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Stop Tokens and a Joining Thread, Rev 8

New in R8

As requested at the LEWG meeting in San Diego 2018:

- Terminology (especially rename `interrupt_token` to `stop_token`.
- Add a deduction guide for `stop_callback`
- Add `std::nostopstate_t` to create stop stop tokens that don't share a stop state
- Several clarifications in wording

New in R7

- Adopt www.wg21.link/P1287 as discussed in the SG1 meeting in San Diego 2018, which includes:
  - Add callbacks for interrupt tokens.
  - Split into `interrupt_token` and `interrupt_source`.

New in R6

- User `condition_variable_any` instead of `consition_variable` to avoid all possible races, deadlocks, and unintended undefined behavior.
- Clarify future binary compatibility for interrupt handling (mention requirements for future callback support and allow `bad_alloc` exceptions on waits.

New in R5

As requested at the SG1 meeting in Seattle 2018:

- Removed exception class `std::interrupted` and the `throw_if_interrupted()` API.
- Removed all TLS extensions and extensions to `std::this_thread`.
- Added support to let `jhread` call a callable that either takes the interrupt token as additional first argument or doesn't get it (taking just all passed arguments).

New in R4

- Removed interruptible CV waiting members that don't take a predicate.
- Removed adding a new `cv_status` value `interrupted`.
- Added CV members for interruptible timed waits.
- Renamed CV members that wait interruptible.
- Several minor fixes (e.g. on `noexcept`) and full proposed wording.

Purpose

This is the proposed wording for a cooperatively interruptible joining thread.

For a full discussion fo the motivation, see www.wg21.link/p0660r0 and www.wg21.link/p0660r1.

A default implementation exists at: http://github.com/josuttis/jthread. Note that the proposed functionality can be fully implemented on top of the existing C++ standard library without special OS support.

Basis examples

— At the end of its lifetime a `jthread` automatically signals a request to stop the started thread (if still joinable) and joins:

```
void testJThreadWithToken()
{
    std::jthread t([] (std::stop_token stoken) {
                     while (!stoken.stop_requested()) {
                       //...
                     }
                   });
    //...
} // jthread destructor signals requests to stop and therefore ends the started thread and joins
```

The stop could also be explicitly requested with `t.request_stop()`.

— If the started thread doesn't take an stop token, the destructor still has the benefit of calling `join()` (if still joinable):

```
void testJThreadJoining()
{
    std::jthread t([] {
                     //...
                   });
    //...
} // jthread destructor calls join()
```

This is a significant improvement over `std::thread` where you had to program the following to get the same behavior (which is common in many scenarios):

```
void compareWithStdThreadJoining()
{
    std::thread t([] {
                    //...
                  });
    try {
      //...
    }
    catch (...) {
      j.join();
      throw;  // rethrow
    }
    t.join();
}
```

— An extended CV API enables to interrupt CV waits using the passed stop token (i.e. interrupting the CV wait without polling):

```
void testInterruptibleCVWait()
{
  bool ready = false;
  std::mutex readyMutex;
  std::condition_variable_any readyCV;
  std::jthread t([&ready, &readyMutex, &readyCV] (std::stop_token st) {
                   while (...) {
                     ...
                     {
                       std::unique_lock lg{readyMutex};
                       readyCV.wait_until(lg,
                                          [&ready] {
                                             return ready;
                                          },
                                          st);  // also ends wait on stop request for st
                     }
                     ...
                   }
                 });
```

```
  ...
} // jthread destructor signals stop request and therefore unblocks the CV wait and ends the started thread
```

Feature Test Macro

This is a new feature so that it shall have the following feature macro:

```
__cpp_lib_jthread
```

Key Design Hints

Guarantees for Races

Other Hints

The terminology was carfully selected with the following reasons

- With a stop token we neither "interrupt" nor "cancel" something. We request a stop that cooperatively has to get handled.
- `stop_possible()` helps to avoid addign new callbacks or checking for stop states. The name was selected to have a common and pretty self-explanatory name that is shared by both `stop_source`s and `stop_token`s.

The deduction guide for `stop_callback`s enables constructing a `stop_callback` with an lvalue callable:

```
auto lambda = []{};
std::stop_callback cb{ token, lambda };  // captures by reference
```

Adding a new callback is `noexcept` (unless moving the passed function throws).

