

Australian/New Zealand Standard™

Programming languages—C++

AS/NZS 14882:1999

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RECONFIRMATION
OF
AS/NZS 14882:1999
Programming languages—C ++

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NOTES

Australian/New Zealand Standard™

Programming languages—C++

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee IT/1, Information Systems—Interconnection. This Standard is identical with and has been reproduced from ISO 14882:1998, Programming languages—C++.

The objective of this Standard is to provide programmers with the requirements for the implementations of the C++ programming language. This language is based on the C programming language and provides additional data types, classes, templates, exceptions, namespaces, inline functions, operator and function name overloading, references, free store management operators and additional library facilities.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the annex to which they apply. A normative annex is an integral part of a Standard, whereas an informative annex is only for information and guidance.

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(all parts)	Vocabulary	(all parts)	
9899	Programming languages—C	3955	Programming languages—C
9899/Amd.1	Amendment 1: C Integrity	—	
		AS/NZS	
10646	Information technology—Universal	4189	Information technology—Universal
	Multiple-Octet Coder Character Set		multiple-octet coder Character Set
	(UCS)		(UCS)
10646-1	Part 1: Architecture and Basic	4189.1	Part 1: Architecture and basic
	Multilingual Plane		multilingual plane

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Programming languages – C++

1 General

[intro]

1.1 Scope

[intro.scope]

- 1 This International Standard specifies requirements for implementations of the C++ programming language. The first such requirement is that they implement the language, and so this International Standard also defines C++. Other requirements and relaxations of the first requirement appear at various places within this International Standard.
- 2 C++ is a general purpose programming language based on the C programming language as described in ISO/IEC 9899:1990 *Programming languages – C* (1.2). In addition to the facilities provided by C, C++ provides additional data types, classes, templates, exceptions, namespaces, inline functions, operator overloading, function name overloading, references, free store management operators, and additional library facilities.

1.2 Normative references

[intro.refs]

- 1 The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.
 - ISO/IEC 2382 (all parts), *Information technology – Vocabulary*
 - ISO/IEC 9899:1990, *Programming languages – C*
 - ISO/IEC 9899/Amd.1:1995, *Programming languages – C, AMENDMENT 1: C Integrity*
 - ISO/IEC 10646-1:1993 *Information technology – Universal Multiple-Octet Coded Character Set (UCS) – Part 1: Architecture and Basic Multilingual Plane*
- 2 The library described in clause 7 of ISO/IEC 9899:1990 and clause 7 of ISO/IEC 9899/Amd.1:1995 is hereinafter called the *Standard C Library*.¹⁾

1.3 Definitions

[intro.defs]

- 1 For the purposes of this International Standard, the definitions given in ISO/IEC 2382 and the following definitions apply. 17.1 defines additional terms that are used only in clauses 17 through 27.
- 2 Terms that are used only in a small portion of this International Standard are defined where they are used and italicized where they are defined.

1.3.1 argument

[defns.argument]

an expression in the comma-separated list bounded by the parentheses in a function call expression, a sequence of preprocessing tokens in the comma-separated list bounded by the parentheses in a function-like macro invocation, the operand of `throw`, or an expression, *type-id* or *template-name* in the comma-separated list bounded by the angle brackets in a template instantiation. Also known as an *actual argument* or *actual parameter*.

¹⁾ With the qualifications noted in clauses 17 through 27, and in C.2, the Standard C library is a subset of the Standard C++ library.

1.3.2 diagnostic message

1 General

1.3.2 diagnostic message

[defns.diagnostic]

a message belonging to an implementation-defined subset of the implementation's output messages.

1.3.3 dynamic type

[defns.dynamic.type]

the type of the most derived object (1.8) to which the lvalue denoted by an lvalue expression refers. [Example: if a pointer (8.3.1) *p* whose static type is "pointer to class B" is pointing to an object of class D, derived from B (clause 10), the dynamic type of the expression **p* is "D." References (8.3.2) are treated similarly.] The dynamic type of an rvalue expression is its static type.

1.3.4 ill-formed program

[defns.ill.formed]

input to a C++ implementation that is not a well-formed program (1.3.14).

1.3.5 implementation-defined behavior

[defns.impl.defined]

behavior, for a well-formed program construct and correct data, that depends on the implementation and that each implementation shall document.

1.3.6 implementation limits

[defns.impl.limits]

restrictions imposed upon programs by the implementation.

1.3.7 locale-specific behavior

[defns.locale.specific]

behavior that depends on local conventions of nationality, culture, and language that each implementation shall document.

1.3.8 multibyte character

[defns.multibyte]

a sequence of one or more bytes representing a member of the extended character set of either the source or the execution environment. The extended character set is a superset of the basic character set (2.2).

1.3.9 parameter

[defns.parameter]

an object or reference declared as part of a function declaration or definition, or in the catch clause of an exception handler, that acquires a value on entry to the function or handler; an identifier from the comma-separated list bounded by the parentheses immediately following the macro name in a function-like macro definition; or a *template-parameter*. Parameters are also known as *formal arguments* or *formal parameters*.

