ISO/IEC JTC1 SC22 WG21 **N4680**

Date: 2017-10-16

ISO/IEC TS 22277

ISO/IEC JTC1 SC22

Secretariat: ANSI

Programming Languages — C++ Extensions for Coroutines

Langages de programmation — Extensions C++ pour les Coroutines

Document type: Proposed Draft Technical Specification
Document stage: (30) Committee
Document Language: E

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 22, *Programming languages, their environments and system software interfaces*.

1   Scope   [intro.scope]

1   This document describes extensions to the C++ Programming Language (Clause 2) that enable definition of coroutines. These extensions include new syntactic forms and modifications to existing language semantics.

2   The International Standard, ISO/IEC 14882:2014, provides important context and specification for this document. This document is written as a set of changes against that specification. Instructions to modify or add paragraphs are written as explicit instructions. Modifications made directly to existing text from the International Standard use underlining to represent added text and ~~strikethrough~~ to represent deleted text.

2   Normative references   [intro.refs]

1   The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

(1.1)   — ISO/IEC 14882:2014, *Programming Languages – C++*

ISO/IEC 14882:2014 is hereafter called the *C++ Standard*. Beginning with Clause 5, all clause and subclause numbers, titles, and symbolic references in [brackets] refer to the corresponding elements of the C++ Standard. Clauses 1 through 4 of this document are unrelated to the similarly-numbered clauses and subclauses of the C++ Standard.

3   Terms and definitions   [intro.defs]

No terms and definitions are listed in this document. ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 General [intro]

4.1 Implementation compliance [intro.compliance]

Conformance requirements for this specification are the same as those defined in subclause 1.4 of the C++ Standard. [*Note:* Conformance is defined in terms of the behavior of programs. — *end note*]

4.2 Feature testing [intro.features]

An implementation that provides support for this document shall define the feature test macro in Table 1.

Table 1 — Feature-test macro

Name	Value	Header
`__cpp_coroutines`	201707	*predeclared*

4.3 Program execution [intro.execution]

In subclause 1.9 of the C++ Standard modify paragraph 7 to read:

7   An instance of each object with automatic storage duration (3.7.3) is associated with each entry into its block. Such an object exists and retains its last-stored value during the execution of the block and while the block is suspended (by a call of a function, suspension of a coroutine (5.3.8), or receipt of a signal).

4.4 Lexical conventions [lex]

In subclause 2.12 of the C++ Standard add the keywords `co_await`, `co_yield`, and `co_return` to Table 4 "Keywords".

4.5 Basic concepts [basic]

In subclause 3.6.1 of the C++ Standard add underlined text to paragraph 3.

3   The function `main` shall not be used within a program. The linkage (3.5) of `main` is implementation-defined. A program that defines `main` as deleted or that declares `main` to be `inline, static,` or `constexpr` is ill-formed. The function `main` shall not be a coroutine (8.4.4). The name `main` is not otherwise reserved. [*Example:* member functions, classes, and enumerations can be called `main`, as can entities in other namespaces. — *end example*]

4.6 Dynamic storage duration [basic.stc.dynamic]

In subclause 3.7.4.1 of the C++ Standard modify paragraph 4 as follows:

4   A global allocation function is only called as the result of a new expression (5.3.4), ~~or~~ called directly using the function call syntax (5.2.2), called indirectly to allocate storage for a coroutine frame (8.4.4), or called indirectly through calls to the functions in the C++ standard library. [*Note:* In particular, a global allocation function is not called to allocate storage for objects with static storage duration (3.7.1), for objects or references with thread storage duration (3.7.2), for objects of type `std::type_info` (5.2.8), or for an exception object (15.1). — *end note*]

5   Expressions [expr]

5.3   Unary expressions [expr.unary]

Add *await-expression* to the grammar production *unary-expression*:

> *unary-expression:*
>> *postfix-expression*
>> `++` *cast-expression*
>> `--` *cast-expression*
>> *await-expression*
>> *unary-operator cast-expression*
>> `sizeof` *unary-expression*
>> `sizeof` (*type-id*)
>> `sizeof` `...` (*identifier*)
>> `alignof` (*type-id*)
>> *noexcept-expression*
>> *new-expression*
>> *delete-expression*

5.3.8   Await [expr.await]

Add this subclause to 5.3.

1   The `co_await` expression is used to suspend evaluation of a coroutine (8.4.4) while awaiting completion of the computation represented by the operand expression.

