Generic \textbf{none()} factories for \textit{Nullable} types

Abstract

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

Note that for \textit{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 1

The 1\textsuperscript{st} 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 \texttt{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 \texttt{none()} and \texttt{none<optional>()}.

**Revision 0**

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

- Do we want \texttt{none_t} to be a separate paper?

<table>
<thead>
<tr>
<th>SF</th>
<th>F</th>
<th>N</th>
<th>A</th>
<th>SA</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

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

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

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

**Introduction**

There are currently two adopted single-value (unit) types, \texttt{nullptr_t} for pointer-like classes and \texttt{nullopt_t} for \texttt{optional<T>}. \texttt{P0088R0} proposes an additional \texttt{monostate_t} as yet another unit type. Most languages get by with just one unit type. \texttt{P0032R0} proposed a new \texttt{none_t} and corresponding \texttt{none} literal for the class \texttt{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 \texttt{none} literal at least for non pointer-like classes.

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

This revision present two kind of \texttt{none} factories \texttt{none()} and \texttt{none<>()}

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 P0338R0) and observe whether this Nullable type contains a value or not (e.g. a visitation type switch as proposed in [P0050], or the getter functions proposed in [P0042], or Functor/Monadic operations). This is left for a future proposal.

Motivation and Scope

Why do we need a generic none literal

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

- nullptr_t for pointer-like objects and std::function,
- std::experimental::nullopt_t for optional<T>,
- std::experimental::monostate unit type for variant<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 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. This is the reason d'être of none_t and none.

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](https://isocpp.org/files/p0091r0.pdf) is adopted we are not able to write 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.

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

### Why `nullopt` was introduced?

Let's continue with `optional<T>`. Why didn't the committee 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 \texttt{none}?

\begin{verbatim}
optional<int> o = none;
any a = none;
o = none;
a = none;
\end{verbatim}

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

We could as well add the overload to \texttt{print} the no-value none

\begin{verbatim}
void print(none_t);
\end{verbatim}

and

\begin{verbatim}
print(none);
print(optional<int>{});
\end{verbatim}

So now we can see \texttt{any} as a \textit{Nullable} if we provide the conversions from \texttt{none_t}

\begin{verbatim}
any a = none;
a = none;
print(any{});
\end{verbatim}

\section*{Nesting \textit{Nullable} types}

We don't provide a solution to the following use case. How to initialize an \texttt{optional<any>} with an \texttt{any} none

\begin{verbatim}
optional<any> oa1 = none; // assert(! o)
optional<any> oo1 = optional<int>{};
\end{verbatim}

\begin{verbatim}
optional<any> oo2 = nullopt;
\end{verbatim}

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>> oa1 = none; // assert(! o)
optional<unique_ptr<int>> oa1 = nullptr; // assert(o)

optional<unique_ptr<int>> oa1 = none<optional>; // assert(! o)
optional<unique_ptr<int>> oa1 = non<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::experimental::any` don't provide order comparison.

However `Nullable` types wrapping a type as `optional<T>` can provide mixed comparison if the type `T` is ordered.

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

**Differences between `nullopt_t` and `monostate_t`**

- `std::experimental::nullopt_t` is not `DefaultConstructible`, while `monostate_t` must be `DefaultConstructible`.

- `std::experimental::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 that a `none_t` that is `DefaultConstructible` but that `{}` is not deduced to `nullopt_t`{}. This is possible if `nullopt_t` default constructor is explicit and CWG 1518 and CWG 1630 are adopted.

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 product type or that can be stored in `any`.

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>()`,
- add some minor changes to `optional`, `any` and `variant` 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. `type_constructor`.

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 *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 below, $u$ denotes an identifier, $t$ denotes a non-const lvalue of type $N$, $x$ denotes a (possibly const) expression of type $N$, and $n$ denotes a value of type (possibly const) `std::experimental::none_t`.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Return Type</th>
<th>Operational Semantics</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N u(n)$</td>
<td></td>
<td>post: $u == N{}$</td>
</tr>
<tr>
<td>$N u = n$</td>
<td></td>
<td>post: $u == N{}$</td>
</tr>
<tr>
<td>$t = n$</td>
<td>$N&amp;$</td>
<td>post: $t == N{}$</td>
</tr>
<tr>
<td>$x$.has_value()</td>
<td>contextually convertible to bool</td>
<td>$x != N{}$</td>
</tr>
</tbody>
</table>

