

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 Status of this paper

This paper has been accepted by LEWG as proposed (with the merge model). This is `fmrgr::forward_like` in the appendix. LWG has approved this paper for a plenary vote with the changes in this revision on 2022-05-13.

3 Revision Log

— R0 -> R1: wording changed to current wording, no semantic changes.

4 Proposal

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

```
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:

```
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>>>;
```

5 Use cases

In order to decide between the three models, let's look at use-cases.

5.1 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:

```
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:

```

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.

5.2 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:

```

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); }
        return "";
    }

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

5.3 Why merge const-qualifiers?

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

```

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

```

```
};
// should be correct and not move
by_ptr<const std::string> x{new std::string("shakespeare")};
```

5.4 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)`.

```
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.

6 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!)

```
int x;
int z;
[&x, &y=x, z](this auto&& self) {
    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.

7 Open Questions

Is LEWG is happy with the name `forward_like`?

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

8 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>(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.

8.1 The common parts

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

n	Owner	Member	<code>forward_like<o>(m)</code>
1			<code>&&</code>
2	<code>&</code>		<code>&</code>
3	<code>&&</code>		<code>&&</code>
4	<code>const</code>		<code>const&&</code>
5	<code>const&</code>		<code>const&</code>
6	<code>const&&</code>		<code>const&&</code>
7		<code>const</code>	<code>const&&</code>
8	<code>&</code>	<code>const</code>	<code>const&</code>
9	<code>&&</code>	<code>const</code>	<code>const&&</code>
10	<code>const</code>	<code>const</code>	<code>const&&</code>
11	<code>const&</code>	<code>const</code>	<code>const&</code>
12	<code>const&&</code>	<code>const</code>	<code>const&&</code>
13	<code>&</code>	<code>&</code>	<code>&</code>
14	<code>&</code>	<code>&&</code>	<code>&</code>
15	<code>&</code>	<code>const &</code>	<code>const&</code>
16	<code>&</code>	<code>const &&</code>	<code>const&</code>
17	<code>const&</code>	<code>const &</code>	<code>const&</code>
18	<code>const&</code>	<code>const &&</code>	<code>const&</code>

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

8.2 The differing parts

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

n	Owner	Member	'merge'	'tuple'	'language'
19		&	&&	&	&
20	&&	&	&&	&	&
21	const	&	const &&	&	&
22	const &	&	const &	&	&
23	const &&	&	const &&	&	&
24		&&	&&	&&	&
25	&&	&&	&&	&&	&
26	const	&&	const &&	&&	&
27	const &	&&	const &	&	&
28	const &&	&&	const &&	&&	&
29		const &	const &&	const &	const &
30	&&	const &	const &&	const &	const &
31	const	const &	const &&	const &	const &
32	const &&	const &	const &&	const &	const &
33		const &&	const &&	const &&	const &
34	&&	const &&	const &&	const &&	const &
35	const	const &&	const &&	const &&	const &
36	const &&	const &&	const &&	const &&	const &

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.

9 Interface

In the **merge** model, the interface is:

```
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:

```
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

```
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.

10 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`:

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

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

5

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

Let `COPY_CONST(A, B)` be `const B` if A is a `const` type, otherwise B.

Let `OVERRIDE_REF(A, B)` be `remove_reference_t<B&&>` if A is an rvalue reference type, otherwise B&.

Let V be `OVERRIDE_REF(T&&, COPY_CONST(remove_reference_t<T>, remove_reference_t<U>))`.

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

7 *Remarks:* The return type is V.

8 *[Example 2:*

```
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.

10.1 Feature-test macro

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

```
#define __cpp_lib_forward_like 20XXXXL // also in <utility>
```

11 Acknowledgements

- *Barry Revzin*, who wrote the wording for the semantics on the LWG session.
- *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.
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- *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.

