span: bounds-safe views for sequences of objects

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Changelog
Changes from R0

- Changed the name of the type being proposed from array_view to span following feedback from LEWG at the Kona meeting.
- Removed multidimensional aspects from the proposal. span is now always single-dimension and contiguous.
- Added details on potential interoperation with the multidimensional view type from P0009 [5].
- Removed functions to convert from span<byte> to span<T> as they are not compatible with type aliasing rules.
- Added section containing proposed wording for inclusion in the standard.
- Simplified span interface based on reviewer feedback.

Introduction
This paper presents a design for a fundamental vocabulary type span.

The span type is an abstraction that provides a view over a contiguous sequence of objects, the storage of which is owned by some other object. The design for span presented here provides bounds-safety guarantees through a combination of compile-time and (configurable) run-time constraints.

The design of the span type discussed in this paper is related to the span previously proposed in N3851 [1] and also draws on ideas in the array_ref and string_ref classes proposed in N3334 [2]. span is closely related to the generalized, multidimensional memory-access abstraction view described in P0009 [5]. The span proposed here is sufficiently compatible with view that interoperability between the two types would be simple and well-defined.

While view is proposed by P0009 [5] as a generalized and highly configurable view type that can address needs for specialized domains such as scientific computing, span is proposed as a simple solution to the common need for a single-dimensional view over contiguous storage.

Motivation and Scope
The evolution of the standard library has demonstrated that it is possible to design and implement abstractions in Standard C++ that improve the reliability of C++ programs without sacrificing either performance or portability. This proposal identifies a new “vocabulary type” for inclusion in the standard library that enables both high performance and bounds-safe access to contiguous sequences of elements. This type would also improve modularity, composability, and reuse by decoupling accesses to array data from the specific container types used to store that data.

These characteristics lead to higher quality programs. Some of the bounds and type safety constraints of span directly support “correct-by-construction” programming methodology – where errors simply do not compile. One of the major advantages of span over the common idiom of a “pointer plus length” pair of parameters is that it provides clearer semantics hints to analysis tools looking to help detect and prevent defects early in a software development cycle.
Impact on the Standard
This proposal is a pure library extension. It does not require any changes to standard classes, functions, or headers. It would be enhanced if could depends on the byte type and changes to type aliasing behavior proposed in P0257 [6].

However – if adopted – it may be useful to overload some standard library functions for this new type (an example would be copy()).

span has been implemented in standard C++ (C++11) and is being successfully used within a commercial static analysis tool for C++ code as well as commercial office productivity software. An open source, reference implementation is available at https://github.com/Microsoft/GSL [3].

Design Decisions
View not container
span is simply a view over another object’s contiguous storage – but unlike array or vector it does not “own” the elements that are accessible through its interface. An important observation arises from this: span never performs any free store allocations.

While span is a view, it is not an iterator. You cannot perform increment or decrement operations on it, nor dereference it.

No configurable view properties
In the related view type described in P0009 [5], properties are used to control policies such as memory layout (column-major, row-major) and location (on heterogenous memory architectures) for specific specializations of view. span does not require properties as it is always a simple view over contiguous storage. Its memory layout and access characteristics are equivalent to those of a built-in array. This difference should not prevent conversions between view and span instances, it merely constrains that they could only be available in cases where view properties are compatible with the characteristics of span.

View length and measurement
The general usage protocol of the span class template supports both static-size (fixed at compile time) and dynamic-size (provided at runtime) views. The Extent template parameter to span is used to provide the extent of the span.

```cpp
constexpr ptrdiff_t dynamic_extent = -1;
```

The default value for Extent is dynamic_extent: a unique value outside the normal range of lengths (0 to PTRDIFF_MAX inclusive) reserved to indicate that the length of the sequence is only known at runtime and must be stored within the span. A dynamic-size span is, conceptually, just a pointer and size field (this is not an implementation requirement, however).

```cpp
int* somePointer = new int[someLength];
// Declaring a dynamic-size span
```
// s will have a dynamic-size specified by someLength at construction
span<int> s = { somePointer, someLength };  

The type used for measuring and indexing into span is `ptrdiff_t`. Using a signed index type helps avoid common mistakes that come from implicit signed to unsigned integer conversions when users employ integer literals (which are nearly always signed). The use of `ptrdiff_t` is natural as it is the type used for pointer arithmetic and array indexing – two operations that `span` explicitly aims to replace but that an implementation of `span` would likely rely upon.