1.3.10 signature

[defns.signature]

the information about a function that participates in overload resolution (13.3): the types of its parameters and, if the function is a class member, the *cv*-qualifiers (if any) on the function itself and the class in which the member function is declared.²⁾ The signature of a template function specialization includes the types of its template arguments (14.5.5.1).

1.3.11 static type

[defns.static.type]

the type of an expression (3.9), which type results from analysis of the program without considering execution semantics. The static type of an expression depends only on the form of the program in which the expression appears, and does not change while the program is executing.

1.3.12 undefined behavior

[defns.undefined]

behavior, such as might arise upon use of an erroneous program construct or erroneous data, for which this International Standard imposes no requirements. Undefined behavior may also be expected when this International Standard omits the description of any explicit definition of behavior. [Note: permissible undefined behavior ranges from ignoring the situation completely with unpredictable results, to behaving during translation or program execution in a documented manner characteristic of the environment (with or without the issuance of a diagnostic message), to terminating a translation or execution (with the issuance of a diagnostic message). Many erroneous program constructs do not engender undefined behavior; they are

²⁾ Function signatures do not include return type, because that does not participate in overload resolution.

1 General

1.3.12 undefined behavior

required to be diagnosed.]

1.3.13 unspecified behavior

[defns.unspecified]

behavior, for a well-formed program construct and correct data, that depends on the implementation. The implementation is not required to document which behavior occurs. [Note: usually, the range of possible behaviors is delineated by this International Standard.]

1.3.14 well-formed program

[defns.well.formed]

a C++ program constructed according to the syntax rules, diagnosable semantic rules, and the One Definition Rule (3.2).

1.4 Implementation compliance

[intro.compliance]

- 1 The set of *diagnosable rules* consists of all syntactic and semantic rules in this International Standard except for those rules containing an explicit notation that “no diagnostic is required” or which are described as resulting in “undefined behavior.”
- 2 Although this International Standard states only requirements on C++ implementations, those requirements are often easier to understand if they are phrased as requirements on programs, parts of programs, or execution of programs. Such requirements have the following meaning:
 - If a program contains no violations of the rules in this International Standard, a conforming implementation shall, within its resource limits, accept and correctly execute³⁾ that program.
 - If a program contains a violation of any diagnosable rule, a conforming implementation shall issue at least one diagnostic message, except that
 - If a program contains a violation of a rule for which no diagnostic is required, this International Standard places no requirement on implementations with respect to that program.
- 3 For classes and class templates, the library clauses specify partial definitions. Private members (clause 11) are not specified, but each implementation shall supply them to complete the definitions according to the description in the library clauses.
- 4 For functions, function templates, objects, and values, the library clauses specify declarations. Implementations shall supply definitions consistent with the descriptions in the library clauses.
- 5 The names defined in the library have namespace scope (7.3). A C++ translation unit (2.1) obtains access to these names by including the appropriate standard library header (16.2).
- 6 The templates, classes, functions, and objects in the library have external linkage (3.5). The implementation provides definitions for standard library entities, as necessary, while combining translation units to form a complete C++ program (2.1).
- 7 Two kinds of implementations are defined: *hosted* and *freestanding*. For a hosted implementation, this International Standard defines the set of available libraries. A freestanding implementation is one in which execution may take place without the benefit of an operating system, and has an implementation-defined set of libraries that includes certain language-support libraries (17.4.1.3).
- 8 A conforming implementation may have extensions (including additional library functions), provided they do not alter the behavior of any well-formed program. Implementations are required to diagnose programs that use such extensions that are ill-formed according to this International Standard. Having done so, however, they can compile and execute such programs.

³⁾ “Correct execution” can include undefined behavior, depending on the data being processed; see 1.3 and 1.9.

1.5 Structure of this International Standard**[intro.structure]**

- 1 Clauses 2 through 16 describe the C++ programming language. That description includes detailed syntactic specifications in a form described in 1.6. For convenience, Annex A repeats all such syntactic specifications.
- 2 Clauses 17 through 27 (the *library clauses*) describe the Standard C++ library, which provides definitions for the following kinds of entities: macros (16.3), values (clause 3), types (8.1, 8.3), templates (clause 14), classes (clause 9), functions (8.3.5), and objects (clause 7).
- 3 Annex B recommends lower bounds on the capacity of conforming implementations.
- 4 Annex C summarizes the evolution of C++ since its first published description, and explains in detail the differences between C++ and C. Certain features of C++ exist solely for compatibility purposes; Annex D describes those features.
- 5 Finally, Annex E says what characters are valid in universal-character names in C++ identifiers (2.10).
- 6 Throughout this International Standard, each example is introduced by “[*Example:*” and terminated by “]”. Each note is introduced by “[*Note:*” and terminated by “]”. Examples and notes may be nested.

