

# std::forward for members (forward\_like)

Document #: P2445R0  
Date: 2021-10-21  
Project: Programming Language C++  
Audience: Library Evolution Working Group  
Library Working Group  
Reply-to: Gašper Ažman  
<[gasper.azman@gmail.com](mailto:gasper.azman@gmail.com)>

## Contents

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

## 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 an additional overload of `std::forward` 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>&amp;&amp;</code>      |
| 2  | <code>&amp;</code>           |                               | <code>&amp;</code>           |
| 3  | <code>&amp;&amp;</code>      |                               | <code>&amp;&amp;</code>      |
| 4  | <code>const</code>           |                               | <code>const&amp;&amp;</code> |
| 5  | <code>const&amp;</code>      |                               | <code>const&amp;</code>      |
| 6  | <code>const&amp;&amp;</code> |                               | <code>const&amp;&amp;</code> |
| 7  |                              | <code>const</code>            | <code>const&amp;&amp;</code> |
| 8  | <code>&amp;</code>           | <code>const</code>            | <code>const&amp;</code>      |
| 9  | <code>&amp;&amp;</code>      | <code>const</code>            | <code>const&amp;&amp;</code> |
| 10 | <code>const</code>           | <code>const</code>            | <code>const&amp;&amp;</code> |
| 11 | <code>const&amp;</code>      | <code>const</code>            | <code>const&amp;</code>      |
| 12 | <code>const&amp;&amp;</code> | <code>const</code>            | <code>const&amp;&amp;</code> |
| 13 | <code>&amp;</code>           | <code>&amp;</code>            | <code>&amp;</code>           |
| 14 | <code>&amp;</code>           | <code>&amp;&amp;</code>       | <code>&amp;</code>           |
| 15 | <code>&amp;</code>           | <code>const &amp;</code>      | <code>const&amp;</code>      |
| 16 | <code>&amp;</code>           | <code>const &amp;&amp;</code> | <code>const&amp;</code>      |
| 17 | <code>const&amp;</code>      | <code>const &amp;</code>      | <code>const&amp;</code>      |
| 18 | <code>const&amp;</code>      | <code>const &amp;&amp;</code> | <code>const&amp;</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>&amp;</code>      | <code>&amp;&amp;</code>       | <code>&amp;</code>      | <code>&amp;</code> |
| 20 | <code>&amp;&amp;</code>       | <code>&amp;</code>      | <code>&amp;&amp;</code>       | <code>&amp;</code>      | <code>&amp;</code> |
| 21 | <code>const</code>            | <code>&amp;</code>      | <code>const &amp;&amp;</code> | <code>&amp;</code>      | <code>&amp;</code> |
| 22 | <code>const &amp;</code>      | <code>&amp;</code>      | <code>const &amp;</code>      | <code>&amp;</code>      | <code>&amp;</code> |
| 23 | <code>const &amp;&amp;</code> | <code>&amp;</code>      | <code>const &amp;&amp;</code> | <code>&amp;</code>      | <code>&amp;</code> |
| 24 |                               | <code>&amp;&amp;</code> | <code>&amp;&amp;</code>       | <code>&amp;&amp;</code> | <code>&amp;</code> |
| 25 | <code>&amp;&amp;</code>       | <code>&amp;&amp;</code> | <code>&amp;&amp;</code>       | <code>&amp;&amp;</code> | <code>&amp;</code> |
| 26 | <code>const</code>            | <code>&amp;&amp;</code> | <code>const &amp;&amp;</code> | <code>&amp;&amp;</code> | <code>&amp;</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>
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>
auto forward_like(__similar<M> auto&& x) noexcept -> __forward_like_t<T, M, decltype(x)> {
    return static_cast<__forward_like_t<T, 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, 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>
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 Wording

While the proposal is probably detailed enough to produce a fully specified implementation, the author welcomes the help of LWG to word the proposal to their satisfaction.

In other words, TBD.

## 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.
- 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, but ran out of time.

## 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 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(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 & , 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 C& 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

[P0847R7] Barry Revzin, Gašper Ažman, Sy Brand, Ben Deane. 2021-07-14. Deducing this.  
<https://wg21.link/p0847r7>