constexpr std::shared_ptr

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Contents

1 Revision History

- R4 2024-10-21
  - Added constexpr qualifier to the wording for std::bad_weak_ptr with [P3068R4]
  - Updated ClangOz reference in motivation
- R3 2024-09-03
  - Removed constexpr specification from reinterpret_pointer_cast (see below here)
  - Added references to [P3309R1] and [P3068R4]
  - Added details of a second implementation based on libc++
- R2 2024-05-24
  - Added wording
  - Removed constexpr specification from some functions (see below here)
  - Removed SG7 from Audience (post 2024 Spring meeting in Tokyo)
- R1 2024-03-05
  - Added a motivating example
  - Included libc++ & MSVC STL in atomic operation considerations
- R0 2023-11-06
  - Original Proposal

2 Introduction

Since the adoption of [P0784R7] in C++20, constant expressions can include dynamic memory allocation; yet support for smart pointers extends only to `std::unique_ptr` (since [P2273R3] in C++23). As at runtime, smart pointers can encourage hygienic memory management during constant evaluation; and with no remaining technical obstacles, parity between runtime and compile-time support for smart pointers should reflect the increased maturity of language support for constant expression evaluation. We therefore propose that `std::shared_ptr` and appropriate class template member functions from 20.3 [smartptr] permit `constexpr` evaluation.

3 Motivation and Scope

It is convenient when the same C++ code can be deployed both at runtime and compile time. Our recent project investigates performance scaling of *parallel* constant expression evaluation in an experimental Clang compiler [ClangOz]. As well as C++17 parallel algorithms, a prototype `constexpr` implementation of the Khronos SYCL API was utilised, where a SYCL `buffer` class abstracts over device and/or host memory. In the simplified code excerpt below, the `std::shared_ptr` data member ensures memory is properly deallocated upon the `buffer`'s destruction, according to its owner status. This is a common approach for runtime code, and a `constexpr` `std::shared_ptr` class implementation helpfully bypasses thoughts of raw pointers and preprocessor macros. The impact of adding `constexpr` functionality to the SYCL implementation is therefore minimised.

```
template <class T, int dims = 1>
struct buffer
{
  constexpr buffer(const range<dims> &r)
    : range_{ r }, data_{ new T[r.size()], [this](auto* p){ delete [] p; } } { }

  constexpr buffer(T* hostData, const range<dims>& r)
    : range_{ r }, data_{ hostData, [](auto){} } { }

  const range<dims> range_{};
  std::shared_ptr<T[]> data_{};
};
```

Adopted C++26 proposal [P2738R1] facilitates a straightforward implementation of comprehensive `constexpr` support for `std::shared_ptr`, allowing the `get_deleter` member function to operate, given the type erasure required within the std::shared_ptr unary class template. We furthermore propose that the relational operators of std::unique_ptr, which can legally operate on pointers originating from a single allocation during constant evaluation, should also adopt the constexpr specifier.

As with C++23 constexpr support for std::unique_ptr, bumping the value __cpp_lib_constexpr_memory is our requested feature macro change; yet in the discussion and implementation presented here, we adopt the macro __cpp_lib_constexpr_shared_ptr.

We below elaborate on points which go beyond the simple addition of the constexpr specifier to the relevant member functions.

3.1 Atomic Operations

The existing std::shared_ptr class can operate within a multithreaded runtime environment. A number of its member functions may therefore be defined using atomic functions; so ensuring that shared state is updated correctly. Atomic functions are not qualified as constexpr; but as constant expressions must be evaluated by a single thread, a constexpr std::shared_ptr implementation can safely skip calls to atomic functions through the predication of std::is_constant_evaluated (or if consteval). For example, here is a modified function from GCC's libstdc++, called from std::shared_ptr::use_count() and elsewhere:

```
constexpr long
_M_get_use_count() const noexcept
{
#ifdef __cpp_lib_constexpr_shared_ptr
  return std::is_constant_evaluated()
           ? _M_use_count
           : __atomic_load_n(&_M_use_count, __ATOMIC_RELAXED);
#else
  return __atomic_load_n(&_M_use_count, __ATOMIC_RELAXED);
#endif
}
```