Acknowledgements

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Proposed Wording

All against N4762.

[*Editorial note:* This proposal uses the LaTeX macros of the draft standard. To adopt it please ask for the LaTeX source code of the proposed wording.]

30 Thread support library [thread]

30.1 General [jthread.general]

1 The following subclauses describe components to create and manage threads (**??**), perform mutual exclusion, and communicate conditions and values between threads, as summarized in Table 1.

Table 1 — Thread support library summary

	Subclause	Header(s)
30.2	Requirements	
30.3	Threads	`<thread>`
30.4	Stop Tokens	`<stop_token>`
30.5	Joining Threads	`<jthread>`
30.6	Mutual exclusion	`<mutex>` `<shared_mutex>`
30.7	Condition variables	`<condition_variable>`
30.8	Futures	`<future>`

30.2 Requirements [thread.req]

...

30.3 Threads [thread.threads]

...

30.4 Stop Tokens [thread.stop_token]

1 30.4 describes components that can be used to asynchonously request an end ("stop") of a running execution. The stop can only be requested exactly once by one of multiple `stop_source`s to one or multiple `stop_token`s. Callbacks can be registered as `stop_callback`s to be called when the stop is requested.

For this, classes `stop_source`, `stop_token` and `stop_callback` implement semantics of shared ownership of an associated atomic stop state (an atomic token to signal a stop request). The last remaining owner of the stop state automatically releases the resources associated with the stop state.

2 Calls to `request_stop()`, `stop_requested()`, `stop_possible()`, and `stop_possible()` are atomic operations (6.8.2.1p3 **??**) on the stop state contained in the stop state object. Hence concurrent calls to these functions do not introduce data races. A call to `request_stop()` synchronizes with any call to `request_stop()` and `stop_requested()` that observes the stop.

30.4.1 Header `<stop_token>` synopsis [thread.stop_token.syn]

```
namespace std {
  // 30.4.4 class stop_token
  template <typename Callback> class stop_callback;
  class stop_source;
  class stop_token;
}
```

30.4.2 Class `stop_callback` [stop_callback]

1

```
namespace std {
  template <Invocable Callback>
    requires MoveConstructible<Callback>
  class stop_callback {
  public:
    // 30.4.2.1 create, destroy:
    explicit stop_callback(const stop_token& st, Callback&& cb)
        noexcept(std::is_nothrow_move_constructible_v<Callback>);
    explicit stop_callback(stop_token&& st, Callback&& cb)
        noexcept(std::is_nothrow_move_constructible_v<Callback>);
    ~stop_callback();

    stop_callback(const stop_callback&) = delete;
    stop_callback(stop_callback&&) = delete;
    stop_callback& operator=(const stop_callback&) = delete;
    stop_callback& operator=(stop_callback&&) = delete;

  private:
    // exposition only
    Callback callback;
  };

  template <typename Callback>
  stop_callback(const stop_token&, Callback&&) -> stop_callback<Callback>;

  template <typename Callback>
  stop_callback(stop_token&&, Callback&&) -> stop_callback<Callback>;
}

template<typename _Callback>
stop_callback(const stop_token&, _Callback&&) -> stop_callback<_Callback>;

template<typename _Callback>
stop_callback(stop_token&&, _Callback&&) -> stop_callback<_Callback>;
```

30.4.2.1 `stop_callback` constructors and destructor [stop_callback.constr]

```
explicit stop_callback(const stop_token& st, Callback&& cb)
  noexcept(std::is_nothrow_move_constructible_v<Callback>);
```

```
explicit stop_callback(stop_token&& st, Callback&& cb)
  noexcept(std::is_nothrow_move_constructible_v<Callback>);
```

1 *Effects:* Initialises `callback` with `static_cast<Callback&&>(cb)`. If `it.stop_requested()` is true then immediately invokes `static_cast<Callback&&>(callback)` with zero arguments on the current thread before the constructor returns. Otherwise, the callback is registered with the shared stop state of `it` such that `static_cast<Callback&&>(callback)` is invoked by first call to `isrc.request_stop()` on an `stop_source` instance `isrc` that references the same shared stop state as `it`. If invoking the callback throws an unhandled exception then `std::terminate()` is called.

```
~stop_callback();
```

2 *Effects:* Deregisters the callback from the associated stop state. If this callback is concurrently executing on another thread then the destructor shall block until the callback returns before calling `callback`'s destructor. The destructor shall not block waiting for the execution of another callback registered with the same shared stop state to finish. A subsequent call to `isrc.request_stop()` on an `stop_source`, `isrc`, with the same associated stop state shall not invoke the callback once the destructor has returned.

