views::enumerate

Abstract

We propose a view enumerate whose value type is a struct with 2 members index and value representing respectively the position and value of the elements in the adapted range.

Revisions

R8

• remove the wording for enumerate result following SG9 consensus to use std::tuple.
• Qualify std::move
• Italicize base_ and simple-view
• Unconditionally use range_difference_type as the index_type
• Model the sentinel wording on elements_view in order to support mixed comparison
• Add missing explicit on the one parameter constructor
• Improve the specification of the begin/end methods
• Add missing enable_borrowed_range specialization
• Greatly simplify the comparison operators
• Propose an index methods to avoid deferencing the underlying iterator when not needed. The * operator of the underlying range might be expensive, if the user only cares about the index, the index method could be used to query the index cheaply in all cases. It is trivial to specify, implement, and could be provided later at no cost. But I'm happy to do that change if it increases consensus.
• Other minor wording fixes.
R7

- This version asks LEWG to choose between tuple or enumerate_result as the reference and value types of enumerate_view. The approach presented in previous revisions of having a value type and a reference type of different types proved not workable. We need to pick one of the two options. Wording is provided for both.

- Add missing iter_move and iter_swap functions.

- Add the markup for freestanding

- Add feature test macro

- Formatting fixes.

R6

Wording changes:

- Add enumerate_result to the list of tuple-like types

- Because enumerate_view::iterator::operator* returns values, enumerate_view::iterator cannot be a Cpp17ForwardIterator. Change iterator_category and add iterator_concept accordingly.

R5

Instead of adding complexity to enumerate_result, we assume changes made by P2165R2 [1]. P2165R2 [1] makes pair constructible from pair-like objects, and associative containers deduction guides work with ranges of pair-like objects. With these changes, enumerate_result can remain a simple aggregate. We just need to implement the tuple protocol for it (get, tuple_element, tuple_size).

P2165R2 [1] ensures a common reference exists between enumerate_result and std::tuple as long as one exists between each element.

count_type is renamed to index_type. I am not sure why I ever chose count_type as the initial name.

R4

This revision is intended to illustrate the effort necessary to support named fields for index and value. In previous revisions, the value and reference types were identical, a regrettable blunder that made the wording and implementation efforts smaller than they are. reference and value_type types however needs to be different, if only to make the ranges::to presented in this very paper.

If that direction is acceptable, better wording will be provided to account for these new reference and value_type types.
This revision also gets rid of the `const index` value as LEWG strongly agreed that it was a terrible idea to begin with, one that would make composition with other views cumbersome.

**R3**

- Typos and minor wording improvements

**R2, following mailing list reviews**

- Make `value_type` different from `reference` to match other views
- Remove inconsistencies between the wording and the description
- Add relevant includes and namespaces to the examples

**R1**

- Fix the index type

**Tony tables**

<table>
<thead>
<tr>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>std::vector days{&quot;Mon&quot;, &quot;Tue&quot;, &quot;Wed&quot;, &quot;Thu&quot;, &quot;Fri&quot;, &quot;Sat&quot;, &quot;Sun&quot;};</code></td>
<td></td>
</tr>
<tr>
<td><code>int idx = 0;</code></td>
<td></td>
</tr>
<tr>
<td><code>for(const auto &amp; d : days) {</code></td>
<td></td>
</tr>
</tbody>
</table>
| `print("{} {} 
", idx, d);` |
| `idx++;` |
| `}` |
| `for(const auto & [index, value]: std::views::enumerate(days)) {` |
| `print("{} {} 
", index, value);` |

**Motivation**

The impossibility to extract an index from a range-based for loop leads to the use of non-range-based `for` loops, or the introduction of a variable in the outer scope. This is both more verbose and error-prone: in the example above, the type of `idx` is incorrect.

`enumerate` is a library solution solving this problem, enabling the use of range-based for loops in more cases.

It also composes nicely with other range facilities: The following creates a map from a vector using the position of each element as key.
This feature exists in some form in Python, Rust, Go (backed into the language), and in many C++ libraries: ranges-v3, folly, boost::ranges (indexed).

The existence of this feature or lack thereof is the subject of recurring StackOverflow questions.