> *await-expression:*
>> `co_await` *cast-expression*

2   An *await-expression* shall appear only in a potentially-evaluated expression within the *compound-statement* of a *function-body* outside of a *handler* (Clause 15). In a *declaration-statement* or in the *simple-declaration* (if any) of a *for-init-statement*, an *await-expression* shall appear only in an *initializer* of that *declaration-statement* or *simple-declaration*. An *await-expression* shall not appear in a default argument (8.3.6). A context within a function where an *await-expression* can appear is called a *suspension context* of the function.

3   Evaluation of an *await-expression* involves the following auxiliary types, expressions, and objects:

(3.1)   — p is an lvalue naming the promise object (8.4.4) of the enclosing coroutine and P is the type of that object.

(3.2)   — a is the *cast-expression* if the *await-expression* was implicitly produced by a *yield-expression* (5.20), an initial suspend point, or a final suspend point (8.4.4). Otherwise, the *unqualified-id* `await_transform` is looked up within the scope of P by class member access lookup (3.4.5), and if this lookup finds at least one declaration, then a is p.`await_transform(`*cast-expression*`)`; otherwise, a is the *cast-expression*.

(3.3)   — o is determined by enumerating the applicable `operator co_await` functions for an argument a (13.3.1.2), and choosing the best one through overload resolution (13.3). If overload resolution is ambiguous, the program is ill-formed. If no viable functions are found, o is a. Otherwise, o is a call to the selected function.

(3.4)   — e is a temporary object copy-initialized from o if o is a prvalue; otherwise e is an lvalue referring to the result of evaluating o.

(3.5)   — *h* is an object of type `std::experimental::coroutine_handle<P>` referring to the enclosing coroutine.

(3.6)   — *await-ready* is the expression *e*.`await_ready()`, contextually converted to `bool`.

(3.7)   — *await-suspend* is the expression *e*.`await_suspend(`*h*`)`, which shall be a prvalue of type `void` or `bool`.

(3.8)   — *await-resume* is the expression *e*.`await_resume()`.

4   The *await-expression* has the same type and value category as the *await-resume* expression.

5   The *await-expression* evaluates the *await-ready* expression, then:

(5.1)   — If the result is `false`, the coroutine is considered suspended. Then, the *await-suspend* expression is evaluated. If that expression has type `bool` and evaluates to `false`, the coroutine is resumed. If that expression exits via an exception, the exception is caught, the coroutine is resumed, and the exception is immediately re-thrown (15.1). Otherwise, control flow returns to the current caller or resumer (8.4.4) without exiting any scopes (6.6).

(5.2)   — If the result is `true`, or when the coroutine is resumed, the *await-resume* expression is evaluated, and its result is the result of the *await-expression*.

6   [*Example:*

```
template <typename T>
struct my_future {
  ...
  bool await_ready();
  void await_suspend(std::experimental::coroutine_handle<>);
  T await_resume();
};

template <class Rep, class Period>
auto operator co_await(std::chrono::duration<Rep, Period> d) {
  struct awaiter {
    std::chrono::system_clock::duration duration;
    ...
    awaiter(std::chrono::system_clock::duration d) : duration(d){}
    bool await_ready() const { return duration.count() <= 0; }
    void await_resume() {}
    void await_suspend(std::experimental::coroutine_handle<> h){...}
  };
  return awaiter{d};
}

using namespace std::chrono;

my_future<int> h();

my_future<void> g() {
  std::cout << "just about go to sleep...\n";
  co_await 10ms;
  std::cout << "resumed\n";
  co_await h();
}

auto f(int x = co_await h()); // error: await-expression outside of function suspension context
int a[] = { co_await h() }; // error: await-expression outside of function suspension context
```

— *end example*]

5.17   Assignment and compound assignment operators [expr.ass]

Add *yield-expression* to the grammar production *assignment-expression*.

> *assignment-expression:*
> > *conditional-expression*
> > *logical-or-expression assignment-operator initializer-clause*
> > *throw-expression*
> > *yield-expression*

5.19   Constant expressions [expr.const]

Add bullets prohibiting *await-expression* and *yield-expression* to paragraph 2.

— an *await-expression* (5.3.8);

— a *yield-expression* (5.20);

5.20   Yield [expr.yield]

Add a new subclause to Clause 5.