A fixed-size `span` provides a value for `Extent` that is between 0 and `PTRDIFF_MAX` (inclusive). A fixed-size `span` requires no storage size overhead beyond a single pointer – using the type system to carry the fixed-length information. This allows `span` to be an extremely efficient type to use for access to fixed-length buffers.

```cpp
int arr[10];

// deduction of size from arrays means that span size is always correct
span<int, 10> s2 = arr; // fixed-size span of 10 ints
span<int, 20> s3 = arr; // error: will fail compilation
span<int> s4 = arr; // dynamic-size span of 10 ints
```

**Value Type Semantics**

`span` is designed as a value type – it is expected to be cheap to construct, copy, move, and use. Users are encouraged to use it as a pass-by-value parameter type wherever they would have passed a pointer by value or a container type by reference, such as `array` or `vector`.

Conceptually, `span` is simply a pointer to some storage and a count of the elements accessible via that pointer. Those two values within a span can only be set via construction or assignment (i.e. all member functions other than constructors and assignment operators are `const`). This property makes it easy for users to reason about the values of a span through the course of a function body.

These value type characteristics also help provide compiler implementations with considerable scope for optimizing the use of `span` within programs. For example, `span` has a trivial destructor, so common ABI conventions allow it to be passed in registers.

**Range-checking and bounds-safety**

All accesses to the data encapsulated by a span are conceptually range-checked to ensure they remain within the bounds of the `span`. What actually happens as the result of a failure to meet `span`’s bounds-safety constraints at runtime is undefined behavior. However, it should be considered effectively fatal to a program’s ability to continue reliable execution. This is a critical aspect of `span`’s design, and allows users to rely on the guarantee that as long as a sequence is accessed via a correctly initialized `span`, then its bounds cannot be overrun.

As an example, in the current reference implementation, violating a range-check results by default in a call to `terminate()` but can also be configured via build-time mechanisms to continue execution (albeit with undefined behavior from that point on).
Conversion between fixed-size and dynamic-size span objects is allowed, but with strict constraints that ensure bounds-safety is always preserved. At least two of these cases can be checked statically by leveraging the type system. In each case, the following rules assume the element types of the span objects are compatible for assignment.

1. A fixed-size span may be constructed or assigned from another fixed-size span of equal length.
2. A dynamic-size span may always be constructed or assigned from a fixed-size span.
3. A fixed-size span may always be constructed or assigned from a dynamic-size span. Undefined behavior will result if the construction or assignment is not bounds-safe. In the reference implementation, for example, this is achieved via a runtime check that results in \texttt{terminate()} on failure.

Element types and conversions

span must be configured with its element type via the template parameter \texttt{ValueType}, which is required to be a complete object type that is not an abstract class type. span supports either read-only or mutable access to the sequence it encapsulates. To access read-only data, the user can declare a \texttt{span<const T>}, and access to mutable data would use a \texttt{span<T>}.

Construction or assignment between span objects with different element types is allowed whenever it can be determined statically that the element types are exactly storage-size equivalent (so there is no difference in the extent of memory being accessed), and that the types can legally be aliased.

As a result of these rules, it is always possible to convert from a \texttt{span<T>} to a \texttt{span<const T>}. It is not allowed to convert in the opposite direction, from \texttt{span<const T>} to \texttt{span<T>}. This property is extremely convenient for calling functions that take span parameters.

