EDAF50 – C++ Programming

# *9. More about resource management and the standard library.*

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# Outline


1. The standard library
   - Sequences
   - Insertion
   - Container adapters
2. std::tie
   - tuples and std::tie()
3. Templates
4. CRTP

# 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()
```

# The classes vector and deque
## Constructors and the function assign

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

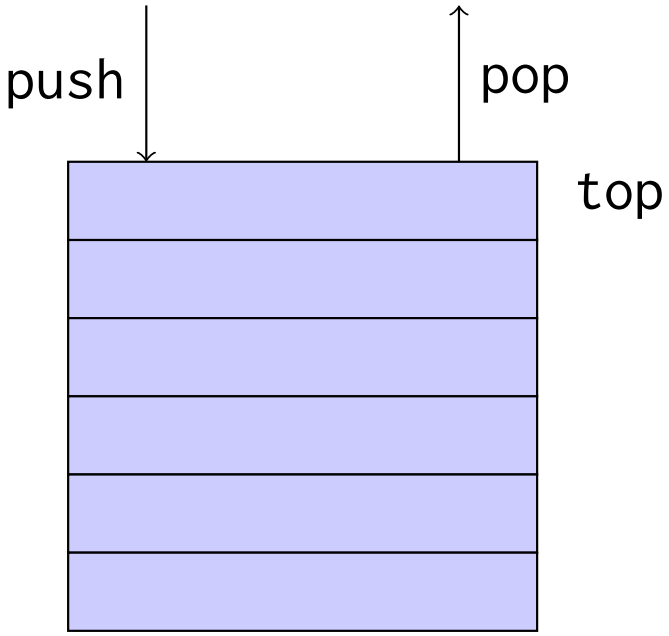
Has a default underlying container. E.g., for `stack`:

```
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()`.

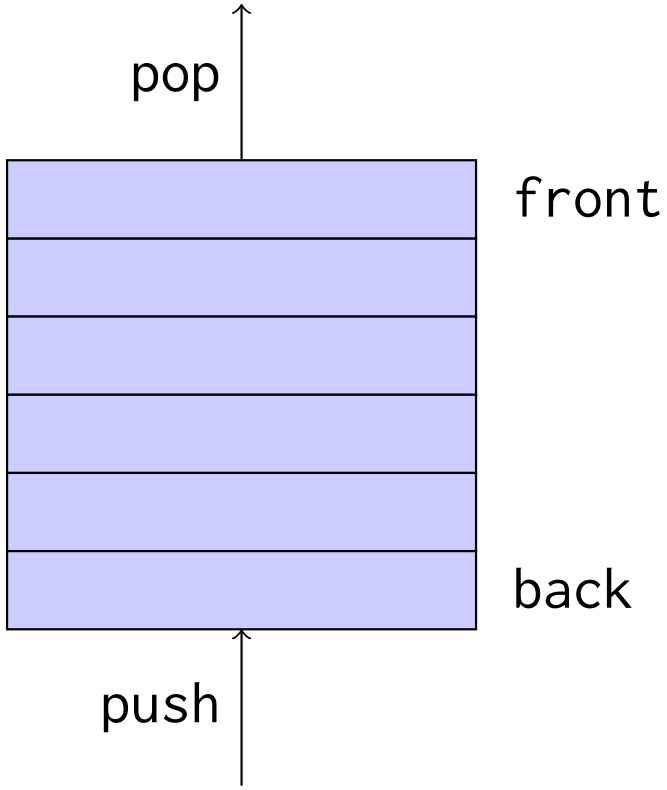
# Queues and stacks

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



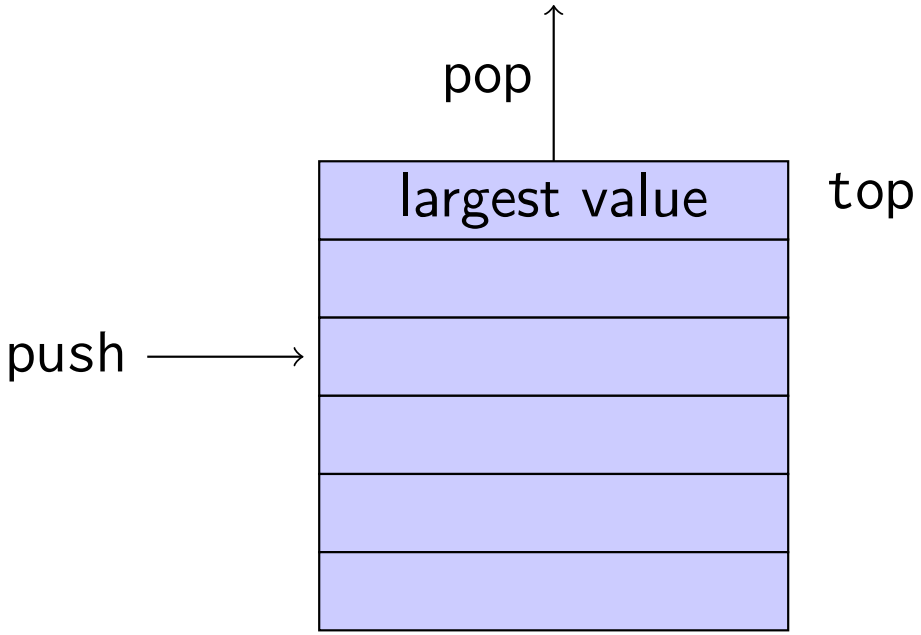
# Queues and stacks

- 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

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

## Operations on `std::map`

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

## Operations on `std::set`

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

*Use the member functions, not algorithms like* `std::find()`

*(It may work, but is more complicated and less efficient – linear time complexity instead of logarithmic.)*

# 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
## 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::tuple
## less than for a Person class

```
#include <tuple>

struct Person
{
    std::string fname;
    std::string lname;

    /* Order Persons by lname, fname */
    bool operator<(const Person& p) const {
        return std::tie(lname, fname) < std::tie(p.lname, p.fname);
    }
};
```

*Tuple has an* **operator<**.