> *yield-expression:*
> > co_yield *assignment-expression*
> > co_yield *braced-init-list*

1   A *yield-expression* shall appear only within a suspension context of a function (5.3.8). Let *e* be the operand of the *yield-expression* and *p* be an lvalue naming the promise object of the enclosing coroutine (8.4.4), then the *yield-expression* is equivalent to the expression co_await *p*.yield_value(*e*).

[*Example:*

```
template <typename T>
struct my_generator {
  struct promise_type {
    T current_value;
    ...
    auto yield_value(T v) {
      current_value = std::move(v);
      return std::experimental::suspend_always{};
    }
  };
  struct iterator { ... };
  iterator begin();
  iterator end();
};

my_generator<pair<int,int>> g1() {
  for (int i = i; i < 10; ++i) co_yield {i,i};
}
my_generator<pair<int,int>> g2() {
  for (int i = i; i < 10; ++i) co_yield make_pair(i,i);
}

auto f(int x = co_yield 5); // error: yield-expression outside of function suspension context
int a[] = { co_yield 1 }; // error: yield-expression outside of function suspension context

int main() {
  auto r1 = g1();
```

```
    auto r2 = g2();
    assert(std::equal(r1.begin(), r1.end(), r2.begin(), r2.end()));
  }
```

— end example]

6 Statements [stmt.stmt]

6.5 Iteration statements [stmt.iter]

Add the underlined text to paragraph 1.

1   Iteration statements specify looping.

> *iteration-statement:*
>> `while` (*condition*) *statement*
>> `do` *statement* `while` (*expression*) ;
>> `for` (*for-init-statement condition$_{opt}$*; *expression$_{opt}$*) *statement*
>> `for` <u>`co_await`$_{opt}$</u> (*for-range-declaration* : *for-range-initializer*) *statement*

6.5.4 The range-based `for` statement [stmt.ranged]

Add the underlined text to paragraph 1.

1   For a range-based `for` statement of the form

> `for` <u>`co_await`$_{opt}$</u> (*for-range-declaration : expression*) *statement*

let *range-init* be equivalent to the *expression* surrounded by parentheses[1]

> (*expression*)

and for a range-based `for` statement of the form

> `for` <u>`co_await`$_{opt}$</u> (*for-range-declaration* : *braced-init-list*) *statement*

let *range-init* be equivalent to the *braced-init-list*. In each case, a range-based `for` statement is equivalent to

```
{
  auto && __range = range-init;
  for ( auto __begin =  co_awaitopt begin-expr,
  __end = end-expr;
  __begin != __end;
   co_awaitopt ++__begin ) {
    for-range-declaration = *__begin;
    statement
  }
}
```

where <u>`co_await` is present if and only if it appears immediately after the `for` keyword, and</u> `__range`, `__begin`, and `__end` are variables defined for exposition only, and `_RangeT` is the type of the expression, and *begin-expr* and *end-expr* are determined as follows: ...

---

1) this ensures that a top-level comma operator cannot be reinterpreted as a delimiter between *init-declarator*s in the declaration of `__range`.

Add the following paragraph after paragraph 2.

3 A range-based `for` statement with `co_await` shall appear only within a suspension context of a function (5.3.8).

6.6 Jump statements   [stmt.jump]

In paragraph 1 add two productions to the grammar:

> *jump-statement:*
> > `break` ;
> > `continue` ;
> > `return` *expression$_{opt}$*;
> > `return` *braced-init-list* ;
> > *coroutine-return-statement*
> > `goto` *identifier* ;

Add the underlined text to paragraph 2:

2 On exit from a scope (however accomplished), objects with automatic storage duration (3.7.3) that have been constructed in that scope are destroyed in the reverse order of their construction. [*Note:* A suspension of a coroutine (5.3.8) is not considered to be an exit from a scope. — *end note*] ...

6.6.3 The `return` statement   [stmt.return]

Add the underlined text to the last sentence of paragraph 2:

2 ... Flowing off the end of a function that is not a coroutine is equivalent to a `return` with no value; this results in undefined behavior in a value-returning function.

6.6.3.1 The `co_return` statement   [stmt.return.coroutine]

Add this subclause to 6.6.

> *coroutine-return-statement:*
> > `co_return` *expression$_{opt}$*;
> > `co_return` *braced-init-list*;

1 A coroutine returns to its caller or resumer (8.4.4) by the `co_return` statement or when suspended (5.3.8). A coroutine shall not return to its caller or resumer by a `return` statement (6.6.3).