The use of atomic intrinsics within Clang's libc++ and MSVC's STL can be elided similarly. In __memory/shared_ptr.h, libc++ makes calls to the atomic intrinsic __atomic_load_n, only via the inline C++ functions __libcpp_relaxed_load and __libcpp_acquire_load; while __atomic_add_fetch is accessed only via __libcpp_atomic_refcount_increment and __libcpp_atomic_refcount_decrement. Each of these four functions is comprised only of return statement pairs, predicated upon *object-like* macros including _LIBCPP_HAS_NO_THREADS; and so could easily be modified to involve std::is_constant_evaluated as above.

In stl/inc/memory, the std::shared_ptr of MSVC's STL inherits a _Ref_count_base member through _Ptr_base. _Ref_count_base has two _Atomic_counter_t members (aliases of unsigned long), updated atomically using the _InterlockedCompareExchange; _InterlockedIncrement (via the macro _MT_INCR); or _InterlockedDecrement (via the macro _MT_DECR) atomic intrinsics. All the (five) functions invoking these intrinsics can again make use of std::is_constant_evaluated to avoid the atomic operations.

Adding constexpr support to an implementation of std::shared_ptr utilising std::atomic would need to take an alternative approach; likely involving the modification of its std::atomic definition. Recently, [P3309R1] has proposed adding such constexpr functionality to std::atomic (and std::atomic_ref) for C++26.

3.2 Two Memory Allocations

Unlike std::unique_ptr, a std::shared_ptr must store not only the managed object, but also the type-erased deleter and allocator, as well as the number of std::shared_ptrs and std::weak_ptrs which own or refer to the managed object. This information is managed as part of a dynamically allocated object referred to as the *control block*.

Existing runtime implementations of std::make_shared, std::allocate_shared, std::make_shared_for_overwrite, and std::allocate_shared_for_overwrite, allocate memory for both the control block, *and* the managed object, from a single dynamic memory allocation; via `reinterpret_cast`. This practise aligns with a remark at 20.3.2.2.7 [util.smartptr.shared.create]; quoted below:

(7.1) — Implementations should perform no more than one memory allocation.
— [*Note 1*: This provides efficiency equivalent to an intrusive smart pointer. — *end note*]

As `reinterpret_cast` is not permitted within a constant expression, an alternative approach is required for `std::make_shared`, `std::allocate_shared`, `std::make_shared_for_overwrite`, and `std::allocate_shared_for_overwrite`. A straightforward solution is to create the object first, and pass its address to the appropriate `std::shared_ptr` constructor. Considering the control block, this approach amounts to two dynamic memory allocations; albeit at compile-time. Assuming that the runtime implementation need not change, the remark quoted above can be left unchanged; as this is only a recommendation, not a requirement.

3.3 Relational Operators

Comparing dynamically allocated pointers within a constant expression is legal, provided the result of the comparison is not unspecified. Such comparisons are defined in terms of a partial order, applicable to pointers which either point "to different elements of the same array, or to subobjects thereof"; or to "different non-static data members of the same object, or to subobjects of such members, recursively…"; from paragraph 4 of 7.6.9 [expr.rel]. A simple example program is shown below:

```
constexpr bool ptr_compare()
{
  int* p = new int[2]{};
  bool b = &p[0] < &p[1];
  delete [] p;
  return b;
}

static_assert(ptr_compare());
```

It is therefore unsurprising that we include the `std::shared_ptr` relational operators within the scope of our proposal to apply `constexpr` to all functions within 20.3 [smartptr]; the `std::shared_ptr` aliasing constructor makes this especially simple to configure:

```
constexpr bool sptr_compare()
{
  double *arr = new double[2];
  std::shared_ptr p{&arr[0]}, q{p, p.get() + 1};
  return p < q;
}

static_assert(sptr_compare());
```

Furthermore, in the interests of `constexpr` consistency, we propose that the relational operators of `std::unique_ptr` *also* now include support for constant evaluation. As discussed above, the results of such comparisons are very often well defined.

