std::forward_like

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1 Introduction

Deducing This [P0847R7] is expected to land in C++23.

Its examples use a hypothetical std::forward_like<decltype(self)>(variable) facility because std::forward<decltype(v)>(v) is insufficient. This paper proposes std::forward_like to cater to this scenario.
2 Proposal

Add the `forward_like` function template to the utility header.

```cpp
template <typename T>
[[nodiscard]] constexpr auto forward_like(auto&& x) noexcept -> __forward_like_t<T, decltype(x)>
    { return static_cast<__forward_like_t<T, decltype(x)>>((x)); }
```

where `__forward_like_t<T, U>` is a metafunction defined with the `merge` model table (below); or, more succinctly:

```cpp
template <typename T, typename U>
using __override_ref_t = std::conditional_t<std::is_rvalue_reference_v<T>, std::remove_reference_t<U> &&, U &>;

template <typename T, typename U>
using __copy_const_t = std::conditional_t<std::is_const_v<std::remove_reference_t<T>>, U const, U &>;

template <typename T, typename U>
using __forward_like_t = __override_ref_t<T &&, __copy_const_t<T, std::remove_reference_t<U>>>;
```

3 Design Discussion

As `forward`, `forward_like` is a type cast that only influences the value category of an expression.

`forward_like` is a facility for forwarding the value category of an object-expression `m` (usually a member) based on the value category of the owning object-expression `o`.

When `m` is an actual member and thus `o.m` a valid expression, this is usually spelled as `forward<decltype(o)>(o).m` in C++20 code.

When `o.m` is not a valid expression, *i.e.* members of lambda closures, one needs `forward_like</*see below*/>(m).` This leads to three possible models, called `merge`, `tuple`, and `language`.

- `merge`: we merge the `const` qualifiers, and adopt the value category of the Owner
- `tuple`: what `std::get<0>(std::tuple<Member> Owner)` does.
- `language`: what `std::forward<decltype(Owner)>(o).m` does.

The main scenario that `forward_like` caters to is adapting “far” objects. Neither the tuple nor the language scenarios do the right thing for that main use-case, so the `merge` model is proposed.

For completeness, the tables of all three approaches to reference-casting are presented below.

4 Use cases

In order to decide between the three models, let’s look at use-cases.
4.1 A lambda that forwards its capture

This was the very first use-case for deducing this: a callback lambda that can be used in either “retry” (lvalue) or “try or fail” (rvalue, use-once) algorithms with optimal efficiency.

With the `merge` model:

```cpp
auto callback = [m=get_message(), &scheduler](this auto &&self) -> bool {
    return scheduler.submit(std::forward_like<decltype(self)>(m));
};
callback(); // retry(callback)
std::move(callback)(); // try-or-fail(rvalue)
```

Or, with the `tuple` or `language` models:

```cpp
auto callback = [m=get_message(), &scheduler](this auto &&self) -> bool {
    return scheduler.submit(std::forward_like<decltype(self), decltype(m)>(m));
};
callback(); // retry(callback)
std::move(callback)(); // try-or-fail(rvalue)
```

Note that `tuple` and `language` models have significant problems when applied to reference captures - see the section on that below.

4.2 Returning “far” owned state

This is a family of cases where we are forwarding a member “owned” by the Owner, but perhaps not directly contained by it.

With the `merge` model:

```cpp
struct fwd {
    std::unique_ptr<std::string> ptr;
    std::optional<std::string> opt;
    std::deque<std::string> container;

    auto get_ptr(this auto &&self) -> std::string {
        if (ptr) { return std::forward_like<decltype(self)>(*ptr); } // *self
        return "";
    }

    auto get_opt(this auto &&self) -> std::string {
        if (opt) { return std::forward_like<decltype(self)>(*opt); } // *self
        return "";
    }

    auto operator[](this auto &&self, size_t i) -> std::string {
        return std::forward_like<decltype(self)>(container[i]);
    }
};
```

and so on.

