element in one container before the swap shall refer to the same element in the other container after the swap.*

Swapping vectors vs. swapping elements

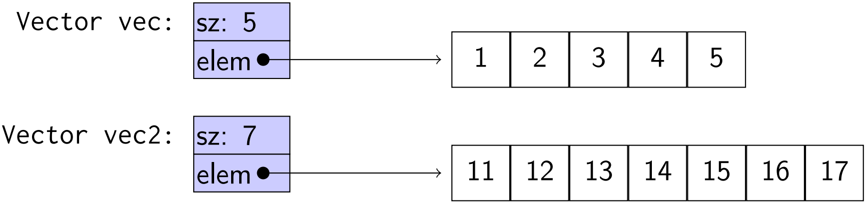
std::swap swaps the pointers



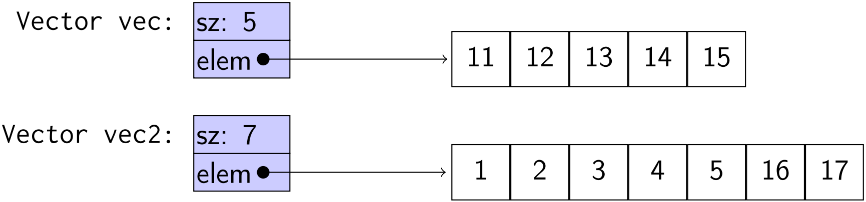

```
using std::swap;
swap(vec, vec2);
```



std::swap_ranges swaps elements




```
std::swap_ranges(vec.begin(), vec.end(), vec2.begin());
```



Standard containers

Sequences (homogeneous)

- `vector<T>`
- `deque<T>`
- `list<T>`

Associative containers (also *unordered*)

- `map<K,V>`, `multimap<K,V>`
- `set<T>`, `multiset<T>`

Heterogeneous sequences (not “containers”)

- `tuple<T1, T2, ...>`
- `pair<T1,T2>`

The classes `vector` and `deque`

The standard library has two main sequence data types

std::vector
: your default sequence type
  - Contigous in memory
  - Grows at the back

std::deque
: Double ended queue
  - Piecewise contigous in memory
  - Grows at front and back

The classes vector and deque

Operations in the class vector

```
v.clear(), v.size(), v.empty()
v.push_back(), v.pop_back(), v.emplace_back()
v.front(), v.back(), v.at(i), v[i]
v.assign(), v.insert(), v.emplace()
v.resize(), v.reserve()
```

Additional operations in deque

```
d.push_front(), d.pop_front(), d.emplace_front()
```

Constructors and `assign` have three overloads:

- *fill*: n elements with the same value

```
void assign (size_type n, const value_type& val);
```

- *initializer list*

```
void assign (initializer_list<value_type> il);
```

- *range*: copies the elements in the interval $[first, last)$ (i.e., from `first` to `last`, excl. `last`)

```
template <class InputIterator>
void assign (InputIterator first, InputIterator last);
```

Use `()` for ctor arguments (e.g., sizes), and `{}` for list of elements.

The classes vector and deque
The member function assign, example

```
vector<int> v{3,4};
print_seq(v);          length = 2: [3][4]

v.assign(3,4);
print_seq(v);          length = 3: [4][4][4]


int a[]{0,1,2,3,4,5,6,7,8,9};

v.assign(a, a+5);
print_seq(v);          length = 5: [0][1][2][3][4]


std::deque<int> d;
d.assign(v.begin(), v.end());
print_seq(d);          length = 5: [0][1][2][3][4]
```

Examples of iterators

The classes vector and deque
Member functions push and pop

push	adds an element, increasing size
pop	removes an element, decreasing size
front, back	get a reference to the first (last) element

*_back operates at the end, available in both

```
void push_back (const value_type& val);    //copy
void pop_back();
reference front();
reference back();
```

only in deque: *_front

```
void push_front (const value_type& val);   //copy
void pop_front();
```

pop_X(), front() and back()

NB! The return type of pop_back() is **void**.

```
auto val = v.back();
v.pop_back();
```

Why separate functions?

