

Lesson 7: Iterate



Array iteration, iterators

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1. Iterators

2. The C++ Iterator Pattern
3. Linked-List Iterators
4. Generic Programming



Iterators

- One common task you want to do on a collection of objects is to iterate through each component
- If we have a standardised method for all collections then it is much easier to remember what to do
- But we can also write code that works for any collection that follows this pattern
- This pattern is known as the **iterator pattern**
- The pattern was first developed in C++, but is commonly used in many other languages

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- In C we would typically use a for-loop to iterate over an array

```
int n = 10; // size of array
int* begin = malloc(n*sizeof(10)); // malloc returns beginning of arry
int* end = begin + n; // address past end of array

int sum = 0;
for(int* pt = begin; pt != end; pt++) { // need to dereference pointer
    sum += *pt;
}
```

- Ugly, but efficient

- Acts a prototype for C++ iterators

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C++ Iterator Pattern

- The C++ iterator pattern says for every `Container<T>` we create a nested class called `Container::iterator` which acts as a pointer (for arrays this could just be a pointer to the array)
- The class should implement
 - * a dereferencing operator `T operator*()`
 - * an increment operator `operator++()`
 - * a not equal function `bool operator!=(const ITER&, const ITER&)` where `ITER` is `Container::iterator`

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A Beginning and an Ending

- In addition the container should have two methods
 - * `begin()`
 - * `end()`
- that return iterators representing the first element and an iterator representing one position past the last element
- Wow! That seems awfully complicated
- Don't panic! We can hack this

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Minimal Iterator

```
template <typename>
class Container<T> {
private:
    class iterator { // this is a nested class
public:
    iterator() {...} // constructor
    iterator operator++() {...} // increment
    T& operator*() {...} // dereference
    friend bool operator!=(const iterator&, const iterator&){ // code to determine inequality
    }
}

public:
    iterator begin() {...} // return begin iter
    iterator end() {...} // return end iter
}
```

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Array-based iterators

- For array based containers such as vector we don't actually need to create an iterator class as we can just use the normal pointer

```
template <typename T>
class Array {
private:
    T *data;
    unsigned length;
    unsigned capacity;

public:
    ...
    typedef T* iterator;           // iterator is pseudonym for T*
    iterator begin() {return data; }
    iterator end() {return data+length; }
};
```

- That's all we need!

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Outline

1. Iterators
2. The C++ Iterator Pattern
3. **Linked-List Iterators**
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Linked-List

```
template <typename T>
class MyList { // My linked list class
private:
    struct Node{ // A simple node nested class
        Node(T value, Node *node): value(value), next(node) {}
        T value;
        Node *next;
    };

    struct iterator { // An iterator class
        Node* entry; // Holds node pointer
        iterator(Node* pt): entry(pt) {} // constructor
        T& operator*() {return entry->value;} // dereferencing
        iterator operator++() { // next entry
            entry = entry->next;
            return iterator(entry);
        }
        bool operator==(const iterator& other) const {
            return entry != other.entry;
        }
};
```

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Increment Operators

- C++ has a pre-increment operator `++a` and a post-increment operator `a++`
- The pre-increment operator increments `a` and returns the incremented version, e.g.
`T& operator++() {++count; return *this;} // defines ++`
- The post-increment operator copies `a` increments it and returns the copy, e.g.
`T operator++(int) {T b=a; ++count; return b;} // defines a++`
- The `int` argument is not used, but tells the compiler which increment is which
- We might want to implement `it++`

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Using Array Iterators

```
main() {
    Array<string> elements(4): {"earth", "water", "wind", "fire"};
    for(Array::iterator it=elements.begin(); it!=elements.end(); ++it) {
        cout << *it << endl;
    }

    for(auto it=elements.begin(); it!=elements.end(); ++it) {
        cout << *it << endl;
    }

    for(string& element: elements) { // range-based loop
        cout << element << endl;
    }
}
```

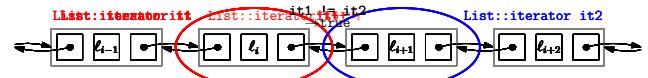
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Linked-List Iterators

