C++

程式語言（二）

Introduction to Programming (II)

Introduction to STL

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Platform/IDE

- Dev-C++

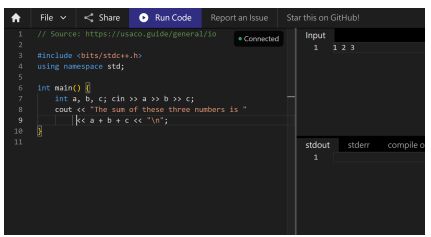
https://www.pngegg.com/en/search?q=Dev-C

- Codeblocks

https://icons8.com/icons/set/code-blocks

- OnlineGDB (https://www.onlinegdb.com/)

- Real-Time Collaborative Online IDE (https://ide.usaco.guide/)



Textbooks (We focusing on C++11)

- ***Learn C++ Programming by Refactoring* (由重構學習 C++ 程式設計). Pang-Feng Liu (劉邦鋒). NTU Press. 2023.**
- ***C++ Primer. 5th Edition.* Stanley B. Lippman, Josée Lajoie, Barbara E. Moo. 2019.**
- *Effective C++*. Scott Meyers. O'Reilly. 2016.
- *Thinking in C++. Vol. 1: Introducing to Standard C++*. 2nd Edition. Bruce Eckel. Prentice Hall PTR. 2000.

Useful Resources

- Tutorialspoint
  - https://www.tutorialspoint.com/cplusplus/index.htm
  - Online C++ Compiler
- Programiz
  - https://www.programiz.com/cpp-programming
- LEARN C++
  - https://www.learncpp.com/
- MIT OpenCourseWare - Introduction to C++
  - https://ocw.mit.edu/courses/6-096-introduction-to-c-january-iap-2011/pages/lecture-notes/
- Learning C++ Programming
  - https://www.programiz.com/cpp-programming
- GeeksforGeeks
  - https://www.geeksforgeeks.org/c-plus-plus/

Standard Template Library (STL)

- Standard Template Library (STL) is a powerful library in C++ that provides a collection of **generic data structures** and **algorithms** to simplify common programming tasks.
  - It is based on **templates.**
  - **Goal:** Facilitate development of reusable and efficient codes.
- Key components:
  - **Containers** (+Adapters): Data structures that store objects.
  - **Algorithms**: Predefined functions or operations.
  - **Iterators**: Objects that help traverse elements in the containers.
  - **Functor**: Classes that overload operator() to work as functions.

Containers

- Sequence Containers:
  - `vector`, `deque`, `list`, , `array`
- Associative Containers:
  - `set`, `map`, `multiset`, `multimap`
- Unordered Containers:
  - `unordered_set, unordered_map`
- Container Adapters:
  - `stack, queue, priority_queue`

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Due to the matter of time, we will only briefly discuss some of them.

Refer to the official documents for more details.

Sequence Containers:

Elements are stored in an ordered fashion!

vector (#include<vector>)

Task	Example: std::vector<int>

Create a vector;
8 copies of zero;
5 copies of 3
	vector<int> v;
	vector<int> v(8);
	vector<int> v(5, 3);

Add k to the end of a vector v	v.push_back(k)
Remove the last element in a vector v	v.pop_back();
Clear the vector	v.clear();
Get the element at index i	w = v.at(i); w = v[i];

Note:

```
std::vector<int> v = { 9, 7 };
v[2] = 5; // undefined; out of bound
```

`vector` (contd.)

Task	Example: `std::vector<int>`
Check if the vector is empty	`if (v.empty())`
Insert `w` at some index `i` of the vector	`v.insert(v.begin()+i, k)`
Remove the element at index `i` of the vector	`v.erase(v.begin()+i)`
Get the sublist in indices `[i, j)`	`vector<int>c(v.begin()+i, v.begin()+j);`
Request capacity for a vector	`v.reserve(100000);`

Note:
`v.begin()` and `v.end()` are iterators (we will introduce them later).

