Generic `none()` factories for Nullable types

Abstract

In the same way we have NullablePointer types with `nullptr` to mean a null value, this proposal defines Nullable requirements for types for which `none()` means the null value. This paper proposes some generic `none()` factories for Nullable types like `optional`, pointers and smart pointers.

Note that for Nullable types the null value doesn't mean an error, it is just a value different from all the other values, it is none of the other values.

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Introduction

There are currently two adopted single-value (unit) types, `nullptr_t` for pointer-like classes and `nullopt_t` for `optional<T>` . P0088R0 proposes an additional `monostate_t` as yet another unit type. Most languages get by with just one unit type. P0032R0 proposed a new `none_t` and corresponding `none` literal for the class `any` . The feedback from the Kona meeting was that should not keep adding new "unit" types like this and that we need to have a generic `none` literal at least for non pointer-like classes.

Revision 0 for this paper presented a proposal for a generic `none_t` and `none` (no-value) factory, creates the appropriate not-a-value for a given Nullable type.

Revision 1 presented two kind of `none` factories `none()` and `none<T>()`.

Revision 2 makes it possible to consider pointer-like types a Nullable.

Revision 3 adds a new `nullable::deref` customization point and a lot of algorithms that can be built on top of Nullable thanks to this addition, as `Functor transform`, `ApplicativeFunctor ap`, `Monad bind`, `SumType visit`, and some minor algorithms `value_or` and `apply_or`.

Revision 4 rollbacks the Nullables cannot provide always a deref. We have moved deref to another concept hierarchy P0786R0. We will need to refactor this proposal in accordance to P0786R0.

Having a common syntax and semantics for this factories would help to have more readable and teachable code, and potentially allows us to define generic algorithms that need to create such a no-value instance.
Note however that we would not be able to define interesting algorithms without having other functions around the Nullable concept as e.g. being able to create a Nullable wrapping instance containing the associated value (the make factory P0338R2) and observe the value or the not-a-value a Nullable type contains, or visitation type switch as proposed in P0050R0, or the getter functions proposed in [P0042], or FunctMonadic operations. This is left for future proposals.

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Motivation and Scope

Why do we need a generic `none()` literal factory

There is a proliferation of “unit” types that mean no-value type,

- `nullptr_t` for pointer-like objects and `std::function`
- `std::nullopt_t` for `optional<T>`
- `std::monostate` unit type for `std::variant<std::monostate_t, Ts...>` (in \texttt{P0088R0})
- `none_t` for any (in \texttt{P0032R0} - rejected as a specific unit type for `any`)

Having a common and uniform way to name these no-value types associated to `Nullable` types would help to make the code more consistent, readable, and teachable.

A single overarching `none_t` type could allow us to define generic algorithms that operate across these generic `Nullable` types.

Generic code working with `Nullable` types, needs a generic way to name the null value associated to a specific `Nullable` type `N`. This is the reason d'être of `none<\texttt{N}>(()).`

Possible ambiguity of a single no-value constant

Before going too far, let me show you the current situation with `nullptr` and to my knowledge why `nullptr` was not retained as no-value constant for `optional<T>` - opening the gates for additional unit types.

`NullablePointer` types

All the pointer-like types in the standard library are implicitly convertible from and equality comparable to `nullptr_t`. 
int* ip = nullptr;
unique_ptr<int> up = nullptr;
shared_ptr<int> sp = nullptr;
if (up == nullptr) ...
if (ip == nullptr) ...
if (sp == nullptr) ...

Up to now everything is ok. We have the needed context to avoid ambiguities.

However, if we have an overloaded function as e.g.

```cpp
template <class T>
void print(unique_ptr<T> ptr);
template <class T>
void print(shared_ptr<T> ptr);
```

The following call would be ambiguous

```cpp
print(nullptr);
```

Wait, who wants to print `nullptr`? Surely nobody wants. Anyway we could add an overload for `nullptr_t`

```cpp
void print(nullptr_t ptr);
```

and now the last overload will be preferred as there is no need to conversion.