- The `language` and `tuple` models fail here - we need an alternative way to cast the far state into an rvalue (they both leave lvalue arguments as lvalues).
- In the `optional` case, we are lucky, and notice `optional` provides an rvalue accessor, which means we could spell the line as `*std::forward<decltype(self)>(self).opt`.
- However, `deque` does not provide an rvalue subscript operator (though it could);
— but `unique_ptr`’s `operator*()` will never provide the appropriate cast, as pointers have shallow semantics. `merge` is the only model that satisfies this use case.

### 4.3 Why `merge` `const`-qualifiers?

Because one never wants to take `const` away from `const` members, that would be wrong.

```cpp
template <typename T>
struct by_ptr {
  std::shared_ptr<T> far;
  auto get(this auto&& self) {
    return std::forward_like<decltype(self)>(*self.far);
  }
};

by_ptr<const std::string> x{new std::string("shakespeare")};
```

### 4.4 Returning “far” owned-state from free-function interfaces

Not all uses require deducing this. The problem already occurs with free-function interfaces like `match(f, g).`

```cpp
template <typename T, typename U>
struct either {
  int idx; // 0 for T, 1 for U
  std::array<std::byte, max(sizeof(T), sizeof(U))> buf;

  friend auto match(similar<either> auto&& self_, auto&& f, auto&& g) -> void {
    if (self_.idx == 0) {
      FWD(f)(std::forward_like<decltype(self_)>(*(T*) self_.buf.data()));
    } else {
      FWD(g)(std::forward_like<decltype(self_)>(*(U*) self_.buf.data()));
    }
  }
};
```

C-style casts used for brevity.

### 5 Issue: Forwarding reference captures

There is a significant gotcha with the language and tuple models.

In lambdas with reference captures, find an unsolvable problem: `&` and `|=` captures do not produce a distinguishing `decltype`. (notice lines (a) and (c) are the same!)

```cpp
int x;
int z;
[this auto&& self] (x, &y=x, z) {
  forward_like<decltype(self), decltype(x)>(x);  // a: int&
  forward_like<decltype(self), decltype(y)>(y);  // b: int& (!)
  forward_like<decltype(self), decltype(z)>(z);  /* c: int&!
  forward_like<decltype(self), decltype(y)>(x);  /* d: int& (and typo!) */
}();
```

The inconsistency here is dangerous.
With the language and tuple models, we get inconsistent behavior between (a) and (b), which is extremely surprising, especially if one considers [&]-style captures.

We also get consistent behavior between lines (a) and (c), which is a surprise in this case.

(d) also exposes the brittle nature of typos with this model; we must reference the parameter twice so we run into problems with typos. This is impossible with the merge model, which is orthogonalized.

With the merge model, we get consistent behavior - rvalue if invoked as an rvalue, lvalue if invoked as lvalue. Simple, predictable, obvious.

6 Open Questions

Is LEWG is happy with the name forward_like?

Some alternative names: forward_member, (feel free to suggest more).

7 Qualifier Tables for the three possible models

7.1 The common parts

All the models agree on the following table of cv-ref qualifiers of the inputs and outputs of the facility:

<table>
<thead>
<tr>
<th>n</th>
<th>Owner</th>
<th>Member</th>
<th>forward_like&lt;o&gt;(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&amp;</td>
<td></td>
<td>kk</td>
</tr>
<tr>
<td>2</td>
<td>&amp;&amp;</td>
<td></td>
<td>k</td>
</tr>
<tr>
<td>3</td>
<td>const</td>
<td></td>
<td>const&amp;kk</td>
</tr>
<tr>
<td>4</td>
<td>const&amp;</td>
<td></td>
<td>constk</td>
</tr>
<tr>
<td>5</td>
<td>const&amp;&amp;</td>
<td></td>
<td>const&amp;&amp;</td>
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<tr>
<td>6</td>
<td>const const&amp;&amp;</td>
<td></td>
<td>const const&amp;&amp;</td>
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<tr>
<td>7</td>
<td>const &amp;</td>
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<td>const &amp;</td>
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<tr>
<td>8</td>
<td>const &amp;&amp;</td>
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<td>9</td>
<td>const &amp; const&amp;</td>
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<td>const &amp; const&amp;</td>
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<td>10</td>
<td>const &amp; const &amp;&amp;</td>
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<td>const &amp; const &amp; const &amp;&amp;</td>
</tr>
<tr>
<td>13</td>
<td>const &amp; const &amp; const &amp; const&amp;</td>
<td></td>
<td>const &amp; const &amp; const &amp; const&amp;</td>
</tr>
<tr>
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<td>const &amp; const &amp; const &amp; const &amp; const &amp;&amp;</td>
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<tr>
<td>17</td>
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<td>const &amp; const &amp; const &amp; const &amp; const &amp; const&amp;</td>
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<tr>
<td>18</td>
<td>const &amp; const &amp; const &amp; const &amp; const &amp; const &amp;&amp;</td>
<td></td>
<td>const &amp; const &amp; const &amp; const &amp; const &amp; const &amp;&amp;</td>
</tr>
</tbody>
</table>