- Don't pay for what you don't need.
  - A non-void pop() has to return by value (copy).
  - front()/back() can return a reference.
  - Let the caller decide if it wants a copy.

Growing a vector
Size and capacity

A container has a *size* and a *capacity*.

On a `push_back`, if `size == capacity` the vector grows

- New storage is allocated
- The elements are copied

If you know how many `push_back` calls you will make,

- first use `reserve()` to (at least) the expected final size.
- then do a series of `push_back`

Container and resource management

- Containers have value semantics
- Elements are copied into the container

The classes vector and deque
Insertion with insert/push_back and emplace(back)

insert: copying (or moving)

```
iterator insert (const_iterator pos, const value_type& val);
iterator insert (const_iterator pos, size_type n,
                 const value_type& val);
template <class InputIterator>
iterator insert (const_iterator pos, InputIterator first,
                 InputIterator last);
iterator insert (const_iterator pos,
                 initializer_list<value_type> il);
```

and push_back.

emplace: construction *"in-place"*

```
template <class... Args>
iterator emplace (const_iterator position, Args&&... args);

template <class... Args>
void emplace_back (Args&&... args);
```

The classes vector and deque
Example with insert and emplace

```
struct Foo {
  int x;
  int y;
  Foo(int a=0,int b=0) :x{a},y{b} {cout<<*this <<"\n";}
  Foo(const Foo& f) :x{f.x},y{f.y} {cout<<"**Copying Foo\n";}
};
std::ostream& operator<<(std::ostream& os, const Foo& f)
{
  return os << "Foo("<< f.x << ","<<f.y<<")";
}
vector<Foo> v;
v.reserve(4);
v.insert(v.begin(), Foo(17,42)); Foo(17,42)
                                 **Copying Foo
print_seq(v);  length = 1: [Foo(17,42)]
v.insert(v.end(), Foo(7,2));     Foo(7,2)
                                 **Copying Foo
print_seq(v);  length = 2: [Foo(17,42)][Foo(7,2)]
v.emplace_back();                Foo(0,0)
print_seq(v);  length = 3: [Foo(17,42)][Foo(7,2)][Foo(0,0)]
v.emplace_back(10);              Foo(10,0)
print_seq(v);  length = 4: [Foo(17,42)][Foo(7,2)][Foo(0,0)][Foo(10,0)]
```

Container and resource management

- Containers have value semantics
- Elements are copied into the container
- When an element is removed, it is destroyed
- The destructor of a container destroys all elements
- Usually a bad idea to store owning raw pointers in a container
  - Requires explicit destruction of the elements
  - Prefer smart pointers

Queues and stacks

- *adapter classes*, providing a limited interface to one of the standard containers: `stack`, `queue`, `priority_queue`
  - fewer operations
  - do not have iterators

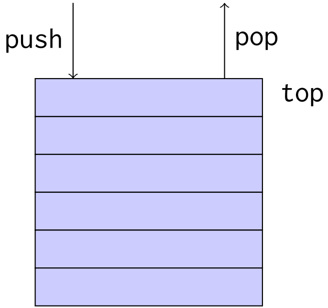
Has a default underlying container. E.g., for `stack`:

```
template<
    class T,
    class Container = std::deque<T>
> class stack;
```

but `stack` can be instantiated with any class that has `push_back()`, `pop_back()` and `back()`.