- Linked-lists are not array based
- To use the iterator we need to implement the iterator class
- The object instantiated from the class should represent the position we are in the linked list



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Linked-List

```
template <typename T>
class MyList {
private:
    struct Node{...}
    struct iterator {...}

    Node* head; // head of linked list
    unsigned no_elements;

public:
    MyList(): head(nullptr), no_elements(0) {}
    void add(T value) {}

    iterator begin() {return iterator(head);}
    iterator end() {return iterator(nullptr);}
};
```

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Const Iterators

- C++ uses the compiler to test whether functions change their argument or not

```
func1(Class obj) // obj is copied so will only modify copy
func2(Class& obj) // passed by reference, might change obj
func3(const Class& obj) // will not change obj
```

- func3 will only call methods of Obj that are const

```
class Class {
    void method() const; // won't change the object
    void change(); // might change the object
};
```

- We want to declare a `const_iterator` with

```
const T& operator*() const // const dereferencing operator
```

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Bidirectional Iterators

- For the linked list we have implemented a **forward iterator**
- This is the only iterator possible for a singly linked list
- For a doubly linked list we can implement a **bidirectional iterator**
- This requires us to implement the decrement operators

```
T& operator--(); // implements --obj
T operator--(int); //implements obj--
```

- There also exist **random-access iterators** that implements methods including

```
T& operator[int i] // returns i'th element
operator+=[int i] // move forward i places
```

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Range-Based For Loop

- C++ allows you to iterate over collections elegantly

```
Collection<string> collection;
for (string& element: collection) {
    print(element); // or whatever function you want
}
```

- This is syntactic sugar! The compiler just replaces this with

```
for(auto& it=collection.begin(); it!=collection.end(); ++it) {
    print(*it);
}
```
- This works for any class that has an iterator
- **auto** just works out the correct type
- By being pretty ranged-based for loops reduce bugs in code

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std::algorithm

- The standard template library includes a library `<algorithm>` that uses iterators to offer generic algorithms
- There are a lot of algorithms available, e.g.
 - ★ `count_if()`: counts elements that satisfies condition
 - ★ `max_element()`: returns maximum element
 - ★ `find()`: find an element
 - ★ `find_if()`: find first element that satisfies condition
 - ★ `all_of()`: true if all elements satisfy condition
 - ★ `any_of()`: true if any element satisfies condition

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Sorting and Searching

- `reverse()`: reverse range
- `rotate()`: cyclically rotate range
- `shuffle()`: random shuffle
- `sort()`: sort collection
- `stable_sort()`: use a stable sort
- `make_heap()`: make a heap
- `binary_search()`: use binary search

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Generic Algorithms

- Iterators allow us to write generic functions

- E.g. summing elements

```
template <typename Iter, typename T>
T accum(Iter it, Iter end, T init) {
    for(; it != end; ++it)
        init += *it;
    return init;
}
```

- This will sum many collections

```
int array[20];
vector<double> v[5];
set<int> s;

cout << " array sum = " << accum(&array[0], &array[20], 0) << endl;
cout << "vector sum = " << accum(v.begin(), v.end(), 0.0) << endl;
cout << " set sum = " << accum(s.begin(), s.end(), 0) << endl;
```

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Modifying Algorithms

- `for_each()`: perform operation of each element
- `move()`: move elements in a range
- `copy()`: copy range of elements
- `copy_if()`: copy range if condition is true
- `merge()`: merge two ranges
- `replace_if()`: replace element if ...

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Why Use Algorithms

- This is just a selection of some algorithms available
- Using these algorithms you will get a correct and efficient implementation
- You could write them yourself, but by when you use standard algorithms it makes your code very readable and maintainable
- It is slightly disappointing you don't get to write your own algorithms as they are cool but you will end up with much more solid code

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Lessons

- C++ iterators are not the easiest thing to get your head around
- They are the major tool for writing generic algorithms
- Once you get used to them, they are not that difficult to code
- They also provide a classic example of how to build generic systems
- Learning to use the `<algorithm>` will take you to yet another level