30.4.3 Class `stop_source` [stop_source]

1 The class `stop_source` implements semantics of signaling stop requests to `stop_token`s (30.4.4) sharing the same associated stop state. All `stop_source`s sharing the same stop state can request a stop. An stop can only be requested once. Subsequent attempts to request a stop are no-ops.

```
namespace std {
  // 30.4.3.1 no-shared-stop-state indicator
  struct nostopstate_t{see below};
  inline constexpr nostopstate_t nostopstate(unspecified);

  class stop_source {
  public:
    // 30.4.3.2 create, copy, destroy:
    stop_source();
    explicit stop_source(nullptr_t) noexcept;

    stop_source(const stop_source&) noexcept;
    stop_source(stop_source&&) noexcept;
    stop_source& operator=(const stop_source&) noexcept;
    stop_source& operator=(stop_source&&) noexcept;
    ~stop_source();
    void swap(stop_source&) noexcept;

    // 30.4.3.6 stop handling:
    [[nodiscard]] stop_token get_token() const noexcept;
    [[nodiscard]] bool stop_possible() const noexcept;
    [[nodiscard]] bool stop_requested() const noexcept;
    [[nodiscard]] bool request_stop() const noexcept;

    friend bool operator== (const stop_source& lhs, const stop_source& rhs) noexcept;
    friend bool operator!= (const stop_source& lhs, const stop_source& rhs) noexcept;
  };
}
```

30.4.3.1 No-shared-stop-state indicator [stop_source.nostopstate]

```
struct nostopstate_t{see below};
inline constexpr nostopstate_t nullopt(unspecified);
```

1 The struct `nostopstate_t` is an empty class type used as a unique type to indicate the state of not containing a shared stop state for `stop_source` objects. In particular, `stop_source` has a constructor with `nostopstate_t` as a single argument; this indicates that a stop source object not sharing a stop state shall be constructed.

2 Type `nostopstate_t` shall not have a default constructor or an initializer-list constructor, and shall not be an aggregate.

30.4.3.2 `stop_source` constructors [stop_source.constr]

```
stop_source();
```

1 *Effects:* Constructs a new `stop_source` object that can be used to request stops.

2 *Ensures:* `stop_possible() == true` and `stop_requested() == false`.

3 *Throws:* `bad_alloc` If memory could not be allocated for the shared stop state.

```
explicit stop_source(nullptr_t) noexcept;
```

4 *Effects:* Constructs a new `stop_source` object that can't be used to request stops. [*Note*: Therefore, no resources have to be associated for the state. — *end note*]

5 *Ensures:* `stop_possible() == false`.

```
stop_source(const stop_source& rhs) noexcept;
```

6 *Effects:* If `rhs.stop_possible() == true`, constructs an `stop_source` that shares the ownership of the stop state with `rhs`.

7 *Ensures:* `stop_possible() == rhs.stop_possible()` and `stop_requested() == rhs.stop_requested()` and `*this == rhs`.

```
stop_source(stop_source&& rhs) noexcept;
```

8 *Effects:* Move constructs an object of type `stop_source` from `rhs`.

9 *Ensures:* `*this` shall contain the old value of `rhs` and `rhs.stop_possible() == false`.

30.4.3.3 `stop_source` destructor [stop_source.destr]

```
~stop_source();
```

1 *Effects:* If `stop_possible()` and `*this` is the last owner of the stop state, releases the resources associated with the stop state.

30.4.3.4 `stop_source` assignment [stop_source.assign]

```
stop_source& operator=(const stop_source& rhs) noexcept;
```

1 *Effects:* Equivalent to: `stop_source(rhs).swap(*this);`

2 *Returns:* `*this`.

```
stop_source& operator=(stop_source&& rhs) noexcept;
```

3 *Effects:* Equivalent to: `stop_source(std::move(rhs)).swap(*this);`

4 *Returns:* `*this`.

30.4.3.5 `stop_source` swap [stop_source.swap]

```
void swap(stop_source& rhs) noexcept;
```

1 *Effects:* Swaps the state of `*this` and `rhs`.