1.6 Syntax notation**[syntax]**

- 1 In the syntax notation used in this International Standard, syntactic categories are indicated by *italic* type, and literal words and characters in `constant width` type. Alternatives are listed on separate lines except in a few cases where a long set of alternatives is presented on one line, marked by the phrase “one of.” An optional terminal or nonterminal symbol is indicated by the subscript “*opt*,” so

$$\{ \textit{expression}_{opt} \}$$

indicates an optional expression enclosed in braces.

- 2 Names for syntactic categories have generally been chosen according to the following rules:
 - *X-name* is a use of an identifier in a context that determines its meaning (e.g. *class-name*, *typedef-name*).
 - *X-id* is an identifier with no context-dependent meaning (e.g. *qualified-id*).
 - *X-seq* is one or more *X*’s without intervening delimiters (e.g. *declaration-seq* is a sequence of declarations).
 - *X-list* is one or more *X*’s separated by intervening commas (e.g. *expression-list* is a sequence of expressions separated by commas).

1.7 The C++ memory model**[intro.memory]**

- 1 The fundamental storage unit in the C++ memory model is the *byte*. A byte is at least large enough to contain any member of the basic execution character set and is composed of a contiguous sequence of bits, the number of which is implementation-defined. The least significant bit is called the *low-order* bit; the most significant bit is called the *high-order* bit. The memory available to a C++ program consists of one or more sequences of contiguous bytes. Every byte has a unique address.
- 2 [*Note:* the representation of types is described in 3.9.]

1.8 The C++ object model**[intro.object]**

- 1 The constructs in a C++ program create, destroy, refer to, access, and manipulate objects. An *object* is a region of storage. [*Note:* A function is not an object, regardless of whether or not it occupies storage in the way that objects do.] An object is created by a *definition* (3.1), by a *new-expression* (5.3.4) or by the implementation (12.2) when needed. The properties of an object are determined when the object is created. An object can have a *name* (clause 3). An object has a *storage duration* (3.7) which influences its *lifetime* (3.8). An object has a *type* (3.9). The term *object type* refers to the type with which the object is created.

Some objects are *polymorphic* (10.3); the implementation generates information associated with each such object that makes it possible to determine that object's type during program execution. For other objects, the interpretation of the values found therein is determined by the type of the *expressions* (clause 5) used to access them.

- 2 Objects can contain other objects, called *sub-objects*. A sub-object can be a *member sub-object* (9.2), a *base class sub-object* (clause 10), or an array element. An object that is not a sub-object of any other object is called a *complete object*.
- 3 For every object *x*, there is some object called *the complete object of x*, determined as follows:
 - If *x* is a complete object, then *x* is the complete object of *x*.
 - Otherwise, the complete object of *x* is the complete object of the (unique) object that contains *x*.
- 4 If a complete object, a data member (9.2), or an array element is of class type, its type is considered the *most derived* class, to distinguish it from the class type of any base class subobject; an object of a most derived class type is called a *most derived object*.
- 5 Unless it is a bit-field (9.6), a most derived object shall have a non-zero size and shall occupy one or more bytes of storage. Base class sub-objects may have zero size. An object of POD⁴⁾ type (3.9) shall occupy contiguous bytes of storage.
- 6 [Note: C++ provides a variety of built-in types and several ways of composing new types from existing types (3.9).]

1.9 Program execution

[intro.execution]

- 1 The semantic descriptions in this International Standard define a parameterized nondeterministic abstract machine. This International Standard places no requirement on the structure of conforming implementations. In particular, they need not copy or emulate the structure of the abstract machine. Rather, conforming implementations are required to emulate (only) the observable behavior of the abstract machine as explained below.⁵⁾
- 2 Certain aspects and operations of the abstract machine are described in this International Standard as implementation-defined (for example, `sizeof(int)`). These constitute the parameters of the abstract machine. Each implementation shall include documentation describing its characteristics and behavior in these respects. Such documentation shall define the instance of the abstract machine that corresponds to that implementation (referred to as the “corresponding instance” below).
- 3 Certain other aspects and operations of the abstract machine are described in this International Standard as unspecified (for example, order of evaluation of arguments to a function). Where possible, this International Standard defines a set of allowable behaviors. These define the nondeterministic aspects of the abstract machine. An instance of the abstract machine can thus have more than one possible execution sequence for a given program and a given input.
- 4 Certain other operations are described in this International Standard as undefined (for example, the effect of dereferencing the null pointer). [Note: this International Standard imposes no requirements on the behavior of programs that contain undefined behavior.]
- 5 A conforming implementation executing a well-formed program shall produce the same observable behavior as one of the possible execution sequences of the corresponding instance of the abstract machine with the same program and the same input. However, if any such execution sequence contains an undefined operation, this International Standard places no requirement on the implementation executing that program

⁴⁾ The acronym POD stands for “plain old data.”