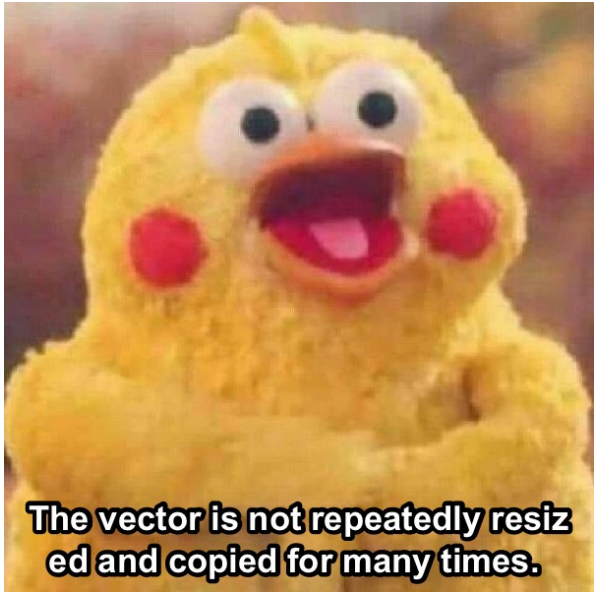
Benefit of `vector<T>.reserve()`

- **Example**: Create a vector of a large number of integers.

```
std::vector<int> v;
for (size_t i = 0; i < 1000000; ++i) {
    v.push_back(i);
}
```

⇕

```
std::vector<int> v;
v.reserve(1000000);
for (size_t i = 0; i < 1000000; ++i) {
    v.push_back(i);
}
```



deque: Similar to vector (#include<deque>)

- `deque` (double-ended queue) supports faster insertion anywhere.

```
deque<int> dq{3, 4}; // {3, 4}
dq.push_front(2); // {2, 3, 4}
dq.pop_back(); // {2, 3}
dq[1] = 0; // {2, 0}
```

Note:
`deque` has `push_front()` and `pop_front()`, while `vector` doesn't.

Container Adapters

- A wrapper of an (other STL) object that changes **how external users can interact with that object.**
- It modifies or restricts the **interface** of existing sequence containers (`vector`, `deque`, `list`) to provide a **specialized behavior**.
- Examples: `stack, qeque, priority_queue`
  - Will be introduced in *Data Structures* course in detail.

Stack (#include<stack>)

https://cplusplus.com/reference/stack/stack/

- Implementation of LIFO (last-in-first-out) structure.