30.4.3.6 `stop_source` members [stop_source.mem]

```
[[nodiscard]] stop_token get_token() const noexcept;
```

1 *Effects:* If `!stop_possible()`, constructs an `stop_token` object that does not share a stop state. Otherwise, constructs an `stop_token` object `it` that shares the ownership of the stop state with `*this`.

2 *Ensures:* `stop_possible() == it.stop_possible()` and `stop_requested() == it.stop_requested()`.

```
[[nodiscard]] bool stop_possible() const noexcept;
```

3 *Returns:* `true` if the stop source can be used to request stops. [*Note*: Returns `false` if the object was created with the `nullptr` or the values were moved away. — *end note*]

```
[[nodiscard]] bool stop_requested() const noexcept;
```

4 *Returns:* `true` if `stop_possible()` and `request_stop()` was called by one of the owners.

```
[[nodiscard]] bool request_stop() const noexcept;
```

5 *Effects:* If `!stop_possible()` or `stop_requested()` the call has no effect. Otherwise, requests a stop so that `stop_requested() == true` and all registered callbacks are synchronously called. [*Note*: Requesting a stop includes notifying all condition variables of type `condition_variable_any` temporarily registered during an interruptable wait (**??**) — *end note*]

6 *Ensures:* `!stop_possible() || stop_requested()`

7 *Returns:* The value of `stop_requested()` prior to the call.

30.4.3.7 `stop_source` comparisons [stop_source.cmp]

```
bool operator== (const stop_source& lhs, const stop_source& rhs) noexcept;
```

1 *Returns:* `!lhs.stop_possible() && !rhs.stop_possible()` or whether `lhs` and `rhs` refer to the same stop state (copied or moved from the same initial `stop_source` object).

```
bool operator!= (const stop_source& lhs, const stop_source& rhs) noexcept;
```

2 *Returns:* `!(lhs==rhs)`.

30.4.4 Class `stop_token` [stop_token]

1 The class `stop_token` provides an interface for responding to stops requested from the `stop_source` object they were created from. All tokens can check whether an stop was requested. When an stop is requested, which is possible only once, any registered `stop_callback` (30.4.2) is called. Registering a callback after an stop was already requested calls the callback immediately.

```
namespace std {
  class stop_token {
  public:
    // 30.4.4.1 create, copy, destroy:
    stop_token() noexcept;

    stop_token(const stop_token&) noexcept;
    stop_token(stop_token&&) noexcept;
    stop_token& operator=(const stop_token&) noexcept;
    stop_token& operator=(stop_token&&) noexcept;
    ~stop_token();
    void swap(stop_token&) noexcept;

    // 30.4.4.5 stop handling:
    [[nodiscard]] bool stop_requested() const noexcept;
    [[nodiscard]] bool stop_possible() const noexcept;

    friend bool operator== (const stop_token& lhs, const stop_token& rhs) noexcept;
    friend bool operator!= (const stop_token& lhs, const stop_token& rhs) noexcept;
  };
}
```

30.4.4.1 `stop_token` constructors [stop_token.constr]

```
stop_token() noexcept;
```

1 *Effects:* Constructs a new `stop_token` object that can't be used to request stops. [*Note*: Therefore, no resources have to be associated for the state. — *end note*]

2 *Ensures:* `stop_possible() == false` and `stop_requested() == false`.

```
stop_token(const stop_token& rhs) noexcept;
```

3 *Effects:* If `rhs.stop_possible() == false`, constructs an `stop_token` object that can't be used to request stops. Otherwise, constructs an `stop_token` that shares the ownership of the stop state with `rhs`.

4 *Ensures:* `stop_possible() == rhs.stop_possible()` and `stop_requested() == rhs.stop_requested()` and `*this == rhs`.

```
stop_token(stop_token&& rhs) noexcept;
```

5 *Effects:* Move constructs an object of type `stop_token` from `rhs`.

6 *Ensures:* `*this` shall contain the old value of `rhs` and `rhs.stop_possible() == false`.

30.4.4.2 `stop_token` destructor [stop_token.destr]

```
~stop_token();
```

1 *Effects:* If `*this` is the last owner of the stop state, releases the resources associated with the stop state.

