

Making `std::vector` constexpr

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1 Revision history

- R0 – Initial draft
- R1 –
 - Per LEWG guidance in RAP, specify that `std::vector`’s iterators are constexpr iterators, as defined in [P0858R0].
 - Remove an easter egg from the wording – I don’t mess with LWG.
 - Other minor fixes from LWG Batavia meeting.

2 Abstract

`std::vector` is not currently **constexpr** friendly. With the loosening of requirements on **constexpr** in [P0784R1] and related papers, we can now make `std::vector` **constexpr**, and we should in order to support the **constexpr** reflection effort (and other evident use cases).

3 Encountered issues

We surveyed the implementation of `std::vector` in libcpp and noted the following issues:

- ASAN and debug annotations (like iterator invalidation checks) can’t work in **constexpr**.
- Assertions won’t work in **constexpr**.
- `pointer_traits<T*>::pointer_to` is used but is not currently **constexpr**.
- Try-catch blocks are used in some places (e.g. `std::vector::insert`), but those can’t appear in **constexpr**.
- Note that making `std::swap` **constexpr** is not a problem since the resolution of [P0859R0], according to Richard Smith.

Assertion and ASAN annotations can be handled by having a mechanism to detect when a function is evaluated as part of a constant expression, as proposed in [P0595R0].

`std::pointer_traits` can be made `constexpr` in the cases we care about; this is handled by P1006, which should be published in the same mailing as this paper.

Try-catch blocks could be allowed inside `constexpr`; this is handled by P1002, which should be published in the same mailing as this paper.

4 Proposed wording

This wording is based on the working draft [N4727]. We basically mark all the member and non-member functions of `std::vector` `constexpr`.

Change in [vector.syn] 21.3.6:

```
#include <initializer_list>

namespace std {
    // 21.3.11, class template vector
    template<class T, class Allocator = allocator<T>> class vector;

    template<class T, class Allocator>
        constexpr bool operator==(const vector<T, Allocator>& x, const vector<T, Allocator>& y);
    template<class T, class Allocator>
        constexpr bool operator!=(const vector<T, Allocator>& x, const vector<T, Allocator>& y);
    template<class T, class Allocator>
        constexpr bool operator< (const vector<T, Allocator>& x, const vector<T, Allocator>& y);
    template<class T, class Allocator>
        constexpr bool operator> (const vector<T, Allocator>& x, const vector<T, Allocator>& y);
    template<class T, class Allocator>
        constexpr bool operator>=(const vector<T, Allocator>& x, const vector<T, Allocator>& y);
    template<class T, class Allocator>
        constexpr bool operator<=(const vector<T, Allocator>& x, const vector<T, Allocator>& y);

    template<class T, class Allocator>
        constexpr void swap(vector<T, Allocator>& x, vector<T, Allocator>& y)
            noexcept(noexcept(x.swap(y)));

    [...]
}
```

Add after [vector.overview] 21.3.11.1/2:

The types `iterator` and `const_iterator` meet the `constexpr` iterator requirements ([iterator.requirements.general]).

Change in [vector.overview] 21.3.11.1:

```
namespace std {
    template<class T, class Allocator = allocator<T>>
```

```

class vector {
public:
    // types
    using value_type          = T;
    using allocator_type      = Allocator;
    using pointer             = typename allocator_traits<Allocator>::pointer;
    using const_pointer       = typename allocator_traits<Allocator>::const_pointer;
    using reference           = value_type&;
    using const_reference     = const value_type&;
    using size_type           = implementation-defined; // see 21.2
    using difference_type     = implementation-defined; // see 21.2
    using iterator            = implementation-defined; // see 21.2
    using const_iterator      = implementation-defined; // see 21.2
    using reverse_iterator    = std::reverse_iterator<iterator>;
    using const_reverse_iterator = std::reverse_iterator<const_iterator>;

    // 21.3.11.2, construct/copy/destroy
    constexpr vector() noexcept(noexcept(Allocator())) : vector(Allocator()) { }
    constexpr explicit vector(const Allocator&) noexcept;
    constexpr explicit vector(size_type n, const Allocator& = Allocator());
    constexpr vector(size_type n, const T& value, const Allocator& = Allocator());
    template<class InputIterator>
        constexpr vector(InputIterator first, InputIterator last, const Allocator& = Allocator());
    constexpr vector(const vector& x);
    constexpr vector(vector&&) noexcept;
    constexpr vector(const vector&, const Allocator&);
    constexpr vector(vector&&, const Allocator&);
    constexpr vector(initializer_list<T>, const Allocator& = Allocator());
    constexpr ~vector();
    constexpr vector& operator=(const vector& x);
    constexpr vector& operator=(vector&& x)
        noexcept(allocator_traits<Allocator>::propagate_on_container_move_assignment::value ||
            allocator_traits<Allocator>::is_always_equal::value);
    constexpr vector& operator=(initializer_list<T>);
    template<class InputIterator>
        constexpr void assign(InputIterator first, InputIterator last);
    constexpr void assign(size_type n, const T& u);
    constexpr void assign(initializer_list<T>);
    constexpr allocator_type get_allocator() const noexcept;

    // iterators
    constexpr iterator      begin() noexcept;
    constexpr const_iterator begin() const noexcept;
    constexpr iterator      end() noexcept;
    constexpr const_iterator end() const noexcept;
    constexpr reverse_iterator rbegin() noexcept;
    constexpr const_reverse_iterator rbegin() const noexcept;
    constexpr reverse_iterator rend() noexcept;
    constexpr const_reverse_iterator rend() const noexcept;

    constexpr const_iterator cbegin() const noexcept;