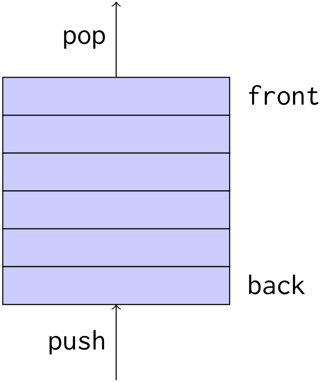
Queues and stacks

- Stack: LIFO queue (Last In First Out)
- Operations: `push`, `pop`, `top`, `size` and `empty`



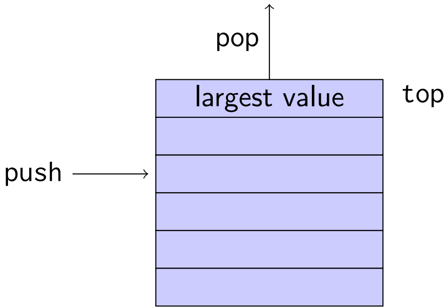
Queues and stacks

- Queue: FIFO-queue (First In First Out)
- Operations: `push`, `pop`, `front`, `back`, `size` and `empty`



Queues and stacks

- Priority queue: sorted queue. The element highest priority is first in the queue.
- Operations: `push`, `pop`, `top`, `size` and `empty`



Compares elements with `std::less<T>` by default.
A custom comparator can be used. E.g., using std::greater<T> would cause the smallest element to be first.

Sets and maps

Associative containers

`map<Key,Value>`	Unique keys
`multimap<Key,Value>`	Can contain duplicate keys
`set<Key>`	Unique keys
`multiset<Key>`	Can contain duplicate keys

`set` is in principle a `map` without values.

- By default orders elements with **`operator<`**

```
template<class Key, class Compare = std::less<Key>>
class set{
    explicit set( const Compare& comp = Compare());
    ...
};
```

- A custom comparator can be provided

Sets and maps

<set>: std::set

```
void test_set()
{
    std::set<int> ints{1,3,7};

    ints.insert(5);

    for(auto x : ints) {
         cout << x << " ";
    }
    cout << endl;

    auto has_one = ints.find(1);

    if(has_one != ints.end()){
        cout << "one is in the set\n";
    } else {
        cout << "one is not in the set\n";
    }
}
```

```
1 3 5 7
one is in the set
```

Or

```
if(ints.count(1))
```

Sets and maps

<map>: std::map

```
map<string, int> msi;
msi.insert(make_pair("Kalle", 1));
msi.emplace("Lisa", 2);
msi["Kim"]= 5;

for(const auto& a: msi) {
    cout << a.first << " : " << a.second << endl;
}

cout << "Lisa --> " << msi.at("Lisa") << endl;
cout << "Hasse --> " << msi["Hasse"] << endl;

auto nisse = msi.find("Nisse");
if(nisse != msi.end()) {
    cout << "Nisse : " << nisse->second << endl;
} else {
    cout << "Nisse not found\n";
}
```

```
Kalle : 1
Kim : 5
Lisa : 2
Lisa --> 2
Hasse --> 0       NB! operator[] default constructs values for new keys
Nisse not found
```

Sets and maps

A `std::set` *is in principle a* `std::map` *without values*

Operations on `std::map`

```
insert, emplace, [], at, find, count,
erase, clear, size, empty,
lower_bound, upper_bound, equal_range
```

Operations on `std::set`

```
insert, emplace, find, count,
erase, clear, size, empty,
lower_bound, upper_bound, equal_range
```

Use the member functions, not algorithms like `std::find()`
(It works, but is less efficient – linear time complexity instead of logarithmic.)

Sets and maps
The return value of insert

insert() returns a pair

```
std::pair<iterator,bool> insert( const value_type& value );
```

The `insert` member function returns two things:

- An iterator to the inserted value
  - or to the element that prevented insertion
- A **bool**: **true** if the element was inserted

`insert()` in `multiset` and `multimap` just returns an iterator.