**Design**

**std::tuple vs aggregate with name members**

Following the trend of using meaningful names instead of returning pairs or tuples, one option is to use a struct with named public members.

```cpp
struct enumerate_result {
    T value;
};
```

This design was previously discussed by LEWGI in Belfast in the context of P1894R0 [3], and many people have expressed a desire for such struct with names.

```cpp
std::vector<double> v;
enumerate(view) | to<std::vector>(); // std::vector<std::tuple<std::size_t, double>>.
enumerate(view) | to<std::map>(); // std::map<std::size_t, double>.
```

**Why not just always return a tuple and rely on structure binding?**

If a range reference type is convertible to the index type, it is error-prone whether one should write

```cpp
for(auto && [value, index] : view | std::views::enumerate)
for(auto && [index, value] : view | std::views::enumerate)
```

Having named members avoids this issue. The feedback I keep getting is "we should use a struct if we can". Which is consistent with previous LEWG guidelines to avoid using pair when a more meaningful type is possible.

**Why use a tuple?**

The drawback of using a distinct type is that

```cpp
auto vec = enumerate(view) | ranges::to<std::vector>();
```

would produce a `vector<enumerate_result<std::size_t, range_value_t<decltype(view)>>` where ideally, I think it should produce a tuple.
Why not `enumerate_result` as reference type and `tuple` as value type?

This was the approach proposed by the previous revision of the paper and my preferred solution. Best of both world. It only has a small drawback: it doesn’t work.

Many algorithms end up requiring `invocable<F&, iter_value_t<I>&> && invocable<F&, iter_reference_t<I>>` (where F is a function), which would require `std::tuple<std::size_t, Foo>&` to be convertible to `enumerate_result<std::size_t, Foo>`.

In practice, this means that many algorithms are not utilizable if reference and values are not the same type.

```cpp
std::ranges::find(enumerate(/*...*/), [](auto const& p) { // constraints not satisfied. 
    return /*...*/; 
})
```

This is simply not acceptable.

Tomasz also observed that it would interract poorly with `as_const`.

```cpp
for (auto const& p : enumerate(/*...*/)) {
    something(p.value); // OK
}
```

```cpp
for (auto const& p : enumerate(/*...*/) | views|as_const) {
    something(p.value); // KO decltype(p) is tuple<std::size_t, const Foo&>
}
```

Which is... not great. The unfortunate `invocable<F&, iter_value_t<I>&>` constraints exists as some algorithms (not find) may constructs value types out of the elements of the range.

Where do we go from here?

We need to choose between using `tuple` or `enumerate_result`, and that type would be used for both the value type and the reference type.

**POLL:** Does LEWG prefer using `enumerate_result` (Option 1) rather than a `tuple` (Option 2) as the value and reference type of `enumerate_view::iterator`?

The wording provides both options.

Why not `zip(iota, view)`?

Zipping the view with `iota` does not actually work (see also P2214R0 [2]), and a custom `index_view` would need to be used as the first range composed with `zip`, so a custom `enumerate` view with appropriately named members is not adding a lot of work.

`enumerate` as presented here is slightly less work for the compiler, but both solutions generate similar assembly.
Performance

An optimizing compiler can generate the same machine code for `views::enumerate` as it would for an equivalent for loop. Compiler Explorer [Editor’s note: This implementation is a prototype not fully reflective of the proposed design].

Implementation

This proposal has been implemented (Github) There exist an implementation in ranges-v3 (where the enumerate view uses zip_with and a pair value type).

Proposal

We propose a view `enumerate` whose value type is a struct with 2 members `index` and `value` representing respectively the position and value of the elements in the adapted range.

Wording

⚠️ Header `<ranges> synopsis` [ranges.syn]

```cpp
template<class R>
using keys_view = elements_view<R, 0>; // freestanding

namespace views {
    template<size_t N>
    inline constexpr unspecified elements = unspecified; // freestanding
    inline constexpr auto keys = elements<0>; // freestanding
    inline constexpr auto values = elements<1>; // freestanding
}

template<input_range View>
requires view<View>
class enumerate_view; // freestanding

template<class View>
inline constexpr bool enable_borrowed_range<enumerate_view<View>> = // freestanding
    enable_borrowed_range<View>;

namespace views { inline constexpr unspecified enumerate = unspecified; } // freestanding

// ??, zip view
template<input_range... Views>
```
Enumerate view

Overview

enumerate_view presents a view whose elements represents both the position and value of the adapted view's elements.

The name views::enumerate denotes a range adaptor object. Given the subexpression \( E \) the expression views::enumerate(\( E \)) is expression-equivalent to enumerate_view<views::all_t<decltype(\( E \))>>(\( E \)).

