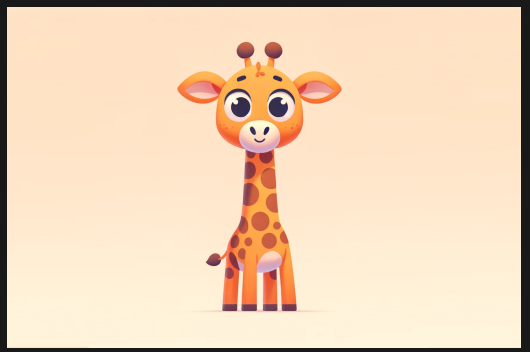
COMP6771

Custom Iterators

Lecture 4.2

Author(s): Hayden Smith



(Download as PDF)

In This Lecture

- **Why? 🤔**
  - When we define our own types, if we want them to be iterable we need to define that functionality ourselves.

- **What? 📰**
  - Custom Iterators
  - Iterator Invalidation
  - Iterator Types

📚 Iterator Revision

- Iterator is an abstract notion of a pointer
- Iterators are types that abstract container data as a sequence of objects
- The glue between containers and algorithms
  - Designers of algorithms don't care about details about data structures
  - Designers of data structures don't have to provide extensive access operations

```
1 std::vector v{1, 2, 3, 4, 5};
2 ++(*v.begin()); // vector<int>'s non-const iterator
3 *v.begin(); // vector<int>'s const iterator
4 v.cbegin(); // vector<int>'s const iterator
```

🤦 Iterator Invalidation

- What happens when we modify the container?
  - What happens to iterators?
  - What happens to references to elements?
- Using an invalid iterator is undefined behaviour

```cpp
#include <vector>

int main()
{
    std::vector v { 1, 2, 3, 4, 5 };
    // Copy all 2s
    for (auto it = v.begin(); it != v.end(); ++it) {
        if (*it == 2) {
            v.push_back(2);
        }
    }
    // Erase all 2s
    for (auto it = v.begin(); it != v.end(); ++it) {
        if (*it == 2) {
            v.erase(it);
        }
    }
}
```

iterator-invalidate.cpp

🤦 Iterator Invalidation

- **push_back**
  - Think about the way a vector is stored
  - "If the new size() is greater than capacity() then all iterators and references (including the past-the-end iterator) are invalidated. Otherwise only the past-the-end iterator is invalidated."

```cpp
#include <vector>

int main()
{
    std::vector v { 1, 2, 3, 4, 5 };
    // Copy all 2s
    for (auto it = v.begin(); it != v.end(); ++it) {
        if (*it == 2) {
            v.push_back(2);
        }
    }
}
```

vector-invalidate.cpp

🤦 Iterator Invalidation

- **erase**
  - "Invalidates iterators and references at or after the point of the erase, including the end() iterator."
  - For this reason, erase returns a new iterator

```cpp
#include <vector>

int main()
{
    std::vector v { 1, 2, 3, 4, 5 };
    // Erase all even numbers (C++11 and later)
    for (auto it = v.begin(); it != v.end();) {
        if (*it % 2 == 0) {
            it = v.erase(it);
        } else {
            ++it;
        }
    }
}
```

erase-invalidate.cpp

🙅 Iterator Invalidation

- In general:
  - Containers generally don't invalidate when you modify values
  - But they may invalidate when removing or adding elements
  - std::vector invalidates everything when adding elements
  - std::unordered_(map/set) invalidates everything when adding elements

 Iterator Traits

- Each iterator has certain properties
  - Category (input, output, forward, bidirectional, random-access)
  - Value type (T)
  - Reference Type (T& or const T&)
  - Pointer Type (T* or T* const)
    - Not strictly required
  - Difference Type (type used to count how far it is between iterators)
- When writing your own iterator, you need to tell the compiler what each of these are

📖 Iterator Requirements

A custom iterator class should look, at minimum, like this

```cpp
class Iterator {
public:
    using iterator_category = std::forward_iterator_tag;
    using value_type = T;
    using reference = T&;
    using pointer = T*; // Not strictly required, but nice to have.
    using difference_type = int;

    reference operator*() const;
    Iterator& operator++();
    Iterator operator++(int)
    {
        auto copy { *this };
        ++(*this);
        return copy;
    }
    // This one isn't strictly required, but it's nice to have.
    pointer operator->() const { return &(operator*()); }

    friend bool operator==(const Iterator& lhs, const Iterator& rhs) {... };
    friend bool operator!=(const Iterator& lhs, const Iterator& rhs) { return !(lhs == rhs); }
};
```

custom-iter-class.cpp

Container Requirements

- All a container needs to do is to allow std::[cr]begin / std::[cr]end
  - This allows use in range-for loops, and std algorithms
- Easiest way is to define begin/end/cbegin/cend methods
- By convention, we also define a type Container::[const_]iterator

```
1  class Container {
2      // Make the iterator using one of these by convention.
3      class iterator {
4          ...
5      };
6      using iterator = ...;
7
8      // Need to define these.
9      iterator begin();
10     iterator end();
11
12     // If you want const iterators (hint: you do), define these.
13     const_iterator begin() const { return cbegin(); }
14     const_iterator cbegin() const;
15     const_iterator end() const { return cend(); }
16     const_iterator cend() const;
17 };
```