Element access and iteration

span's interface for accessing elements is largely similar to that of \texttt{array}. It overloads \texttt{operator[]} for element access, and offers random access iterators, making it adoptable with a minimum of source changes in code that previously used an array, an \texttt{array} object, or a pointer to access more than one object. span also overloads \texttt{operator()} for element access, to provide compatibility with code written to operate against \texttt{view}.

span provides both const and mutable random-access iterators over its data, just like \texttt{vector} and \texttt{array}. All accesses to elements made through these iterators are range-checked (subject to configuration as previously described), just as if they had been performed via the subscript operator on span.

```cpp
// [span.elem], span element access
constexpr reference operator[](index_type idx) const;
constexpr reference operator() (index_type idx) const;
constexpr pointer data() const noexcept;

// [span.iter], span iterator support
iterator begin() const noexcept;
iterator end() const noexcept;

const_iterator cbegin() const noexcept;
```
Construction

The `span` class is expected to become a frequently used vocabulary type in function interfaces (as a safer replacement of “(pointer, length)” idioms), as it specifies a minimal set of requirements for safely accessing a sequence of objects and decouples a function that needs to access a sequence from the details of the storage that holds such elements.

To simplify use of `span` as a simple parameter, `span` offers a number of constructors for common container types that store contiguous sequences of elements. A summarized extract from the specification illustrates this:

```cpp
// [span.cons], span constructors, copy, assignment, and destructor
constexpr span();
constexpr span(nullptr_t);
constexpr span(pointer ptr, index_type count);
constexpr span(pointer firstElem, pointer lastElem);
template <size_t N>
  constexpr span(element_type (&arr)[N]);
template <size_t N>
  constexpr span(array<remove_const_t<element_type>, N>& arr);
template <class Container>
  constexpr span(Container& cont);
template <class OtherElementType, ptrdiff_t OtherExtent>
  constexpr span(span<OtherElementType, OtherExtent>& other);
```

To avoid being mistakenly treated as a container – which would lead to invalid memory accesses – `span` deletes rvalue reference constructors that would bind to an expiring temporary object and requires callers to provide explicit containers to bind the `span` against.

It is allowed to construct a span from the null pointer, and this creates an object with `.size() == 0`. Any attempt to construct a span with a null pointer value and a non-zero length is considered a range-check error.
Byte representations and conversions

*span* depends upon a distinct “byte” type that represents a single addressable byte on any system, for object representation— in preference to common practice of using character types for this purpose. Such a type is defined in the standard library as:

```cpp
enum class byte : unsigned char {};
```

For more details on the proposed byte type please refer to P0257 [6].

A span of any element type that is a standard-layout type can be converted to a span<`const byte`> or a span<`byte`> via the free functions `as_bytes()` and `as_writeable_bytes()` respectively. These operations are considered useful for systems programming where byte-oriented access for serialization and data transmission is essential.

```cpp
// [span.objectrep], views of object representation
template <class ElementType, ptrdiff_t Extent>
  constexpr span<const byte, ((Extent == dynamic_extent) ? dynamic_extent : (sizeof(ElementType) * Extent))> as_bytes(span<ElementType, Extent> s) noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr span<byte, ((Extent == dynamic_extent) ? dynamic_extent : (sizeof(ElementType) * Extent))> as_writeable_bytes(span<ElementType, Extent> ) noexcept;
```

These byte-representation conversions still preserve const-correctness, however. It is not possible to convert from a `span<const T>` be converted to a span<`byte`> (through SFINAE overload restriction).

Comparisons

*span* supports all the same comparison operations as a sequential standard library container: element-wise comparison and a total ordering by lexicographical comparison. This helps make it an effective replacement for existing uses of sequential contiguous container types like *array* or *vector*.

```cpp
// [span.comparison], span comparison operators
template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator==(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator!=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator<(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator<=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator>=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;
```

constexpr bool operator>(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
constexpr bool operator>=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

Regardless of whether they contain a valid pointer or null pointer, zero-length spans are all considered equal. This is considered a useful property when writing library code. If users wish to distinguish between a zero-length span with a valid pointer value and a span containing the null pointer, then they can do so by calling the data() member function and examining the pointer value directly.