If we want however to call to a specific overload we need to build the specific pointer-like type, e.g if wanted the `shared_ptr<T>` overload, we will write

```cpp
print(shared_ptr<int>{});
```

Note that the last call contains more information than should be desired. The `int` type is in some way redundant. It would be great if we could give as less information as possible as in

```cpp
print(nullptr<shared_ptr>);
```

Clearly the type for `nullptr<shared_ptr>` couldn’t be `nullptr_t`, nor a specific `shared_ptr<T>` . So the type of `nullptr<shared_ptr>` should be something different, let me call it e.g. `nullptr_t<shared_ptr>`

You can read `nullptr<shared_ptr>` as the null pointer value associated to `shared_ptr`.

Note that even if template parameter deduction for constructors P0091R0 is adopted we are not able to write the following, as the deduced type will not be the expected one.

```cpp
print(shared_ptr(nullptr));
```

We are not proposing these for `nullptr` in this paper, it is just to present the context. To the authors knowledge it has been accepted that the user needs to be as explicit as needed.
`print(shared_ptr<int>{});`

**Why `nullopt` was introduced?**

Let's continue with `optional<T>` . Why the committee didn't want to reuse `nullptr` as the no-value for `optional<T>`?

```cpp
optional<int> oi = nullptr;
oi = nullptr;
```

I believe that the two main concerns were that `optional<T>` is not a pointer-like type even if it defines all the associated operations and that having an `optional<int*>`, the following would be ambiguous:

```cpp
optional<int*> sp = nullptr;
```

We need a different type that can be used either for all the Nullable types or for those that are wrapping an instance of a type, not pointing to that instance. At the time, as the problem at hand was to have an `optional<T>` , it was considered that a specific solution will be satisfactory. So now we have:

```cpp
template <class T>
void print(optional<T> o);

optional<int> o = nullopt;
o = nullopt;
print(nullopt);
```

### Moving to Nullable types

Some could think that it is better to be specific. But what would be wrong having a single way to name this no-value for a specific class using `none`?

```cpp
optional<int> o = none();
any a = none();
o = none();
a = none();
```

So long as the context is clear there is no ambiguity.

We could as well add the overload to `print` the no-value `none`

```cpp
void print(none_t);
```

and

```cpp
print(none());
print(optional<int>{})
```

So now we can see `any` as a Nullable if we provide the conversions from `none_t`.
We don’t provide a solution to the following use case. How to initialize an `optional<any>` with an `std::any` `none()`

```cpp
optional<any> oo2 = any(); // assert(o)
optional<any> oo1 = none(); // assert(! o)
```

If we want that

```cpp
optional<any> oo1 = none<Any>(); // assert(o)
```

the resulting type for `none<any>()` shouldn’t `none_t` and we will need a `nullany_t`. This paper don’t includes yet this `nullany_t`, but the author considers that this is the best direction. Have a common `none_t` that can be used when there is no ambiguity and `none<T>` to disambiguate.

Note that `any` is already `Nullable`, so how will this case be different from

```cpp
optional<optional<int>> oo1 = optional<int>();
optional<optional<int>> oo2 = nullopt;
```

or from nested smart pointers.

```cpp
shared_ptr<unique_ptr<int>> sp1 = unique_ptr<int>();
shared_ptr<unique_ptr<int>> sp2 = nullptr;
```

However we propose a solution when the result type of not-a-value of the two `Nullables` is a different type.

```cpp
optional<unique_ptr<int>> oup1 = none(); // assert(! o)
optional<unique_ptr<int>> oup1 = nullptr; // assert(o)

optional<unique_ptr<int>> oup1 = none<optional>(); // assert(! o)
optional<unique_ptr<int>> oup1 = none<unique_ptr>(); // assert(o)
```

The result type of `none<Tmpl>()` depends on the `Tmpl` parameter.

Other operations involving the unit type

There are other operations between the wrapping type and the unit type, such as the mixed equality comparison:

```cpp
o == nullopt;
a == any();
```

Type erased classes as `std::any` don’t provide comparison.
However Nullable types wrapping a type as `optional<T>` can provide mixed comparison if the type `T` is ordered.

```cpp
template < Nullable C >
bool operator==(none_t, C const& x) { return !std::has_value(x); }
template < Nullable C >
bool operator==(C const& x, none_t) { return !std::has_value(x); }
template < Nullable C >
bool operator!=(none_t, C const& x) { return std::has_value(x); }
template < Nullable C >
bool operator!=(C const& x, none_t) { return std::has_value(x); }
```

So the question is whether we can define these mixed comparisons once for all on a generic `none_t` type and a model of Nullable.