30.4.4.3 `stop_token` assignment [stop_token.assign]

```
stop_token& operator=(const stop_token& rhs) noexcept;
```

1 *Effects:* Equivalent to: `stop_token(rhs).swap(*this);`

2 *Returns:* `*this`.

```
stop_token& operator=(stop_token&& rhs) noexcept;
```

3 *Effects:* Equivalent to: `stop_token(std::move(rhs)).swap(*this);`

4 *Returns:* `*this`.

30.4.4.4 `stop_token` swap [stop_token.swap]

```
void swap(stop_token& rhs) noexcept;
```

1 *Effects:* Swaps the state of `*this` and `rhs`.

30.4.4.5 `stop_token` members [stop_token.mem]

```
[[nodiscard]] bool stop_requested() const noexcept;
```

1 *Returns:* `true` if `stop_possible() == true` and `request_stop()` was called by one of the owners, otherwise[2] `false`. *Synchronization:* If `true` is returned then synchronizes with the first call to `request_stop()` by one of the owners.

```
[[nodiscard]] bool stop_possible() const noexcept;
```

3 *Returns:* `false` if `stop_requested()` will never yield `true` (the underlying shared stop state will never be able to signal a stop). [*Note*: To return `true` a `stop_token` must share a stop state, for which either a stop already was requested or still a `stop_source` exists that can potentially be used to call `request_stop()`. — *end note*]

30.4.4.6 `stop_token` comparisons [stop_token.cmp]

```
bool operator== (const stop_token& lhs, const stop_token& rhs) noexcept;
```

1 *Returns:* `!lhs.stop_possible() && !rhs.stop_possible()` or whether `lhs` and `rhs` refer to the same stop state (copied or moved from the same initial `stop_source` object).

```
bool operator!= (const stop_token& lhs, const stop_token& rhs) noexcept;
```

2 *Returns:* `!(lhs==rhs)`.

30.5 Joining Threads [thread.jthreads]

1 30.5 describes components that can be used to create and manage threads with the ability to request stops to cooperatively cancel the running thread.

30.5.1 Header <jthread> synopsis [thread.jthread.syn]

```
#include <stop_token>

namespace std {
  // 30.5.2 class jthread
  class jthread;

  void swap(jthread& x, jthread& y) noexcept;
}
```

30.5.2 Class jthread [thread.jthread.class]

1 The class `jthread` provides a mechanism to create a new thread of execution. The functionality is the same as for class `thread` (??) with the additional ability to request a stop and to automatically `join()` the started thread.

[*Editorial note:* This color signals differences to class `std::thread`.]

```
namespace std {
  class jthread {
  public:
    // types
    using id = thread::id;
    using native_handle_type = thread::native_handle_type;

    // construct/copy/destroy
    jthread() noexcept;
    template<class F, class... Args> explicit jthread(F&& f, Args&&... args);
    ~jthread();
    jthread(const jthread&) = delete;
    jthread(jthread&&) noexcept;
    jthread& operator=(const jthread&) = delete;
    jthread& operator=(jthread&&) noexcept;

    // members
    void swap(jthread&) noexcept;
    bool joinable() const noexcept;
    void join();
    void detach();
    [[nodiscard]] id get_id() const noexcept;
    [[nodiscard]] native_handle_type native_handle();     // see ??

    // stop token handling
    [[nodiscard]] stop_token get_stop_source() const noexcept;
    [[nodiscard]] bool request_stop() noexcept;

    // static members
    [[nodiscard]] static unsigned int hardware_concurrency() noexcept;

  private:
    stop_token isource;                 // exposition only
  };
}
```

30.5.2.1 jthread constructors [thread.jthread.constr]

```
jthread() noexcept;
```

1 *Effects:* Constructs a `jthread` object that does not represent a thread of execution.

2 *Ensures:* `get_id() == id()` and `isource.stop_possible() == false`.

```
template<class F, class... Args> explicit jthread(F&& f, Args&&... args);
```

3 *Requires:* `F` and each T_i in `Args` shall satisfy the *Cpp17MoveConstructible* requirements. *INVOKE*(*DECAY_COPY*(std::forward<F>(f)), isource, *DECAY_COPY*(std::forward<Args>(args))...) or *INVOKE*(*DECAY_COPY*(std::forward<F>(f)), *DECAY_COPY*(std::forward<Args>(args))...) (??) shall be a valid expression.

4 *Remarks:* This constructor shall not participate in overload resolution if `remove_cvref_t<F>` is the same type as `std::jthread`.