Creating sub-spans

span offers convenient member functions for generating a new span that is a reduced view over its sequence. In each case, the newly constructed span is returned by value from the member function. As the design requires bounds-safety, these member functions are guaranteed to either succeed and return a valid span, or fail with undefined behavior (e.g. calling terminate()) if the parameters were not within range.

```cpp
// [span.sub], span subviews
constexpr span<element_type, dynamic_extent> first(index_type count) const;
constexpr span<element_type, dynamic_extent> last(index_type count) const;
constexpr span<element_type, dynamic_extent> subspan(index_type offset, index_type count = dynamic_extent) const;
```

first() returns a new span that is limited to the first N elements of the original sequence. Conversely, last() returns a new span that is limited to the last N elements of the original sequence. subspan() allows an arbitrary sub-range within the sequence to be selected and returned as a new span.

All three member functions are overloaded in forms that accept their parameters as template parameters, rather than function parameters. These overloads are helpful for creating fixed-size span objects from an original input span, whether fixed- or dynamic-size.

```cpp
template <ptrdiff_t Count>
constexpr span<element_type, Count> first() const;
template <ptrdiff_t Count>
constexpr span<element_type, Count> last() const;
template <ptrdiff_t Offset, ptrdiff_t Count = dynamic_extent>
constexpr span<element_type, Count> subspan() const;
```

Multidimensional span

span as presented here only supports a single-dimension view of a sequence. This covers the most common usage of contiguous sequences in C++. span has convenience (such as iterators, first(), last(), and subspan()) and default behaviors that make most sense in a single-dimension.

Adding support for multidimensional and noncontiguous (strided) views of data is deferred to a separate type not described here. One such candidate would be the more general view facility described in P0009 [5]. The interface of span is sufficiently compatible with that of view, that users should not feel
any significant discontinuity between the two. In fact, it is entirely possible to implement a span using view.

Proposed Wording Changes

The following proposed wording changes against the working draft of the standard are relative to N4567 [7]. If byte type would be available in the working draft, as proposed in P0257 [6] then the functions in section [span.objectrep] would use “byte” for the placeholder byte.

In these changes,

Yellow highlight is used to indicate modified text or sections.

Red highlight is used to indicate deleted text.

Green highlight is used to indicate newly added text.

17.6.1.2 Headers [headers]

2 The C++ standard library provides 54 C++ library headers, as shown in Table 14.

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 Containers</td>
<td>[containers]</td>
</tr>
<tr>
<td>23.1 General</td>
<td>[containers.general]</td>
</tr>
</tbody>
</table>

2 The following subclauses describe container requirements, and components for sequence containers, associative containers, and views as summarized in Table 94.

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Header(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.2 Requirements</td>
<td></td>
</tr>
<tr>
<td>23.3 Sequence containers</td>
<td>&lt;array&gt; &lt;deque&gt; &lt;forward_list&gt;</td>
</tr>
</tbody>
</table>
23.7 Views [views]

23.7.1 General [views.general]

The header `<span>` defines the view `span`. A `span` is a view over a contiguous sequence of objects, the storage of which is owned by some other object.

Header `<span>` synopsis

```cpp
namespace std {

// [views.constants], constants
constexpr ptrdiff_t dynamic_extent = -1;

// [span], class template span
template <class ValueType, ptrdiff_t Extent = dynamic_extent>
class span;

// [span.comparison], span comparison operators
template <class ElementType, ptrdiff_t Extent>
constexpr bool operator==(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
constexpr bool operator!=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
constexpr bool operator<(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
constexpr bool operator<=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
constexpr bool operator>(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
constexpr bool operator>=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;
```

23.7.2 Class template `span` [views.span]

1 A `span` is a view over a contiguous sequence of objects, the storage of which is owned by some other object.

2 `ElementType` is required to be a complete object type that is not an abstract class type.

3 Throughout this section, whenever a requirement fails to be met, the result is considered undefined behavior. It may – for example – cause immediate termination via a call to `terminate()`, or cause an exception to be thrown.