The ordered comparison operations should be defined only if the Nullable class is Ordered.

### Differences between `nullopt_t` and `monostate_t`

- `std::nullopt_t` is not `DefaultConstructible`, while `monostate_t` must be `DefaultConstructible`.
- `std::nullopt_t` was required not to be `DefaultConstructible` so that the following syntax is well formed for an optional object `o`:

```cpp
o = {};
```

So we need a `none_t` that is `DefaultConstructible` but that `{}` is not deduced to `nullopt_t{}`. This is possible if `nullopt_t` default constructor is explicit (See [LWG 2510](https://www.lwg-ml.org/MeetingMinutes/2021/n2738.pdf), [CWG 1518](https://gcc.gnu.org/ml/gcc/2019-07/msg00017.html) and [CWG 1630](https://gcc.gnu.org/ml/gcc/2019-07/msg00026.html)).

The `std::experimental::none_t` is a user defined type that has a single value `std::experimental::none()`. The explicit default construction of `none_t{}` is equal to `none()`. We say `none_t` is a unit type.

Note that neither `nullopt_t`, `monostate_t` nor the proposed `none_t` behave like a tag type so that [LWG 2510](https://www.lwg-ml.org/MeetingMinutes/2021/n2738.pdf) should not apply.

Waiting for [CWG 1518](https://gcc.gnu.org/ml/gcc/2019-07/msg00017.html) the workaround could be to move the assignment of `optional<T>` from a `nullopt_t` to a template as it was done for `T`.

### Differences between `nonesuch` and `none_t`

Even if both types contains the none word they are completely different. `std::experimental::nonesuch` is a bottom type with no instances and, `std::experimental::none_t` is a unit type with a single instance.

The intent of `nonesuch` is to represent a type that is not used at all, so that it can be used to mean not detected. `none_t` intent is to represent a type that is none of the other alternatives in the sum type.

`nullable::none_type_t` and `nullable::value_type_t`. 
A Nullable can be considered as a sum type. It is always useful reflect the related types. `nullable::none_type_t` and `nullable::value_type_t` give respectively the associated non-a-value and the value types.

Proposal

This paper proposes to

- add `none_t / none()`,
- add `none<TC>()`, `none<Tmpl>()`,
- add requirements for Nullable and StrictWeaklyOrderedNullable types, and derive the mixed comparison operations on them,
- add some minor changes to `optional`, `any` to be constructed from `none_t` and to customize the Nullable requirements.

Impact on the standard

These changes are entirely based on library extensions and do not require any language features beyond what is available in C++14. There are however some classes in the standard that needs to be customized.

This paper depends in some way on the helper classes proposed in P0343R1, as e.g. the place holder `_t` and the associated specialization for the type constructors `optional<_t>`, `unique_ptr<_t>`, `shared_ptr<_t>`.

Proposed Wording

The proposed changes are expressed as edits to N4617 the Working Draft - C++ Extensions for Library Fundamentals V2.

Add a "Nullable Objects" section

Nullable Objects

No-value state indicator

The `std::experimental::none_t` is a user defined type that has a factory `std::experimental::none()`. The explicit default construction of `none_t{}` is equal to `none()`. `std::experimental::none_t` shall be a literal type. We say `none_t` is a unit type.

[Note: `std::experimental::none_t` is a distinct unit type to indicate the state of not containing a value for Nullable objects. The single value of this type `none()` is a constant that can be converted to any Nullable type and that must equally compare to a default constructed Nullable. — endnote]

Nullable requirements

A Nullable type is a type that supports a distinctive null value. A type `N` meets the requirements of Nullable if:

- `N` satisfies the requirements of EqualityComparable DefaultConstructible, and Destructible,
- the expressions shown in the table below are valid and have the indicated semantics, and
- `N` satisfies all the other requirements of this sub-clause.

A value-initialized object of type `N` produces the null value of the type. The null value shall be equivalent only to itself. A default-initialized object of type `N` may have an indeterminate value. [ Note: Operations involving indeterminate values may cause undefined behavior. — end note ]
No operation which is part of the Nullable requirements shall exit via an exception.