It may be argued that a `std::unique_ptr` which is the sole owner of an array, or an object with data members, presents less need for relational operators. Yet we must consider that a custom deleter can easily change the operational semantics; as demonstrated in the example below. A `std::unique_ptr` should also be legally comparable with itself.

```
constexpr bool uptr_compare()
{
  short* p = new short[2]{};
  auto del = [](short*){};
  std::unique_ptr<short[]>                a{p+0};
  std::unique_ptr<short[],decltype(del)> b{p+1, del};
  return a < b;
}

static_assert(uptr_compare());
```

3.4 Maybe Not Now, But Soon

The functions from 20.3 [smartptr] listed below cannot possibly be evaluated within a constant expression. We *do not* propose that their specifications should change. While C++23's [P2448R2] allows such functions to be annotated as `constexpr`, we suggest that in this instance the C++ community will be served better by a future update; when their constant evaluation becomes possible.

- 20.3.3 [util.smartptr.hash]: The `operator()` member of the class template specialisations for `std::hash<std::unique_ptr<T,D>>` and `std::hash<std::shared_ptr<T>>` cannot be defined according to the *Cpp17Hash* requirements (16.4.4.5 [hash.requirements]). (A pointer cannot, during constant evaluation, be converted to an `std::size_t` using `reinterpret_cast`; or otherwise.)
- 20.3.2.5 [util.smartptr.owner.hash]: The two `operator()` member functions of the recently adopted `owner_hash` class, also cannot be defined according to the *Cpp17Hash* requirements.
- 20.3.2.2.6 [util.smartptr.shared.obs]: The recently adopted `owner_hash()` member function of `std::shared_ptr`, also cannot be defined according to the *Cpp17Hash* requirements.
- 20.3.2.3.6 [util.smartptr.weak.obs]: The recently adopted `owner_hash()` member function of `std::weak_ptr`, also cannot be defined according to the *Cpp17Hash* requirements.
- 20.3.2.2.10 [util.smartptr.shared.cast]: Neither of the two `reinterpret_pointer_cast` overloads can be included as their implementations will typically call `reinterpret_cast`, which is prohibited here.

We also *do not* propose any specification change for the overloads of `operator<<` for `std::shared_ptr` and `std::unique_ptr`, from 20.3.2.2.12 [util.smartptr.shared.io] and 20.3.1.7 [unique.ptr.io]. Unlike the functions above, a `constexpr` implementation for the overloads could today use a vendor-specific extension; do nothing; or simply report an error. But such possibilities should be discussed in a separate proposal focused on I/O.

4 Impact on the Standard

This proposal is a pure library extension, and does not require any new language features.

5 Implementation

An implementation based on the GNU C++ Library (libstdc++) can be found here. A comprehensive test suite is included there within `tests/shared_ptr_constexpr_tests.cpp`; alongside a standalone bash script to run it. All tests pass with recent GCC and Clang (i.e. versions supporting [P2738R1]; `__cpp_constexpr >= 202306L`).

A second implementation, by Hana Dusíková, based on the "libc++" C++ Library is also available: on Github here (via commit 23217d0); and with a corresponding Compiler Explorer instance here.

6 Proposed Wording

The following wording changes apply to [N4981] and can also be viewed on Github via a fork of the *C++ Standard Draft Sources* repository here.

Add to 17.3.2 [version.syn] (Header `<version>` synopsis):

```
- #define __cpp_lib_constexpr_memory                202202L // freestanding, also in <memory>
+ #define __cpp_lib_constexpr_memory                YYYYMML // freestanding, also in <memory>
```