2 The *expression* or *braced-init-list* of a `co_return` statement is called its operand. Let p be an lvalue naming the coroutine promise object (8.4.4) and P be the type of that object, then a `co_return` statement is equivalent to:

> `{` S`;` `goto` $final\_suspend$`; }`

where $final\_suspend$ is as defined in 8.4.4 and S is defined as follows:

(2.1) — S is p.`return_value`(*braced-init-list*), if the operand is a *braced-init-list*;

(2.2) — S is p.`return_value`(*expression*), if the operand is an expression of non-`void` type;

(2.3) — S is `{` *expression$_{opt}$* `;` p.`return_void();` `}`, otherwise;

S shall be a prvalue of type `void`.

3 If p.`return_void()` is a valid expression, flowing off the end of a coroutine is equivalent to a `co_return` with no operand; otherwise flowing off the end of a coroutine results in undefined behavior.

7   Declarations   [dcl.dcl]

7.1   Specifiers   [dcl.spec]

7.1.5   The `constexpr` specifier   [dcl.constexpr]

Insert a new bullet after paragraph 3 bullet 1.

3   The definition of a `constexpr` function shall satisfy the following constraints:

(3.1)   — it shall not be virtual (10.3);

(3.2)   — it shall not be a coroutine (8.4.4);

(3.3)   — . . .

7.1.6.4   `auto` specifier   [dcl.spec.auto]

Add the following paragraph.

15   A function declared with a return type that uses a placeholder type shall not be a coroutine
        (8.4.4).

8   Declarators   [dcl.decl]

8.4   Function definitions   [dcl.fct.def]

8.4.4   Coroutines   [dcl.fct.def.coroutine]

Add this subclause to 8.4.

1   A function is a *coroutine* if it contains a *coroutine-return-statement* (6.6.3.1), an *await-expression*
        (5.3.8), a *yield-expression* (5.20), or a range-based `for` (6.5.4) with `co_await`. The *parameter-
        declaration-clause* of the coroutine shall not terminate with an ellipsis that is not part of a
        parameter-declaration.

2   [*Example:*

```
task<int> f();

task<void> g1() {
  int i = co_await f();
  std::cout << "f() => " << i << std::endl;
}

template <typename... Args>
task<void> g2(Args&&...) { // OK: ellipsis is a pack expansion
  int i = co_await f();
  std::cout << "f() => " << i << std::endl;
}

task<void> g3(int a, ...) { // error: variable parameter list not allowed
  int i = co_await f();
  std::cout << "f() => " << i << std::endl;
}
```

3   For a coroutine *f* that is a non-static member function, let P_1 denote the type of the implicit object parameter (13.3.1) and P_2 ... P_n be the types of the function parameters; otherwise let P_1 ... P_n be the types of the function parameters. Let p_1 ... p_n be lvalues denoting those objects. Let R be the return type and F be the *function-body* of *f*, T be the type `std::experimental::coroutine_traits<`$R,P_1,\ldots,P_n$`>`, and P be the class type denoted by T`::promise_type`. Then, the coroutine behaves as if its body were:

```
{
    P p;
    co_await p.initial_suspend(); // initial suspend point
    try { F } catch(...) { p.unhandled_exception(); }
final_suspend:
    co_await p.final_suspend(); // final suspend point
}
```

where an object denoted as *p* is the *promise object* of the coroutine and its type *P* is the *promise type* of the coroutine.

4   The *unqualified-id*s `return_void` and `return_value` are looked up in the scope of class P. If both are found, the program is ill-formed. If the *unqualified-id* `return_void` is found, flowing off the end of a coroutine is equivalent to a `co_return` with no operand. Otherwise, flowing off the end of a coroutine results in undefined behavior.

5   When a coroutine returns to its caller, the return value is produced by a call to *p*`.get_return_object()`. A call to a `get_return_object` is sequenced before the call to `initial_suspend` and is invoked at most once.

6   A suspended coroutine can be resumed to continue execution by invoking a resumption member function (18.11.2.4) of an object of type `coroutine_handle<`P`>` associated with this instance of the coroutine. The function that invoked a resumption member function is called *resumer*. Invoking a resumption member function for a coroutine that is not suspended results in undefined behavior.