```

```

constexpr const_iterator      cend() const noexcept;
constexpr const_reverse_iterator crbegin() const noexcept;
constexpr const_reverse_iterator crend() const noexcept;

// 21.3.11.3, capacity
constexpr [[nodiscard]] bool empty() const noexcept;
constexpr size_type size() const noexcept;
constexpr size_type max_size() const noexcept;
constexpr size_type capacity() const noexcept;
constexpr void      resize(size_type sz);
constexpr void      resize(size_type sz, const T& c);
constexpr void      reserve(size_type n);
constexpr void      shrink_to_fit();

// element access
constexpr reference      operator[](size_type n);
constexpr const_reference operator[](size_type n) const;
constexpr const_reference at(size_type n) const;
constexpr reference      at(size_type n);
constexpr reference      front();
constexpr const_reference front() const;
constexpr reference      back();
constexpr const_reference back() const;

// 21.3.11.4, data access
constexpr T*      data() noexcept;
constexpr const T* data() const noexcept;

// 21.3.11.5, modifiers
template<class... Args> constexpr reference emplace_back(Args&&... args);
constexpr void push_back(const T& x);
constexpr void push_back(T&& x);
constexpr void pop_back();

template<class... Args> constexpr iterator emplace(const_iterator position, Args&&... args);
constexpr iterator insert(const_iterator position, const T& x);
constexpr iterator insert(const_iterator position, T&& x);
constexpr iterator insert(const_iterator position, size_type n, const T& x);
template<class InputIterator>
constexpr iterator insert(const_iterator position, InputIterator first, InputIterator last);
constexpr iterator insert(const_iterator position, initializer_list<T> il);
constexpr iterator erase(const_iterator position);
constexpr iterator erase(const_iterator first, const_iterator last);
constexpr void      swap(vector&)
    noexcept(allocator_traits<Allocator>::propagate_on_container_swap::value ||
             allocator_traits<Allocator>::is_always_equal::value);
constexpr void      clear() noexcept;
};

template<class InputIterator,
        class Allocator = allocator<iter-value-type<InputIterator>>>

```

```

        vector(InputIterator, InputIterator, Allocator = Allocator())
            -> vector<iter-value-type<InputIterator>, Allocator>;

// swap
template<class T, class Allocator>
    constexpr void swap(vector<T, Allocator>& x, vector<T, Allocator>& y)
        noexcept(noexcept(x.swap(y)));
}

```

Change in [vector.cons] 21.3.11.2:

```

constexpr explicit vector(const Allocator&);

[...]

constexpr explicit vector(size_type n, const Allocator& = Allocator());

[...]

constexpr vector(size_type n, const T& value,
                 const Allocator& = Allocator());

[...]

template<class InputIterator>
    constexpr vector(InputIterator first, InputIterator last,
                     const Allocator& = Allocator());

[...]

```

Change in [vector.capacity] 21.3.11.3:

```

constexpr size_type capacity() const noexcept;

[...]

constexpr void reserve(size_type n);

[...]

constexpr void shrink_to_fit();

[...]

constexpr void swap(vector& x)
    noexcept(allocator_traits<Allocator>::propagate_on_container_swap::value ||
             allocator_traits<Allocator>::is_always_equal::value);

[...]

constexpr void resize(size_type sz);

[...]

constexpr void resize(size_type sz, const T& c);

[...]

```

Change in [vector.data] 21.3.11.4:

```
constexpr T*      data() noexcept;
constexpr const T* data() const noexcept;
```

Change in [vector.modifiers] 21.3.11.5:

```
constexpr iterator insert(const_iterator position, const T& x);
constexpr iterator insert(const_iterator position, T&& x);
constexpr iterator insert(const_iterator position, size_type n, const T& x);
template<class InputIterator>
    constexpr iterator insert(const_iterator position, InputIterator first, InputIterator last);
constexpr iterator insert(const_iterator position, initializer_list<T>);

template<class... Args> constexpr reference emplace_back(Args&&... args);
template<class... Args> constexpr iterator emplace(const_iterator position, Args&&... args);
constexpr void push_back(const T& x);
constexpr void push_back(T&& x);

[...]

constexpr iterator erase(const_iterator position);
constexpr iterator erase(const_iterator first, const_iterator last);
constexpr void pop_back();
```

Change in [vector.special] 21.3.11.6:

```
template<class T, class Allocator>
    constexpr void swap(vector<T, Allocator>& x, vector<T, Allocator>& y)
        noexcept(noexcept(x.swap(y)));
```

Change in [vector.bool] 21.3.12/1:

