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
- This pattern is known as the **iterator pattern**
- The pattern was first developed in C++, but is commonly used in many other languages

Iterating Over C Arrays

- 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 arr
int* end = begin + n;                 // address past end of array

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

- 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 derefenecing operator `T operator*()`
  - an increment operator `operator++()`
  - a not equal function
    `bool operator!=(const ITER&, const ITER&)`
    where `ITER` is `container::iterator`

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

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

}
```

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

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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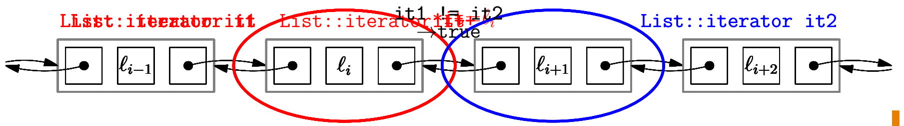
Linked-List Iterators

- 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



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;
    }
  };
```


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);}
}
```


Increment Operators

- C++ has a pre-increment opeator `++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 ++a
```

- 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++`

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 derefencing operator
```

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
```


Outline

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 syntatic 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

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;
```

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

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 ...

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

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

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