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Reply to: Vincent Reverdy and Robert J. Brunner
University of Illinois at Urbana-Champaign
vince.rev@gmail.com

Enriching type modification traits

Note: this is an early draft. It's known to be incomplet and incorrekt, and it has lots of bad formatting.

Abstract

We introduce additional type traits to the standard library focused on type modification. The new type traits we present considerably simplify qualifiers manipulation. We also introduce a new type trait to remove all pointers on a type for the sake of completeness. These type traits have been especially useful in the design of proxy classes, included an updated design for bit manipulation utilities. They also have been used extensively in the implementation of a library dedicated to the creation of custom overload sets that will be proposed for standardization in a separate proposal.

Contents

1 Proposal [proposal]

1.1 Introduction [proposal.introduction]

Since their introduction with C++11, the standard library type traits have been of great help for template metaprogramming. They contributed to the standardization of common metaprogramming patterns, such as SFINAE with `enable_if`, and since C++17 with `void_t`. In this paper, we introduce new type traits corresponding to metaprogramming patterns that turned out to be very useful to implement template proxy classes as well as to implement a tool to build custom overload sets. This tool will be proposed for standardization in a separate paper. We believe that the listed type traits are of common use and could benefit the entire community. The new type traits fall in three different categories:

— pointers removal: `remove_all_pointers` inspired from `remove_all_extents`

— qualifiers manipulation: `copy_*` type traits

— combined removal and qualifiers manipulation: `clone_*` type traits

An implementation is available at `https://github.com/vreverdy/type-utilities`.

1.2 Background [proposal.background]

These type traits have been proposed before in P1016R0. However, back then it was not clear whether this kind of type traits should wait for reflection. In San Diego, SG7 clarified that these type traits are pure library facilities that do not need to be first reviewed by them. They also clarified the fact that type traits in their current form live in a different space than reflection, and that the second one will not make the first one disappear. As a consequence, basic type traits should not wait for reflection. In San Diego, LEWGI recommended the extraction of simple type modification traits from the original P1016R0 proposal, which led to this proposal in its current form.

1.3 Impact on the standard [proposal.impact]

This proposal is a pure library extension. It does not require changes to any standard classes or functions. All the extensions belong to the `<type_traits>` header.

1.4 Motivations and design decisions [proposal.design]

1.4.1 Pointers removal [proposal.design.removal]

```
// Pointers removal
template <class T> struct remove_all_pointers;

// Type alias
template <class T> using remove_all_pointers_t = typename remove_all_pointers<T>::type;
```

The current standard library includes two type traits to manipulate extents: `remove_extent` which removes the first array dimension, and `remove_all_extents` which removes all dimensions. For pointers, only one is currently provided: `remove_pointer` which removes one pointer. However, in some contexts it can be useful to access the "raw" type

However for the same reason that it can be useful to remove all dimensions, it can sometimes be useful to remove all pointers and access the "raw" type. Also, in the context of qualifiers manipulation (see (1.4.2) and (1.4.3)), it makes sense to provide tools to transform a `int***` into a `double***` by transferring all pointers from one type to another: `copy_all_pointers` and `clone_all_pointers`. In this context, being able to remove all pointers seems to be a natural addition to the standard library, for completeness. For all these reasons, we propose to introduce the type trait: `remove_all_pointers`.

1.4.2 Qualifiers manipulation [proposal.design.copy]

```
// Qualifiers manipulation
template <class From, class To> struct copy_const;
template <class From, class To> struct copy_volatile;
template <class From, class To> struct copy_cv;
template <class From, class To> struct copy_reference;
template <class From, class To> struct copy_signedness;
template <class From, class To> struct copy_extent;
template <class From, class To> struct copy_all_extents;
template <class From, class To> struct copy_pointer;
template <class From, class To> struct copy_all_pointers;
template <class From, class To> struct copy_cvref;

// Type aliases
template <class F, class T> using copy_const_t = typename copy_const<F, T>::type;
template <class F, class T> using copy_volatile_t = typename copy_volatile<F, T>::type;
template <class F, class T> using copy_cv_t = typename copy_cv<F, T>::type;
template <class F, class T> using copy_reference_t = typename copy_reference<F, T>::type;
template <class F, class T> using copy_signedness_t = typename copy_signedness<F, T>::type;
template <class F, class T> using copy_extent_t = typename copy_extent<F, T>::type;
template <class F, class T> using copy_all_extents_t = typename copy_all_extents<F, T>::type;
template <class F, class T> using copy_pointer_t = typename copy_pointer<F, T>::type;
template <class F, class T> using copy_all_pointers_t = typename copy_all_pointers<F, T>::type;
template <class F, class T> using copy_cvref_t = typename copy_cvref<F, T>::type;
```