Getting the result of an insert

```
auto result = set.insert(value);
bool inserted = result.second;
```

Sets and maps
The return value of insert

insert() returns a pair

```
std::pair<iterator,bool> insert( const value_type& value );
```

The `insert` member function returns two things:

- An iterator to the inserted value
  - or to the element that prevented insertion
- A **bool**: **true** if the element was inserted

Using `std::tie` to unpack a pair (or tuple)

```
bool inserted;
std::tie(std::ignore, inserted) = set.insert(value);
```

pairs and std::tie
Example: explicit element access

Getting the elements of a pair

```
void example1()
{
    auto t = std::make_pair(10, "Hello");

    int i = t.first;
    string s = t.second;

    cout << "i: " << i << ", s: " << s << endl;
}
```

pairs and std::tie

Example: using `std::tie`

Getting the elements of a pair

```
void example1b()
{
    auto t = std::make_pair(10, "Hello");

    int i;
    string s;

    std::tie(i,s) = t;

    cout << "i: " << i << ", s: " << s << endl;
}
```

tuples and std::tie
Example: using `std::get(std::tuple)`

Getting the elements of a tuple

```
void example2()
{
    auto t = std::make_tuple(10, "Hello",4.2);

    int i;
    string s;
    double d;

    i = std::get<0>(t);
    s = std::get<1>(t);
    d = std::get<2>(t);

    cout << "i: " << i << ", s: " << s << ", d: " << d << endl;
}
```

NB! `std::get(std:tuple)` takes the index as a *template parameter*.

tuples and std::tie

Example: using `std::tie`

Getting the elements of a tuple

```
void example2b()
{
    auto t = std::make_tuple(10, "Hello",4.2);

    int i;
    string s;
    double d;

    std::tie(i,s,d) = t;

    cout << "i: " << i << ", s: " << s << ", d: " << d << endl;
}
```

std::tie
Example: ignoring values with `std::ignore`

Getting the elements of a tuple

```
void example2c()
{
    auto t = std::make_tuple(10, "Hello",4.2);

    int i;
    double d;

    std::tie(i,std::ignore,d) = t;

    cout << "i: " << i << ", d: " << d << endl;
}
```

`std::ignore` is *an object of unspecified type such that assigning any value to it has no effect.*

std::tie
Example: implementation sketch

tie for a pair<int, string>

```
std::pair<int&, string&> mytie(int& x, string& y)
{
    return std::pair<int&, string&>(x,y);
}
```

- returns a *temporary* pair of *lvalue references*
- the assignment operator of pair assigns each member
- the references are *aliases for the variables* passed as arguments
- assigning to the references is the same as assigning to the variables

```
int i;
string s;

mytie(i,s) = t;
```

std::tie
Comments

possible implementation

```
template <typename... Args>
std::tuple<Args&...> tie(Args&... args)
{
    return std::tuple<Args&...>(args...);
}
```

- `std::tie` can be used on both `std::pair` and `std::tuple`, as a tuple has an implicit conversion from pair.
- The variables used with `std::tie` must have been declared.
- C++17 introduces *structured bindings* that lets you write code like `const auto& [i,s,d] = some_tuple;`
  - No need to declare variables before
  - Cannot use `std::ignore`: compiler warning if you don't use all variables.

Iterator traits
Exempel: `find`

```
template <class InIt, class T>
InIt find (InIt first, InIt last, const T& val);
```

Alternative: the compiler knows the actual value type.

With `std::iterator_traits` from `<Iterator>`

```
template <class InIt>
InIt find (InIt first, InIt last,
           const typename iterator_traits<InIt>::value_type& val);
```

NB! This is more restrictive on the value type

type traits

<type_traits> contains metafunctions for working with types. E.g.:

Type categories

`is_void` `is_scalar` `is_array` `is_class` `is_function`

Type properties

`is_const` `is_empty` `is_signed` `is_reference` `is_pointer`

Type relations

`is_same` `is_convertible` `is_base_of`

Modifiers

`add_const` `remove_const` `remove_reference` `add_lvalue_reference`
`make_signed` `make_unsigned` `remove_extent`

Suggested reading

References to sections in Lippman

Sequential containers 9.1 – 9.3

Container Adapters 9.6

Associative containers chapter 11

Tuples 17.1

Swap 13.3

Moving objects 13.6