⁵⁾ This provision is sometimes called the “as-if” rule, because an implementation is free to disregard any requirement of this International Standard as long as the result is *as if* the requirement had been obeyed, as far as can be determined from the observable behavior of the program. For instance, an actual implementation need not evaluate part of an expression if it can deduce that its value is not used and that no side effects affecting the observable behavior of the program are produced.

with that input (not even with regard to operations preceding the first undefined operation).

- 6 The observable behavior of the abstract machine is its sequence of reads and writes to `volatile` data and calls to library I/O functions.⁶⁾
- 7 Accessing an object designated by a `volatile lvalue` (3.10), modifying an object, calling a library I/O function, or calling a function that does any of those operations are all *side effects*, which are changes in the state of the execution environment. Evaluation of an expression might produce side effects. At certain specified points in the execution sequence called *sequence points*, all side effects of previous evaluations shall be complete and no side effects of subsequent evaluations shall have taken place.⁷⁾
- 8 Once the execution of a function begins, no expressions from the calling function are evaluated until execution of the called function has completed.⁸⁾
- 9 When the processing of the abstract machine is interrupted by receipt of a signal, the values of objects with type other than `volatile sig_atomic_t` are unspecified, and the value of any object not of `volatile sig_atomic_t` that is modified by the handler becomes undefined.
- 10 An instance of each object with automatic storage duration (3.7.2) 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 or receipt of a signal).
- 11 The least requirements on a conforming implementation are:
- At sequence points, `volatile` objects are stable in the sense that previous evaluations are complete and subsequent evaluations have not yet occurred.
 - At program termination, all data written into files shall be identical to one of the possible results that execution of the program according to the abstract semantics would have produced.
 - The input and output dynamics of interactive devices shall take place in such a fashion that prompting messages actually appear prior to a program waiting for input. What constitutes an interactive device is implementation-defined.

[*Note:* more stringent correspondences between abstract and actual semantics may be defined by each implementation.]

- 12 A *full-expression* is an expression that is not a subexpression of another expression. If a language construct is defined to produce an implicit call of a function, a use of the language construct is considered to be an expression for the purposes of this definition.
- 13 [*Note:* certain contexts in C++ cause the evaluation of a full-expression that results from a syntactic construct other than *expression* (5.18). For example, in 8.5 one syntax for *initializer* is

(*expression-list*)

but the resulting construct is a function call upon a constructor function with *expression-list* as an argument list; such a function call is a full-expression. For example, in 8.5, another syntax for *initializer* is

= *initializer-clause*

but again the resulting construct might be a function call upon a constructor function with one *assignment-expression* as an argument; again, the function call is a full-expression.]

⁶⁾ An implementation can offer additional library I/O functions as an extension. Implementations that do so should treat calls to those functions as “observable behavior” as well.

⁷⁾ Note that some aspects of sequencing in the abstract machine are unspecified; the preceding restriction upon side effects applies to that particular execution sequence in which the actual code is generated. Also note that when a call to a library I/O function returns, the side effect is considered complete, even though some external actions implied by the call (such as the I/O itself) may not have completed yet.

⁸⁾ In other words, function executions do not interleave with each other.

14 [Note: the evaluation of a full-expression can include the evaluation of subexpressions that are not lexically part of the full-expression. For example, subexpressions involved in evaluating default argument expressions (8.3.6) are considered to be created in the expression that calls the function, not the expression that defines the default argument.]

15 [Note: operators can be regrouped according to the usual mathematical rules only where the operators really are associative or commutative.⁹⁾ For example, in the following fragment

```
int a, b;
/*...*/
a = a + 32760 + b + 5;
```

the expression statement behaves exactly the same as

```
a = ((a + 32760) + b) + 5);
```

due to the associativity and precedence of these operators. Thus, the result of the sum (a + 32760) is next added to b, and that result is then added to 5 which results in the value assigned to a. On a machine in which overflows produce an exception and in which the range of values representable by an int is [-32768,+32767], the implementation cannot rewrite this expression as

```
a = ((a + b) + 32765);
```

since if the values for a and b were, respectively, -32754 and -15, the sum a + b would produce an exception while the original expression would not; nor can the expression be rewritten either as

```
a = ((a + 32765) + b);
```

or

```
a = (a + (b + 32765));
```

since the values for a and b might have been, respectively, 4 and -8 or -17 and 12. However on a machine in which overflows do not produce an exception and in which the results of overflows are reversible, the above expression statement can be rewritten by the implementation in any of the above ways because the same result will occur.]

16 There is a sequence point at the completion of evaluation of each full-expression¹⁰⁾.

17 When calling a function (whether or not the function is inline), there is a sequence point after the evaluation of all function arguments (if any) which takes place before execution of any expressions or statements in the function body. There is also a sequence point after the copying of a returned value and before the execution of any expressions outside the function¹¹⁾. Several contexts in C++ cause evaluation of a function call, even though no corresponding function call syntax appears in the translation unit. [Example: evaluation of a new expression invokes one or more allocation and constructor functions; see 5.3.4. For another example, invocation of a conversion function (12.3.2) can arise in contexts in which no function call syntax appears.] The sequence points at function-entry and function-exit (as described above) are features of the function calls as evaluated, whatever the syntax of the expression that calls the function might be.