In the heavy template metaprogramming involved in the building of template proxy classes and custom overload sets, one pattern happened to be very useful: being able to transfer the qualifiers of one type to another one. For example, to transform a `const int&` into a `const double&`, a `int[1][2][3]` into a `double[1][2][3]`, or an `int***` to a `double***`. It can be also used in a function taking a universal reference as an input, to qualify another type based on the qualification of the input:

```
template <class T> void f(T&& x) {
    // An integer with the same qualification as the input
    using integer = std::copy_cvref_t<T&&, int>;
    /* function contents */
}
```

or to make a type `const` depending on another type:

```
template <class T> struct foo {
    // Data members
    T a;
    std::copy_const_t<T, int> n;
    std::copy_const_t<T, double> x;
    /* class contents */
};
```

Another uses are illustrated in P0847R0, where `copy_cvref_t` is called `like_t`.

For completeness, qualifier manipulators are added to all existing categories of type transformations: cv (2.1.7.1), reference (2.1.7.2), sign (2.1.7.3), array (2.1.7.4) and pointer (2.1.7.5). Additionally, depending on the behavior regarding the second template parameter, two kinds of qualifier parameters are introduced: the copiers `copy_*` and the cloners `clone_*` presented in the next section.

The complete list of proposed `copy_*` traits is:

— const-volatile modifications: `copy_const`, `copy_volatile`, `copy_cv`

— reference modifications: `copy_reference`

— sign modifications: `copy_signedness`

— array modifications: `copy_extent`, `copy_all_extents`

— pointer modifications: `copy_pointer` `copy_all_pointers`

— other transformations: `copy_cvref`

As a note, in the same way `remove_pointer` deals with cv-qualified pointers, `copy_pointer` `copy_all_pointers` copy the cv-qualifiers of pointers. Also `copy_signedness` is preferred over `copy_sign` to avoid confusion with the existing mathematical function `copysign`.

1.4.3 Combined removal and qualifiers manipulation [proposal.design.clone]

```
// Combined removal and qualifiers manipulation
template <class From, class To> struct clone_const;
template <class From, class To> struct clone_volatile;
template <class From, class To> struct clone_cv;
template <class From, class To> struct clone_reference;
template <class From, class To> struct clone_extent;
template <class From, class To> struct clone_all_extents;
template <class From, class To> struct clone_pointer;
template <class From, class To> struct clone_all_pointers;
template <class From, class To> struct clone_cvref;

// Type aliases
template <class F, class T> using clone_const_t = typename clone_const<F, T>::type;
template <class F, class T> using clone_volatile_t = typename clone_volatile<F, T>::type;
template <class F, class T> using clone_cv_t = typename clone_cv<F, T>::type;
template <class F, class T> using clone_reference_t = typename clone_reference<F, T>::type;
template <class F, class T> using clone_signedness_t = typename clone_signedness<F, T>::type;
template <class F, class T> using clone_extent_t = typename clone_extent<F, T>::type;
template <class F, class T> using clone_all_extents_t = typename clone_all_extents<F, T>::type;
template <class F, class T> using clone_pointer_t = typename clone_pointer<F, T>::type;
template <class F, class T> using clone_all_pointers_t = typename clone_all_pointers<F, T>::type;
template <class F, class T> using clone_cvref_t = typename clone_cvref<F, T>::type;
```

When the second template parameter is also coming from a context where it can be qualified, it can be useful to first remove its qualifiers before copying the new one. The difference between cloners and copiers is that the copiers directly copy the qualifiers of the first argument to the second, while cloners first discard the qualifiers of the second argument. For example `copy_cv_t<volatile int, const double>` evaluates to `const volatile double` while `clone_cv_t<volatile int, const double>` evaluates to `volatile double`, and `copy_all_pointers_t<int***, double*>` evaluates to `double****` while `clone_all_pointers_t<int***, double*>` evaluates to `double***`.

For example:

```
template <class T> struct foo {
    // Function member
    template <class U> void bar (U&& x) {
        std::clone_cvref_t<T, U> something;
        /* function contents */
    }
    /* class contents */
};
```

For completeness, qualifier manipulators are added to all existing categories of type transformations: cv (2.1.7.1), reference (2.1.7.2), sign (2.1.7.3), array (2.1.7.4) and pointer (2.1.7.5).

