Range constructors for standard containers and views

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1 Abstract

Most standard containers and views can be constructed from an iterators-pair. This paper, complementing [P0896R3], proposing that all standard views, containers and string classes be constructible from a range.

2 Motivation

Most containers of the standard library provide a constructors taking a pair of iterators.

```
std::list<int> lst;
std::vector<int> vec{std::begin(lst), std::end(lst)};
//equivalent too
std::vector<int> vec;
std::copy(it, end, std::back_inserter(vec));
```

While, this feature is very useful, as converting from one container type to another is a frequent use-case, it can be greatly improved by taking full advantage of the notions and tools offer by the Range TS.

Indeed, given all containers are ranges (ie: an iterator-sentinel pair) the above example can be rewritten, without semantic of performance changes, as:

```
std::list<int> lst;
std::vector<int> vec{lst};
```

The above example is a common pattern as it is frequently preferable to copy the content of a `std::list` to a `std::vector` before feeding it an algorithm and then copying it back to a `std::vector`.

All containers and views being ranges, it is logical they can themselves be built out of ranges. Note that all containers and views already provide constructors for iterator-pairs, which themselves represent a range. They also provide copy and move constructors for ranges of the same type

(`std::vector` provide a copy constructor from another `std::vector`, etc). This proposal is a generalization of these existing features.

2.1 View Materialization

The main motivation for this proposal is what is colloquially called *view materialization*. In Ranges TS terminology, a view can generate its elements lazily (upon increment or decrement), such as the value at a given position of the sequence iterated over only exist transiently in memory if an iterator is pointing to that position. (Note: while all lazy ranges are views, not all views are lazy).

View materialization consists in committing all the elements of such view in memory by putting them into a container.

The following code iterates over the numbers 0 to 1023 but only one number actually exists in memory at any given time.

```
std::iota_view v{0, 1024};
for (auto i : v) {
        std::cout << i << ' ';
}
```

While this offers great performance and reduced memory footprint, it is often necessary to put the result of the transformation operated by the view into memory. The facilities provided by [P0896R3] allow to do that in the following way:

```
std::iota_view v{0, 1024};
std::vector<int> materialized;
std::ranges::copy v{v, std::back_inserter(materialized)};
```

This proposal allows to rewrite the above snippet as:

```
std::vector materialized = std::iota_view v{0, 1024};
```

Perhaps the most important aspect of view materialization is that it allow simple code such as:

```
namespace std {
        split_view<std::string_view> split(std:std::string_view);
}
std::vector<std::string> words = std::split("Splitting strings made easy");
```

Indeed, a function such as `split` is notoriously hard to standardize ([P0540], [N3593]), because without lazy views and `std::string_view`, it has to allocate or expose an expert-friendly interface. The view materialization pattern further let the *caller* choose the best container and allocation strategy for their use case (or to never materialize the view should it not be necessary). And while it would not make sense for a standard-library function to split a string into a vector it would allocate, it's totally reasonable for most applications to do so.

This paper do not propose to standardize such `split` function, however, view materialization is something the SG-16 working group is interested in. Indeed, they have considered APIs that could

rely heavily on this idiom, as it has proven a natural way to handle the numerous ways to iterate over Unicode text. Similar ideas have been presented in [P1004].

```
std::vector<std::u8string> sentences =
        text::unicode_codepoint_view<text::utf8>(blob)
        text::normalize<text::nfc> |
        text::graphemes_view |
        text::split<sentences>;
```

3 Design considerations

3.1 Ranges and sentinel

Iterators from the Ranges TS are not always compatible with iterators from the `std` namespace. Namely,

- They do not have the same set of requirements.
- `std`'s iterator do not support unbounded ranges and `Sentinel`
- Work is being done to allow Ranges's iterators to be move only

Therefore, in the general case, the iterator-pair constructor offered by standard containers can not be use, but instead the `ranges::copy` should be use. Deferring to the design decisions of [P0896R3], we think it's better avoided not to have support for both type of iterator-pairs in the same overload set as to avoid breaking code in subtle ways.