Example:

```cpp
vector<int> vec{ 1, 2, 3 };  
for (auto [index, value] : enumerate(vec) )  
    cout << index << "::" << value << ":" ; // prints: 0:1 1:2 2:3
```

Class template enumerate_view

```cpp
template<input_range V>  
requires view<V>  
class enumerate_view : public view_interface<enumerate_view<V>> {

private:  
    V base_ = V(); // exposition only

    template <bool Const>  
    class iterator; // exposition only
    template <bool Const>  
    class sentinel; // exposition only

public:

    constexpr enumerate_view() requires default_initializable<V> = default;  
    constexpr explicit enumerate_view(V base);
```
constexpr auto begin() requires (!\textit{simple-view}<V>) 
{ return \textit{iterator}<false>(\textit{ranges}::begin(base_, \emptyset)); }

constexpr auto begin() const requires range<const V> 
{ return \textit{iterator}<true>(\textit{ranges}::begin(base_, \emptyset)); }

constexpr auto end() requires (!\textit{simple-view}<V>) 
{ 
  if constexpr (\textit{common_range<V>} && \textit{sized_range<V>} ) { 
    return \textit{iterator}<false>(\textit{ranges}::end(base_), \textit{ranges}::distance(base_)); 
  } else { 
    return \textit{sentinel}<false>(\textit{ranges}::end(base_)); 
  }
}

constexpr auto end() const 
{ 
  if constexpr (\textit{common_range<const V>} && \textit{sized_range<const V>} ) { 
    return \textit{iterator}<true>(\textit{ranges}::end(base_), \textit{ranges}::distance(base_)); 
  } else { 
    return \textit{sentinel}<true>(\textit{ranges}::end(base_)); 
  }
}

constexpr auto size() requires sized_range<V> 
{ return \textit{ranges}::size(base_); }

constexpr auto size() const requires sized_range<const V> 
{ return \textit{ranges}::size(base_); }

constexpr V base() const & requires copy_constructible<V> { return base_; }
constexpr V base() && { return std::move(base_); }

};
template<class R>
enumerate_view(R&&) -> enumerate_view<\textit{views}::all_t<R>>;

constexpr enumerate_view(V base);

\textbf{Effects:} Initializes base_ with std::move(base).

\textbf{Class} enumerate_view::\textit{iterator} 

\textbf{namespace} std::ranges {
  template<input_range V> 
  requires view<V>
  template<bool Const> 
  class enumerate_view<V>::\textit{iterator} {
    public:

using iterator_category = input_iterator_tag;
using iterator_concept = see below;
using value_type = tuple<index_type, range_value_t<Base>>;
using difference_type = range_difference_t<Base>;
using index_type = difference_type;

private:
  using Base = maybe-const<Const, V>;
  iterator_t<Base> current_ = iterator_t<Base>(); // exposition only
  index_type pos_ = 0; // exposition only

  constexpr explicit iterator(iterator_t<Base> current, index_type pos); // exposition only

public:

  iterator() = default;

  constexpr iterator(iterator<!Const> i)
  requires Const && convertible_to<iterator_t<V>, iterator_t<Base>>;

  constexpr iterator_t<Base> base() const &
  requires copyable<iterator_t<Base>>;
  constexpr iterator_t<Base> base() &&;

  constexpr index_type index() const;

  constexpr auto operator*() const {
    return tuple<index_type, range_reference_t<Base>>{ pos_, *current_};
  }

  constexpr iterator& operator++();
  constexpr void operator++(int);
  constexpr iterator operator++(int) requires forward_range<Base>;

  constexpr iterator& operator--() requires bidirectional_range<Base>;
  constexpr iterator operator--(int) requires bidirectional_range<Base>;

  constexpr iterator& operator+=(difference_type x)
  requires random_access_range<Base>;
  constexpr iterator& operator-=(difference_type x)
  requires random_access_range<Base>;

  constexpr auto operator[](difference_type n) const
  requires random_access_range<Base>
  { return reference{pos_ + n, *(current_ + n)}; }

  friend constexpr bool operator==(const iterator& x, const iterator& y);
  friend constexpr auto operator<=>(const iterator& x, const iterator& y);
friend constexpr iterator operator+(const iterator& x, difference_type y)  
requires random_access_range<Base>;
friend constexpr iterator operator+(difference_type x, const iterator& y)  
requires random_access_range<Base>;
friend constexpr iterator operator-(const iterator& x, difference_type y)  
requires random_access_range<Base>;
friend constexpr difference_type operator-(const iterator& x, const iterator& y);

friend constexpr auto iter_move(const iterator& i)  
noexcept(noexcept(ranges::iter_move(i.current_)))  
{  
    return tuple<index_type,  
        range_rvalue_reference_t<Base>>{pos_, ranges::iter_move(i.current_)};
}
};

iterator::iterator_concept is defined as follows:

• If Base models random_access_range, then iterator_concept denotes random_access_iterator_tag.
• Otherwise, if Base models bidirectional_range, then iterator_concept denotes bidirectional_iterator_tag.
• Otherwise, if Base models forward_range, then iterator_concept denotes forward_iterator_tag.
• Otherwise, iterator_concept denotes input_iterator_tag.

constexpr explicit iterator(iterator_t<
    Base> current, index_type pos = 0);

    Effects: Initializes current_ with std::move(current) and pos_ with pos.

constexpr iterator(iterator_t<
    !Const> i)  
requires Const && convertible_to<iterator_t<V>, iterator_t<Base>>;

    Effects: Initializes current_ with std::move(i.current_) and pos_ with i.pos_.

constexpr iterator_t<
    Base> base() const&  
requires copyable<iterator_t<Base>>;

    Effects: Equivalent to: return current_;

constexpr iterator_t<
    Base> base() &&;

    Effects: Equivalent to: return std::move(current_);

constexpr index_type index() const;

    Effects: Equivalent to: return pos_;

constexpr iterator& operator++();

    Effects: Equivalent to:
constexpr void operator++(int);

**Effects:** Equivalent to:

```
++current_;  
++pos_;  
return *this;
```

constexpr iterator operator++(int) requires forward_range<Base>;

**Effects:** Equivalent to:

```
auto temp = *this;  
++*this;  
return temp;
```

constexpr iterator operator--() requires bidirectional_range<Base>;

**Effects:** Equivalent to:

```
--current_;  
--pos_;  
return *this;
```

constexpr iterator operator--(int) requires bidirectional_range<Base>;

**Effects:** Equivalent to:

```
auto temp = *this;  
--*this;  
return temp;
```

constexpr iterator& operator+=(difference_type n);
requires random_access_range<Base>;

**Effects:** Equivalent to:

```
current_ += n;  
pos_ += n;  
return *this;
```

constexpr iterator& operator-=(difference_type n)
requires random_access_range<Base>;
Effects: Equivalent to:
   
   ```cpp
   current_ -= n;
   pos_ -= n;
   return *this;
   ```

friend constexpr bool operator==(const iterator& x, const iterator& y);

Effects: Equivalent to: return x.pos_ == y.pos_;

friend constexpr auto operator<=>(const iterator& x, const iterator& y);

Effects: Equivalent to: return x.pos_ <=> y.pos_;

friend constexpr iterator operator+(const iterator& x, difference_type y)
requires random_access_range<Base>;

Effects: Equivalent to: return iterator(x) += y;

friend constexpr iterator operator+(difference_type x, const iterator& y)
requires random_access_range<Base>;

Effects: Equivalent to: return y + x;

constexpr iterator operator-(const iterator& x, difference_type y)
requires random_access_range<Base>;

Effects: Equivalent to: return iterator(x) -= y;

class template enumerate_view::sentinel [range.enumerate.sentinel]

namespace std::ranges {
    template<input_range V, size_t N>
    requires view<V>
    template<bool Const>
    class enumerate_view<V, N>::sentinel {
        // exposition only
        private:
            using Base = maybe-const<Const, V>;
            // exposition only
            sentinel_t<Base> end_ = sentinel_t<Base>();
            // exposition only
        public:
            sentinel() = default;
            constexpr explicit sentinel(sentinel_t<Base> end);
            constexpr sentinel(sentinel<!Const> other)
            requires Const && convertible_to<sentinel_t<V>, sentinel_t<Base>>;
            constexpr sentinel_t<Base> base() const;

    template<bool OtherConst>

12
requires sentinel_for<sentinel_t<Base>, iterator_t<maybe-const<OtherConst, V>>>
friend constexpr bool operator==(const iterator<OtherConst>& x, const sentinel& y);

template<bool OtherConst>
requires sized_sentinel_for<sentinel_t<Base>, iterator_t<maybe-const<OtherConst, V>>>
friend constexpr range_difference_t<maybe-const<OtherConst, V>>
operator-(const iterator<OtherConst>& x, const sentinel& y);

};
constexpr explicit sentinel(sentinel_t<Base> end);

Effects: Initializes end_ with end.

customexpr sentinel(sentinel<!Const> other)
requires Const && convertible_to<sentinel_t<V>, sentinel_t<Base>>;

Effects: Initializes end_ with std::move(other.end_).

customexpr sentinel_t<Base> base() const;

Effects: Equivalent to: return end_;
Acknowledgments

Thanks a lot to Tomasz Kamiński for finding defects in the design proposed in earlier revisions, as well as his invaluable wording feedbacks. Thanks to Barry Revzin and Christopher Di Bella for their inputs on the design.

References