3 The iterators for `span` are all random access iterators and contiguous iterators.

4 For a `span<const T>`, the `iterator` and `const_iterator` types are allowed to be synonyms.

```cpp
namespace std {

// A view over a contiguous, single-dimension sequence of objects
class span {
public:

    // constants and types
    using element_type = ElementType;
    using index_type = ptrdiff_t;
    using pointer = element_type*;
    using reference = element_type&;
    using iterator = /* implementation-defined */;
    using const_iterator = /* implementation-defined */;
    using reverse_iterator = reverse_iterator<iterator>;
    using const_reverse_iterator = reverse_iterator<const_iterator>;

    constexpr static index_type extent = Extent;

    // [span.cons], span constructors, copy, assignment, and destructor
    constexpr span();
    constexpr span(nullptr_t);
    constexpr span(pointer ptr, index_type count);
    constexpr span(pointer firstElem, pointer lastElem);
    template <size_t N>
    constexpr span(element_type (&arr)[N]);
};
```

template <size_t N>
    constexpr span(array<remove_const_t<element_type>, N>& arr);
template <size_t N>
    constexpr span(const array<remove_const_t<element_type>, N>& arr);
template <class Container>
    constexpr span(Container& cont);
template <class Container>
    span(const Container&&) = delete;
constexpr span(const span& other) noexcept = default;
constexpr span(span&& other) noexcept = default;

// [span.sub], span subviews
template <ptrdiff_t Count>
    constexpr span<element_type, Count> first() const;
template <ptrdiff_t Count>
    constexpr span<element_type, Count> last() const;
template <ptrdiff_t Offset, ptrdiff_t Count = dynamic_extent>
    constexpr span<element_type, Count> subspan() const;
constexpr span<element_type, dynamic_extent> first(index_type count) const;
constexpr span<element_type, dynamic_extent> last(index_type count) const;
constexpr span<element_type, dynamic_extent> subspan(index_type offset, index_type count = dynamic_extent) const;

// [span.obs], span observers
constexpr index_type length() const noexcept;
constexpr index_type size() const noexcept;
constexpr index_type length_bytes() const noexcept;
constexpr index_type size_bytes() const noexcept;
constexpr bool empty() const noexcept;

// [span.elem], span element access
constexpr reference operator[](index_type idx) const;
constexpr reference operator()(index_type idx) const;
constexpr pointer data() const noexcept;

// [span.iter], span iterator support
iterator begin() const noexcept;
iterator end() const noexcept;
const_iterator cbegin() const noexcept;
const_iterator cend() const noexcept;
reverse_iterator rbegin() const noexcept;
reverse_iterator rend() const noexcept;
const_reverse_iterator crbegin() const noexcept;
const_reverse_iterator crbegin() const noexcept;
private:
  // exposition only
  pointer data_
  index_type size_
};

// [span.comparison], span comparison operators
template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator==(const span<ElementType, Extent>& l, const
  span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator!=(const span<ElementType, Extent>& l, const
  span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator<(const span<ElementType, Extent>& l, const
  span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator<=(const span<ElementType, Extent>& l, const
  span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator>(const span<ElementType, Extent>& l, const
  span<ElementType, Extent>& r) const noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr bool operator>=(const span<ElementType, Extent>& l, const
  span<ElementType, Extent>& r) const noexcept;

// [span.objectrep], views of object representation
template <class ElementType, ptrdiff_t Extent>
  constexpr span<const
textexpr byte, ((Extent == dynamic_extent) ?
  dynamic_extent : (sizeof(ElementType) * Extent))> as_bytes(span<ElementType, Extent>& s) noexcept;

template <class ElementType, ptrdiff_t Extent>
  constexpr span<byte, ((Extent == dynamic_extent) ?
  dynamic_extent : (sizeof(ElementType) * Extent))> as_writeable_bytes(span<ElementType, Extent>& s) noexcept;

} // namespace std

23.7.2.1 span constructors, copy, assignment, and destructor [span.cons]

constexpr span();
constexpr span(nullptr_t);
	extexpr span
	constexpr span();
	constexpr span(nullptr_t);

Requires: extent == dynamic_extent || extent == 0

Effects: Constructs an empty span.
Postconditions: \( \text{size()} == 0 \land \text{data()} == \text{nullptr} \)

Complexity: Constant

```
constexpr \text{span}(\text{pointer } \text{ptr}, \text{index\_type } \text{count});
```

**Requires:** When \( \text{ptr} \) is null pointer then \( \text{count} \) shall be 0. When \( \text{ptr} \) is not null pointer, then it shall point to the beginning of a valid sequence of objects of at least \( \text{count} \) length. \( \text{count} \) shall always be \( \geq 0 \). If \( \text{extent} \) is not \text{dynamic\_extent}, then \( \text{count} \) shall be equal to \( \text{extent} \).