Therefore, adding support for `ranges::`'s ranges seem the best solution to make `std::` containers constructible from objects meeting the requirements specified in th `ranges::` namespace.

Ranges are also a better, safer, stronger abstraction compared to iterator-pairs.

3.2 `explicit`

Because copy of containers is costly, the authors of this paper believe it is important that the range-based constructors for containers be `explicit`. However, there is a strong interest for this syntax to be supported:

```
container c = view | transform;
```

But, at the same time, the following pitfalls should be avoided:

```
auto map m = /*...*/;
vector a = m;   //implicit conversion map -> vector (O(n))
vector b = m;   //implicit conversion map -> vector (O(n))
```

```
void foo(const vector<type> &);
deque a =  /*...*/;
foo(a);  //implicit conversion deque -> vector (O(n))
foo(a);  //implicit conversion deque -> vector (O(n))
```

—

```
std::list<type> foo();
void bar(const vector<type> &);
bar(foo()); //implicit conversion vector -> list (O(n))
```

—

```
void foo(const vector<type> &);
auto view = zip(...);
foo(view); // View materialized once
foo(view); // View materialized twice
```

All the above example crystallize concerns over performances traps that would indubitably arise. Therefore we think it is to best follow the existing practice not to allow implicit copy construction from object of different types.

But because expiring views can only be materialize once and can therefore not be considered a copy, we think it is reasonable that containers can be constructed *implicitly* from `rvalue-reference` views.

3.3 Movability

Beside being desirable to have different `explicit`-ness policies for containers and views, the content of `rvalue-reference` `Containers` can be moved-from, as if per `std::move_iterator` rather than copied. This is however generally undecidable for views which may not own the underlying data, and so views should only be copied-from.

3.4 Range constructor for views

Views (span, basic_string_view), can only be constructed from a `ContiguousRange` of the same type. Because they don't copy the data, they do not need to be explicit as constructing a view is cheap. On they other end, because they don't own the data, we must take care to only construct them from lvalue reference.

3.5 `constexpr`

Views (`std::span`, `std::basic_string_view`) constructors can be `constexpr` and so, they shall be. Other containers are currently not `constexpr`-constructable, but work is being down in this area. As more containers gain `constexpr` constructors, the range-based constructors as proposed here should be made `constexpr` too.

4 Existing practices

4.1 Abseil

View materialization is a technique notably adopted by the [Abseil] library. As per their documentation:

> One of the more useful features of the StrSplit() API is its ability to adapt its result set to the desired return type. StrSplit() returned collections may contain std::string, absl::string_view, or any object that can be explicitly created from an absl::string_view. This pattern works for all standard STL containers including std::vector, std::list, std::deque, std::set, std::multiset, std::map, and std::multimap, and even std::pair, which is not actually a container.

Because they can not modify existing containers, view materialization in Abseil is done by the mean of a conversion operator:

```
template<Container C>
operator C();
```

However, because it stand to reason to expect that there are many more views than containers, and because conversions between containers is also useful, it is a more general solution to accept ranges in container constructors than it is to make each view convertible to a container.

4.2 Range V3

4.3 Previous work

[N3686] explores similar solutions and was discussed by LEWG long before the Ranges TS

5 Future work

Whether `std::vector` can be converted to and from `std::std::string` in $\mathcal{O}(1)$ is an area of interest, notably for SG-16. Should such conversion exist, it should take precedence over the generic range-constructor proposed here.