std::stack<T>

class template

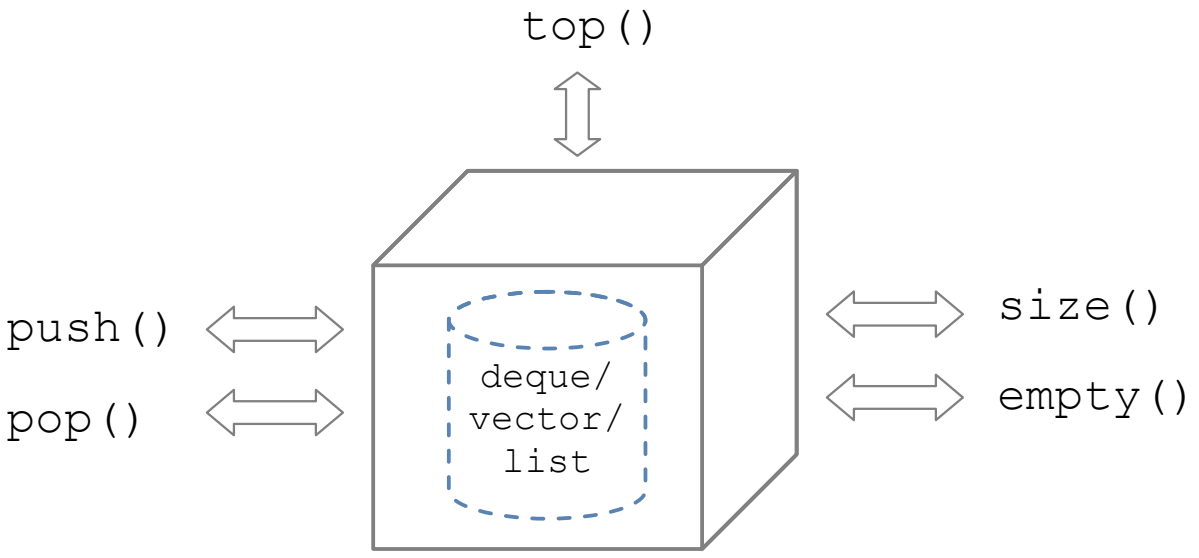
std::stack <stack>

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

LIFO stack

Stacks are a type of container adaptor, specifically designed to operate in a LIFO context (last-in first-out), where elements are inserted and extracted only from one end of the container.

stacks are implemented as ***container adaptors***, which are classes that use an encapsulated object of a specific container class as its ***underlying container***, providing a specific set of member functions to access its elements. Elements are ***pushed***/***popped*** from the ***"back"*** of the specific container, which is known as the ***top*** of the stack.



Queue
(#include<queue>)

https://cplusplus.com/reference/queue/queue/

- Implementation of FIFO (first-in-first-out) structure.

`std::queue<T>`

class template

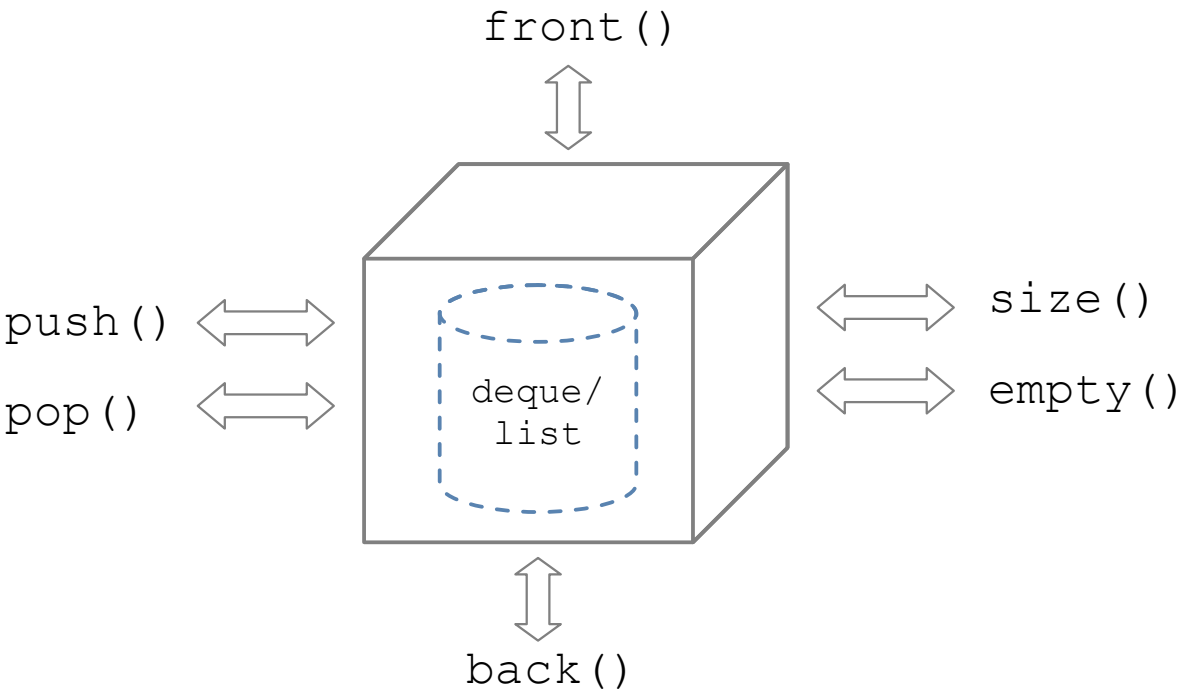
std::queue <queue>

```
template <class T, class Container = deque<T> > class queue;
```

FIFO queue

queues are a type of container adaptor, specifically designed to operate in a FIFO context (first-in first-out), where elements are inserted into one end of the container and extracted from the other.