18 In the evaluation of each of the expressions

```
a && b
a || b
a ? b : c
a , b
```

using the built-in meaning of the operators in these expressions (5.14, 5.15, 5.16, 5.18), there is a sequence

⁹⁾ Overloaded operators are never assumed to be associative or commutative.

¹⁰⁾ As specified in 12.2, after the "end-of-full-expression" sequence point, a sequence of zero or more invocations of destructor functions for temporary objects takes place, usually in reverse order of the construction of each temporary object.

¹¹⁾ The sequence point at the function return is not explicitly specified in ISO C, and can be considered redundant with sequence points at full-expressions, but the extra clarity is important in C++. In C++, there are more ways in which a called function can terminate its execution, such as the throw of an exception.

point after the evaluation of the first expression¹²⁾.

1.10 Acknowledgments

[intro.ack]

- 1 The C++ programming language as described in this International Standard is based on the language as described in Chapter R (Reference Manual) of Stroustrup: *The C++ Programming Language* (second edition, Addison-Wesley Publishing Company, ISBN 0-201-53992-6, copyright © 1991 AT&T). That, in turn, is based on the C programming language as described in Appendix A of Kernighan and Ritchie: *The C Programming Language* (Prentice-Hall, 1978, ISBN 0-13-110163-3, copyright © 1978 AT&T).
- 2 Portions of the library clauses of this International Standard are based on work by P.J. Plauger, which was published as *The Draft Standard C++ Library* (Prentice-Hall, ISBN 0-13-117003-1, copyright © 1995 P.J. Plauger).
- 3 All rights in these originals are reserved.

¹²⁾ The operators indicated in this paragraph are the built-in operators, as described in clause 5. When one of these operators is overloaded (clause 13) in a valid context, thus designating a user-defined operator function, the expression designates a function invocation, and the operands form an argument list, without an implied sequence point between them.

2 Lexical conventions

[lex]

- 1 The text of the program is kept in units called *source files* in this International Standard. A source file together with all the headers (17.4.1.2) and source files included (16.2) via the preprocessing directive `#include`, less any source lines skipped by any of the conditional inclusion (16.1) preprocessing directives, is called a *translation unit*. [Note: a C++ program need not all be translated at the same time.]
- 2 [Note: previously translated translation units and instantiation units can be preserved individually or in libraries. The separate translation units of a program communicate (3.5) by (for example) calls to functions whose identifiers have external linkage, manipulation of objects whose identifiers have external linkage, or manipulation of data files. Translation units can be separately translated and then later linked to produce an executable program. (3.5).]

2.1 Phases of translation

[lex.phases]

- 1 The precedence among the syntax rules of translation is specified by the following phases.¹³⁾
 - 1 Physical source file characters are mapped, in an implementation-defined manner, to the basic source character set (introducing new-line characters for end-of-line indicators) if necessary. Trigraph sequences (2.3) are replaced by corresponding single-character internal representations. Any source file character not in the basic source character set (2.2) is replaced by the universal-character-name that designates that character. (An implementation may use any internal encoding, so long as an actual extended character encountered in the source file, and the same extended character expressed in the source file as a universal-character-name (i.e. using the `\uXXXX` notation), are handled equivalently.)
 - 2 Each instance of a new-line character and an immediately preceding backslash character is deleted, splicing physical source lines to form logical source lines. If, as a result, a character sequence that matches the syntax of a universal-character-name is produced, the behavior is undefined. If a source file that is not empty does not end in a new-line character, or ends in a new-line character immediately preceded by a backslash character, the behavior is undefined.
 - 3 The source file is decomposed into preprocessing tokens (2.4) and sequences of white-space characters (including comments). A source file shall not end in a partial preprocessing token or partial comment¹⁴⁾. Each comment is replaced by one space character. New-line characters are retained. Whether each nonempty sequence of white-space characters other than new-line is retained or replaced by one space character is implementation-defined. The process of dividing a source file's characters into preprocessing tokens is context-dependent. [Example: see the handling of `<` within a `#include` preprocessing directive.]
 - 4 Preprocessing directives are executed and macro invocations are expanded. If a character sequence that matches the syntax of a universal-character-name is produced by token concatenation (16.3.3), the behavior is undefined. A `#include` preprocessing directive causes the named header or source file to be processed from phase 1 through phase 4, recursively.
 - 5 Each source character set member, escape sequence, or universal-character-name in character literals and string literals is converted to a member of the execution character set (2.13.2, 2.13.4).
 - 6 Adjacent ordinary string literal tokens are concatenated. Adjacent wide string literal tokens are concatenated.
 - 7 White-space characters separating tokens are no longer significant. Each preprocessing token is

¹³⁾ Implementations must behave as if these separate phases occur, although in practice different phases might be folded together.