7   An implementation may need to allocate additional storage for a coroutine. This storage is known as the *coroutine state* and is obtained by calling a non-array allocation function (3.7.4.1). The allocation function's name is looked up in the scope of P. If this lookup fails, the allocation function's name is looked up in the global scope. If the lookup finds an allocation function in the scope of P, overload resolution is performed on a function call created by assembling an argument list. The first argument is the amount of space requested, and has type `std::size_t`. The lvalues p_1 ... p_n are the succeeding arguments. If no matching function is found, overload resolution is performed again on a function call created by passing just the amount of space required as an argument of type `std::size_t`.

8   The *unqualified-id* `get_return_object_on_allocation_failure` is looked up in the scope of class P by class member access lookup (3.4.5). If a declaration is found, then the result of a call to an allocation function used to obtain storage for the coroutine state is assumed to return `nullptr` if it fails to obtain storage, and if a global allocation function is selected, the `::operator new(size_t, nothrow_t)` form shall be used. If an allocation function returns `nullptr`, the coroutine returns control to the caller of the coroutine and the return value is obtained by a call to P`::get_return_object_on_allocation_failure()`. The allocation function used in this case must have a non-throwing *noexcept-specification*.

[*Example:*

```
#include <iostream>
```

```
#include <experimental/coroutine>

// ::operator new(size_t, nothrow_t) will be used if allocation is needed
struct generator {
  struct promise_type;
  using handle = std::experimental::coroutine_handle<promise_type>;
  struct promise_type {
    int current_value;
    static auto get_return_object_on_allocation_failure() { return generator{nullptr}; }
    auto get_return_object() { return generator{handle::from_promise(*this)}; }
    auto initial_suspend() { return std::experimental::suspend_always{}; }
    auto final_suspend() { return std::experimental::suspend_always{}; }
    void unhandled_exception() { std::terminate(); }
    void return_void() {}
    auto yield_value(int value) {
      current_value = value;
      return std::experimental::suspend_always{};
    }
  };
  bool move_next() { return coro ? (coro.resume(), !coro.done()) : false; }
  int current_value() { return coro.promise().current_value; }
  generator(generator const&) = delete;
  generator(generator && rhs) : coro(rhs.coro) { rhs.coro = nullptr; }
  ~generator() { if (coro) coro.destroy(); }
private:
  generator(handle h) : coro(h) {}
  handle coro;
};
generator f() { co_yield 1; co_yield 2; }
int main() {
  auto g = f();
  while (g.move_next()) std::cout << g.current_value() << std::endl;
}
```

— end example]

9   The coroutine state is destroyed when control flows off the end of the coroutine or the `destroy`
     member function (18.11.2.4) of an object of type `std::experimental::coroutine_handle<P>`
     associated with this coroutine is invoked. In the latter case objects with automatic storage
     duration that are in scope at the suspend point are destroyed in the reverse order of the con-
     struction. The storage for the coroutine state is released by calling a non-array deallocation
     function (3.7.4.2). If `destroy` is called for a coroutine that is not suspended, the program has
     undefined behavior.

10   The deallocation function's name is looked up in the scope of *P*. If this lookup fails, the dealloca-
     tion function's name is looked up in the global scope. If deallocation function lookup finds both a
     usual deallocation function with only a pointer parameter and a usual deallocation function with
     both a pointer parameter and a size parameter, then the selected deallocation function shall be
     the one with two parameters. Otherwise, the selected deallocation function shall be the function
     with one parameter. If no usual deallocation function is found, the program is ill-formed. The
     selected deallocation function shall be called with the address of the block of storage to be re-
     claimed as its first argument. If a deallocation function with a parameter of type `std::size_t`
     is used, the size of the block is passed as the corresponding argument.

11   When a coroutine is invoked, a copy is created for each coroutine parameter. Each such copy
     is an object with automatic storage duration that is direct-initialized from an lvalue referring to

the corresponding parameter if the parameter is an lvalue reference, and from an xvalue referring
to it otherwise. A reference to a parameter in the function-body of the coroutine is replaced by
a reference to its copy. The initialization and destruction of each parameter copy occurs in the
context of the called coroutine. Initializations of parameter copies are sequenced before the call
to the coroutine promise constructor and indeterminately sequenced with respect to each other.
The lifetime of parameter copies ends immediately after the lifetime of the coroutine promise
object ends. [*Note:* If a coroutine has a parameter passed by reference, resuming the coroutine
after the lifetime of the entity referred to by that parameter has ended is likely to result in
undefined behavior. — *end note*]

9   Classes [class]

No changes are made to Clause 9 of the C++ Standard.