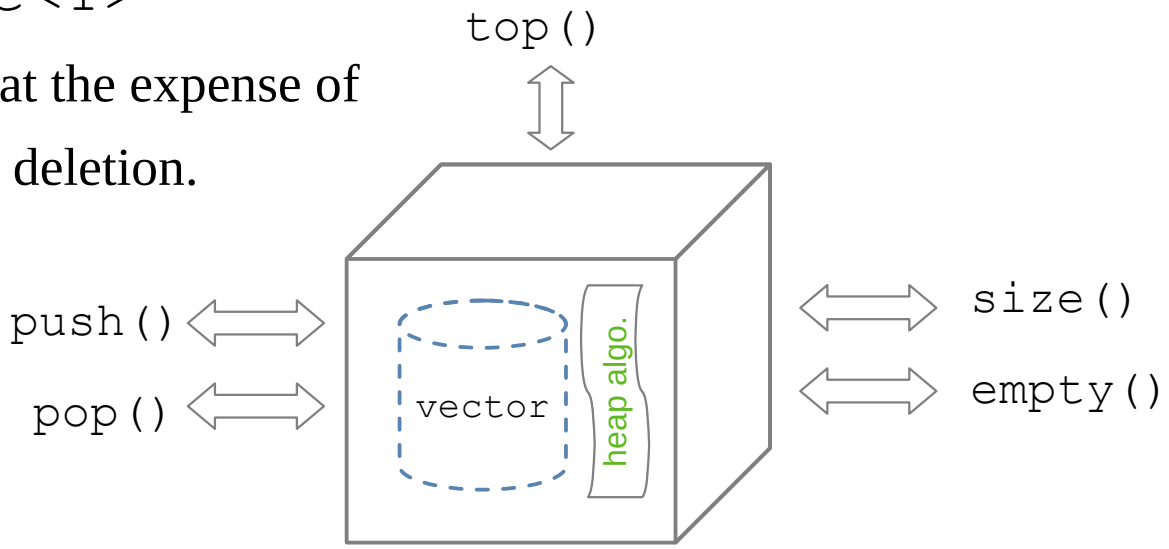
queues are implemented as ***containers adaptors***, which are classes that use an encapsulated object of a specific container class as its ***underlying container***, providing a specific set of member functions to access its elements. Elements are ***pushed*** into the ***"back"*** of the specific container and ***popped*** from its ***"front"***.



priority_queue
(#include<queue>)

- Implementation of heap-based priority queue structure.
  - Elements are ranked based on a certain priority.

    `std::priority_queue<T>`
  - It supports constant time lookup at the expense of logarithmic time of insertion and deletion.



priority_queue

https://cplusplus.com/reference/queue/priority_queue/

class template

<queue>

std::priority_queue

```
template <class T, class Container = vector<T>, class Compare = less<typename Container::value_type> > class priority_queue;
```

Priority queue

Priority queues are a type of container adaptors, specifically designed such that its first element is always the greatest of the elements it contains, according to some ***strict weak ordering*** criterion.

This context is similar to a ***heap***, where elements can be inserted at any moment, and only the ***max heap*** element can be retrieved (the one at the top in the ***priority queue***).

Priority queues are implemented as ***container adaptors***, which are classes that use an encapsulated object of a specific container class as its ***underlying container***, providing a specific set of member functions to access its elements. Elements are ***popped*** from the ***"back"*** of the specific container, which is known as the ***top*** of the priority queue.

Illustrating Examples

class template

std::stack

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

```
// Container = std::deque
std::stack<int> stack_deq;
// Container = std::vector
std::stack<int, std::vector<int>> stack_vec;
// Container = std::list
std::stack<int, std::list<int>> stack_list;
```

Associative Containers:

Elements are organized and managed automatically using **keys**!