container-requirements.cpp

🔃 Custom Bidirectional Iterators

- Need to define operator--() on your iterator
  - Need to move from c.end() to the last element
    - c.end() can't just be nullptr
- Need to define the following on your container:

```
1  class Container {
2      // Make the iterator
3      class reverse_iterator {
4          ...
5      };
6      // or
7      using reverse_iterator = ...;
8
9      // Need to define these.
10     reverse_iterator rbegin();
11     reverse_iterator rend();
12
13     // If you want const reverse iterators (hint: you do), define these.
14     const_reverse_iterator rbegin() const { return crbegin(); }
15     const_reverse_iterator crbegin();
16     const_reverse_iterator rend() const { return crend(); }
17     const_reverse_iterator crend() const;
18 };
```

custom-bidirectional.cpp

⏮ Automatic Reverse Iterators

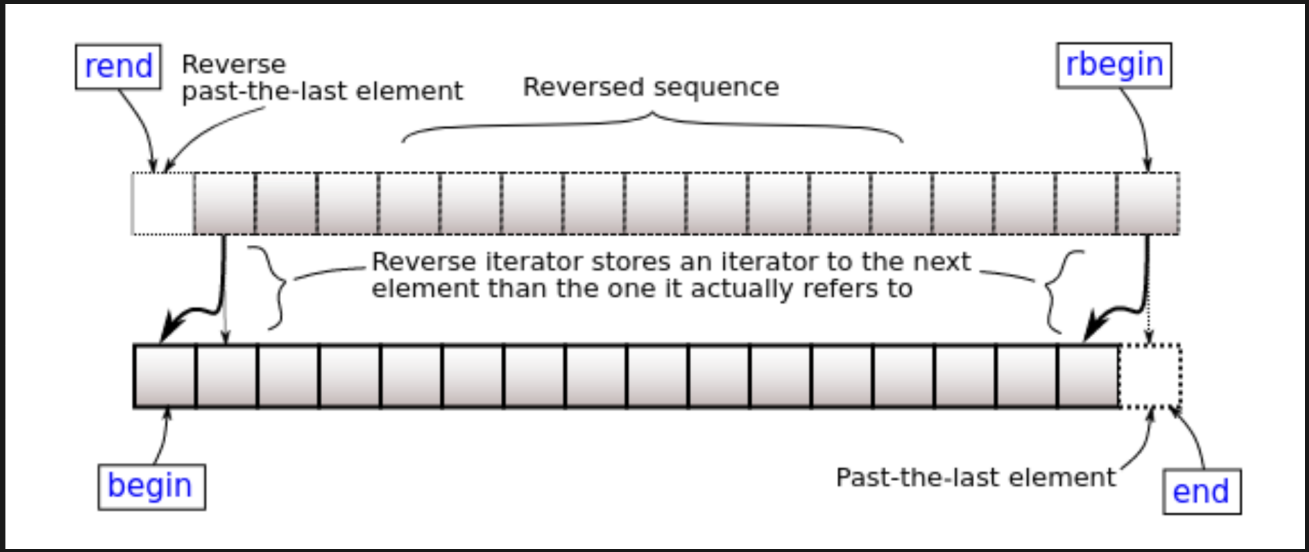
- Reverse iterators can be created by std::reverse_iterator
  - Requires a bidirectional iterator
- You should be able to just copy-and-paste the following code

```cpp
class Container {
    // Make the iterator using these.
    using reverse_iterator = std::reverse_iterator<iterator>;
    using const_reverse_iterator = std::reverse_iterator<const_iterator>;

    // Need to define these.
    reverse_iterator rbegin() { return reverse_iterator { end() }; }
    reverse_iterator rend() { return reverse_iterator { begin() }; }

    // If you want const reverse iterators (hint: you do), define these.
    const_reverse_iterator rbegin() const { return crbegin(); }
    const_reverse_iterator rend() const { return crend(); }
    const_reverse_iterator crbegin() const { return const_reverse_iterator { cend() }; }
    const_reverse_iterator crend() const { return const_reverse_iterator { cbegin() }; }
};
```

auto-reverse.cpp

⏮ Automatic Reverse Iterators

- Reverse iterators can be created by std::reverse_iterator
  - rbegin() stores end(), so *rbegin is actually *(--end())



🔀 Random Access Iterators

- Reverse iterators can be created by std::reverse_iterator
  - Requires a bidirectional iterator
- You should be able to just copy-and-paste the following code

```
class Iterator {
    ... using reference = T&;
    using difference_type = int;

    Iterator& operator+=(difference_type rhs) {... } Iterator& operator-=(difference_type rhs) { return *this += (-rhs); }
    reference operator[](difference_type index) { return *(*this + index); }

    friend Iterator operator+(const Iterator& lhs, difference_type rhs)
    {
        Iterator copy { *this };
        return copy += rhs;
    }
    friend Iterator operator+(difference_type lhs, const Iterator& rhs) { return rhs + lhs; }
    friend Iterator operator-(const Iterator& lhs, difference_type rhs) { return lhs + (-rhs); }
    friend difference_type operator-(const Iterator& lhs, const Iterator& rhs) { ... }

    friend bool operator<(Iterator lhs, Iterator rhs) { return rhs - lhs > 0; }
    friend bool operator>(Iterator lhs, Iterator rhs) { return rhs - lhs < 0; }
    friend bool operator<=(Iterator lhs, Iterator rhs) { !(lhs > rhs); }
    friend bool operator>=(Iterator lhs, Iterator rhs) { !(lhs < rhs); }
}
```

random-access.cpp

🦻 Feedback

Or go to the form here.