10   Derived classes [class.derived]

No changes are made to Clause 10 of the C++ Standard.

11   Member Access Control [class.access]

No changes are made to Clause 11 of the C++ Standard.

12   Special member functions [special]

12.1   Constructors [class.ctor]

Add new paragraph after paragraph 5.

6   A constructor shall not be a coroutine.

12.4   Destructors [class.dtor]

Add new paragraph after paragraph 16.

17   A destructor shall not be a coroutine.

12.8   Copying and moving class objects [class.copy]

Add a bullet to paragraph 31:

— in a coroutine (8.4.4), a copy of a coroutine parameter can be omitted and references to
that copy replaced with references to the corresponding parameter if the meaning of the
program will be unchanged except for the execution of a constructor and destructor for the
parameter copy object

Modify paragraph 33 as follows:

33   When the criteria for elision of a copy/move operation are met, but not for an *exception-declaration*,
and the object to be copied is designated by an lvalue, or when the *expression* in a `return`
or `co_return` statement is a (possibly parenthesized) *id-expression* that names an object with

automatic storage duration declared in the body or *parameter-declaration-clause* of the innermost enclosing function or *lambda-expression*, overload resolution to select the constructor for the copy or the `return_value` overload to call is first performed as if the object were designated by an rvalue. If the first overload resolution fails or was not performed, or if the type of the first parameter of the selected constructor or `return_value` overload is not an rvalue reference to the object's type (possibly cv-qualified), overload resolution is performed again, considering the object as an lvalue. [*Note:* This two-stage overload resolution must be performed regardless of whether copy elision will occur. It determines the constructor or `return_value` overload to be called if elision is not performed, and the selected constructor or `return_value` overload must be accessible even if the call is elided. — *end note*]

13 Overloading [over]

13.5 Overloaded operators [over.oper]

Add `co_await` to the list of operators in paragraph 1 before operators `()` and `[]`.

Add the following paragraph after paragraph 5.

6   The `co_await` operator is described completely in 5.3.8. The attributes and restrictions found in the rest of this subclause do not apply to it unless explicitly stated in 5.3.8.

14 Templates [temp]

No changes are made to Clause 14 of the C++ Standard.

15 Exception handling [except]

No changes are made to Clause 15 of the C++ Standard.

16 Preprocessing directives [cpp]

No changes are made to Clause 16 of the C++ Standard.

17   Library introduction [library]

17.6.1.3   Freestanding implementations [compliance]

Add a row to Table 16 for coroutine support header `<experimental/coroutine>`.

Table 16 — C++ headers for freestanding implementations

	Subclause	Header(s)
		`<ciso646>`
18.2	Types	`<cstddef>`
18.3	Implementation properties	`<cfloat> <limits> <climits>`
18.4	Integer types	`<cstdint>`
18.5	Start and termination	`<cstdlib>`
18.6	Dynamic memory management	`<new>`
18.7	Type identification	`<typeinfo>`
18.8	Exception handling	`<exception>`
18.9	Initializer lists	`<initializer_list>`
18.10	Other runtime support	`<cstdalign> <cstdarg> <cstdbool>`
18.11	Coroutines support	`<experimental/coroutine>`
20.10	Type traits	`<type_traits>`
	Atomics	`<atomic>`

18   Language support library [language.support]

18.1   General [support.general]

Add a row to Table 30 for coroutine support header `<experimental/coroutine>`.

Table 30 — Language support library summary

	Subclause	Header(s)
18.2	Types	`<cstddef>`
18.3	Implementation properties	`<limits>`
		`<climits>`
		`<cfloat>`
18.4	Integer types	`<cstdint>`
18.5	Start and termination	`<cstdlib>`
18.6	Dynamic memory management	`<new>`
18.7	Type identification	`<typeinfo>`
18.8	Exception handling	`<exception>`
18.9	Initializer lists	`<initializer_list>`
18.10	Other runtime support	`<csignal>`
		`<csetjmp>`
		`<cstdalign>`
		`<cstdarg>`
		`<cstdbool>`
		`<cstdlib>`
		`<ctime>`
18.11	Coroutines support	`<experimental/coroutine>`

18.10   Other runtime support [support.runtime]

Add underlined text to paragraph 4.

4   The function signature `longjmp(jmp_buf jbuf, int val)` has more restricted behavior in this International Standard. A `setjmp`/`longjmp` call pair has undefined behavior if replacing the `setjmp` and `longjmp` by `catch` and `throw` would invoke any non-trivial destructors for any automatic objects. A call to `setjmp` or `longjmp` has undefined behavior if invoked in a suspension context of a coroutine (5.3.8).