In Table X below, \( u \) denotes an identifier, \( t \) denotes a non-const lvalue of type \( \text{N} \), \( a \) and \( b \) denote values of type (possibly const) \( \text{N} \), \( x \) denotes a (possibly const) expression of type \( \text{N} \), and \( \text{nN} \) denotes \( \text{std::experimental::none<N>()} \) and \( n \) denotes \( \text{std::experimental::none()} \).

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<th>Expression</th>
<th>Return Type</th>
<th>Operational Semantics</th>
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<tr>
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<td>none_type_t&lt;N&gt;</td>
<td></td>
</tr>
<tr>
<td>( \text{N}() )</td>
<td></td>
<td>post: ( \text{N}() == \text{nN} )</td>
</tr>
<tr>
<td>( \text{N} u(n) )</td>
<td></td>
<td>post: ( u == \text{nN} )</td>
</tr>
<tr>
<td>( \text{N} u(nN) )</td>
<td></td>
<td>post: ( u == \text{nN} )</td>
</tr>
<tr>
<td>( \text{N} u = n )</td>
<td></td>
<td>post: ( u == \text{nN} )</td>
</tr>
<tr>
<td>( \text{N} u = \text{nN} )</td>
<td></td>
<td>post: ( u == \text{nN} )</td>
</tr>
<tr>
<td>( \text{N}(n) )</td>
<td></td>
<td>post: ( \text{N}(n) == \text{nN} )</td>
</tr>
<tr>
<td>( \text{N}(nN) )</td>
<td></td>
<td>post: ( \text{N}(nN) == \text{nN} )</td>
</tr>
<tr>
<td>( \text{std::has_value(x)} )</td>
<td>contextually convertible to bool</td>
<td>true if ( x ) != ( \text{nN} )</td>
</tr>
<tr>
<td>( a != b )</td>
<td></td>
<td>contextually convertible to bool</td>
</tr>
<tr>
<td>( a == n, n )</td>
<td></td>
<td>contextually convertible to bool</td>
</tr>
<tr>
<td>( a != n, n != a )</td>
<td></td>
<td>contextually convertible to bool</td>
</tr>
</tbody>
</table>

**StrictWeaklyOrderedNullable requirements**

A type \( \text{N} \) meets the requirements of StrictWeaklyOrderedNullable if:

- \( \text{N} \) satisfies the requirements of StrictWeaklyOrdered and Nullable.

**Header synopsis [nullable.synop]**

```cpp
namespace std {
namespace experimental {
inline namespace fundamentals_v3 {
namespace nullable {

    template <class T>
    constexpr bool has_value(T && v) noexcept;

    // class none_t
    struct none_t;

    // none_t relational operators
    constexpr bool operator==(none_t, none_t) noexcept;
    constexpr bool operator!=(none_t, none_t) noexcept;
    constexpr bool operator<(none_t, none_t) noexcept;
    constexpr bool operator<=(none_t, none_t) noexcept;
    constexpr bool operator>(none_t, none_t) noexcept;
    constexpr bool operator>=(none_t, none_t) noexcept;
```
// none_t factory
constexpr none_t none() noexcept;

// class traits
template <class T, class Enabler=void>
struct traits {};

// class traits_pointer_like
struct traits_pointer_like;

// class traits specialization for pointers
template <class T>
struct traits<T*>;

template <class T>
constexpr auto none() noexcept = "see below";

template <template <class...> class TC>
constexpr auto none() noexcept = "see below";

template <class T>
using none_type_t = decltype(nullable::none<T>());

using nullable::none_t;
using nullable::none_type_t;
using nullable::none;
using nullable::has_value;

template <class T>
struct is_nullable;

template <class T>
struct is_nullable<const T> : is_nullable<T> {};

template <class T>
struct is_nullable<volatile T> : is_nullable<T> {};

template <class T>
constexpr bool is_nullable_v = is_nullable<T>::value;

namespace nullable {
    // Comparison with none_t
    template <class C>
    bool operator==(none_t, C const& x) noexcept;
    template <class C>
    bool operator==(C const& x, none_t) noexcept;
    template <class C>
    bool operator!=(none_t, C const& x) noexcept;
    template <class C>
    bool operator!=(C const& x, none_t) noexcept;

    template <class C>
    bool operator<(none_t, C const& x) noexcept;
}
null-value state indicator [nullable.none_t]