# std::tuple
## get of type

```
auto t = std::make_tuple<17, 42.1, "Hello">;

auto i = std::get<int>(t);
auto d = std::get<double>(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
```

# The Curiously Recurring Template Pattern
## Static polymorphism

- Polymorphism without the run-time overhead
  - Common functionality in base class
    - E.g., compute value
  - Specific functionality in derived classes
    - E.g., output to different devices (console, file, socket)
- Reuse of generic functionality in unrelated classes
  - Related to *Mixin classes*
  - E.g., counting allocations and instances

# The Curiously Recurring Template Pattern
## Dyanamic polymorphism

### Normal abstract class

```
class Base{
public:
    virtual void method() =0;
};

class Derived1 :public Base{
public:
    void method() override{
        cout << "Derived1::method\n";
    }
};
```

# The Curiously Recurring Template Pattern
## Static polymorphism

### The CRTP structure

```
template <typename T>
class Base {
public:
    void method() {
        static_cast<T*>(this)->method();
    }
};

class Derived : public Base<Derived> {
public:
    void method() {
        std::cout << "Derived method" << std::endl;
    }
};
```

# The Curiously Recurring Template Pattern
## Example: Animal sounds

```
class Animal {
public:
  Animal(const std::string& name) :name(name) {}
  void speak() const {cout << name << " says "<< get_sound() << "!\n";
  virtual std::string get_sound() const = 0;
  virtual ~Animal() =default;
private:
  std::string name;
};

class Dog : public Animal {
public:
  using Animal::Animal;
  virtual std::string get_sound() const override {return {"Woof"};}
};

class Cat : public Animal {
public:
  using Animal::Animal;
  virtual std::string get_sound() const override {return {"Meow"};}
};
```

# The Curiously Recurring Template Pattern
## Example: Animal sounds

If we don't need run-time polymorphism:

```
Dog d{"Fido"};
Cat c{"Caesar"};

d.speak();      Fido says Woof!
c.speak();      Caesar says Meow!
```

### Base class template

```
template <typename Derived>
class Animal {
public:
    Animal(const std::string& name) :name(name) {}
    void speak() const {
        cout << name << " says "
        << static_cast<const Derived*>(this)->get_sound()
        << "!\n";
    }
private:
    std::string name;
};
```

# The Curiously Recurring Template Pattern
## Example: Animal sounds

### Concrete derived classes

```
class Dog : public Animal<Dog> {
public:
    using Animal::Animal;
    std::string get_sound() const {
        return {"Woof"};
    }
};

class Cat : public Animal<Cat> {
public:
    using Animal::Animal;
    std::string get_sound() const {
        return {"Meow"};
    }
};
```

*NB! No* **`override`**

# The Curiously Recurring Template Pattern
## Example:

### Base class template

```
template <typename Derived>
class Computer{
public:
    void print_answer(){
        auto ans = incredibly_complex_computation();
        static_cast<Derived*>(this)->do_print_answer(ans);
    }
private:
    int incredibly_complex_computation() {return 42;}
};
```

Behaves like it had a pure virtual function

```
    virtual void do_print_answer(int) =0;
```

# The Curiously Recurring Template Pattern
## Example:

### Concrete classes

```
class Local_Computer :public Computer<Local_Computer>{
public:
    void do_print_answer(int ans) {
        cout << "Answer:" << ans << endl;
    }
};

class Networked_Computer :public Computer<Networked_Computer>{
public:
    Networked_Computer(ServerConnection c) :conn{c} {}
    void do_print_answer(int ans) {
        conn.upload(ans);
    }
private:
    ServerConnection conn;
};
```

```
    Local_Computer l{};
    l.print_answer();    Answer: 42
```

# The Curiously Recurring Template Pattern
## Static polymorphism

- Polymorphism without the run-time overhead
  - Common functionality in base class
    - E.g., compute value
  - Specific functionality in derived classes
    - E.g., output to different devices (console, file, socket)
- Reusing generic functionality in unrelated classes
  - E.g., counting allocations and instances

# The Curiously Recurring Template Pattern
## Example: counting instances

### Base class template

```
template <typename Derived>
class Counted{
public:
    static int get_alive() {return alive;}
    static int get_created() {return created;}
protected:
    Counted() {++created; ++alive;}
    Counted(const Counted&) {++created; ++alive;}
    ~Counted() {--alive;}
private:
    static int created;
    static int alive;
};

template <typename Derived>
int Counted<Derived>::created {0};

template <typename Derived>
int Counted<Derived>::alive {0};
```

- The variables are **static**: one variable per *class* (not per object).
- This is a *class template*: a new Counted<T> *class* will be instantiated for each subclass
- Each subclass will have its own counters

# The Curiously Recurring Template Pattern
## Example: counting instances

### Concrete subclass and helper function

```
class Foo  :public Counted<Foo>
{
public:
    Foo(int i) :x(i) {}
private:
    int x;

};

template <typename T>
void print_counts()
{
  cout << typeid(T).name() << " alive: " << T::get_alive()
       << ", created: " << T::get_created() << endl;
}
```

# 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 |