

Making `std::vector` `constexpr`

Document #: D1004R0
Date: 2018-03-18
Project: Programming Language C++
Audience: LEWG
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1 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).

2 Encountered issues

We surveyed the implementation of `std::vector` in `libc++` 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`; 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.

3 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] 26.3.6:

```
#include <initializer_list>

namespace std {
    // 26.3.11, 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)));

    [...]
}
```

Change in [vector.overview] 26.3.11.1:

```
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 26.2
        using difference_type      = implementation-defined; // see 26.2
        using iterator             = implementation-defined; // see 26.2
        using const_iterator       = implementation-defined; // see 26.2
        using reverse_iterator     = std::reverse_iterator<iterator>;
        using const_reverse_iterator = std::reverse_iterator<const_iterator>;
```

// 26.3.11.2, 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;
```

// 26.3.11.3, 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;

// 26.3.11.4, data access
constexpr T*      data() noexcept;
constexpr const T* data() const noexcept;

// 26.3.11.5, 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<typename iterator_traits<InputIterator>::value_type>>
constexpr vector(InputIterator, InputIterator, Allocator = Allocator())
    -> vector<typename iterator_traits<InputIterator>::value_type, Allocator>;

// 26.3.11.6, specialized algorithms
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] 26.3.11.2:

```

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]** 26.3.11.3:

```
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]** 26.3.11.4:

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

Change in **[vector.modifiers]** 26.3.11.5:

```
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] 26.3.11.6:

```
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] 26.3.12/1:

To optimize space allocation, a specialization of vector for bool elements is provided ([we are sorry](#)):

```
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 26.2
        using difference_type     = implementation-defined; // see 26.2
        using iterator            = implementation-defined; // see 26.2
        using const_iterator      = implementation-defined; // see 26.2
        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 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] 26.3.12/4:

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

Change in [vector.bool] 26.3.12/5:

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

4 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 Vandevoorde, *The constexpr Operator*
<http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2017/p0595r0.html>