5 *Effects:* Initializes `isource` and constructs an object of type `jthread`. The new thread of execution executes *INVOKE*(*DECAY_COPY*(std::forward<F>(f)), isource,*DECAY_COPY*(std::forward<Args>(args))...) if that expression is well-formed, otherwise *INVOKE*(*DECAY_COPY*(std::forward<F>(f)), *DECAY_COPY*(std::forward<Args>(args))...) with the calls to *DECAY_COPY* being evaluated in the constructing thread. Any return value from this invocation is ignored. [*Note*: This implies that any exceptions not thrown from the invocation of the copy of `f` will be thrown in the constructing thread, not the new thread. — *end note*] If the invocation with *INVOKE*() terminates with an uncaught exception, `terminate()` shall be called.

6 *Synchronization:* The completion of the invocation of the constructor synchronizes with the beginning of the invocation of the copy of `f`.

7 *Ensures:* `get_id() != id()`. `isource.stop_possible() == true`. `*this` represents the newly started thread. [*Note*: Note that the calling thread can request a stop only once, because it can't replace this stop token. — *end note*]

8 *Throws:* `system_error` if unable to start the new thread.

9 *Error conditions:*

(9.1) — `resource_unavailable_try_again` — the system lacked the necessary resources to create another thread, or the system-imposed limit on the number of threads in a process would be exceeded.

```
jthread(jthread&& x) noexcept;
```

10 *Effects:* Constructs an object of type `jthread` from `x`, and sets `x` to a default constructed state.

11 *Ensures:* `x.get_id() == id()` and `get_id()` returns the value of `x.get_id()` prior to the start of construction. `isource` yields the value of `x.isource` prior to the start of construction and `x.isource.stop_possible() == false`.

30.5.2.2 `jthread` destructor [thread.jthread.destr]

```
~jthread();
```

1 If `joinable()`, calls `request_stop()` and `join()`. Otherwise, has no effects. [*Note*: Operations on `*this` are not synchronized. — *end note*]

30.5.2.3 `jthread` assignment [thread.jthread.assign]

```
jthread& operator=(jthread&& x) noexcept;
```

1 *Effects:* If `joinable()`, calls `request_stop()` and `join()`. Assigns the state of `x` to `*this` and sets `x` to a default constructed state.

2 *Ensures:* `x.get_id() == id()` and `get_id()` returns the value of `x.get_id()` prior to the assignment. `isource` yields the value of `x.isource` prior to the assignment and `x.isource.stop_possible() == false`.

3 *Returns:* `*this`.

30.5.2.4 `jthread` stop members [thread.jthread.stop]

```
[[nodiscard]] stop_token get_stop_source() const noexcept
```

1 *Effects:* Equivalent to: `return isource;`

```
[[nodiscard]] bool request_stop() noexcept;
```

2 *Effects:* Equivalent to: `return isource.request_stop();`

30.6 Mutual exclusion [thread.mutex]

...

30.7 Condition variables [thread.condition]

...

30.7.1 Header `<condition_variable>` synopsis [condition_variable.syn]

...

30.7.2 Non-member functions [thread.condition.nonmember]

...

30.7.3 Class `condition_variable` [thread.condition.condvar]

...

30.7.4 Class `condition_variable_any` [thread.condition.condvarany]

...

```
namespace std {
  class condition_variable_any {
  public:
    condition_variable_any();
    ~condition_variable_any();

    condition_variable_any(const condition_variable_any&) = delete;
    condition_variable_any& operator=(const condition_variable_any&) = delete;

    void notify_one() noexcept;
    void notify_all() noexcept;

    // 30.7.4.1 noninterruptable waits:
    template<class Lock>
      void wait(Lock& lock);
    template<class Lock, class Predicate>
      void wait(Lock& lock, Predicate pred);

    template<class Lock, class Clock, class Duration>
      cv_status wait_until(Lock& lock, const chrono::time_point<Clock, Duration>& abs_time);
    template<class Lock, class Clock, class Duration, class Predicate>
      bool wait_until(Lock& lock, const chrono::time_point<Clock, Duration>& abs_time,
                      Predicate pred);
    template<class Lock, class Rep, class Period>
      cv_status wait_for(Lock& lock, const chrono::duration<Rep, Period>& rel_time);
    template<class Lock, class Rep, class Period, class Predicate>
      bool wait_for(Lock& lock, const chrono::duration<Rep, Period>& rel_time, Predicate pred);

    // 30.7.4.2 stop_token waits:
    template <class Lock, class Predicate>
      bool wait_until(Lock& lock,
                      Predicate pred,
                      stop_token stoken);
    template <class Lock, class Clock, class Duration, class Predicate>
      bool wait_until(Lock& lock,
                      const chrono::time_point<Clock, Duration>& abs_time
                      Predicate pred,
                      stop_token stoken);
    template <class Lock, class Rep, class Period, class Predicate>
      bool wait_for(Lock& lock,
                    const chrono::duration<Rep, Period>& rel_time,
                    Predicate pred,
                    stop_token stoken);

  };
}
```