**Effects:** Constructs a \text{span} that is a view over the sequence of objects pointed to by \( \text{ptr} \). If \( \text{ptr} \) is null pointer or \( \text{count} \) is 0 then an empty \text{span} is constructed.

Postconditions: \( \text{size()} == \text{count} \land \text{data()} == \text{ptr} \)

Complexity: Constant

```
constexpr \text{span}(\text{pointer } \text{firstElem}, \text{pointer } \text{lastElem});
```

**Requires:** [\( \text{firstElem}, \text{lastElem} \)] is a valid range and \( \text{distance}(\text{firstElem}, \text{lastElem}) \geq 0 \). If \( \text{extent} \) is not equal to \text{dynamic\_extent}, then \( \text{distance}(\text{firstElem}, \text{lastElem}) \) shall be equal to \( \text{extent} \).

**Effects:** Constructs a \text{span} that is a view over the range [\( \text{firstElem}, \text{lastElem} \)]. If \( \text{distance}(\text{firstElem}, \text{lastElem}) \) then an empty \text{span} is constructed.

Postconditions: \( \text{size()} == \text{distance}(\text{first}, \text{last}) \land \text{data()} == \text{firstElem} \)

Complexity: The same as for \( \text{distance}(\text{first}, \text{last}) \)

```
template <\text{size\_t } \text{N}>
\text{constexpr } \text{span}(\text{element\_type } (&\text{arr})[\text{N}]);
template <\text{size\_t } \text{N}>
\text{constexpr } \text{span}(\text{array<remove\_const\_t<element\_type>, } \text{N}>& \text{arr});
template <\text{size\_t } \text{N}>
\text{constexpr } \text{span}(\text{const array<remove\_const\_t<element\_type>, } \text{N}>& \text{arr});
```

**Requires:** If \( \text{extent} \) is not equal to \text{dynamic\_extent}, then \( \text{N} == \text{extent} \).

**Effects:** Constructs a \text{span} that is a view over the supplied array.

Postconditions: \( \text{size()} == \text{N} \land (\text{N} == 0 \land \text{data()} == \text{nullptr} \lor \text{data()} == \text{addressof}(\text{arr}[0])) \)

Complexity: Constant
template <class Container>
constexpr span(Container& cont);

**Requires:** The constructor shall not participate in overload resolution unless:
- Container meets the requirements of both a contiguous container (defined in 23.2.1/13) and a sequence container (defined in 23.2.3).
- The Container implements the optional sequence container requirement of operator[] (defined in Table 100).
- Container::value_type is the same as remove_const_t<element_type>.

The constructor shall not participate in overload resolution if Container is a span or array.

If extent is not equal to dynamic_extent, then cont.size() shall be equal to extent.

**Effects:** Constructs a span that is a view over the sequence owned by cont.

**Postconditions:** size() == cont.size() && data() == addressof(cont[0]).

**Complexity:** Constant.

```cpp
template <class Container>
span(const Container&&) = delete;
```

**Requires:** The constructor shall not participate in overload resolution unless:
- Container meets the requirements of both a contiguous container (defined in 23.2.1/13) and a sequence container (defined in 23.2.3).
- The Container implements the optional sequence container requirement of operator[] (defined in Table 100).
- Container::value_type is the same as remove_const_t<element_type>.

