

Algorithms and Analysis

Lesson 7: Iterate



Array iteration, iterators

Outline

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
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- The pattern was first developed in C++, but is commonly used in many other languages

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Iterating Over C Arrays

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

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

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- Ugly, but efficient
- Acts as 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

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 - ★ `begin()`
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- Wow! That seems awfully complicated
- Don't panic! We can hack this

Minimal Iterator

```
template <typename>
class Container<T> {
private:

    class iterator { // this is a nested class
public:
    iterator() {...} // constructor
    iterator operator++() {...} // increment
    T& operator*() {...} // dereference
    bool operator==(const iterator& rhs) {
        // code to determine inequality
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public:
    iterator begin() {...} // return begin 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; }
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- That's all we need

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) {  
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    }  
  
    for(string& element: elements) { // range-based loop  
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- 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

Linked-List Iterators

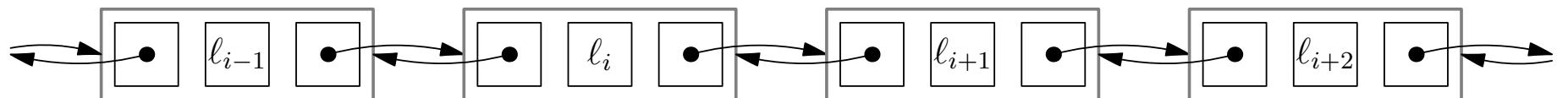
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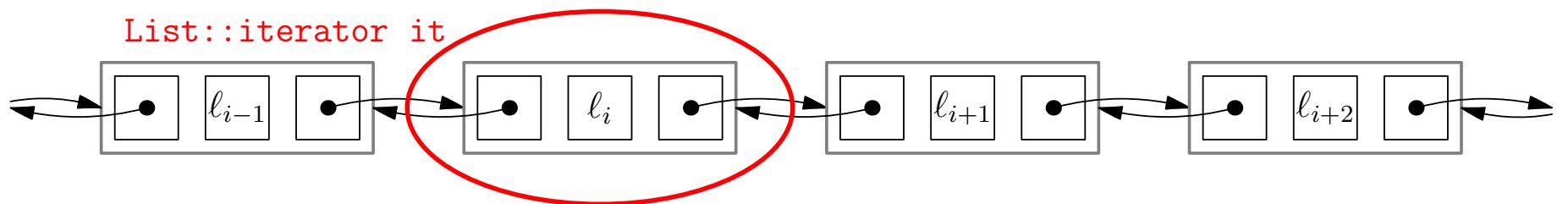
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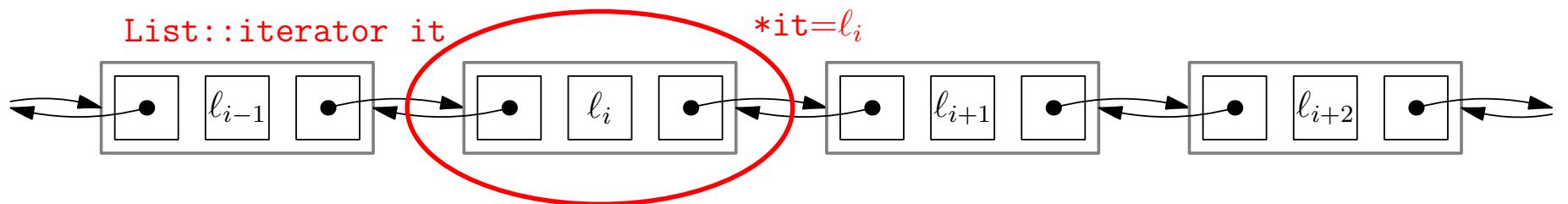
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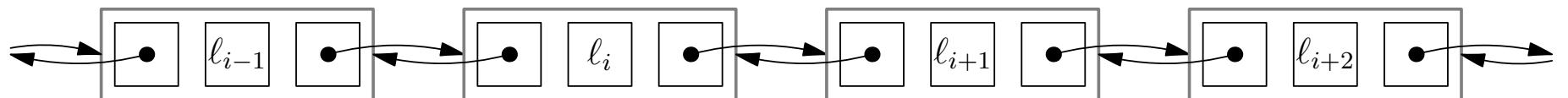
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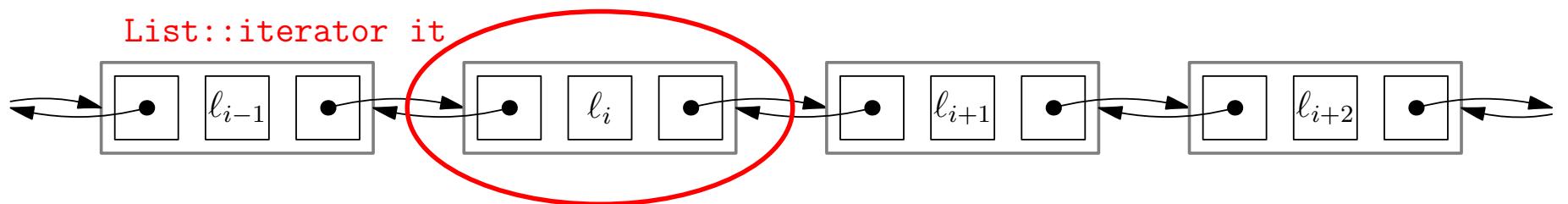
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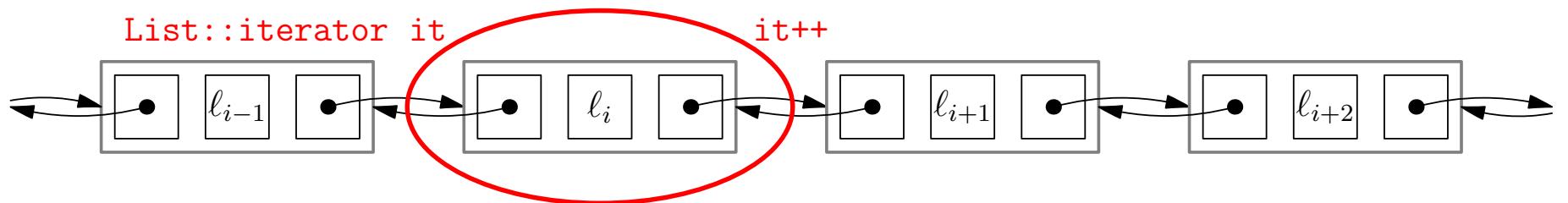
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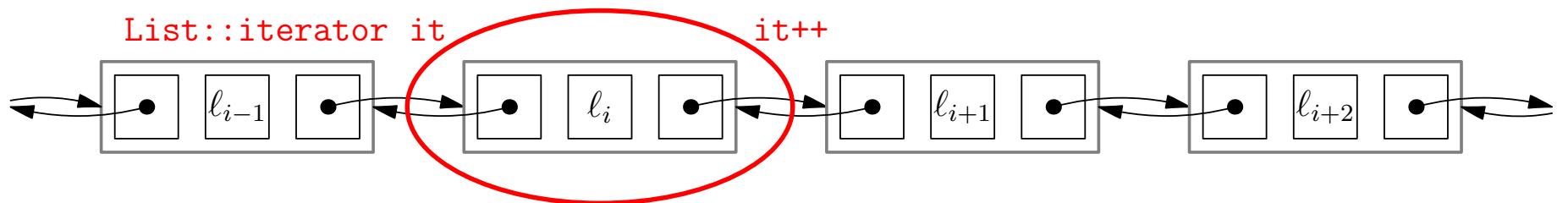
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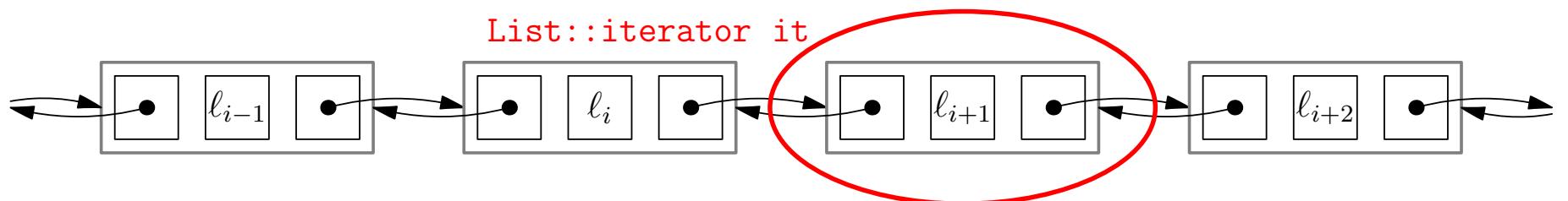
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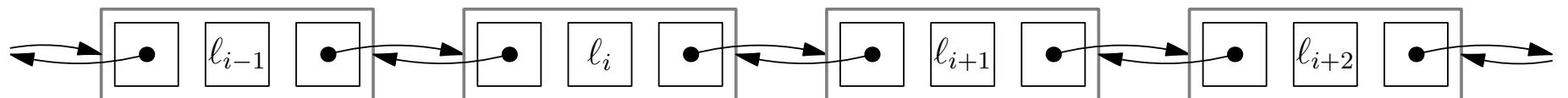
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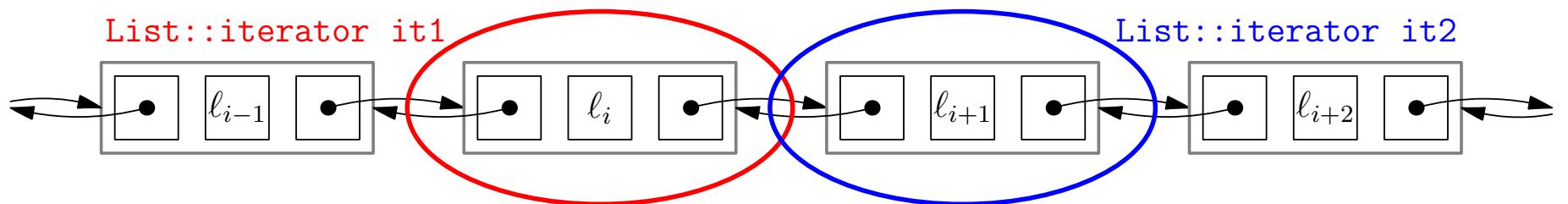
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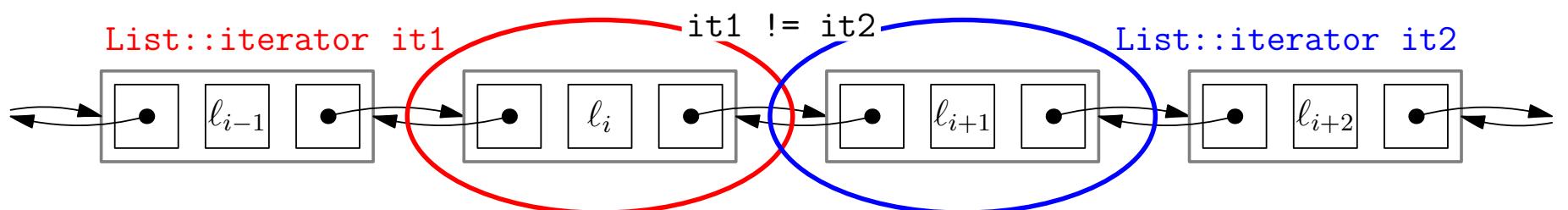
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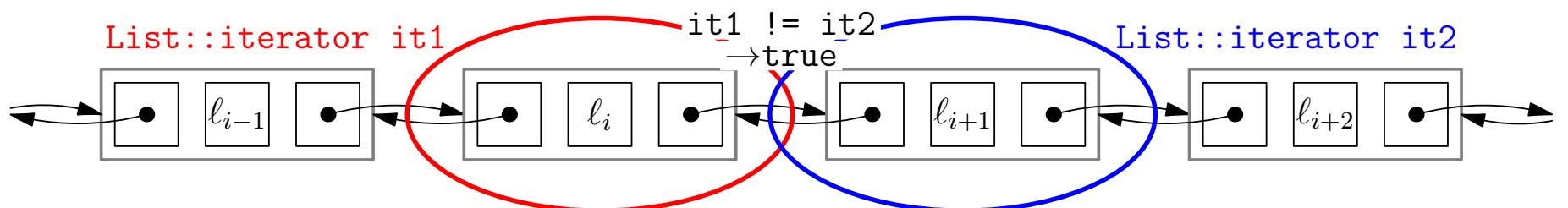
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    iterator end() { return iterator(nullptr); }
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Increment Operators

- C++ has a pre-increment operator `++a` and a post-increment operator `a++`

- The pre-increment operator increments `it` and returns the incremented version, e.g.

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T& operator++() {++pt; return pt->value;} // defines ++it
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- The post-increment operator copies `it` increments it and returns the copy, e.g.

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T operator++(int) {T v = pt->value; ++pt; return v;} // defines it++
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- The `int` argument is not used, but tells the compiler which increment is which
- We might want to implement `it++`

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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Outline

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



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

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- 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

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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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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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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Sorting and Searching

- `reverse()`: reverse range
- `rotate()`: cyclically rotate range
- `shuffle()`: random shuffle
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- 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
- It is slightly disappointing you don't get to write your own algorithms as they are cool

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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

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