Commentary:

- For value-type members, we follow the forwarding category of the parent.
- If the parent is an lvalue, the result is an lvalue even for references.
- const is merged for these cases

7.2 The differing parts

The models differ in the following cases (for the three models of forward_like).
Commentary:

— language is obviously wrong in all cases (25, 28, 34, 36) where both are rvalues - those should be rvalues. In addition, it requires both Owner and Member types to be explicit template parameters.

— tuple: collapses the value category of Owner and Member, inherits const from member. Plausible, but has problems with use-cases, and needs both Owner and Member types to be explicit template parameters.

— merge: merges the const from Owner and Member, uses the value category of Owner. Needs only Owner to be an explicit template parameter.

8 Interface

In the merge model, the interface is:

```cpp
template <typename T>
[[nodiscard]] constexpr auto forward_like(auto&& x) noexcept -> __forward_like_t<T, decltype(x)> {
    return static_cast<__forward_like_t<T, decltype(x)>>((x));
}
```

In the tuple and language models, we would need both to be explicit:

```cpp
template <typename T, typename M>
[[nodiscard]] constexpr
auto forward_like(__similar<M> auto&& x) noexcept -> __forward_like_t<T, M, decltype(x)> {
    return static_cast<__forward_like_t<T, M, decltype(x)>>((x));
}
```

(__similar<T, U> is a concept that is satisfied by the two types if they are equal up to cv-ref qualifiers.) However, because we need two explicit template parameters, the definition is compatible with calling it just forward, so we could use

```cpp
std::forward<decltype(o), decltype(m)>(m)
```

instead of the longer forward_like<decltype(o), decltype(m)>(m) in these cases. This orthogonalizes the interface, which eases teaching. If forwarding members, just supply both!
The language and tuple models have bigger problems with the use cases, however, so this is just silver lining on a very dark cloud.

9 Proposed Wording

Notes on wording: should we endeavor to define the \( U \) parameter as not-explicitly-specifiable by the user, as above, or do it old-style as now?

Relative to [N4892].

Insert the following section in Header <utility> synopsis [utility.syn], under the last overload of `forward`:

\[
\text{template<class T, class U>}
\text{[[nodiscard]] constexpr auto forward_like(U&& x) noexcept -> see below;}
\]

Insert a new paragraph under [forward]/4 (which is example 1):

Let \( U' \) be `remove_reference_t<U>`, and \( T' \) be `remove_reference_t<T>`.

Let \( U'' \) be cv-qualified \( U' \) if either \( U' \) or \( T' \) are cv-qualified.

Let \( V \) be “lvalue-reference to cv-\( U'' \)” if \( T \) is an lvalue-reference, and “rvalue-reference to cv-\( U'' \)” otherwise.

6 Returns: `static_cast<V>(x)`.

7 Remarks: The return type is \( V \).

8 [Example 2:]

```cpp
struct accessor {
    vector<string> *container;
    
    decltype(auto) operator[](this auto&& self, size_t i) {
        return std::forward_like<decltype(self)>((*container)[i]);
    }
};

void g() {
    vector v{"a"s, "b"s};
    accessor a(&v);
    string x = a[0]; // OK, binds to lvalue reference
    string&& y = std::move(a)[0]; // OK, is rvalue reference
    string const&& z = std::move(as_const(a))[1]; // OK, is const&&
    string&& w = as_const(a)[1]; // error: will not bind to non-const
}
```

– end example:

and renumber section.