SEE ALSO: ISO C 7.10.4, 7.8, 7.6, 7.12.

18.11   Coroutines support library [support.coroutine]

Add this subclause to Clause 18.

1   The header `<experimental/coroutine>` defines several types providing compile and run-time support for coroutines in a C++ program.

Header `<experimental/coroutine>` synopsis

```
namespace std {
namespace experimental {
inline namespace coroutines_v1 {

  // 18.11.1 coroutine traits
  template <typename R, typename... ArgTypes>
    struct coroutine_traits;

  // 18.11.2 coroutine handle
  template <typename Promise = void>
    struct coroutine_handle;

  // 18.11.2.6 comparison operators:
  constexpr bool operator==(coroutine_handle<> x, coroutine_handle<> y) noexcept;
  constexpr bool operator!=(coroutine_handle<> x, coroutine_handle<> y) noexcept;
  constexpr bool operator<(coroutine_handle<> x, coroutine_handle<> y) noexcept;
  constexpr bool operator<=(coroutine_handle<> x, coroutine_handle<> y) noexcept;
  constexpr bool operator>=(coroutine_handle<> x, coroutine_handle<> y) noexcept;
  constexpr bool operator>(coroutine_handle<> x, coroutine_handle<> y) noexcept;

  // 18.11.3 trivial awaitables
  struct suspend_never;
  struct suspend_always;

} // namespace coroutines_v1
} // namespace experimental

// 18.11.2.7 hash support:
template <class T> struct hash;
template <class P> struct hash<std::experimental::coroutine_handle<P>>;

} // namespace std
```

18.11.1   Coroutine traits   [coroutine.traits]

1   This subclause defines requirements on classes representing *coroutine traits*, and defines the class
     template `coroutine_traits` that satisfies those requirements.

18.11.1.1   Struct template `coroutine_traits`   [coroutine.traits.primary]

1   The header `<experimental/coroutine>` defines the primary template `coroutine_traits` such
     that if `ArgTypes` is a parameter pack of types and if `R` is a type that has a valid (14.8.2) mem-
     ber type `promise_type`, then `coroutine_traits<R,ArgTypes...>` has the following publicly
     accessible member:

```
using promise_type = typename R::promise_type;
```

Otherwise, `coroutine_traits<R,ArgTypes...>` has no members.

2   All specializations of this template shall define a publicly accessible nested type named `promise_-
     type`.

18.11.2   Struct template `coroutine_handle`   [coroutine.handle]

```
namespace std {
namespace experimental {
inline namespace coroutines_v1 {
```

```
template <>
struct coroutine_handle<void>
{
  // 18.11.2.1 construct/reset
  constexpr coroutine_handle() noexcept;
  constexpr coroutine_handle(nullptr_t) noexcept;
  coroutine_handle& operator=(nullptr_t) noexcept;

  // 18.11.2.2 export/import
  constexpr void* address() const noexcept;
  constexpr static coroutine_handle from_address(void* addr);

  // 18.11.2.3 observers
  constexpr explicit operator bool() const noexcept;
  bool done() const;

  // 18.11.2.4 resumption
  void operator()();
  void resume();
  void destroy();

private:
  void* ptr; // exposition only
};

template <typename Promise>
struct coroutine_handle : coroutine_handle<>
{
  // 18.11.2.1 construct/reset
  using coroutine_handle<>::coroutine_handle;
  static coroutine_handle from_promise(Promise&);
  coroutine_handle& operator=(nullptr_t) noexcept;

  // 18.11.2.2 export/import
  constexpr static coroutine_handle from_address(void* addr);

  // 18.11.2.5 promise access
  Promise& promise() const;
};

} // namespace coroutines_v1
} // namespace experimental
} // namespace std
```

1   Let *P* be the promise type of a coroutine (8.4.4). An object of type `coroutine_handle<P>` is called a *coroutine handle* and can be used to refer to a suspended or executing coroutine. A default constructed `coroutine_handle` object does not refer to any coroutine.

2   If a program declares an explicit or partial specialization of `coroutine_handle`, the behavior is undefined.

18.11.2.1   coroutine_handle construct/reset   [coroutine.handle.con]

```
constexpr coroutine_handle() noexcept;
constexpr coroutine_handle(nullptr_t) noexcept;
```

¹ *Postconditions:* `address() == nullptr`.

```
static coroutine_handle from_promise(Promise& p);
```
² *Requires:* `p` is a reference to a promise object of a coroutine.

