

std::forward_like

Document #: P2445R0
Date: 2021-09-26
Project: Programming Language C++
Audience: Library Evolution Working Group
Library Working Group
Reply-to: Gašper Ažman
<gasper.azman@gmail.com>

Contents

1	Introduction	1
2	Design Discussion	1
2.1	The common parts	2
2.2	The differing parts	2
3	Interface	3
4	Use cases	3
4.1	A lambda that forwards its capture	4
4.2	Returning “far” owned state	4
4.3	Forwarding reference captures	5
5	Open Questions	5
6	Proposal	5
7	Proposed Wording	6
7.1	Feature-test macro	6
8	Acknowledgements	7
9	Appendix: code listing for implementation and tables	7
10	References	11

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 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.

2.1 The common parts

All the models agree on the following table:

n	Owner	Member	Forwarded
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

2.2 The differing parts

The models differ in the following cases:

n	Owner	Member	‘merge’	‘tuple’	‘language’
19		<code>&</code>	<code>&&</code>	<code>&</code>	<code>&</code>
20	<code>&&</code>	<code>&</code>	<code>&&</code>	<code>&</code>	<code>&</code>
21	<code>const</code>	<code>&</code>	<code>const &&</code>	<code>&</code>	<code>&</code>
22	<code>const &</code>	<code>&</code>	<code>const &</code>	<code>&</code>	<code>&</code>
23	<code>const &&</code>	<code>&</code>	<code>const &&</code>	<code>&</code>	<code>&</code>
24		<code>&&</code>	<code>&&</code>	<code>&&</code>	<code>&</code>
25	<code>&&</code>	<code>&&</code>	<code>&&</code>	<code>&&</code>	<code>&</code>
26	<code>const</code>	<code>&&</code>	<code>const &&</code>	<code>&&</code>	<code>&</code>

n	Owner	Member	‘merge’	‘tuple’	‘language’
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.

3 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 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.

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:

```
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.

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:

```
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.

4.3 Forwarding reference captures

There is another 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(x); /* a: int&& */
    forward_like(y); /* b: int& (!) */
    forward_like(z); /* c: int&& */
    forward_like(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.

5 Open Questions

Is LEWG is happy with the name `forward_like`?

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

6 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; 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>>>>;
```

7 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 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:*

```
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.

7.1 Feature-test macro

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

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

8 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.

9 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 fmrq

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(fmrg::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(flang::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 & >();
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(flang::forward<decltype(self), decltype(y)>(y))>();
        is_same<override_ref_t<decltype(self), probe>,
            decltype(flang::forward<decltype(self), decltype(x)>(x))>();
        is_same<override_ref_t<decltype(self), probe>,
            decltype(flang::forward<decltype(self), decltype(z)>(z))>();
    };
    l(l); // lvalue-call emulation
    l(std::move(l)); // sortish like a this-auto-self with a && 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();
}

```

10 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>