The complete list of proposed `clone_*` traits is:

— const-volatile modifications: `clone_const`, `clone_volatile`, `clone_cv`

— reference modifications: `clone_reference`

— array modifications: `clone_extent`, `clone_all_extents`

— pointer modifications: `clone_pointer` `clone_all_pointers`

— other transformations: `clone_cvref`

As a note, in the same way `remove_pointer` deals with cv-qualified pointers, `clone_pointer` `clone_all_pointers` clone the cv-qualifiers of pointers. Finally, `clone_signedness` is not introduced, because `remove_sign` does not exist, and does not seem to be a relevant type trait to introduce, the only interesting use case being to transform a `signed char` or an `unsigned char` into a `char`. The difference between `copy_signedness` and a hypothetical `clone_signedness` would be the following: `copy_signedness_t<char, unsigned char>` would evaluate to `unsigned char` while `clone_signedness_t<char, unsigned char>` would evaluate to `char`. In both cases `copy/clone_signedness_t<unsigned int, int>` would evaluate to `unsigned int` and `copy/clone_signedness_t<signed int, unsigned int>` would evaluate to `signed int`.

1.5 Technical specification [proposal.spec]

See the wording (part 2).

1.6 Discussion and open questions [proposal.discussion]

1.6.1 Bikeshedding [proposal.discussion.bikeshed]

While some names are straightforward and follow existing patterns in standard library, the following names are the most likely to be debated:

— `copy_*`

— `clone_*`

— `copy_signedness`

1.7 Acknowledgements [proposal.ackwldgmnts]

The authors would like to thank the participants to the related discussion on the future-proposals group. This work has been made possible thanks to the National Science Foundation through the awards CCF-1647432 and SI2-SSE-1642411.

1.8 References [proposal.references]

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P0847R0, Deducing this, Gasper Azman et al., *ISO/IEC JTC1/SC22/WG21* (February 2018)

General purpose utilities for template metaprogramming and type manipulation, ISO C++ Standard - Future Proposals, *Google Groups* (March 2018)

2 Wording [wording]

2.1 Metaprogramming and type traits [meta]

2.1.1 Requirements [meta.rqmts]

1 No modification.

2.1.2 Header <type_traits> synopsis [meta.type.synop]

1 Add the following to the synopsis of `<type_traits>`:

```
namespace std {
    // 2.1.3, helper classes

    // 2.1.4.1, primary type categories

    // 2.1.4.2, composite type categories

    // 2.1.4.3, type properties

    // 2.1.5, type property queries

    // 2.1.6, type relations

    // 2.1.7.1, const-volatile modifications
    template <class From, class To> struct copy_const;
    template <class From, class To> struct clone_const;
    template <class From, class To> struct copy_volatile;
    template <class From, class To> struct clone_volatile;
    template <class From, class To> struct copy_cv;
    template <class From, class To> struct clone_cv;

    template <class From, class To>
    using copy_const_t = typename copy_const<From, To>::type;
    template <class From, class To>
    using clone_const_t = typename clone_const<From, To>::type;
    template <class From, class To>
    using copy_volatile_t = typename copy_volatile<From, To>::type;
    template <class From, class To>
    using clone_volatile_t = typename clone_volatile<From, To>::type;
    template <class From, class To>
    using copy_cv_t = typename copy_cv<From, To>::type;
    template <class From, class To>
    using clone_cv_t = typename clone_cv<From, To>::type;

    // 2.1.7.2, reference modifications
    template <class From, class To> struct copy_reference;
    template <class From, class To> struct clone_reference;

    template <class From, class To>
    using copy_reference_t = typename copy_reference<From, To>::type;
    template <class From, class To>
```

```
    using clone_reference_t = typename clone_reference<From, To>::type;

    // 2.1.7.3, sign modifications
    template <class From, class To> struct copy_signedness;

    template <class From, class To>
    using copy_signedness_t = typename copy_signedness<From, To>::type;

    // 2.1.7.4, array modifications
    template <class From, class To> struct copy_extent;
    template <class From, class To> struct clone_extent;
    template <class From, class To> struct copy_all_extents;
    template <class From, class To> struct clone_all_extents;

    template <class From, class To>
    using copy_extent_t = typename copy_extent<From, To>::type;
    template <class From, class To>
    using clone_extent_t = typename clone_extent<From, To>::type;
    template <class From, class To>
    using copy_all_extents_t = typename copy_all_extents<From, To>::type;
    template <class From, class To>
    using clone_all_extents_t = typename clone_all_extents<From, To>::type;

    // 2.1.7.5, pointer modifications
    template <class T> struct remove_all_pointers;
    template <class From, class To> struct copy_pointer;
    template <class From, class To> struct clone_pointer;
    template <class From, class To> struct copy_all_pointers;
    template <class From, class To> struct clone_all_pointers;

    template <class T>
    using remove_all_pointers_t = typename remove_all_pointers<T>::type;
    template <class From, class To>
    using copy_pointer_t = typename copy_pointer<From, To>::type;
    template <class From, class To>
    using clone_pointer_t = typename clone_pointer<From, To>::type;
    template <class From, class To>
    using copy_all_pointers_t = typename copy_all_pointers<From, To>::type;
    template <class From, class To>
    using clone_all_pointers_t = typename clone_all_pointers<From, To>::type;

    // 2.1.7.6, other transformations
    template <class From, class To> struct copy_cvref;
    template <class From, class To> struct clone_cvref;

    // 2.1.8, logical operator traits

    // 2.1.9, endian
}
```