Add to 20.2.2 [memory.syn] (Header `<memory>` synopsis):

```
constexpr bool operator<(const unique_ptr<T1, D1>& x, const unique_ptr<T2, D2>& y);
constexpr bool operator>(const unique_ptr<T1, D1>& x, const unique_ptr<T2, D2>& y);
constexpr bool operator<=(const unique_ptr<T1, D1>& x, const unique_ptr<T2, D2>& y);
constexpr bool operator>=(const unique_ptr<T1, D1>& x, const unique_ptr<T2, D2>& y);
constexpr compare_three_way_result_t<typename unique_ptr<T1, D1>::pointer,
constexpr shared_ptr<T> make_shared(Args&&... args);
constexpr shared_ptr<T> allocate_shared(const A& a, Args&&... args);
constexpr shared_ptr<T> make_shared(size_t N);
constexpr shared_ptr<T> allocate_shared(const A& a, size_t N);
constexpr shared_ptr<T> make_shared();
constexpr shared_ptr<T> allocate_shared(const A& a);
constexpr shared_ptr<T> make_shared(size_t N, const remove_extent_t<T>& u);
constexpr shared_ptr<T> allocate_shared(const A& a, size_t N,
constexpr shared_ptr<T> make_shared(const remove_extent_t<T>& u);
constexpr shared_ptr<T> allocate_shared(const A& a, const remove_extent_t<T>& u);
constexpr shared_ptr<T> make_shared_for_overwrite();
constexpr shared_ptr<T> allocate_shared_for_overwrite(const A& a);
constexpr shared_ptr<T> make_shared_for_overwrite(size_t N);
constexpr shared_ptr<T> allocate_shared_for_overwrite(const A& a, size_t N);
constexpr bool operator==(const shared_ptr<T>& a, const shared_ptr<U>& b) noexcept;
constexpr strong_ordering operator<=>(const shared_ptr<T>& a, const shared_ptr<U>& b) noexcept;
constexpr bool operator==(const shared_ptr<T>& x, nullptr_t) noexcept;
constexpr strong_ordering operator<=>(const shared_ptr<T>& x, nullptr_t) noexcept;
constexpr void swap(shared_ptr<T>& a, shared_ptr<T>& b) noexcept;
constexpr shared_ptr<T> static_pointer_cast(const shared_ptr<U>& r) noexcept;
constexpr shared_ptr<T> static_pointer_cast(shared_ptr<U>&& r) noexcept;
constexpr shared_ptr<T> dynamic_pointer_cast(const shared_ptr<U>& r) noexcept;
constexpr shared_ptr<T> dynamic_pointer_cast(shared_ptr<U>&& r) noexcept;
constexpr shared_ptr<T> const_pointer_cast(const shared_ptr<U>& r) noexcept;
constexpr shared_ptr<T> const_pointer_cast(shared_ptr<U>&& r) noexcept;
constexpr D* get_deleter(const shared_ptr<T>& p) noexcept;
template<class T> constexpr void swap(weak_ptr<T>& a, weak_ptr<T>& b) noexcept;
constexpr auto out_ptr(Smart& s, Args&&... args);
constexpr auto inout_ptr(Smart& s, Args&&... args);
```

Add to 20.3.1.6 [unique.ptr.special] (Specialized algorithms):

```
constexpr bool operator<(const unique_ptr<T1, D1>& x, const unique_ptr<T2, D2>& y);
constexpr bool operator>(const unique_ptr<T1, D1>& x, const unique_ptr<T2, D2>& y);
constexpr bool operator<=(const unique_ptr<T1, D1>& x, const unique_ptr<T2, D2>& y);
constexpr bool operator>=(const unique_ptr<T1, D1>& x, const unique_ptr<T2, D2>& y);
constexpr compare_three_way_result_t<typename unique_ptr<T1, D1>::pointer,
```

Add to 20.3.2.1 [util.smartptr.weak.bad] (Class `bad_weak_ptr`):

```
constexpr const char* what() const noexcept override;
constexpr const char* what() const noexcept override;
```