The struct `none_t` is an empty structure type used as a unique type to indicate the state of not containing a value for Nullable objects. It shall be a literal type.

```cpp
namespace nullable {
    struct none_t {
        explicit none_t() = default;
        template <class T>
        operator T*() const noexcept { return nullptr; }
    };
}
```

none_t relational operators [nullable.none_t.rel]

```cpp
namespace nullable {
    constexpr bool operator== (none_t, none_t) noexcept { return true; }
    constexpr bool operator!= (none_t, none_t) noexcept { return false; }
    constexpr bool operator<(none_t, none_t) noexcept { return false; }
    constexpr bool operator<=(none_t, none_t) noexcept { return true; }
    constexpr bool operator>(none_t, none_t) noexcept { return false; }
    constexpr bool operator>=(none_t, none_t) noexcept { return true; }
}
```

[ Note: none_t objects have only a single state; they thus always compare equal. — end note ]

none_t factory [nullable.none_t.fact]

```cpp
namespace nullable {
    constexpr none_t none() noexcept { return none_t(); }
}
```

class traits [nullable.traits]
namespace nullable {
    template <class T, class Enabler=void>
    struct traits {
    
        // class traits_pointer_like
        struct traits_pointer_like {
            static constexpr nullptr_t none() noexcept { return nullptr; }
            template <class Ptr>
            static constexpr bool has_value(Ptr ptr) { return bool(ptr); }
        };

        // class traits specialization for pointers
        template <class T>
        struct traits<T*> : traits_pointer_like<T*> {}
    };
}

namespace nullable {
    template <class T>
    constexpr bool has_value(T const& v) noexcept;
}

namespace nullable {
    template <class T>
    constexpr auto none() noexcept;
}

namespace nullable {
    template <class T>
    constexpr auto none() noexcept;
}
template <class T>
    struct is_nullable;

template <class T>
    struct is_nullable< const T>: is_nullable<T> {};

template <class T>
    struct is_nullable< volatile T>: is_nullable<T> {};

template <class T>
    struct is_nullable< const volatile T>: is_nullable<T> {};

template <class T>
    constexpr bool is_nullable_v = is_nullable<T>::value;

Template class is_strict_weakly_ordered_nullable
[nullable.isstrictweaklyorderednullable]

namespace nullable {

    template <class T>
        struct is_strict_weakly_ordered_nullable :
            conjunction<is_strict_weakly_ordered<T>, is_nullable<T>> {};


Nullable comparison with none_t [nullable.noneteq_ops]

    template <class C>
        bool operator==(none_t, C const& x) noexcept
            { return !::std::has_value(x); }

    template <class C>
        bool operator==(C const& x, none_t) noexcept
            { return !::std::has_value(x); }

    template <class C>
        bool operator!=(none_t, C const& x) noexcept
            { return ::std::has_value(x); }

    template <class C>
        bool operator!=(C const& x, none_t) noexcept
            { return ::std::has_value(x); }

Remark: The previous functions shall not participate in overload resolution unless C satisfies "Nullable".

StrictWeaklyOrderedNullable comparison with none_t [nullable.nonetord_ops]

template < class C >
bool operator<(none_t, C const & x) noexcept
  { return ::std::has_value(x); }

template < class C >
bool operator<(C const & x, none_t) noexcept
  { return false; }

template < class C >
bool operator<=(none_t, C const & x) noexcept
  { return true; }

template < class C >
bool operator<=(C const & x, none_t) noexcept
  { return !::std::has_value(x); }

template < class C >
bool operator>(none_t, C const & x) noexcept
  { return false; }

template < class C >
bool operator>(C const & x, none_t) noexcept
  { return ::std::has_value(x); }

template < class C >
bool operator>=(none_t, C const & x) noexcept
  { return !::std::has_value(x); }

template < class C >
bool operator>=(C const & x, none_t) noexcept
  { return true; }

Remark: The previous functions shall not participate in overload resolution unless C satisfies StrictWeaklyOrderedNullable.