9.1 Feature-test macro

Insert the following in Header synopsis [version.syn], in section 2:

\[
#define __cpp_lib_forward_like 20XXXXL // also in <utility>
\]
10 Acknowledgements

— Sarah from the #include discord for pointing out std::tuple’s `get` has a better view on how to treat reference members than the language does, thus saving the facility from being a mess that duplicates the language.
— Yunlan Tang, who did some of the research for an early version of this paper.
— Barry Revzin, Sy Brand and Ben Deane, my dear co-authors of [P0847R7], without whom this paper would be irrelevant.
— Vittorio Romeo, who tried writing this paper first a few years ago.
— Jens Maurer, who wrote the initial wording, and Corentin Jabot also writing the wording. The current is a merge between both. And Jens Maurer again, for fixing the wording yet again.
— Tomasz Kamiński, for pointing out typos.
— JohelEGP from the cpplang slack for pointing out typos.

11 Appendix: code listing for implementation and tables

```cpp
#include <type_traits>
#include <utility>
#include <tuple>
#include <memory>
#include <string>

template <typename T, typename U>
concept _similar =
    std::is_same_v<std::remove_cvref_t<T>, std::remove_cvref_t<U>>;

template <typename T, typename U>
using _copy_ref_t = std::conditional_t<
    std::is_rvalue_reference_v<T>, U &&,
    std::conditional_t<std::is_lvalue_reference_v<T>, U &, U>>;

template <typename T, typename U>
using _override_ref_t = std::conditional_t<
    std::is_rvalue_reference_v<T>,
    std::remove_reference_t<U> &&, U &>

template <typename T, typename U>
using _copy_const_t = std::conditional_t<
    std::is_const_v<std::remove_reference_t<T>>,
    _copy_ref_t<U, std::remove_reference_t<T> const>, U>;

constexpr bool _is_reference_v =
    std::is_lvalue_reference_v<T> || std::is_rvalue_reference_v<T>;

template <typename T, typename U>
using _copy_cvref_t = _copy_ref_t<T &&, _copy_const_t<T, U>>;

// test utilities
#define FWD(...) std::forward<decltype((__VA_ARGS__))>(__VA_ARGS__)

template <typename Expected, typename Actual> constexpr void is_same() {
```
```cpp
static_assert(std::is_same_v<Expected, Actual>);
}

namespace ftpl {
using std::forward;

template <typename T, typename U>
using _fwd_like_tuple_t =
  std::conditional_t<_is_reference_v<U>, _copy_ref_t<T, U>,
                     _copy_cvref_t<T, U>>;

// implementation
template <typename T, typename M, _similar<M> U>
auto forward_like_tuple(U &&x) noexcept -> decltype(auto) {
  return static_cast<_fwd_like_tuple_t<T, M>>(x);
}

template <typename T, typename M, _similar<M> U>
auto forward(U &&x) noexcept -> decltype(auto) {
  return forward_like_tuple<T, M>(static_cast<U &&>(x));
}
} // namespace ftpl

namespace flang {
using std::forward;

template <typename T, typename U>
using _fwd_like_lang_t =
  std::conditional_t<_is_reference_v<U>, U &,
                    _copy_ref_t<T, _copy_const_t<T, U>> &&>;

template <typename T, typename M, _similar<M> U>
auto forward(U &&x) noexcept -> decltype(auto) {
  return static_cast<_fwd_like_lang_t<T, _copy_const_t<T, U>>>(x);
}
} // namespace flang

namespace fmrg {
using _copy_const_t =
  std::conditional_t<std::is_const_v<std::remove_reference_t<T>>, U const, U>;

template <typename T, typename U>
using _fwd_like_merge_t =
  _override_ref_t<T &&, _copy_const_t<T, std::remove_reference_t<T>>>;

template <typename T, typename U>
auto forward_like(U &&x) noexcept -> decltype(auto) {
  return static_cast<_fwd_like_merge_t<T, U>>(x);
}
} // namespace fmrg

struct probe {};

template <typename M> struct S {
```
M m;
using value_type = M;
);