Add to 20.3.2.2.1 [util.smartptr.shared.general] (General):

```
constexpr explicit shared_ptr(Y* p);
constexpr shared_ptr(Y* p, D d);
constexpr shared_ptr(Y* p, D d, A a);
constexpr shared_ptr(nullptr_t p, D d);
constexpr shared_ptr(nullptr_t p, D d, A a);
template<class Y> constexpr shared_ptr(const shared_ptr<Y>& r, element_type* p) noexcept;
```

```
template<class Y> constexpr shared_ptr(shared_ptr<Y>&& r, element_type* p) noexcept;
constexpr shared_ptr(const shared_ptr& r) noexcept;
template<class Y> constexpr shared_ptr(const shared_ptr<Y>& r) noexcept;
constexpr shared_ptr(shared_ptr&& r) noexcept;
template<class Y> constexpr shared_ptr(shared_ptr<Y>&& r) noexcept;
template<class Y> constexpr explicit shared_ptr(const weak_ptr<Y>& r);
constexpr shared_ptr(unique_ptr<Y, D>&& r);
constexpr ~shared_ptr();
constexpr shared_ptr& operator=(const shared_ptr& r) noexcept;
template<class Y> constexpr shared_ptr& operator=(const shared_ptr<Y>& r) noexcept;
constexpr shared_ptr& operator=(shared_ptr&& r) noexcept;
template<class Y> constexpr shared_ptr& operator=(shared_ptr<Y>&& r) noexcept;
constexpr shared_ptr& operator=(unique_ptr<Y, D>&& r);
constexpr void swap(shared_ptr& r) noexcept;
constexpr void reset() noexcept;
constexpr void reset(Y* p);
constexpr void reset(Y* p, D d);
constexpr void reset(Y* p, D d, A a);
constexpr element_type* get() const noexcept;
constexpr T& operator*() const noexcept;
constexpr T* operator->() const noexcept;
constexpr element_type& operator[](ptrdiff_t i) const;
constexpr long use_count() const noexcept;
constexpr explicit operator bool() const noexcept;
template<class U> constexpr bool owner_before(const shared_ptr<U>& b) const noexcept;
template<class U> constexpr bool owner_before(const weak_ptr<U>& b) const noexcept;
constexpr bool owner_equal(const shared_ptr<U>& b) const noexcept;
constexpr bool owner_equal(const weak_ptr<U>& b) const noexcept;
```

Add to 20.3.2.2.2 [util.smartptr.shared.const] (Constructors):

```
template<class Y> constexpr explicit shared_ptr(Y* p);
template<class Y, class D> constexpr shared_ptr(Y* p, D d);
template<class Y, class D, class A> constexpr shared_ptr(Y* p, D d, A a);
template<class D> constexpr shared_ptr(nullptr_t p, D d);
template<class D, class A> constexpr shared_ptr(nullptr_t p, D d, A a);
template<class Y> constexpr shared_ptr(const shared_ptr<Y>& r, element_type* p) noexcept;
template<class Y> constexpr shared_ptr(shared_ptr<Y>&& r, element_type* p) noexcept;
constexpr shared_ptr(const shared_ptr& r) noexcept;
template<class Y> constexpr shared_ptr(const shared_ptr<Y>& r) noexcept;
constexpr shared_ptr(shared_ptr&& r) noexcept;
template<class Y> constexpr shared_ptr(shared_ptr<Y>&& r) noexcept;
template<class Y> constexpr explicit shared_ptr(const weak_ptr<Y>& r);
template<class Y, class D> constexpr shared_ptr(unique_ptr<Y, D>&& r);
```

Add to 20.3.2.2.3 [util.smartptr.shared.dest] (Destructor):

```
constexpr ~shared_ptr();
```

Add to 20.3.2.2.4 [util.smartptr.shared.assign] (Assignment):

```
constexpr shared_ptr& operator=(const shared_ptr& r) noexcept;
template<class Y> constexpr shared_ptr& operator=(const shared_ptr<Y>& r) noexcept;
constexpr shared_ptr& operator=(shared_ptr&& r) noexcept;
template<class Y> constexpr shared_ptr& operator=(shared_ptr<Y>&& r) noexcept;
template<class Y, class D> constexpr shared_ptr& operator=(unique_ptr<Y, D>&& r);
```

Add to 20.3.2.2.5 [util.smartptr.shared.mod] (Modifiers):

```
constexpr void swap(shared_ptr& r) noexcept;
constexpr void reset() noexcept;
template<class Y> constexpr void reset(Y* p);
template<class Y, class D> constexpr void reset(Y* p, D d);
template<class Y, class D, class A> constexpr void reset(Y* p, D d, A a);
```