Elements are stored using a specific ordering mechanism so that it’s more efficient for searching, insertion and deletion

map (#include<map>)

Task	Example: `std::map<int, char>`
Create a map	`map<int, char> m;`
Add key `k` with value `v` into the map	`m.insert({k, v});` `m[k] = v;`
Remove key `k` from the map	`m.erase(k);`
Check if key `k` is in the map	`if (m.count(k))`
Check if the map is empty	`if (m.empty())`
Retrieve or overwrite value associated with key `k`	`char c = m[k];` `m[k] = v;`

Note: Actually, the underlying type stored in `std::map<K, V>` is `std::pair<const K, V>`

Comparison operator is required for `map` (also for set)

```
class Person {
public:
    std::string name;
    int age;
    Person(std::string n, int a) : name(n), age(a) {}
};
```

```
std::map<int, int> map1; // OKAY - comparable
std::map<Person, int> map2; // ERROR - not comparable
// No operator < defined for Person!
```

Iterators

Have a look at looping over a collection

```
std::vector<int> v{5, 4, 3, 2, 1, 0};
for (size_t i=0; i < v.size(); i++) { // looks good!
    const auto& e = v[i];
    cout << e << endl;
}
// The following way looks great, too.
for (auto &e: v) {
    cout << e << endl;
}
// But how about looping over a set or a map?
// some_element++?? What does ++ mean here?
```

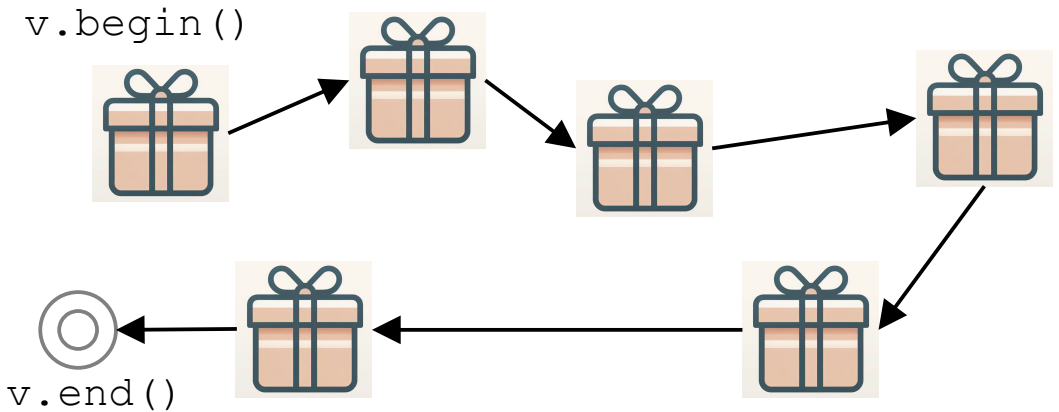
Note: Structured binding is available in C++17, not C++11.

```
std::map<int, char> m;
for (const auto& [key, value]: m) // structure binding here
    // work with key, value ...
```

Iterators

```
auto it = v.begin()
```

- Iterator can help in iterating over ANY container.
- It becomes more flexible and consistent to traverse and manipulate elements in a container (say `v`).
- The iterator always knows “the next element”.