¹⁴⁾ A partial preprocessing token would arise from a source file ending in the first portion of a multi-character token that requires a terminating sequence of characters, such as a *header-name* that is missing the closing `"` or `>`. A partial comment would arise from a source file ending with an unclosed `/*` comment.

converted into a token. (2.6). The resulting tokens are syntactically and semantically analyzed and translated. [Note: Source files, translation units and translated translation units need not necessarily be stored as files, nor need there be any one-to-one correspondence between these entities and any external representation. The description is conceptual only, and does not specify any particular implementation.]

- 8 Translated translation units and instantiation units are combined as follows: [Note: some or all of these may be supplied from a library.] Each translated translation unit is examined to produce a list of required instantiations. [Note: this may include instantiations which have been explicitly requested (14.7.2).] The definitions of the required templates are located. It is implementation-defined whether the source of the translation units containing these definitions is required to be available. [Note: an implementation could encode sufficient information into the translated translation unit so as to ensure the source is not required here.] All the required instantiations are performed to produce *instantiation units*. [Note: these are similar to translated translation units, but contain no references to uninstantiated templates and no template definitions.] The program is ill-formed if any instantiation fails.
- 9 All external object and function references are resolved. Library components are linked to satisfy external references to functions and objects not defined in the current translation. All such translator output is collected into a program image which contains information needed for execution in its execution environment.

2.2 Character sets

[lex.charset]

- 1 The *basic source character set* consists of 96 characters: the space character, the control characters representing horizontal tab, vertical tab, form feed, and new-line, plus the following 91 graphical characters:¹⁵⁾

```
a b c d e f g h i j k l m n o p q r s t u v w x y z
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
0 1 2 3 4 5 6 7 8 9
_ { } [ ] # ( ) < > % : ; . ? * + - / ^ & | ~ ! = , \ " '

```

- 2 The *universal-character-name* construct provides a way to name other characters.

hex-quad:

hexadecimal-digit hexadecimal-digit hexadecimal-digit hexadecimal-digit

universal-character-name:

\u hex-quad
\U hex-quad hex-quad

The character designated by the universal-character-name `\UNNNNNNNNN` is that character whose character short name in ISO/IEC 10646 is `NNNNNNNN`; the character designated by the universal-character-name `\uNNNN` is that character whose character short name in ISO/IEC 10646 is `0000NNNN`. If the hexadecimal value for a universal character name is less than `0x20` or in the range `0x7F-0x9F` (inclusive), or if the universal character name designates a character in the basic source character set, then the program is ill-formed.

- 3 The *basic execution character set* and the *basic execution wide-character set* shall each contain all the members of the basic source character set, plus control characters representing alert, backspace, and carriage return, plus a *null character* (respectively, *null wide character*), whose representation has all zero bits. For each basic execution character set, the values of the members shall be non-negative and distinct from one another. The *execution character set* and the *execution wide-character set* are supersets of the basic execution character set and the basic execution wide-character set, respectively. The values of the members of the execution character sets are implementation-defined, and any additional members are locale-specific.

¹⁵⁾ The glyphs for the members of the basic source character set are intended to identify characters from the subset of ISO/IEC 10646 which corresponds to the ASCII character set. However, because the mapping from source file characters to the source character set (described in translation phase 1) is specified as implementation-defined, an implementation is required to document how the basic source characters are represented in source files.

2.3 Trigraph sequences

[lex.trigraph]

- 1 Before any other processing takes place, each occurrence of one of the following sequences of three characters (“*trigraph sequences*”) is replaced by the single character indicated in Table 1.

Table 1—trigraph sequences

<i>trigraph</i>	<i>replacement</i>	<i>trigraph</i>	<i>replacement</i>	<i>trigraph</i>	<i>replacement</i>
??=	#	?? (	[	??<	{
??/	\	??)	]	??>	}
??'	^	??!		??-	~

- 2 [Example:

```
??=define arraycheck(a,b) a??(b??) ??!??! b??(a??)
```

becomes

```
#define arraycheck(a,b) a[b] || b[a]
```

—end example]

- 3 No other trigraph sequence exists. Each ? that does not begin one of the trigraphs listed above is not changed.