2.1.3 Helper classes [meta.help]

1 No modification.

2.1.4 Unary type traits [meta.unary]

1 No modification.

2.1.4.1 Primary type categories [meta.unary.cat]

1 No modification.

2.1.4.2 Composite type traits [meta.unary.comp]

1 No modification.

2.1.4.3 Type properties [meta.unary.prop]

1 No modification.

2.1.5 Type property queries [meta.unary.prop.query]

1 No modification.

2.1.6 Relationships between types [meta.rel]

1 No modification.

2.1.7 Transformations between types [meta.trans]

2.1.7.1 Const-volatile modifications [meta.trans.cv]

1 Add the following to the table “Const-volatile modifications”:

Table 1 — Const-volatile modifications

Template	Comments
`template<class From, class To>` `struct copy_const;`	The member typedef `type` names the same type as `add_const_t<To>` if `is_const_v<From>`, and `To` otherwise.
`template<class From, class To>` `struct clone_const;`	The member typedef `type` names the same type as `copy_const_t<From, remove_const_t<To>>`.
`template<class From, class To>` `struct copy_volatile;`	The member typedef `type` names the same type as `add_volatile_t<To>` if `is_volatile_v<From>`, and `To` otherwise.
`template<class From, class To>` `struct clone_volatile;`	The member typedef `type` names the same type as `copy_volatile_t<From, remove_volatile_t<To>>`.
`template<class From, class To>` `struct copy_cv;`	The member typedef `type` names the same type as `copy_const_t<From, copy_volatile_t<From, To>>`.
`template<class From, class To>` `struct clone_cv;`	The member typedef `type` names the same type as `copy_cv_t<From, remove_cv_t<To>>`.

2.1.7.2 Reference modifications [meta.trans.ref]

1 Add the following to the table “Reference modifications”:

Table 2 — Reference modifications (continued)

Template	**Comments**

Table 2 — Reference modifications

Template	**Comments**
`template<class From, class To>` `struct copy_reference;`	The member typedef `type` names the same type as `add_rvalue_reference_t<To>` if `is_rvalue_reference_v<From>`, `add_lvalue_reference_t<To>` if `is_lvalue_reference_v<From>`, and `To` otherwise.
`template<class From, class To>` `struct clone_reference;`	The member typedef `type` names the same type as `copy_reference_t<From, remove_reference_t<To>>`.

2.1.7.3 Sign modifications [meta.trans.sign]

1 Add the following to the table “Sign modifications”:

Table 3 — Sign modifications

Template	**Comments**
`template<class From, class To>` `struct copy_signedness;`	The member typedef `type` names the same type as `make_signed_t<To>` if `is_same_v<From, make_signed_t<From>>`, `make_unsigned_t<To>` if `is_same_v<From, make_unsigned_t<From>>`, and `To` otherwise. *Requires:* `From` and `To` shall be (possibly cv-qualified) integral types or enumerations but not `bool` types.