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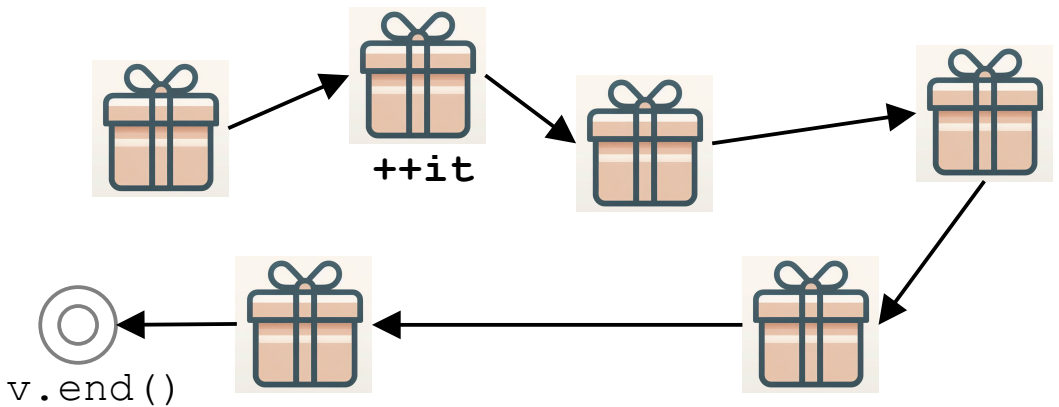

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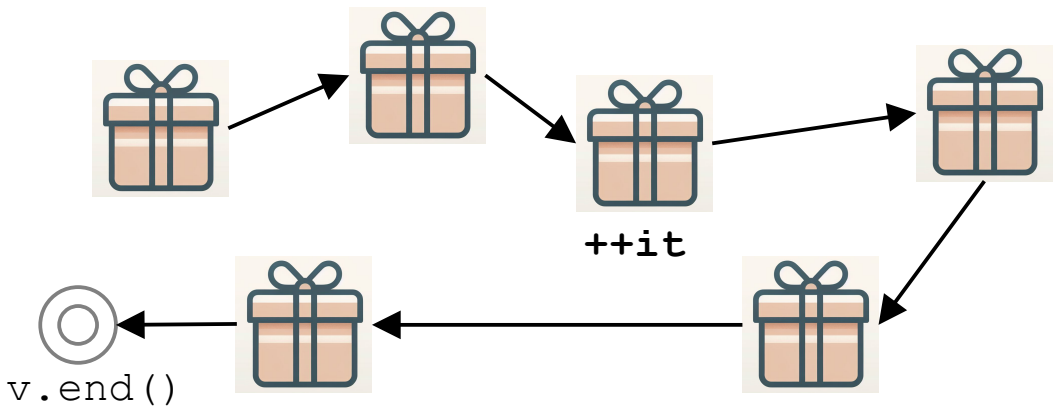