2.4 Preprocessing tokens

[lex.pptoken]

preprocessing-token:
header-name
identifier
pp-number
character-literal
string-literal
preprocessing-op-or-punc
 each non-white-space character that cannot be one of the above

- 1 Each preprocessing token that is converted to a token (2.6) shall have the lexical form of a keyword, an identifier, a literal, an operator, or a punctuation.
- 2 A *preprocessing token* is the minimal lexical element of the language in translation phases 3 through 6. The categories of preprocessing token are: *header names*, *identifiers*, *preprocessing numbers*, *character literals*, *string literals*, *preprocessing-op-or-punc*, and single non-white-space characters that do not lexically match the other preprocessing token categories. If a ' or a " character matches the last category, the behavior is undefined. Preprocessing tokens can be separated by *white space*; this consists of comments (2.7), or *white-space characters* (space, horizontal tab, new-line, vertical tab, and form-feed), or both. As described in clause 16, in certain circumstances during translation phase 4, white space (or the absence thereof) serves as more than preprocessing token separation. White space can appear within a preprocessing token only as part of a header name or between the quotation characters in a character literal or string literal.
- 3 If the input stream has been parsed into preprocessing tokens up to a given character, the next preprocessing token is the longest sequence of characters that could constitute a preprocessing token, even if that would cause further lexical analysis to fail.
- 4 [Example: The program fragment 1Ex is parsed as a preprocessing number token (one that is not a valid floating or integer literal token), even though a parse as the pair of preprocessing tokens 1 and Ex might produce a valid expression (for example, if Ex were a macro defined as +1). Similarly, the program fragment 1E1 is parsed as a preprocessing number (one that is a valid floating literal token), whether or not E is a macro name.]

2.4 Preprocessing tokens

2 Lexical conventions

- 5 [Example: The program fragment `x+++++y` is parsed as `x ++ ++ + y`, which, if `x` and `y` are of built-in types, violates a constraint on increment operators, even though the parse `x ++ + ++ y` might yield a correct expression.]

2.5 Alternative tokens

[lex.digraph]

- 1 Alternative token representations are provided for some operators and punctuators¹⁶⁾.
- 2 In all respects of the language, each alternative token behaves the same, respectively, as its primary token, except for its spelling¹⁷⁾. The set of alternative tokens is defined in Table 2.

Table 2—alternative tokens

<i>alternative</i>	<i>primary</i>	<i>alternative</i>	<i>primary</i>	<i>alternative</i>	<i>primary</i>
<%	{	and	&&	and_eq	&=
%>	}	bitor		or_eq	=
<:	[	or		xor_eq	^=
:>	]	xor	^	not	!
%:	#	compl	~	not_eq	!=
%:%:	##	bitand	&		

2.6 Tokens

[lex.token]

token:

identifier
keyword
literal
operator
punctuator

- 1 There are five kinds of tokens: identifiers, keywords, literals,¹⁸⁾ operators, and other separators. Blanks, horizontal and vertical tabs, newlines, formfeeds, and comments (collectively, “white space”), as described below, are ignored except as they serve to separate tokens. [Note: Some white space is required to separate otherwise adjacent identifiers, keywords, numeric literals, and alternative tokens containing alphabetic characters.]

2.7 Comments

[lex.comment]

- 1 The characters `/*` start a comment, which terminates with the characters `*/`. These comments do not nest. The characters `//` start a comment, which terminates with the next new-line character. If there is a form-feed or a vertical-tab character in such a comment, only white-space characters shall appear between it and the new-line that terminates the comment; no diagnostic is required. [Note: The comment characters `//`, `/*`, and `*/` have no special meaning within a `//` comment and are treated just like other characters. Similarly, the comment characters `//` and `/*` have no special meaning within a `/*` comment.]

¹⁶⁾ These include “digraphs” and additional reserved words. The term “digraph” (token consisting of two characters) is not perfectly descriptive, since one of the alternative preprocessing-tokens is `%: %:` and of course several primary tokens contain two characters. Nonetheless, those alternative tokens that aren’t lexical keywords are colloquially known as “digraphs”.

¹⁷⁾ Thus the “stringized” values (16.3.2) of `[` and `<:` will be different, maintaining the source spelling, but the tokens can otherwise be freely interchanged.

¹⁸⁾ Literals include strings and character and numeric literals.

2.8 Header names**[lex.header]***header-name:*

<h-char-sequence>
"q-char-sequence"

h-char-sequence:

h-char
h-char-sequence h-char

h-char:

any member of the source character set except
 new-line and >

q-char-sequence:

q-char
q-char-sequence q-char

q-char:

any member of the source character set except
 new-line and "

- 1 Header name preprocessing tokens shall only appear within a `#include` preprocessing directive (16.2). The sequences in both forms of *header-names* are mapped in an implementation-defined manner to headers or to external source file names as specified in 16.2.
- 2 If either of the characters ' or \, or either of the character sequences /* or // appears in a *q-char-sequence* or a *h-char-sequence*, or the character " appears in a *h-char-sequence*, the behavior is undefined.¹⁹⁾

2.9 Preprocessing numbers**[lex.ppnumber]***pp-number:*

digit
. digit
pp-number digit
pp-number nondigit
pp-number e sign
pp-number E sign
pp-number .

- 1 Preprocessing number tokens lexically include all integral literal tokens (2.13.1) and all floating literal tokens (2.13.3).
- 2 A preprocessing number does not have a type or a value; it acquires both after a successful conversion (as part of translation phase 7, 2.1) to an integral literal token or a floating literal token.