Optional Objects

Add conversions from none_t in [optional.object].


constexpr optional(none_t) noexcept;


optional<T>& operator=(none_t) noexcept;

Add Specialization of Nullable [optional.object.nullable].

20.6.x Nullable
namespace nullable {
    template <class T>
    struct traits<optional<T>> : traits_pointer_like{
        static constexpr
        nullopt_t none() noexcept { return nullopt; }
    };
}

Class Any

Add conversions from `none_t` in [any.object].

class any {
    // ...
    // 20.7.3.1, construction and destruction
    constexpr any(none_t) noexcept;

    // 20.7.3.2, assignments
    any &operator=(none_t) noexcept;
};

Update [any.cons] adding before p 1.

constexpr any(none_t) noexcept;

Effects: As if `reset()`

Postcondition: `this->has_value()` == false.

Update [any.assign] adding after p 12.

any<T>& operator=(none_t) noexcept;

Effects: As if `reset()`

Returns: `*this`

Postcondition: `has_value()` == false.

Add Specialization of Nullable [any.object.nullable].

20.6.x Nullable

any is a model of Nullable.
namespace nullable {
    template <>
    struct traits<any> {
        template <class A>
        static constexpr bool has_value(A && v) noexcept { return v.has_value(); }
        static constexpr none_t none() noexcept { return none_t{}; }
    };
}

## Variant Objects

Add Specialization of Nullable [any.object.nullable].

x.y.z Nullable

```
variant<none_t, Ts...> is a models of Nullable.
```

namespace nullable {
    template <class ...Ts>
    struct traits<variant<none_t, Ts...>> {
        static constexpr none_t none() noexcept { return none_t{}; }
        template <class U>
        static constexpr bool has_value(U && v) noexcept { return v.index() > 0; }
    };
}

## Smart Pointers

```
unique_ptr<T, D> is a models of Nullable.
```

```
namespace nullable {
    template <class T, class D>
    struct traits<unique_ptr<T, D>> : traits_pointer_like {};
}
```

```
shared_ptr<T> is a models of Nullable.
```

```
namespace nullable {
    template <class T>
    struct traits<shared_ptr<T>> : traits_pointer_like {};
}
```

## Implementability

This proposal can be implemented as pure library extension, without any language support, in C++14. However the adoption of [CWG 1518, CWG 1630](https://www.open-std.org/jtc1/sc22/wg21/docs/cwg_main.html#1518) makes it simpler.
Open points

The authors would like to have an answer to the following points if there is any interest at all in this proposal:

- Should we include `none_t` in `<experimental/functional>` or in a specific file?
  - We believe that a specific file is a better choice as this is needed in `<experimental/optional>`, `<experimental/any>` and `<experimental/variant>`. We propose `<experimental/nullable>`.

- Should the mixed comparison with `none_t` be defined implicitly?
  - An alternative is to don't define them. In this case it could be better to remove the Nullable and `StrictWeaklyOrderedNullable` requirements as the "reason d'être" of those requirements is to define these operations.

- Should Nullable require in addition the expression `n = {}` to mean reset?

- Should `std::any` be considered as Nullable? Note that `std::any` is not `EqualityComparable`. Should we relaxe the Nullable requirements?

- Should we add `nullany_t` type as the `none_type_t<any>` to avoid ambiguities?

- Should `variant<none_t, Ts...>` be considered as Nullable?

Acknowledgements

Thanks to Tony Van Eerd and Titus Winters for helping me to improve globally the paper. Thanks to Agustín Bergé K-ballo for his useful comments. Thanks to Ville Voutilainen for the pointers about explicit default construction.

Special thanks and recognition goes to Technical Center of Nokia - Lannion for supporting in part the production of this proposal.

History

Revision 4

- Rollback the modifications of revision 3, as they belong to `ValueOrError` `P0786R0` kind of types.