template<
typename T, typename Merge, typename Tuple, typename Lang>
void test() {

using value_type = typename std::remove_cvref_t<T>::value_type;

using mrg = decltype(std::forward<

using tpls = decltype(std::forward<

using tpls = decltype(std::forward<

using lng_model = decltype(

using lng_model = decltype(

using lng_model = decltype(

is_same<

is_same<

is_same<

// sanity checks

is_same<

is_same<

}

void test() {

using p = probe;
// clang-format off

// TEST

// clang-format on
```cpp
test<S<p &x > &k, p &k, p &k, p &k, p &k, p &k, p &k, p &k>()

test<S<p &x > const &k, p const &k, p const &k, p const &k, p const &k>()

test<S<p &x > const &k, p const &k, p const &k, p const &k>()

test<S<p &x > const &k, p const &k, p const &k, p const &k>()

test<S<p &x > const &k, p const &k, p const &k, p const &k>()

test<S<p &x > const &k, p const &k, p const &k, p const &k>()

test<S<p &x > const &k, p const &k, p const &k, p const &k>()

test<S<p &x > const &k, p const &k, p const &k, p const &k>()

test<S<p &x > const &k, p const &k, p const &k, p const &k>()

test<S<p &x > const &k, p const &k, p const &k, p const &k>()
```

```cpp
void test_lambdas() {
    probe x;
    probe z;
    auto l = [x, &y = x, z](auto &&self) mutable {
        // correct, this is what we *meant*, consistently
        // If we didn't mean to forward the capture, we wouldn't have used
        // forward_like.
        is_same<override_ref_t<decltype(self), probe>,
            decltype(fmpl::forward_like<decltype(self)>(y))>()
        is_same<override_ref_t<decltype(self), probe>,
            decltype(fmpl::forward_like<decltype(self)>(y))()()
    is_same<override_ref_t<decltype(self), probe>,
        decltype(fmpl::forward_like<decltype(self)>(z))>()

    // x and y behave differently with the tuple model (problem)
    is_same<probe &, decltype(ftpl::forward<decltype(self), decltype(y)>(y))>()
    is_same<override_ref_t<decltype(self), probe>,
        decltype(ftpl::forward<decltype(self), decltype(x)>(x))>()
    is_same<override_ref_t<decltype(self), probe>,
        decltype(ftpl::forward<decltype(self), decltype(z)>(z))>()

    // x and y behave differently with the language model (problem)
    is_same<probe &,
        decltype(lang::forward<decltype(self), decltype(y)>(y))>()
    is_same<override_ref_t<decltype(self), probe>,
        decltype(lang::forward<decltype(self), decltype(x)>(x))>()
    is_same<override_ref_t<decltype(self), probe>,
        decltype(lang::forward<decltype(self), decltype(z)>(z))>()
    l(1); // lvalue-call emulation
    l(std::move(l)); // sortish like a this-auto-self with a && call operator
}
```

```cpp
struct owns_far_string {  
    std::unique_ptr<std::string> s;
};
```

```cpp
void test_far_objects() {
```
// problem is that *unique_ptr returns a reference
owns_far_string fs;
auto l = [] (auto &&fs) {
    using mrg = decltype(fmr::forward_like<decltype(fs)>(*fs.s));
    using tpl = decltype(ftpl::forward<decltype(fs), decltype(*fs.s)>(*fs.s));
    using lng = decltype(flang::forward<decltype(fs), decltype(*fs.s)>(*fs.s));

    // fit for purpose
    is_same<_override_ref_t<decltype(fs), std::string>, mrg> ();
    // these are not fit for purpose
    is_same<std::string &, tpl> ();
    is_same<std::string &, lng> ();
};
l(fs); // lvalue call
l(std::move(fs)); // rvalue call - we want to move the string out
}

int main() {
    test();
    test_lambda();
    test_far_objects();
}

12 References

https://wg21.link/n4892

https://wg21.link/p0847r7