2.1.7.4 Array modifications [meta.trans.arr]

1 Add the following to the table “Array modifications”:

Table 4 — Array modifications

Template	**Comments**
`template<class From, class To>` `struct copy_extent;`	The member typedef `type` names the same type as `To[extent_v<From>]` if `rank_v<From> > 0 && extent_v<From> > 0`, `To[]` if `rank_v<From> > 0 && extent_v<From> == 0`, and `To` otherwise. *Requires:* `To` shall not be an array of unknown bound along its first dimension if `From` is an array of unknown bound along its first dimension.
`template<class From, class To>` `struct clone_extent;`	The member typedef `type` names the same type as `copy_extent_t<From, remove_extent_t<To>>`. *Requires:* `From` and `To` shall not be arrays of unknown bounds along their first dimension at the same time.

Table 4 — Array modifications (continued)

Template	Comments
template<class From, class To> struct copy_all_extents;	The member typedef type names the same type as copy_extent_t<From, copy_all_extents_t<std::remove_extent_t<From>, To>> if rank_v<From> > 0, and To otherwise. *Requires:* From and To shall not be arrays of unknown bounds along their first dimension at the same time.
template<class From, class To> struct clone_all_extents;	The member typedef type names the same type as copy_all_extents_t<From, remove_all_extents_t<To>>.

2.1.7.5 Pointer modifications [meta.trans.ptr]

1 Add the following to the table “Pointer modifications”:

Table 5 — Pointer modifications

Template	Comments
template<class T> struct remove_all_pointers;	The member typedef type names the same type as remove_all_pointers_t<remove_pointer_t<T>> if is_pointer_v<T>, and T otherwise.
template<class From, class To> struct copy_pointer;	The member typedef type names the same type as copy_cv_t<From, add_pointer_t<To>> if is_pointer_v<From>, and To otherwise.
template<class From, class To> struct clone_pointer;	The member typedef type names the same type as copy_pointer_t<From, remove_pointer_t<To>>.
template<class From, class To> struct copy_all_pointers;	The member typedef type names the same type as copy_pointer_t<From, copy_all_pointers_t<std::remove_pointer_t<From>, To>> if is_pointer_v<From>, and To otherwise.
template<class From, class To> struct clone_all_pointers;	The member typedef type names the same type as copy_all_pointers_t<From, remove_all_pointers_t<To>>.

2.1.7.6 Other transformations [meta.trans.other]

1 Add the following to the table “Other transformations”:

Table 6 — Other transformations

Template	Comments
template<class From, class To> struct copy_cvref;	The member typedef type names the same type as copy_reference_t<From, copy_reference_t<To, copy_cv_t<remove_reference_t<From>, remove_reference_t<To>>>>.
template<class From, class To> struct clone_cvref;	The member typedef type names the same type as copy_cvref_t<From, remove_cvref<To>>.