To optimize space allocation, a specialization of vector for bool elements is provided:

```
namespace std {
    template<class Allocator>
    class vector<bool, Allocator> {
    public:
        // types
        using value_type           = bool;
        using allocator_type       = Allocator;
        using pointer              = implementation-defined;
        using const_pointer        = implementation-defined;
        using const_reference      = bool;
        using size_type            = implementation-defined; // see 21.2
        using difference_type      = implementation-defined; // see 21.2
        using iterator             = implementation-defined; // see 21.2
        using const_iterator       = implementation-defined; // see 21.2
        using reverse_iterator     = std::reverse_iterator<iterator>;
        using const_reverse_iterator = std::reverse_iterator<const_iterator>;

        // bit reference
        class reference {
```

```

    friend class vector;
    constexpr reference() noexcept;
public:
    constexpr ~reference();
    constexpr reference(const reference&) = default;
    constexpr operator bool() const noexcept;
    constexpr reference& operator=(const bool x) noexcept;
    constexpr reference& operator=(const reference& x) noexcept;
    constexpr void flip() noexcept;    // flips the bit
};

// construct/copy/destroy
constexpr vector() : vector(Allocator()) { }
constexpr explicit vector(const Allocator&);
constexpr explicit vector(size_type n, const Allocator& = Allocator());
constexpr vector(size_type n, const bool& value, const Allocator& = Allocator());
template<class InputIterator>
    constexpr vector(InputIterator first, InputIterator last, const Allocator& = Allocator());
constexpr vector(const vector& x);
constexpr vector(vector&& x);
constexpr vector(const vector&, const Allocator&);
constexpr vector(vector&&, const Allocator&);
constexpr vector(initializer_list<bool>, const Allocator& = Allocator());
constexpr ~vector();
constexpr vector& operator=(const vector& x);
constexpr vector& operator=(vector&& x);
constexpr vector& operator=(initializer_list<bool>);
template<class InputIterator>
    constexpr void assign(InputIterator first, InputIterator last);
constexpr void assign(size_type n, const bool& t);
constexpr void assign(initializer_list<bool>);
constexpr allocator_type get_allocator() const noexcept;

// iterators
constexpr iterator          begin() noexcept;
constexpr const_iterator    begin() const noexcept;
constexpr iterator          end() noexcept;
constexpr const_iterator    end() const noexcept;
constexpr reverse_iterator  rbegin() noexcept;
constexpr const_reverse_iterator rbegin() const noexcept;
constexpr reverse_iterator  rend() noexcept;
constexpr const_reverse_iterator rend() const noexcept;

constexpr const_iterator    cbegin() const noexcept;
constexpr const_iterator    cend() const noexcept;
constexpr const_reverse_iterator crbegin() const noexcept;
constexpr const_reverse_iterator crend() const noexcept;

// capacity
constexpr [[nodiscard]] bool empty() const noexcept;
constexpr size_type size() const noexcept;

```

```

constexpr size_type max_size() const noexcept;
constexpr size_type capacity() const noexcept;
constexpr void      resize(size_type sz, bool c = false);
constexpr void      reserve(size_type n);
constexpr void      shrink_to_fit();

// element access
constexpr reference      operator[] (size_type n);
constexpr const_reference operator[] (size_type n) const;
constexpr const_reference at(size_type n) const;
constexpr reference      at(size_type n);
constexpr reference      front();
constexpr const_reference front() const;
constexpr reference      back();
constexpr const_reference back() const;

// modifiers
template<class... Args> constexpr reference emplace_back(Args&&... args);
constexpr void push_back(const bool& x);
constexpr void pop_back();
template<class... Args> constexpr iterator emplace(const_iterator position, Args&&... args);
constexpr iterator insert(const_iterator position, const bool& x);
constexpr iterator insert(const_iterator position, size_type n, const bool& x);
template<class InputIterator>
    constexpr iterator insert(const_iterator position, InputIterator first, InputIterator last)
constexpr iterator insert(const_iterator position, initializer_list<bool> il);

constexpr iterator erase(const_iterator position);
constexpr iterator erase(const_iterator first, const_iterator last);
constexpr void swap(vector&);
constexpr static void swap(reference x, reference y) noexcept;
constexpr void flip() noexcept;           // flips all bits
constexpr void clear() noexcept;
};
}

```

Change in [vector.bool] 21.3.12/4:

```
constexpr void flip() noexcept;
```

Change in [vector.bool] 21.3.12/5:

```
constexpr static void swap(reference x, reference y) noexcept;
```

5 References

[N4727] Richard Smith, *Working Draft, Standard for Programming Language C++*
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2018/n4727.pdf>

- [P0784R1] Multiple authors, *Standard containers and constexpr*
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2018/p0784r1.html>
- [P0859R0] Richard Smith, *Core Issue 1581: When are constexpr member functions defined?*
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2017/p0859r0.html>
- [P0595R0] David Vandevor, *The constexpr Operator*
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2017/p0595r0.html>
- [P0858R0] Antony Polukhin, *Constexpr iterator requirements*
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2018/p0858r0.html>