Add to 20.3.2.2.6 [util.smartptr.shared.obs] (Observers):

```
constexpr element_type* get() const noexcept;
constexpr T& operator*() const noexcept;
constexpr T* operator->() const noexcept;
constexpr element_type& operator[](ptrdiff_t i) const;
constexpr long use_count() const noexcept;
constexpr explicit operator bool() const noexcept;
template<class U> constexpr bool owner_before(const shared_ptr<U>& b) const noexcept;
template<class U> constexpr bool owner_before(const weak_ptr<U>& b) const noexcept;
constexpr bool owner_equal(const shared_ptr<U>& b) const noexcept;
constexpr bool owner_equal(const weak_ptr<U>& b) const noexcept;
```

Add to 20.3.2.2.7 [util.smartptr.shared.create] (Creation):

```
constexpr shared_ptr<T> make_shared(argc);
constexpr shared_ptr<T> allocate_shared(const A& a, argc);
constexpr shared_ptr<T> make_shared_for_overwrite(argc);
constexpr shared_ptr<T> allocate_shared_for_overwrite(const A& a, argc);
constexpr shared_ptr<T> make_shared(Args&&... args);
constexpr shared_ptr<T> allocate_shared(const A& a, Args&&... args);
constexpr make_shared(size_t N);
constexpr shared_ptr<T> allocate_shared(const A& a, size_t N);
constexpr shared_ptr<T> make_shared();
constexpr shared_ptr<T> allocate_shared(const A& a);
constexpr shared_ptr<T> make_shared(size_t N, const remove_extent_t<T>& u);
constexpr shared_ptr<T> allocate_shared(const A& a, size_t N, const remove_extent_t<T>& u);
constexpr shared_ptr<T> make_shared(const remove_extent_t<T>& u);
constexpr shared_ptr<T> allocate_shared(const A& a, const remove_extent_t<T>& u);
constexpr shared_ptr<T> make_shared_for_overwrite();
constexpr shared_ptr<T> allocate_shared_for_overwrite(const A& a);
constexpr shared_ptr<T> make_shared_for_overwrite(size_t N);
constexpr shared_ptr<T> allocate_shared_for_overwrite(const A& a, size_t N);
```

Add to 20.3.2.2.8 [util.smartptr.shared.cmp] (Comparison):

```
constexpr bool operator==(const shared_ptr<T>& a, const shared_ptr<U>& b) noexcept;
template<class T> constexpr bool operator==(const shared_ptr<T>& a, nullptr_t) noexcept;
constexpr strong_ordering operator<=>(const shared_ptr<T>& a, const shared_ptr<U>& b) noexcept;
constexpr strong_ordering operator<=>(const shared_ptr<T>& a, nullptr_t) noexcept;
```

Add to 20.3.2.2.9 [util.smartptr.shared.spec] (Specialized algorithms):

```
constexpr void swap(shared_ptr<T>& a, shared_ptr<T>& b) noexcept;
```

Add to 20.3.2.2.10 [util.smartptr.shared.cast] (Casts):

```
constexpr shared_ptr<T> static_pointer_cast(const shared_ptr<U>& r) noexcept;
constexpr shared_ptr<T> static_pointer_cast(shared_ptr<U>&& r) noexcept;
constexpr shared_ptr<T> dynamic_pointer_cast(const shared_ptr<U>& r) noexcept;
constexpr shared_ptr<T> dynamic_pointer_cast(shared_ptr<U>&& r) noexcept;
constexpr shared_ptr<T> const_pointer_cast(const shared_ptr<U>& r) noexcept;
constexpr shared_ptr<T> const_pointer_cast(shared_ptr<U>&& r) noexcept;
```

Add to 20.3.2.2.11 [util.smartptr.getdeleter] (`get_deleter`):

```
constexpr D* get_deleter(const shared_ptr<T>& p) noexcept;
```