2.1.8 Logical operator traits [meta.logical]

1 No modification.

2.1.9 Endian [meta.endian]

1 No modification.

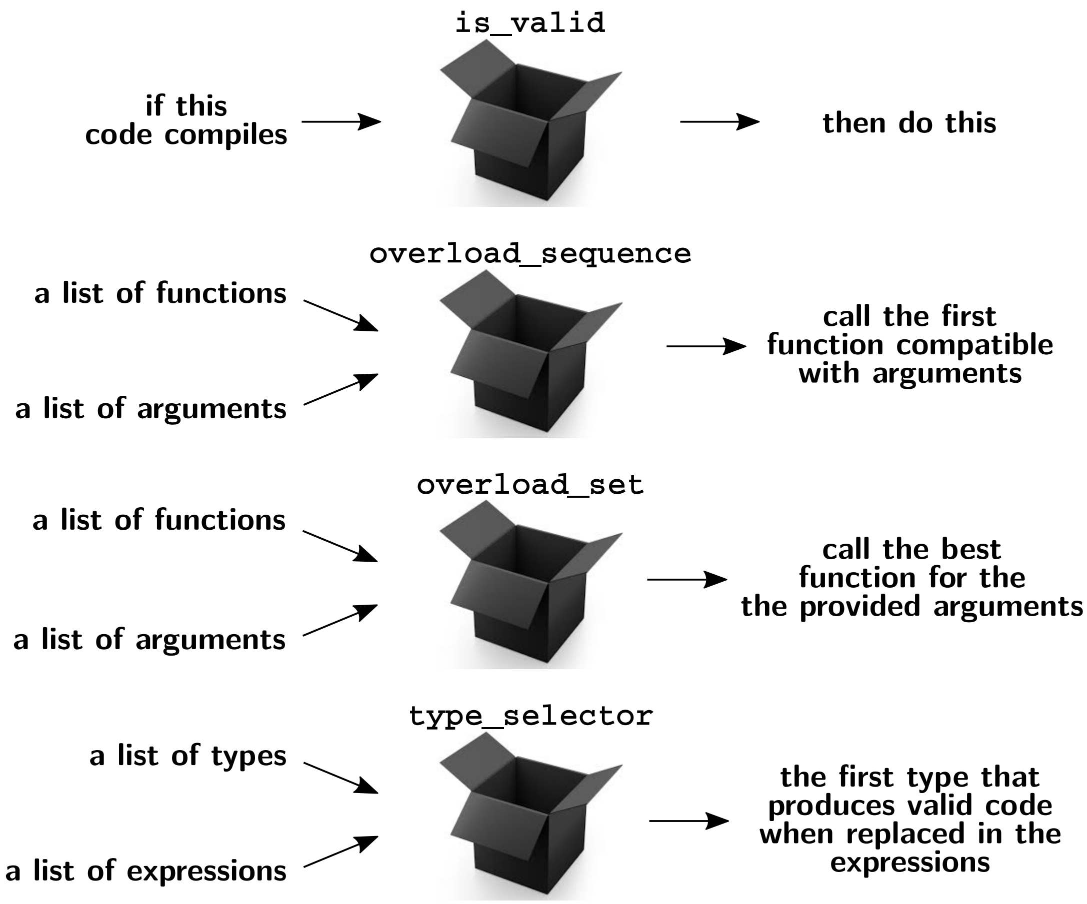
Enriching type modification traits

Vincent Reverdy

Context

CppCon Talk 2018

From Metaprogramming Tricks to Elegance: Custom Overload Sets and Inline SFINAE for Truly Generic Interfaces



Summary

What?

Additional type traits for the <type_traits> header and corresponding to common metaprogramming patterns. Originally developed for a library to create custom overload sets (to be proposed separately).

Overview

3 domains: pointers removal, qualifiers manipulation, combined removal and qualifiers manipulation.
Implementation available at `https://github.com/vreverdy/type-utilities`.

Pointers removal

`remove_all_pointers`

Qualifiers copy

`copy_const`
`copy_volatile`
`copy_cv`
`copy_reference`
`copy_signedness`
`copy_extent`
`copy_all_extents`
`copy_pointer`
`copy_all_pointers`
`copy_cvref`

Qualifiers cloning

`clone_const`
`clone_volatile`
`clone_cv`
`clone_reference`
`clone_extent`
`clone_all_extents`
`clone_pointer`
`clone_all_pointers`
`clone_cvref`

Pointers removal

Current pointer and extent transformation traits

```
template <class T> struct add_pointer;
template <class T> struct remove_pointer;
template <class T> struct remove_extent;
template <class T> struct remove_all_extents;

template <class T> using add_pointer_t = typename add_pointer<T>::type;
template <class T> using remove_pointer_t = typename remove_pointer<T>::type;
template <class T> using remove_extent_t = typename remove_extent<T>::type;
template <class T> using remove_all_extents_t = typename remove_all_extents<T>::type;
```

Synopsis of the proposed additions

```
template <class T> struct remove_all_pointers;
template <class T> using remove_all_pointers_t = typename remove_all_pointers<T>::type;
```

Motivations

- Symmetry with `remove_extent` and `remove_all_extents`
- As useful as `remove_all_extents`
- Completeness with qualifier manipulation traits (see next section)

Example

```
// Arrays
using arr0_t = int[2][3][4];
using arr1_t = remove_extent_t<arr0_t>;        // int[3][4]
using type_a = remove_all_extents_t<arr0_t>;   // int

// Pointers
using ptr0_t = int***;
using ptr1_t = remove_pointer_t<ptr0_t>;       // int**
using type_p = remove_all_pointers_t<ptr0_t>; // int
```