12 Appendix: code listing for implementation and tables

```
#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<U> const>, U>;

template <typename T>
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() {
    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<U, M>>>(x);
}
} // namespace flang

namespace fmrq {
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 _fwd_like_merge_t =
    _override_ref_t<T &&, _copy_const_t<T, std::remove_reference_t<U>>>;

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

```

```

} // namespace fmrng

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(fmrng::forward_like<T>(std::declval<value_type>()));
    using tpl_model = decltype(std::get<0>(
        std::declval<copy_cvref_t<T, std::tuple<value_type>>>()));
    using tpl =
        decltype(ftpl::forward<T, value_type>(std::declval<value_type>()));
    using lng_model = decltype((std::forward<T>(std::declval<T>()).m));
    using lng =
        decltype(flmg::forward<T, value_type>(std::declval<value_type>()));

    is_same<Merge, mrg>();
    is_same<Tuple, tpl>();
    is_same<Lang, lng>();
    // sanity checks
    is_same<Tuple, tpl_model>();
    is_same<Lang, lng_model>();
}

void test() {
    using p = probe;
    // clang-format off
    // TEST TYPE           , 'merge'   , 'tuple'   , 'language'
    test<S<p               >           , p &&     , p &&     , p &&     >();
    test<S<p               > &        , p &      , p &      , p &      >();
    test<S<p               > &&       , p &&     , p &&     , p &&     >();
    test<S<p               > const    , p const && , p const && , p const && >();
    test<S<p               > const & , p const & , p const & , p const & >();
    test<S<p               > const && , p const && , p const && , p const && >();
    test<S<p const        >           , p const && , p const && , p const && >();
    test<S<p const        > &        , p const & , p const & , p const & >();
    test<S<p const        > &&       , p const && , p const && , p const && >();
    test<S<p const        > const    , p const && , p const && , p const && >();
    test<S<p const        > const & , p const & , p const & , p const & >();
    test<S<p const        > const && , p const && , p const && , p const && >();
    test<S<p &           > &        , p &      , p &      , p &      >();
    test<S<p &&         > &        , p &      , p &      , p &      >();
    test<S<p const &    > &        , p const & , p const & , p const & >();
    test<S<p const &&   > &        , p const & , p const & , p const & >();
    test<S<p const &    > const & , p const & , p const & , p const & >();
    test<S<p const &&   > const & , p const & , p const & , p const & >();
}

```

```

test<S<p & > >, p &&, p &, p & >();
test<S<p & > &&, p &&, p &, p & >();
test<S<p & > const &, p const &&, p &, p & >();
test<S<p & > const &, p const &, p &, p & >();
test<S<p & > const &&, p const &&, p &, p & >();
test<S<p && > >, p &&, p &&, p & >();
test<S<p && > &&, p &&, p &&, p & >();
test<S<p && > const &, p const &&, p &&, p & >();
test<S<p && > const &, p const &, p &, p & >();
test<S<p && > const &&, p const &&, p &&, p & >();
test<S<p const & > >, p const &&, p const &, p const & >();
test<S<p const & > &&, p const &&, p const &, p const & >();
test<S<p const & > const &, p const &&, p const &, p const & >();
test<S<p const & > const &&, p const &&, p const &, p const & >();
test<S<p const && > >, p const &&, p const &&, p const & >();
test<S<p const && > &&, p const &&, p const &&, p const & >();
test<S<p const && > const &, p const &&, p const &&, p const & >();
test<S<p const && > const &&, p const &&, p const &&, p const & >();
// clang-format on
}

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(fmrg::forward_like<decltype(self)>(y))>();
        is_same<_override_ref_t<decltype(self), probe>,
            decltype(fmrg::forward_like<decltype(self)>(x))>();
        is_same<_override_ref_t<decltype(self), probe>,
            decltype(fmrg::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(fl原因ang::forward<decltype(self), decltype(y)>(y))>();
        is_same<_override_ref_t<decltype(self), probe>,
            decltype(fl原因ang::forward<decltype(self), decltype(x)>(x))>();
        is_same<_override_ref_t<decltype(self), probe>,
            decltype(fl原因ang::forward<decltype(self), decltype(z)>(z))>();
    };
    l(l); // lvalue-call emulation
    l(std::move(l)); // sortish like a this-auto-self with a ES call operator
}

```

```

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

void test_far_objects() {
    // problem is that *unique_ptr returns a reference
    owns_far_string fs;
    auto l = [](auto &&fs) {
        using mrg = decltype(fmrg::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_lambdas();
    test_far_objects();
}

```

13 References

- [N4892] Thomas Köppe. 2021-06-18. Working Draft, Standard for Programming Language C++. <https://wg21.link/n4892>
- [P0847R7] Barry Revzin, Gašper Ažman, Sy Brand, Ben Deane. 2021-07-14. Deducing this. <https://wg21.link/p0847r7>