The constructor shall not participate in overload resolution if Container is a span or array.

```cpp
constexpr span(const span& other) noexcept = default;
constexpr span(span&& other) noexcept = default;
```

**Effects:** Constructs a span by copying the implementation data members of another span.

**Postconditions:** other.size() == size() && other.data() == data().

**Complexity:** Constant.
template <class OtherElementType, ptrdiff_t OtherExtent>
constexpr span(const span<OtherElementType, OtherExtent>& other);

requires
these constructors shall not participate in overload resolution unless trying to access
otherElementType through an ElementType* would meet the rules for well-defined object access
defined in 3.10/10. If extent is not equal to dynamic_extent, then other.size() shall be equal to
extent.

effects: Constructs a span by copying the implementation data members of another span, performing
suitable conversions.

postconditions: size() == other.size() &&
data() == reinterpret_cast<pointer>(other.data())

complexity: Constant

span& operator=(const span& other) noexcept = default;

effects: Assigns the implementation data of one span into another.

postconditions: size() == other.size() && data() == other.data()

complexity: Constant

23.7.2.2 span subviews [span.sub]

template <ptrdiff_t Count>
constexpr span<element_type, Count> first() const;

requires: Count >= 0 && Count <= size()

effects: Returns a new span that is a view over the initial Count elements of the current span.

returns: span(data(), Count);

complexity: Constant

template <ptrdiff_t Count>
constexpr span<element_type, Count> last() const;

requirements: Count >= 0 && Count <= size()
**Effects:** Returns a new span that is a view over the final Count elements of the current span.

**Returns:** \( \text{span}(\text{Count} == 0 \ ? \ \text{data()} : \ \text{data()} + (\text{size()} - \text{Count}), \ \text{Count}) \)

**Complexity:** Constant

```cpp
template <ptrdiff_t Offset, ptrdiff_t Count = dynamic_extent>
constexpr span<element_type, Count> subspan() const;
```

**Requires:** \((\text{Offset} == 0 || \text{Offset} > 0 && \text{Offset} < \text{size()}) && (\text{Count} == \text{dynamic_extent} \ || \ \text{Count} >= 0 && \text{Offset} + \text{Count} <= \text{size()})\)

**Effects:** Returns a new span that is a view over Count elements of the current span starting at element Offset. If Count is equal to dynamic_extent, then a span over all elements from Offset onwards is returned.

**Returns:** \( \text{span}(\text{data()} + \text{Offset}, \ \text{Count} == \text{dynamic_extent} \ ? \ \text{size()} - \text{Offset} : \ \text{Count}) \)

**Complexity:** Constant

```cpp
constexpr span<element_type, dynamic_extent> first(index_type count) const;
```

**Requires:** \( \text{count} >= 0 && \text{count} <= \text{size()} \)

**Effects:** Returns a new span that is a view over the initial count elements of the current span.

**Returns:** \( \text{span}(\text{data()}, \ \text{count}) \)

**Complexity:** Constant

```cpp
constexpr span<element_type, dynamic_extent> last(index_type count) const;
```

**Requires:** \( \text{Count} >= 0 && \text{Count} <= \text{size()} \)

**Effects:** Returns a new span that is a view over the final Count elements of the current span.

**Returns:** \( \text{span}(\text{Count} == 0 \ ? \ \text{data()} : \ \text{data()} + (\text{size()} - \text{Count}), \ \text{Count}) \)

**Complexity:** Constant

```cpp
constexpr span<element_type, dynamic_extent> subview(index_type offset, index_type count = dynamic_extent) const;
```
**Requires:** (Offset == 0 || Offset > 0 && Offset < size()) && (Count == dynamic_extent
|| Count >= 0 && Offset + Count <= size())

**Effects:** Returns a new span that is a view over Count elements of the current span starting at element Offset. If Count is equal to dynamic_extent, then a span over all elements from Offset onwards is returned.

**Returns:** span(data() + Offset, Count == dynamic_extent ? size() - Offset : Count)

**Complexity:** Constant

### 23.7.2.2 span observers [span.obs]

```cpp
constexpr index_type length() const noexcept;
```

**Effects:** Equivalent to size().

```cpp
constexpr index_type size() const noexcept;
```

**Effects:** Returns the number of elements accessible through the span.

**Returns:** >= 0

**Complexity:** Constant

```cpp
constexpr index_type length_bytes() const noexcept;
```

**Effects:** Equivalent to size_bytes().

```cpp
constexpr index_type size_bytes() const noexcept;
```

**Effects:** Returns the number of bytes used for the object representation of all elements accessible through the span.

**Returns:** size() * sizeof(element_type)

**Complexity:** Constant

```cpp
constexpr bool empty() const noexcept;
```

**Effects:** Equivalent to size() == 0.
Returns: \( \text{size()} == 0 \)

Complexity: Constant

### 23.7.2.3 span element access [span.elem]

```cpp
cconstexpr reference operator[](index_type idx) const;
cconstexpr reference operator[](index_type idx) const;
```

Requires: \( \text{idx} \geq 0 \) && \( \text{idx} < \text{size()} \)

Effects: Returns a reference to the element at position \( \text{idx} \).