Qualifiers manipulation: synopsis

```
template <class From, class To> struct copy_const;
template <class From, class To> struct clone_const;
template <class From, class To> struct copy_volatile;
template <class From, class To> struct clone_volatile;
template <class From, class To> struct copy_cv;
template <class From, class To> struct clone_cv;
template <class From, class To> struct copy_reference;
template <class From, class To> struct clone_reference;
template <class From, class To> struct copy_signedness;
template <class From, class To> struct copy_extent;
template <class From, class To> struct clone_extent;
template <class From, class To> struct copy_all_extents;
template <class From, class To> struct clone_all_extents;
template <class From, class To> struct copy_pointer;
template <class From, class To> struct clone_pointer;
template <class From, class To> struct copy_all_pointers;
template <class From, class To> struct clone_all_pointers;
template <class From, class To> struct copy_cvref;
template <class From, class To> struct clone_cvref;

template <class F, class T> using copy_const_t = typename copy_const<F, T>::type;
template <class F, class T> using clone_const_t = typename clone_const<F, T>::type;
template <class F, class T> using copy_volatile_t = typename copy_volatile<F, T>::type;
template <class F, class T> using clone_volatile_t = typename clone_volatile<F, T>::type;
template <class F, class T> using copy_cv_t = typename copy_cv<F, T>::type;
template <class F, class T> using clone_cv_t = typename clone_cv<F, T>::type;
template <class F, class T> using copy_reference_t = typename copy_reference<F, T>::type;
template <class F, class T> using clone_reference_t = typename clone_reference<F, T>::type;
template <class F, class T> using copy_signedness_t = typename copy_signedness<F, T>::type;
template <class F, class T> using copy_extent_t = typename copy_extent<F, T>::type;
template <class F, class T> using clone_extent_t = typename clone_extent<F, T>::type;
template <class F, class T> using copy_all_extents_t = typename copy_all_extents<F, T>::type;
template <class F, class T> using clone_all_extents_t = typename clone_all_extents<F, T>::type;
template <class F, class T> using copy_pointer_t = typename copy_pointer<F, T>::type;
template <class F, class T> using clone_pointer_t = typename clone_pointer<F, T>::type;
template <class F, class T> using copy_all_pointers_t = typename copy_all_pointers<F, T>::type;
template <class F, class T> using clone_all_pointers_t = typename clone_all_pointers<F, T>::type;
template <class F, class T> using copy_cvref_t = typename copy_cvref<F, T>::type;
template <class F, class T> using clone_cvref_t = typename clone_cvref<F, T>::type;
```

Qualifiers manipulation: design

Functionality

Apply qualifiers or attributes of one type to another type.

Example

```
// Copy cv qualifiers
using type0 = copy_cv_t<const int, double>;                      // const double
using type1 = copy_cv_t<volatile int, double>;                   // volatile double
using type2 = copy_cv_t<const volatile int, double>;             // const volatile double

// Copy cv-ref qualifiers
using type3 = copy_cvref_t<int&, double>;                        // double&
using type4 = copy_cvref_t<volatile int&, double>;               // volatile double&
using type5 = copy_cvref_t<const volatile int&&, double>;        // const volatile double&&

// Copy vs clone
using type6 = copy_cvref_t<volatile int&, const double>;         // const volatile double&
using type7 = clone_cvref_t<volatile int&, const double>;        // volatile double&
using type8 = copy_all_pointers_t<int**, double***>;             // double*****;
using type9 = clone_all_pointers_t<int**, double***>;            // double**;
```

Design

- Two types of transformations: `copy_*` and `clone_*`
- `copy_*`: add the given qualifiers/attributes of `From` to `To`
- `clone_*`: apply the given qualifiers/attributes of `From` to `To` by first removing the given qualifiers/attributes of `To`
- Same list as existing transformation traits `add_*` and `remove_*`

Qualifiers manipulation: overview

Overview

	cv	reference	sign	array	pointer	cvref
remove_*	remove_const remove_volatile remove_cv	remove_reference		remove_extent remove_all_extents	remove_pointer remove_all_pointers	remove_cvref
add_*	add_const add_volatile add_cv	add_lvalue_reference add_rvalue_reference			add_pointer	
make_*			make_signed make_unsigned			
copy_*	copy_const copy_volatile copy_cv	copy_reference	copy_signedness	copy_extent copy_all_extents	copy_pointer copy_all_pointers	copy_cvref
clone_*	clone_const clone_volatile clone_cv	clone_reference		clone_extent clone_all_extents	clone_pointer clone_all_pointers	clone_cvref

Qualifiers manipulation: examples

Use case: manipulation of universal refs

```
template <class T, class U>
void f(T&& x, U&& y) {
    using type = T&&;
    using other = clone_cvref_t<T&&, U&&>;
    /* function contents */
}
```

Use case: in class templates

```
template <class T>
class foo {
    T a;
    copy_cvref_t<T, int> n;
    copy_cvref_t<T, double> x;
    /* class contents */
};
```

Use case: storing the qualifiers of a type

```
struct placeholder {};

template <class T>
struct qualifiers {
    using type = copy_cvref_t<T, placeholder>;
};

template <class T>
using qualifiers_t
    = typename qualifiers<T>::type;
```