`condition_variable_any();`

1 *Effects:* Constructs an object of type `condition_variable_any`.

2 *Throws:* `bad_alloc` or `system_error` when an exception is required (**??**).

3 *Error conditions:*

(3.1) — `resource_unavailable_try_again` — if some non-memory resource limitation prevents initialization.

(3.2) — `operation_not_permitted` — if the thread does not have the privilege to perform the operation.

`~condition_variable_any();`

4 *Requires:* There shall be no thread blocked on `*this`. [*Note*: That is, all threads shall have been notified; they may subsequently block on the lock specified in the wait. This relaxes the usual rules, which would have required all wait calls to happen before destruction. Only the notification to unblock the wait needs to happen before destruction. The user should take care to ensure that no threads wait on `*this` once the destructor has been started, especially when the waiting threads are calling the wait functions in a loop or using the overloads of `wait`, `wait_for`, or `wait_until` that take a predicate. — *end note*]

5 *Effects:* Destroys the object.

`void notify_one() noexcept;`

6 *Effects:* If any threads are blocked waiting for `*this`, unblocks one of those threads.

`void notify_all() noexcept;`

7 *Effects:* Unblocks all threads that are blocked waiting for `*this`.

30.7.4.1 Noninterruptable waits [thread.condvarany.wait]

```
template<class Lock>
  void wait(Lock& lock);
```

1 *Effects:*

(1.1) — Atomically calls `lock.unlock()` and blocks on `*this`.

(1.2) — When unblocked, calls `lock.lock()` (possibly blocking on the lock) and returns.

(1.3) — The function will unblock when requested by a call to `notify_one()`, a call to `notify_all()`, or spuriously.

2 *Remarks:* If the function fails to meet the postcondition, `terminate()` shall be called (**??**). [*Note*: This can happen if the re-locking of the mutex throws an exception. — *end note*]

3 *Ensures:* `lock` is locked by the calling thread.

4 *Throws:* Nothing.

```
template<class Lock, class Predicate>
  void wait(Lock& lock, Predicate pred);
```

5 *Effects:* Equivalent to:

```
while (!pred())
  wait(lock);
```

```
template<class Lock, class Clock, class Duration>
  cv_status wait_until(Lock& lock, const chrono::time_point<Clock, Duration>& abs_time);
```

6 *Effects:*

(6.1) — Atomically calls `lock.unlock()` and blocks on `*this`.

(6.2) — When unblocked, calls `lock.lock()` (possibly blocking on the lock) and returns.

(6.3) — The function will unblock when requested by a call to `notify_one()`, a call to `notify_all()`, expiration of the absolute timeout (**??**) specified by `abs_time`, or spuriously.

(6.4) — If the function exits via an exception, `lock.lock()` shall be called prior to exiting the function.

7 *Remarks:* If the function fails to meet the postcondition, `terminate()` shall be called (**??**). [*Note*: This can happen if the re-locking of the mutex throws an exception. — *end note*]

8 *Ensures:* `lock` is locked by the calling thread.

9 *Returns:* `cv_status::timeout` if the absolute timeout (**??**) specified by `abs_time` expired, otherwise `cv_status::no_timeout`.

10 *Throws:* Timeout-related exceptions (**??**).

```
template<class Lock, class Rep, class Period>
  cv_status wait_for(Lock& lock, const chrono::duration<Rep, Period>& rel_time);
```

11 *Effects:* Equivalent to:

```
return wait_until(lock, chrono::steady_clock::now() + rel_time);
```

12 *Returns:* `cv_status::timeout` if the relative timeout (**??**) specified by `rel_time` expired, otherwise `cv_status::no_timeout`.