  - We should move `deref()` to `ValueOrNone`, as `std::any` cannot define it, as it has not a unique value. As consequence the functions added in the previous version `value_or` and `apply_or` should be moved as well.
  - The same applies to the added `visit` function. We cannot visit any Nullable as we don’t know what are its possibly values. This function belongs to `ValueOrNone` and to `ValueOrError`. `ValueOrNone` is a Nullable that has only one possible value type. `ValueOrNone` is specialization of `ValueOrError` where the Error is a unit type.
  - Next follows the concept hierarchy:

    - `SuccessOrValue` (succeeded, success value, failure value) (examples result => TRY
      - `ValueOrError` (has_value, deref, error) (examples: expected, result => SumType, Functor, Applicative, Monad, MonadError
        - `ValueOrNone`
    - `Nullable` (has_value, none) (examples std::variant<none, Ts...>, std::any)
      - `ValueOrNone` (deref) (examples T*, std::optional, std::unique_ptr, ...) => ValueOrError
Revision 3

Added the following specific Nullable functions and types to see Nullables as Functors, Applicatives, Monads and SumType:

- Added customization point nullable::deref.  
- Added nullable::none_type_t and nullable::value_type_t.  
- Added nullable::transform (Functor), nullable::ap (Applicative) and nullable::bind (Monad) when the Nullable is also TypeConstructible.  
- Added nullable::visit (sumtype) [SUMTYPE].  
- Added nullable::value_or and nullable::apply_or.

Revision 2

Fixes some typos and take in account the feedback from Oulu meeting. Next follows the direction of the committee:

- Add more examples in the documentation, including nesting of Nullables.  
- More explicit tests in the implementation.  
- Pointers should be Nullable.  
- has_value should be non-member.  
- Added a before/after comparison table.

Unfortunately initializing the nested Nullables with a nested none is not possible if the associated none-type are the same. This is in line with optional<optional<T>>.

Other changes:

- Consider having none_type<T> traits derived from the none<T>() function.  
- Consider adding is_nullable type trait and nullable::tag.  
- std::any cannot be considered as Nullable as far as we request EqualityComparable as we do for NullablePointer.  
- Add examples using Template argument deduction for constructors.

Revision 1

The 1st revision of [P0196R0] fixes some typos and takes in account the feedback from Jacksonville meeting. Next follows the direction of the committee: the explicit approach none<optional> should be explored.

The approach taken by this revision is to provide both factories but instead of a literal we use a functions none() and none<optional>().

Revision 0

This takes in account the feedback from Kona meeting P0032R0. The direction of the committee was:

- Do we want none_t to be a separate paper?

SF F N A SA  
11 1 3 0 0

- Do we want the operator bool changes? No, instead a .something() member function (e.g. has_value) is
preferred for the 3 classes. This doesn't mean yet that we replace the existing explicit \texttt{operator bool} in \texttt{optional}.

- Do we want emptiness checking to be consistent between \texttt{any} / \texttt{optional}? Unanimous yes

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<th>N: 5</th>
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<td>Provide \texttt{==std::none}</td>
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<tr>
<td>Provide \texttt{something(any/optional)}</td>
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References

- **N4617** N4617 - Working Draft, C++ Extensions for Library Fundamentals, Version 2 DTS
  

- **P0032R0** Homogeneous interface for variant, any and optional
  
  http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2015/p0032r0.pdf

- **P0050R0** C++ generic match function
  
  http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2015/p0050r0.pdf

- **P0088R0** Variant: a type-safe union that is rarely invalid (v5)
  
  http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2015/p0088r0.pdf

- **P0091R0** Template parameter deduction for constructors (Rev. 3)
  
  http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2015/p0091r0.html

- **P0338R2** C++ generic factories
  
  http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2017/p0338r2.pdf

- **P0343R1** - Meta-programming High-Order functions
  

- **P0650R0** C++ Monadic interface
  
  http://www.open-std.org/JTC1/SC22/WG21/docs/papers/2017/p0650r0.pdf

- **P0786R0** \texttt{ValuedOrError} and \texttt{ValueOrNone} types
  
  http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2017/p0786r0.html

- **LWG 2510** Tag types should not be DefaultConstructible
  
  http://cplusplus.github.io/LWG/lwg-active.html#2510

- **CWG 1518** Explicit default constructors and copy-list-initialization
  
  http://open-std.org/JTC1/SC22/WG21/docs/cwg_active.html#1518

- **CWG 1630** Multiple default constructor templates
SUM_Type

Generic Sum Types

https://github.com/viboes/std-make/tree/master/include/experimental/fundamental/v3/sum_type