6 Proposed wording

Change in **[basic.string] 20.3.2**:

```
namespace std {
template<class charT, class traits = char_traits<charT>,
class Allocator = allocator<charT>>
class basic_string {
        public:
```

```
        [...]

        basic_string() noexcept(noexcept(Allocator())) : basic_string(Allocator()) { }
        explicit basic_string(const Allocator& a) noexcept;
        basic_string(const basic_string& str);
        basic_string(basic_string&& str) noexcept;
        basic_string(const basic_string& str, size_type pos, const Allocator& a = Allocator());
        basic_string(const basic_string& str, size_type pos, size_type n,
        const Allocator& a = Allocator());
        template<class T>
        basic_string(const T& t, size_type pos, size_type n, const Allocator& a = Allocator());
        template<class T>
        explicit basic_string(const T& t, const Allocator& a = Allocator());
        basic_string(const charT* s, size_type n, const Allocator& a = Allocator());
        basic_string(const charT* s, const Allocator& a = Allocator());
        basic_string(size_type n, charT c, const Allocator& a = Allocator());
        template<class InputIterator>
        basic_string(InputIterator begin, InputIterator end, const Allocator& a = Allocator());
        basic_string(initializer_list<charT>, const Allocator& = Allocator());
        basic_string(const basic_string&, const Allocator&);
        basic_string(basic_string&&, const Allocator&);

        template<Container C>
        explicit basic_string(C&&, const Allocator& = Allocator());

        template<InputRange Rng>
        explicit(see-below)
        basic_string(Rng&&, const Allocator& = Allocator());
        ~basic_string();

        [...]
};

template<class InputIterator,
class Allocator = allocator<typename iterator_traits<InputIterator>::value_type>>
basic_string(InputIterator, InputIterator, Allocator = Allocator())
-> basic_string<typename iterator_traits<InputIterator>::value_type,
char_traits<typename iterator_traits<InputIterator>::value_type>,
Allocator>;

template<class charT,
class traits,
class Allocator = allocator<charT>>
explicit basic_string(basic_string_view<charT, traits>, const Allocator& = Allocator())
-> basic_string<charT, traits, Allocator>;

template<class charT,
class traits,
class Allocator = allocator<charT>>
basic_string(basic_string_view<charT, traits>,
```

```
typename see below::size_type, typename see below::size_type,
const Allocator& = Allocator())
-> basic_string<charT, traits, Allocator>;
}
```

Change in **[string.cons] 20.3.2.2**:

Add after 23

```
template<Container C>
requires Constructible<charT, iter_value_t<iterator_t<C>>>
explicit basic_string(C&& rng, const Allocator& = Allocator());
```

Effects: In a move constructor, constructs a string by moving from the elements of `rng` in a way equivalent to

```
ranges::move(rng, std::back_inserter(*this));
```

Otherwise, constructs a string from the values in the range [`ranges::begin(rng)`, `ranges::end(rng)`).

Complexity: Linear in `ranges::size(rng)`.

—

```
template<InputRange Rng>
requires Constructible<charT, iter_value_t<iterator_t<C>>>
explicit(see-below)
basic_string(Rng&& rng, const Allocator& = Allocator());
```

Effects: Constructs a string from the values in the range [`ranges::begin(rng)`, `ranges::end(rng)`)

Remarks: This constructor shall not participate in overload resolution unless

- `Rng` does not meet the requirements of `Container`

Complexity: Linear in `ranges::size(rng)`.

The expression inside explicit is equivalent to:

```
!is_rvalue_reference_v<V&&>
```

7 References

[P0896R3] Eric Niebler, Casey Carter, Christopher Di Bella *The One Range Ts Proposal* https://wg21.link/P0896

[P1004] Louis Dionne *Making std::vector constexpr* https://wg21.link/P1004

[P1004] Tom Honermann *Text_view: A C++ concepts and range based character encoding and code point enumeration library*
https://wg21.link/P0244

[P0540] Laurent Navarro *A Proposal to Add split/join of string/string_view to the Standard Library*
https://wg21.link/P0540

[N3593] Greg Miller *std::split(): An algorithm for splitting strings*
https://wg21.link/N3593

[P1035] Christopher Di Bella *Input range adaptors*
https://wg21.link/P1035

[Abseil] Abseil Maintainers https://abseil.io/docs/cpp/guides/strings

[N3686] Jeffrey Yasskin *[Ranges] Traversable arguments for container constructors and methods*
https://wg21.link/n3686