13 *Remarks:* If the function fails to meet the postcondition, `terminate()` shall be called (**??**). [*Note*: This can happen if the re-locking of the mutex throws an exception. — *end note*]

14 *Ensures:* `lock` is locked by the calling thread.

15 *Throws:* Timeout-related exceptions (**??**).

```
template<class Lock, class Clock, class Duration, class Predicate>
  bool wait_until(Lock& lock, const chrono::time_point<Clock, Duration>& abs_time, Predicate pred);
```

16 *Effects:* Equivalent to:

```
while (!pred())
  if (wait_until(lock, abs_time) == cv_status::timeout)
    return pred();
return true;
```

17 [*Note*: There is no blocking if `pred()` is initially `true`, or if the timeout has already expired. — *end note*]

18 [*Note*: The returned value indicates whether the predicate evaluates to `true` regardless of whether the timeout was triggered. — *end note*]

```
template<class Lock, class Rep, class Period, class Predicate>
  bool wait_for(Lock& lock, const chrono::duration<Rep, Period>& rel_time, Predicate pred);
```

19 *Effects:* Equivalent to:

```
return wait_until(lock, chrono::steady_clock::now() + rel_time, std::move(pred));
```

30.7.4.2 Interruptable waits [thread.condvarany.interruptwait]

The following functions ensure to get notified if a stop is requested for the passed `stop_token`. In that case they return (returning `false` if the predicate evaluates to `false`). [*Note*: Because all signatures here call `stop_requested()`, their calls synchronize with `request_stop()`. — *end note*]

```
template <class Lock, class Predicate>
  bool wait_until(Lock& lock,
                  Predicate pred,
                  stop_token stoken);
```

1 *Effects:* Registers `*this` to get notified when a stop is requested on `stoken` during this call and then equivalent to:

```
while(!pred() && !stoken.stop_requested()) {
  wait(lock, [&pred, &stoken] {
                return pred() || stoken.stop_requested();
              });
}
return pred();
```

2 [*Note*: The returned value indicates whether the predicate evaluated to `true` regardless of whether a stop was requested. — *end note*]

3 *Ensures:* Exception or `lock` is locked by the calling thread.

4 *Remarks:* If the function fails to meet the postcondition, `terminate()` shall be called (**??**). [*Note*: This can happen if the re-locking of the mutex throws an exception. — *end note*]

5 *Throws:* `std::bad_alloc` if memory for the internal data structures could not be allocated, or any exception thrown by `pred`.

```
template <class Lock, class Clock, class Duration, class Predicate>
  bool wait_until(Lock& lock,
                  const chrono::time_point<Clock, Duration>& abs_time
                  Predicate pred,
                  stop_token stoken);
```

6 *Effects:* Registers `*this` to get notified when a stop is requested on `stoken` during this call and then equivalent to:

```
while(!pred() && !stoken.stop_requested() && Clock::now() < abs_time) {
  cv.wait_until(lock,
                abs_time,
                [&pred, &stoken] {
                  return pred() || stoken.stop_requested();
                });
}
return pred();
```

7 [*Note*: There is no blocking, if `pred()` is initially `true`, stoken is not stop_possible, a stop was already requested, or the timeout has already expired. — *end note*]

8 [*Note*: The returned value indicates whether the predicate evaluates to `true` regardless of whether the timeout was triggered. — *end note*]

9 [*Note*: The returned value indicates whether the predicate evaluated to `true` regardless of whether the timeout was triggered or a stop was requested. — *end note*]

10 *Ensures:* Exception or `lock` is locked by the calling thread.

11 *Remarks:* If the function fails to meet the postcondition, `terminate()` shall be called (**??**). [*Note*: This can happen if the re-locking of the mutex throws an exception. — *end note*]

12 *Throws:* `std::bad_alloc` if memory for the internal data structures could not be allocated, any timeout-related exception (**??**), or any exception thrown by `pred`.

```
template <class Lock, class Rep, class Period, class Predicate>
  bool wait_for(Lock& lock,
                const chrono::duration<Rep, Period>& rel_time,
                Predicate pred,
```

```
            stop_token stoken);
```

13 *Effects:* Equivalent to:

```
return wait_until(lock, chrono::steady_clock::now() + rel_time, std::move(pred), std::move(stoken));
```

30.8 Futures [futures]

...