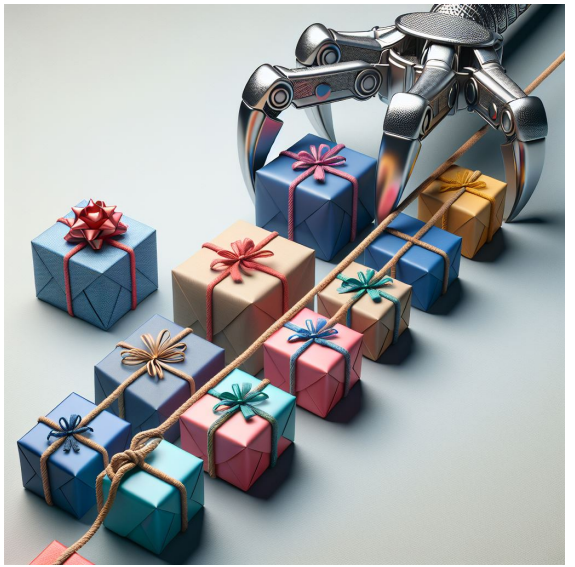

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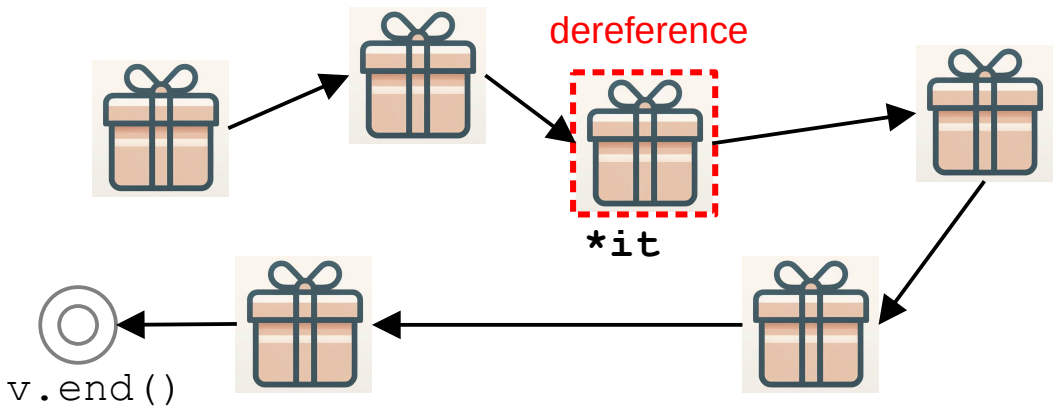

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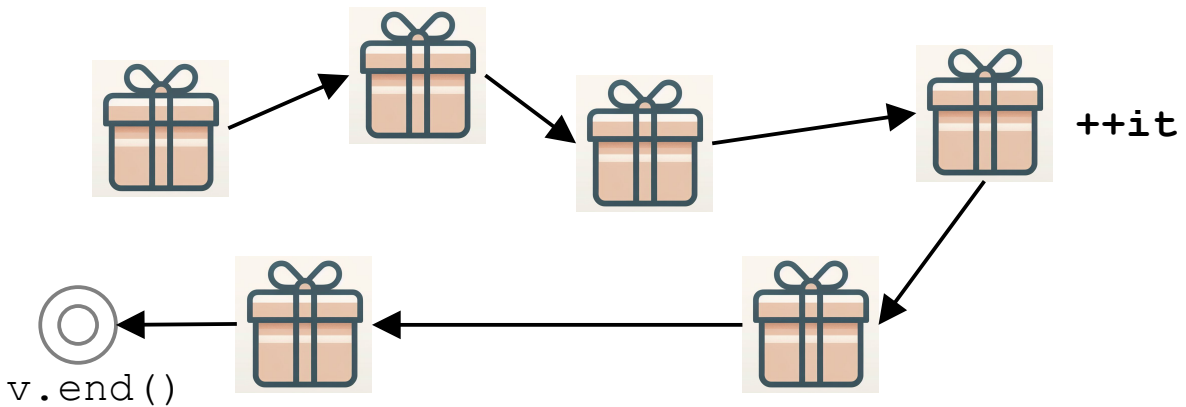

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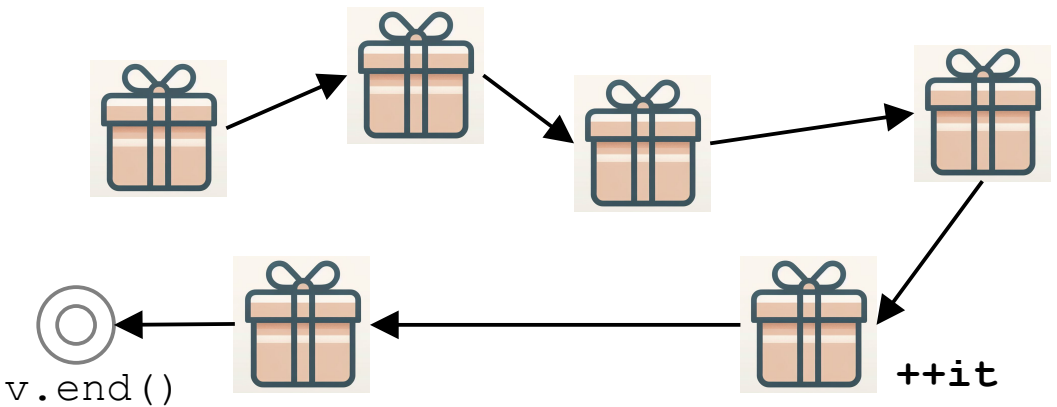