Add to 20.3.2.3.1 [util.smartptr.weak.general] (General):

```
constexpr weak_ptr(const shared_ptr<Y>& r) noexcept;
constexpr weak_ptr(const weak_ptr& r) noexcept;
constexpr weak_ptr(const weak_ptr<Y>& r) noexcept;
constexpr weak_ptr(weak_ptr&& r) noexcept;
constexpr weak_ptr(weak_ptr<Y>&& r) noexcept;
constexpr ~weak_ptr();
constexpr weak_ptr& operator=(const weak_ptr& r) noexcept;
constexpr weak_ptr& operator=(const weak_ptr<Y>& r) noexcept;
constexpr weak_ptr& operator=(const shared_ptr<Y>& r) noexcept;
constexpr weak_ptr& operator=(weak_ptr&& r) noexcept;
constexpr weak_ptr& operator=(weak_ptr<Y>&& r) noexcept;
constexpr void swap(weak_ptr& r) noexcept;
constexpr void reset() noexcept;
constexpr long use_count() const noexcept;
constexpr bool expired() const noexcept;
constexpr shared_ptr<T> lock() const noexcept;
constexpr bool owner_before(const shared_ptr<U>& b) const noexcept;
constexpr bool owner_before(const weak_ptr<U>& b) const noexcept;
constexpr bool owner_equal(const shared_ptr<U>& b) const noexcept;
constexpr bool owner_equal(const weak_ptr<U>& b) const noexcept;
```

Add to 20.3.2.3.2 [util.smartptr.weak.const] (Constructors):

```
constexpr weak_ptr(const weak_ptr& r) noexcept;
template<class Y> constexpr weak_ptr(const weak_ptr<Y>& r) noexcept;
template<class Y> constexpr weak_ptr(const shared_ptr<Y>& r) noexcept;
constexpr weak_ptr(weak_ptr&& r) noexcept;
template<class Y> constexpr weak_ptr(weak_ptr<Y>&& r) noexcept;
```

Add to 20.3.2.3.3 [util.smartptr.weak.dest] (Destructor):

```
constexpr ~weak_ptr();
```

Add to 20.3.2.3.4 [util.smartptr.weak.assign] (Assignment):

```
constexpr weak_ptr& operator=(const weak_ptr& r) noexcept;
template<class Y> constexpr weak_ptr& operator=(const weak_ptr<Y>& r) noexcept;
template<class Y> constexpr weak_ptr& operator=(const shared_ptr<Y>& r) noexcept;
constexpr weak_ptr& operator=(weak_ptr&& r) noexcept;
template<class Y> constexpr weak_ptr& operator=(weak_ptr<Y>&& r) noexcept;
```

Add to 20.3.2.3.5 [util.smartptr.weak.mod] (Modifiers):

```
constexpr void swap(weak_ptr& r) noexcept;
constexpr void reset() noexcept;
```

Add to 20.3.2.3.6 [util.smartptr.weak.obs] (Observers):

```
constexpr long use_count() const noexcept;
constexpr bool expired() const noexcept;
constexpr shared_ptr<T> lock() const noexcept;
template<class U> constexpr bool owner_before(const shared_ptr<U>& b) const noexcept;
template<class U> constexpr bool owner_before(const weak_ptr<U>& b) const noexcept;
constexpr bool owner_equal(const shared_ptr<U>& b) const noexcept;
constexpr bool owner_equal(const weak_ptr<U>& b) const noexcept;
```

Add to 20.3.2.3.7 [util.smartptr.weak.spec] (Specialized algorithms):

```
constexpr void swap(weak_ptr<T>& a, weak_ptr<T>& b) noexcept;
```