Returns: \( *(\text{data()} + \text{idx}) \)

Complexity: Constant

```cpp
cconstexpr pointer data() const noexcept;
```

Effects: Returns either a pointer to the first element in the sequence accessible via the span or the null pointer if that was the value used to construct the span.

Returns: (for exposition) \( \text{data} \)

Complexity: Constant

### 23.7.2.4 span iterator support [span.iterators]

```cpp
 iterator begin() const noexcept;
c const_iterator cbegin() const noexcept;
```

Returns: An iterator referring to the first element in the span.

Complexity: Constant

```cpp
 iterator end() const noexcept;
c const_iterator cend() const noexcept;
```

Returns: An iterator which is the past-the-end value.

Complexity: Constant

```cpp
 reverse_iterator rbegin() const noexcept;
c const_reverse_iterator crbegin() const noexcept;
```
Returns: An iterator that is semantically equivalent to `reverse_iterator(end())`.

Complexity: Constant

```cpp
class reverse_iterator
{
public:
  reverse_iterator();  // Construction
  ~reverse_iterator(); // Destruction
  reverse_iterator(const iterator &other); // Copy construction
  iterator operator*() const; // Dereference
  iterator &operator*(); // Dereference
  reverse_iterator &operator=(const reverse_iterator &other); // Assignment

private:
  const_iterator cbegin_; // Constant beginning iterator
  const_iterator cend_;   // Constant end iterator
};
```

Returns: An iterator that is semantically equivalent to `reverse_iterator(begin())`.

Complexity: Constant

```
template <class ElementType, ptrdiff_t Extent>
constexpr bool operator==(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;
```

Effects: Equivalent to `equal(l.begin(), l.end(), r.begin(), r.end())`.

```
template <class ElementType, ptrdiff_t Extent>
constexpr bool operator!=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;
```

Effects: Equivalent to `!(l == r)`.

```
template <class ElementType, ptrdiff_t Extent>
constexpr bool operator<(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;
```

Effects: Equivalent to `lexicographical_compare(l.begin(), l.end(), r.begin(), r.end())`.

```
template <class ElementType, ptrdiff_t Extent>
constexpr bool operator>(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;
```

Effects: Equivalent to `!(r < l)`.
template <class ElementType, ptrdiff_t Extent>
constexpr bool operator<=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

**Effects:** Equivalent to !(l > r).

template <class ElementType, ptrdiff_t Extent>
constexpr bool operator>=(const span<ElementType, Extent>& l, const span<ElementType, Extent>& r) const noexcept;

**Effects:** Equivalent to !(l < r).

### 23.7.2.6 views of object representation [span.objectrep]

```cpp
template <class ElementType, ptrdiff_t Extent>
constexpr span<const byte, ((Extent == dynamic_extent) ? dynamic_extent : (sizeof(ElementType) * Extent))> as_bytes(span<ElementType, Extent> s) noexcept;
```

**Effects:** Constructs a span over the object representation of the elements in s.

**Returns:** `{ reinterpret_cast<const byte*>(s.data()), sizeof(ElementType) * s.size() }`

```cpp
template <class ElementType, ptrdiff_t Extent>
constexpr span<byte, ((Extent == dynamic_extent) ? dynamic_extent : (sizeof(ElementType) * Extent))> as_writeable_bytes(span<ElementType, Extent> s) noexcept;
```

**Requires:** This function will not participate in overload resolution when `is_const<ElementType>::true` exists.

**Effects:** Constructs a span over the object representation of the elements in s.

**Returns:** `{ reinterpret_cast<byte*>(s.data()), sizeof(ElementType) * s.size() }`

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References