Mixed equality comparison between a *Nullable* and a `none_t` are defined as

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

**StrictWeaklyOrderedNullable requirements**

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

- $N$ satisfies the requirements of *StrictWeaklyOrdered* and *Nullable*. 
Mixed ordered comparison between a `StrictWeaklyOrderedNullable` and a `none_t` are defined as

```cpp
// Template for comparing with none_t

template < StrictWeaklyOrderedNullable C >
bool operator<(none_t, C const & x) { return x.has_value(); }

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

// Template for comparing < with none_t

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

template < StrictWeaklyOrderedNullable C >
bool operator<=(C const & x, none_t) { return !x.has_value(); }

// Template for comparing > with none_t

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

template < StrictWeaklyOrderedNullable C >
bool operator>(C const & x, none_t) { return x.has_value(); }

// Template for comparing >= with none_t

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

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

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

            struct none_t{
                explicit none_t() {} 
            };
            constexpr bool operator==(none_t, none_t) { return true; }
            constexpr bool operator!=(none_t, none_t) { return false; }
            constexpr bool operator<(none_t, none_t) { return false; }
            constexpr bool operator<=(none_t, none_t) { return true; }
            constexpr bool operator>(none_t, none_t) { return false; }
            constexpr bool operator>=(none_t, none_t) { return true; }

            // Comparison with none_t
            template < Nullable C >
                bool operator==(none_t, C const & x) noexcept { return !x.has_value(); }
            template < Nullable C >
                bool operator==(C const & x, none_t) noexcept { return !x.has_value(); }
            template < Nullable C >
                bool operator!=(none_t, C const & x) noexcept { return x.has_value(); }
        }
    }
}
```

`Header synopsis [nullable.synop]`
bool operator!=(C const& x, none_t) noexcept { return x.has_value(); }

template < StrictWeaklyOrderedNullable C >
bool operator<(none_t, C const& x) { return x.has_value(); }

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

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

template < StrictWeaklyOrderedNullable C >
bool operator>=(none_t, C const& x) { return !x.has_value(); }

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

constexpr none_t none() { return none_t{}; }

template <class T>
struct nullable_traits;

template <class T>
struct nullable_traits<T*> {
    static constexpr
    nullptr_t none() { return nullptr; }
};

template <class TC>
constexpr auto none() -> decltype(nullable_traits<TC>::none());

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

Optional Objects

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

Add `optional<T>` is a model of `StrictWeaklyOrderedNullable` if `T` is a model of `StrictWeaklyOrdered`. 
Add conversions from `none_t`.

```cpp
template <class T>
struct nullable_traits<optional<T>> {
  static constexpr nullopt_t none() { return nullopt; }
};
```

**Class Any**

Add `any` is a model of `Nullable`.

Add a constructor from `none_t` equivalent to the default constructor.

Add an assignment from `none_t` equivalent assigning a default constructed object.

```cpp
template <class T>
struct nullable_traits<any> {
  static constexpr none_t none() { return none_t{}; }
};
```

**Variant Objects**

Waiting for a specific wording for `variant` in a TS or in the IS.

Add conversions from `none_t`.

Replace any additional use of `monostate_t` by `none_t`.

```cpp
template <class ...Ts>
struct nullable_traits<variant<Ts...>> {
  static constexpr monostate_t none() { return monostate_t{}; }
};
```

**Implementability**

This proposal can be implemented as pure library extension, without any language support, in C++14. However the adoption of [CWG 1518](https://www.open-std.org/jtc1/sc22/wg21/docs/cwg_main.html#1518), [CWG 1630](https://www.open-std.org/jtc1/sc22/wg21/docs/cwg_main.html#1630) will make 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 `any` be considered as `Nullable`?
  - This will need the addition of a `nullany_t` type. Do we want to use `none_t` as the `none_type` for `any`?

- Should `variant<none_t, Ts ...>` be considered as `Nullable`?
  - This will need the addition of `v.has_value()`.

- Should smart pointers be considered as `Nullable`?

- Bike-shading - `Nullable` versus `NullableValue`

Acknowledgements

Thanks to Tony Van Eer 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.

References


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

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

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

- **P0338R0** C++ generic factories
  http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2016/p0338r0.pdf

- **P0343R0** - Meta-programming High-Order functions
  http://www.open-std.org/JTC1/SC22/WG21/docs/papers/2016/p0343r0.pdf

- **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
  http://open-std.org/JTC1/SC22/WG21/docs/cwg_defects.html#1630