Add to 20.3.2.4 [util.smartptr.ownerless] (Class template `owner_less`):

```
constexpr bool operator()(const shared_ptr<T>&, const shared_ptr<T>&) const noexcept;
constexpr bool operator()(const shared_ptr<T>&, const weak_ptr<T>&) const noexcept;
constexpr bool operator()(const weak_ptr<T>&, const shared_ptr<T>&) const noexcept;
constexpr bool operator()(const weak_ptr<T>&, const weak_ptr<T>&) const noexcept;
constexpr bool operator()(const shared_ptr<T>&, const weak_ptr<T>&) const noexcept;
constexpr bool operator()(const weak_ptr<T>&, const shared_ptr<T>&) const noexcept;
constexpr bool operator()(const shared_ptr<T>&, const shared_ptr<U>&) const noexcept;
constexpr bool operator()(const shared_ptr<T>&, const weak_ptr<U>&) const noexcept;
constexpr bool operator()(const weak_ptr<T>&, const shared_ptr<U>&) const noexcept;
constexpr bool operator()(const weak_ptr<T>&, const weak_ptr<U>&) const noexcept;
```

Add to 20.3.2.6 [util.smartptr.owner.equal] (Struct `owner_equal`):

```
constexpr bool operator()(const shared_ptr<T>&, const shared_ptr<U>&) const noexcept;
constexpr bool operator()(const shared_ptr<T>&, const weak_ptr<U>&) const noexcept;
constexpr bool operator()(const weak_ptr<T>&, const shared_ptr<U>&) const noexcept;
constexpr bool operator()(const weak_ptr<T>&, const weak_ptr<U>&) const noexcept;
constexpr bool operator()(const shared_ptr<T>& x, const shared_ptr<U>& y) const noexcept;
constexpr bool operator()(const shared_ptr<T>& x, const weak_ptr<U>& y) const noexcept;
constexpr bool operator()(const weak_ptr<T>& x, const shared_ptr<U>& y) const noexcept;
constexpr bool operator()(const weak_ptr<T>& x, const weak_ptr<U>& y) const noexcept;
```

Add to 20.3.2.7 [util.smartptr.enab] (Class template `enable_shared_from_this`):

```
constexpr enable_shared_from_this(const enable_shared_from_this&) noexcept;
constexpr enable_shared_from_this& operator=(const enable_shared_from_this&) noexcept;
constexpr ~enable_shared_from_this();
constexpr shared_ptr<T> shared_from_this();
constexpr shared_ptr<T const> shared_from_this() const;
constexpr weak_ptr<T> weak_from_this() noexcept;
constexpr weak_ptr<T const> weak_from_this() const noexcept;
constexpr enable_shared_from_this(const enable_shared_from_this<T>&) noexcept;
constexpr enable_shared_from_this<T>& operator=(const enable_shared_from_this<T>&) noexcept;
constexpr shared_ptr<T>       shared_from_this();
constexpr shared_ptr<T const> shared_from_this() const;
constexpr weak_ptr<T>       weak_from_this() noexcept;
constexpr weak_ptr<T const> weak_from_this() const noexcept;
```

Add to 20.3.4.1 [out.ptr.t] (Class template `out_ptr_t`):

```
constexpr explicit out_ptr_t(Smart&, Args...);
constexpr ~out_ptr_t();
constexpr operator Pointer*() const noexcept;
constexpr operator void**() const noexcept;
constexpr explicit out_ptr_t(Smart& smart, Args... args);
constexpr ~out_ptr_t();
constexpr operator Pointer*() const noexcept;
constexpr operator void**() const noexcept;
```

Add to 20.3.4.2 [out.ptr] (Function template `out_ptr`):

```
constexpr auto out_ptr(Smart& s, Args&&... args);
```

Add to 20.3.4.3 [inout.ptr.t] (Class template `inout_ptr_t`):

```
constexpr explicit inout_ptr_t(Smart&, Args...);
constexpr ~inout_ptr_t();
constexpr operator Pointer*() const noexcept;
constexpr operator void**() const noexcept;
constexpr explicit inout_ptr_t(Smart& smart, Args... args);
constexpr ~inout_ptr_t();
constexpr operator Pointer*() const noexcept;
constexpr operator void**() const noexcept;
```

Add to 20.3.4.4 [inout.ptr] (Function template `inout_ptr`):

```
constexpr auto inout_ptr(Smart& s, Args&&... args);
```

7 Acknowledgements

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8 References

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