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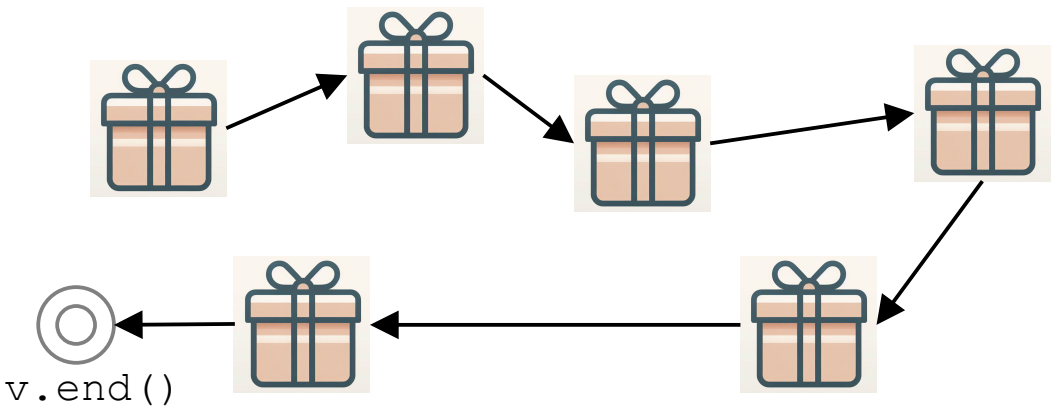

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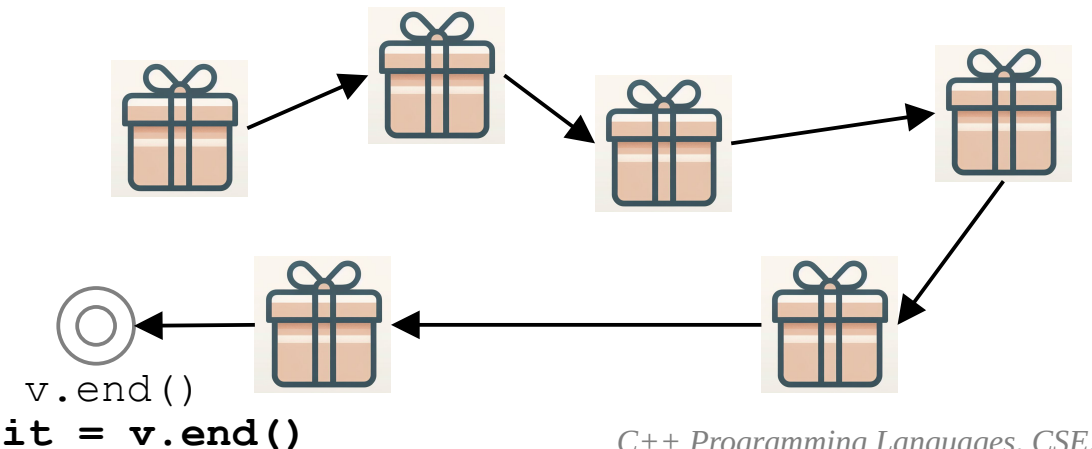


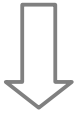
Why use `++it` instead of `it++`?

- `++it` increments the iterator first and then returns the updated iterator.
- `it++` returns the current iterator first, and then increments it.
  - An extra step is required here! We have to store a copy of the original iterator!

- However, it still depends on the scenario.

Example: Printing all elements in a map

```
std::map<int, int> map {{1, 6}, {1, 8}, {0, 3}, {3, 9}};
for (auto iter = map.begin(); iter != map.end(); ++iter) {
    const auto& [key, value] = *iter; // structured binding!
    cout << key << ":" << value << endl;
}
```



```
std::map<int, int> map {{1, 6}, {1, 8}, {0, 3}, {3, 9}};
for (auto iter = map.begin(); iter != map.end(); ++iter) {
    const auto& key = (*iter).first; //resolving the issue in C++11
    const auto& value = (*iter).second;
    cout << key << ":" << value << endl;
}
```

Discussions & Questions