Use case: C array conversion

```
int array1[5][4][3][2];
using array_type = decltype(array1);
copy_all_extents_t<array_type, double> array2;
```

Use case: P0847R0: Deducing this

```
// Example provided in P0847R0
template <class From, class To> using like_t = clone_cvref_t<From, To>;

struct B {
    template <typename Self>
    auto&& f(Self&& this self) {
        return forward<Self>(*this).i;              // ok if Self and *this are the same type
                                                    // compile other if Self is a derived type
        return forward<like_t<Self, B>>(*this).i;   // always ok
        return forward_like<Self>(*this).i;         // always ok
    }
};
```

Qualifiers manipulation: examples

Use case: wrapper with a wrapped data member

```
template <class T>
class wrapper {
    /* ... */

    // Data members
    private:
    other_wrapper<copy_cvref_t<T, foo>> _wrapped;
};
```

Use case: class template argument deduction and universal references

```
template <class T>
class something {
    template <class U, class = std::enable_if_t</* ... */>>
    explicit constexpr something(U&& x);
};

template <class U, class = std::enable_if_t</* ... */>>
something(U&&) -> something<copy_cvref_t<U&&, foo>>;
```

Qualifiers manipulation: about signedness

Current sign manipulators

- make_signed
- make_unsigned
- is_same_v<char, signed char> and is_same_v<char, unsigned char> are both false: therefore, contrarily to other integral types once make_signed or make_unsigned has been applied to char it is impossible to recover it easily (a remove_sign trait would be necessary)

Proposed behavior

```
using type0 = copy_signedness_t<unsigned int, char>;           // unsigned char
using type1 = copy_signedness_t<signed int, char>;             // signed char
using type2 = copy_signedness_t<char, unsigned int>;           // unsigned int
using type3 = copy_signedness_t<unsigned char, unsigned int>;  // unsigned int
using type4 = copy_signedness_t<signed char, unsigned int>;    // signed int
using type5 = copy_signedness_t<char, unsigned char>;          // unsigned char

// using type6 = clone_signedness_t<char, unsigned char>;      // char (hypothetical)

using type7 = copy_signedness_t<signed char, unsigned int>;
// is equivalent to "make_signed_t<unsigned int>" since "signed unsigned int" would not compile
```

Qualifiers manipulation: discussion and open questions

Bikeshedding

- Alternative names for `copy_*`?
- Alternative names for `clone_*`?
- Alternative names for `copy_signedness`?

Remarks on `copy_reference`

`copy_reference_t<T&, U&>`, `copy_reference_t<T&&, U&>`, `copy_reference_t<T&, U&&>` and `copy_reference_t<T&&, U&&>` use reference collapsing rules to compute the resulting type. As `clone_reference` first removes the ref-qualifier of the second type, there is no need for reference collapsing in this case.

Remarks on `copy_pointer`

`copy/clone_pointer` and `copy/clone_all_pointer` copy cv-qualification of pointers:

```
using type = int* const* volatile** const volatile*;
using other = copy_all_pointers_t<type, double>; // double* const* volatile** const volatile*
```

Remarks on `copy_signedness`

- `clone_signedness` is not introduced because `remove_sign` does not exist
- The name `copy_signedness` is chosen because `copysign` already exists
- `copy_signedness` does not add a sign keyword (contrarily to the others `copy_*`) but uses `make_signed` and `make_unsigned` instead

Conclusion: overview of design decisions

Bikeshedding

- Alternative names for `copy_*`?
- Alternative names for `clone_*`?
- Alternative names for `copy_signedness`?

Main open questions and remarks

- `copy/clone_pointer` and `copy/clone_all_pointer`: copy cv-qualification
- `copy_signedness` does not add a sign keyword (contrarily to the others `copy_*`) but uses `make_signed` and `make_unsigned` instead
- `clone_signedness` is not introduced because `remove_sign` does not exist

Conclusion: overview of functionalities

	SF	F	N	A	SA
remove_all_pointers					
copy_*/clone_*					
copy_signedness					

Pointers removal

remove_all_pointers

Qualifiers copy

copy_const
copy_volatile
copy_cv
copy_reference
copy_signedness
copy_extent
copy_all_extents
copy_pointer
copy_all_pointers
copy_cvref

Qualifiers cloning

clone_const
clone_volatile
clone_cv
clone_reference
clone_extent
clone_all_extents
clone_pointer
clone_all_pointers
clone_cvref

Thank you for your attention