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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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History

Revision 2

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

- Add more examples in the documentation, including nesting of *Nullable*s.
- 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` can not 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 `operator bool` in `optional`.

- Do we want emptiness checking to be consistent between `any` / `optional`? Unanimous yes

```
Provide operator bool for both  Y:  6 N: 5
Provide .something()            Y: 17 N: 0
Provide =={}                    Y:  0 N: 5
Provide ==std::none             Y:  5 N: 2
something(any/optional)         Y:  3 N: 8
```

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>()`

This revision make it possible to consider pointer-like types a *Nullable*

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 p0338r1) 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 Functor/Monadic operations. This is left for future proposals.

<table>
<tr><th>BEFORE</th><th>AFTER</th></tr>
<tr><td>Construction</td><td></td></tr>
<tr><td>

```
int* p          = nullptr;
unique_ptr<int> sp = nullptr;
shared_ptr<int> sp = nullptr;
optional<int> o    = nullopt;



//unique_ptr<int> sp = unique_ptr{};
//shared_ptr<int> sp = shared_ptr{};
//optional<int> o    = optional{};
any a          = any{};
```

</td><td>

```
int* p          = none();
unique_ptr<int> sp = none();
shared_ptr<int> sp = none();
optional<int> o    = none();
any a           = none();

//int* p          = none<add_pointer>();
shared_ptr<int> sp = none<shared_ptr>();
shared_ptr<int> sp = none<unique_ptr>();
optional<int> o    = none<optional>();
any a           = none<any>();
```

</td></tr>
<tr><td>Conversion</td><td></td></tr>
<tr><td>

```
void g(int*);
void f(unique_ptr<int>);
void f(optional<int>);
void f(any);

g(nullptr);
f(nullptr);
f(nullopt);

//f(unique_ptr{});
//f(optional{});
f(any{});
```

</td><td>

```
void g(int*);
void f(unique_ptr<int>);
void f(optional<int>);
void f(any);




//g(none<add_pointer>());
f(none<unique_ptr>());
f(none<optional>());
f(none<any>());
```

</td></tr>
<tr><td>Return</td><td></td></tr>
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</table>

```
template <template <class ...> class TC, class T>
TC<T> f(T) {
    return TC<T>{};
}

f<add_pointer_t>(a)
f<optional>(a)
f<unique_ptr>(a)
f<shared_ptr>(a)
```

```
template <template <class ...> class TC, class T>
invoke_t<quote<TC>,T> f(T) {
    return none<TC>();
}

//f<add_pointer>(a)
f<optional>(a)
f<unique_ptr>(a)
f<shared_ptr>(a)

template <class TC, class T>
invoke_t<TC,T> f(T) {
    return none<TC>();
}

f<add_pointer<_t>>(a)
f<optional<_t>>(a)
f<unique_ptr<_t>>(a)
f<shared_ptr<_t>>(a)
f<any>(a)
```

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 (P0088R0),
- `none_t` for `any` (in 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<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. `print`

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

The following call would be ambiguous

```
print(nullptr);
```

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

```
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

```
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

```
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.

```
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?

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

```
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

```
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

```
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`?

```
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

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

and

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

So now we can see `any` as a *Nullable* if we provide the conversions from `none_t`

```
    any a = none();
    a = none();
    print(any{});
```

Nesting *Nullable* types

We don't provide a solution to the following use case. How to initialize an `optional<any>` with an `std::any` `none()`

```
optional<any> oa2 = any{};  // assert(o)
optional<any> oa1 = none(); // assert(! o)
```

If we want that

```
optional<any> oa1 = 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 canbe 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

```
optional<optional<int>> oo1 = optional<int>{};
optional<optional<int>> oo2 = nullopt;
```

or from nested smart pointers.

```
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.

```
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:

```
    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.

```
o > none()
o >= none()
! (o < none())
! (o <= none())
```

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*.

```
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); }
```

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`

```
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], [CWG 1518] and [CWG 1630]).

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] should not apply.

Waiting for [CWG 1518] 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.

Proposal

This paper proposes to

- add `none_t` / `none()`,
- add requirements for *Nullable* and *StrictWeaklyOrderedNullable* types, and derive the mixed comparison operations on them,
- add `none<TC>()`, `none<Tmpl>()`,
- add some minor changes to `optional`, `any` to take `none_t` as their no-value type.

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 P0343R0, 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 N4564 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 `N`, a and b denote values of type (possibly const) N, `x` denotes a (possibly const) expression of type `N`, and `nN` denotes `std::experimental::none<N>()` and `n` denotes `std::experimental::none()`.

Expression	Return Type	Operational Semantics
nullable::none<N>()	none_type_t<N>	
N{}		post: N{} == nN
N u(n)		post: u == nN
N u(nN)		post: u == nN
N u = n		post: u == nN
N u = nN		post: u == nN
N(n)		post: N(n) == nN
N(nN)		post: N(nN) == nN
std::has_value(x)	contextually convertible to bool	true if x != nN
a != b	contextually convertible to bool	!(a == b)
a == np, np == a	contextually convertible to bool	a == N{}
a != np , np != a	contextually convertible to bool	!(a == N{})

StrictWeaklyOrderedNullable requirements

A type `N` meets the requirements of *StrictWeaklyOrderedNullable* if:

- `N` satisfies the requirements of *StrictWeaklyOrdered* and *Nullable*.

Header synopsis [nullable.synop]

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

    // 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() -> `see below` noexcept;

    template <template <class ...> class TC>
        constexpr auto none() -> `see below` noexcept;

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

    template <class T>
        bool has_value(T const& v) noexcept;
    template <class T>
        bool has_value(T* v) noexcept;
}

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

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

  template <class T>
    struct is_strict_weakly_ordered_nullable;

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;
    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;
    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;

}
}
}
}
```

No-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.

```
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]

```
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]

```
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*>
        {};
}
```

Template function `none` [nullable.none]

```
namespace nullable {
    template <class T>
        constexpr auto none() ->
            decltype(nullable::traits<T>::none()) noexcept;

    template <template <class ...> class TC>
        constexpr auto none() ->
            decltype(none<type_constructor_t<meta::quote<TC>>>()) noexcept;
}
```

Template function `has_value` [nullable.has_value]

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

Template class `is_nullable` [nullable.is_nullable]

```
    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 T>
        struct is_nullable<T*> : true_type {};
```

Template class `is_strict_weakly_ordered_nullable` [nullable.isstrictweaklyorderednullable]

```
  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]

```
namespace nullable {
    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].

```
template <class T> class optional {
// ...
// 20.6.3.1, constructors
constexpr optional(none_t) noexcept;

// 20.6.3.3, assignment
optional &operator=(none_t) noexcept;
};
```

Update [optional.object.ctor] adding before p 1.

```
constexpr optional(none_t) noexcept;
```

Update [optional.object.assign] adding before p 1.

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

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

20.6.x Nullable

`optional<T>` is a model of *Nullable*.

```
namespace nullable {
    template <class T>
    struct traits<optional<T>> {
      static constexpr
      nullopt_t none() noexcept { return nullopt; }
      template <class U>
      static constexpr
      bool has_value(optional<U> const& v) noexcept { return v.has_value(); }
    };
}
```

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> {
      static constexpr
      none_t none() noexcept { return none_t{}; }
      static constexpr
      bool has_value(any const& v) noexcept { return v.has_value(); }
    };
}
```

Variant Objects

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 ...Us>
      static constexpr
      bool has_value(variant<none_t, Us...> const& 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 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/none>`.
- 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*?

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