³ *Returns:* a coroutine handle *h* referring to the coroutine.

⁴ *Postconditions:* `addressof(`*h*`.promise()) == addressof(p)`.

```
coroutine_handle& operator=(nullptr_t) noexcept;
```
⁵ *Postconditions:* `address() == nullptr`.

⁶ *Returns:* `*this`.

18.11.2.2   `coroutine_handle` export/import   [coroutine.handle.export.import]

```
constexpr void* address() const noexcept;
```
¹ *Returns:* `ptr`.

```
constexpr static coroutine_handle<> coroutine_handle<>::from_address(void* addr);
constexpr static coroutine_handle<Promise> coroutine_handle<Promise>::from_address(void* addr);
```
² *Requires:* `addr` was obtained via a prior call to `address`.

³ *Postconditions:* `from_address(address()) == *this`.

18.11.2.3   `coroutine_handle` observers   [coroutine.handle.observers]

```
constexpr explicit operator bool() const noexcept;
```
¹ *Returns:* `true` if `address() != nullptr`, otherwise `false`.

```
bool done() const;
```
² *Requires:* `*this` refers to a suspended coroutine.

³ *Returns:* `true` if the coroutine is suspended at its final suspend point, otherwise `false`.

18.11.2.4   `coroutine_handle` resumption   [coroutine.handle.resumption]

```
void operator()();
void resume();
```
¹ *Requires:* `*this` refers to a suspended coroutine.

² *Effects:* resumes the execution of the coroutine. If the coroutine was suspended at its final suspend point, behavior is undefined.

³ *Synchronization:* a concurrent resumption of the coroutine via `resume`, `operator()`, or `destroy` may result in a data race.

```
void destroy();
```
⁴ *Requires:* `*this` refers to a suspended coroutine.

⁵ *Effects:* destroys the coroutine (8.4.4).

⁶ *Synchronization:* a concurrent resumption of the coroutine via `resume`, `operator()`, or `destroy` may result in a data race.

18.11.2.5   `coroutine_handle` promise access   [coroutine.handle.promise]

```
Promise& promise() const;
```
¹ *Requires:* `*this` refers to a coroutine.

² *Returns:* a reference to the promise of the coroutine.

18.11.2.6   Comparison operators   [coroutine.handle.compare]

```
constexpr bool operator==(coroutine_handle<> x, coroutine_handle<> y) noexcept;
```
1   *Returns:* `x.address() == y.address()`.

```
constexpr bool operator<(coroutine_handle<> x, coroutine_handle<> y) noexcept;
```
2   *Returns:* `less<void*>()(x.address(), y.address())`.

```
constexpr bool operator!=(coroutine_handle<> x, coroutine_handle<> y) noexcept;
```
3   *Returns:* `!(x == y)`.

```
constexpr bool operator>(coroutine_handle<> x, coroutine_handle<> y) noexcept;
```
4   *Returns:* `(y < x)`.

```
constexpr bool operator<=(coroutine_handle<> x, coroutine_handle<> y) noexcept;
```
5   *Returns:* `!(x > y)`.

```
constexpr bool operator>=(coroutine_handle<> x, coroutine_handle<> y) noexcept;
```
6   *Returns:* `!(x < y)`.

18.11.2.7   Hash support   [coroutine.handle.hash]

```
template <class P> struct hash<experimental::coroutine_handle<P>>;
```
1   The template specialization shall meet the requirements of class template hash (20.9.12).

18.11.3   Trivial awaitables   [coroutine.trivial.awaitables]

The header **<experimental/coroutine>** defines `suspend_never` and `suspend_always` as follows.

```
namespace std {
namespace experimental {
inline namespace coroutines_v1 {

  struct suspend_never {
    constexpr bool await_ready() const noexcept { return true; }
    constexpr void await_suspend(coroutine_handle<>) const noexcept {}
    constexpr void await_resume() const noexcept {}
  };
  struct suspend_always {
    constexpr bool await_ready() const noexcept { return false; }
    constexpr void await_suspend(coroutine_handle<>) const noexcept {}
    constexpr void await_resume() const noexcept {}
  };

} // namespace coroutines_v1
} // namespace experimental
} // namespace std
```