2.10 Identifiers**[lex.name]***identifier:*

nondigit
identifier nondigit
identifier digit

¹⁹⁾ Thus, sequences of characters that resemble escape sequences cause undefined behavior.

2.10 Identifiers

2 Lexical conventions

nondigit: one of
universal-character-name
 _ a b c d e f g h i j k l m
 n o p q r s t u v w x y z
 A B C D E F G H I J K L M
 N O P Q R S T U V W X Y Z

digit: one of
 0 1 2 3 4 5 6 7 8 9

- 1 An identifier is an arbitrarily long sequence of letters and digits. Each universal-character-name in an identifier shall designate a character whose encoding in ISO 10646 falls into one of the ranges specified in Annex E. Upper- and lower-case letters are different. All characters are significant.²⁰⁾
- 2 In addition, some identifiers are reserved for use by C++ implementations and standard libraries (17.4.3.1.2) and shall not be used otherwise; no diagnostic is required.

2.11 Keywords

[lex.key]

- 1 The identifiers shown in Table 3 are reserved for use as keywords (that is, they are unconditionally treated as keywords in phase 7):

Table 3—keywords

asm	do	if	return	typedef
auto	double	inline	short	typeid
bool	dynamic_cast	int	signed	typename
break	else	long	sizeof	union
case	enum	mutable	static	unsigned
catch	explicit	namespace	static_cast	using
char	export	new	struct	virtual
class	extern	operator	switch	void
const	false	private	template	volatile
const_cast	float	protected	this	wchar_t
continue	for	public	throw	while
default	friend	register	true	
delete	goto	reinterpret_cast	try	

- 2 Furthermore, the alternative representations shown in Table 4 for certain operators and punctuators (2.5) are reserved and shall not be used otherwise:

Table 4—alternative representations

and	and_eq	bitand	bitor	compl	not
not_eq	or	or_eq	xor	xor_eq	

²⁰⁾ On systems in which linkers cannot accept extended characters, an encoding of the universal-character-name may be used in forming valid external identifiers. For example, some otherwise unused character or sequence of characters may be used to encode the \u in a universal-character-name. Extended characters may produce a long external identifier, but C++ does not place a translation limit on significant characters for external identifiers. In C++, upper- and lower-case letters are considered different for all identifiers, including external identifiers.

2.12 Operators and punctuators

[lex.operators]

- 1 The lexical representation of C++ programs includes a number of preprocessing tokens which are used in the syntax of the preprocessor or are converted into tokens for operators and punctuators:

preprocessing-op-or-punc: one of

{	}	[	]	#	##	(	)	
<:	:>	<%	%>	%:	%%:	;	:	...
new	delete	?	::	.	.*			
+	-	*	/	%	^	&		~
!	=	<	>	+=	-=	*=	/=	%=
^=	&=	=	<<	>>	>>=	<<=	==	!=
<=	>=	&&		++	--	,	->*	->
and	and_eq	bitand	bitor	compl	not	not_eq		
or	or_eq	xor	xor_eq					

Each *preprocessing-op-or-punc* is converted to a single token in translation phase 7 (2.1).

2.13 Literals

[lex.literal]

- 1 There are several kinds of literals.²¹⁾

literal:

integer-literal
character-literal
floating-literal
string-literal
boolean-literal

2.13.1 Integer literals

[lex.icon]

integer-literal:

decimal-literal integer-suffix_{opt}
octal-literal integer-suffix_{opt}
hexadecimal-literal integer-suffix_{opt}

decimal-literal:

nonzero-digit
decimal-literal digit

octal-literal:

0
octal-literal octal-digit

hexadecimal-literal:

0x *hexadecimal-digit*
 0X *hexadecimal-digit*
hexadecimal-literal hexadecimal-digit

nonzero-digit: one of

1 2 3 4 5 6 7 8 9

octal-digit: one of

0 1 2 3 4 5 6 7

²¹⁾ The term “literal” generally designates, in this International Standard, those tokens that are called “constants” in ISO C.

2.13.1 Integer literals

2 Lexical conventions

hexadecimal-digit: one of

0	1	2	3	4	5	6	7	8	9
a	b	c	d	e	f				
A	B	C	D	E	F				

integer-suffix:

unsigned-suffix *long-suffix*_{opt}
long-suffix *unsigned-suffix*_{opt}

unsigned-suffix: one of

u U

long-suffix: one of

l L

- 1 An integer literal is a sequence of digits that has no period or exponent part. An integer literal may have a prefix that specifies its base and a suffix that specifies its type. The lexically first digit of the sequence of digits is the most significant. A *decimal* integer literal (base ten) begins with a digit other than 0 and consists of a sequence of decimal digits. An *octal* integer literal (base eight) begins with the digit 0 and consists of a sequence of octal digits.²²⁾ A *hexadecimal* integer literal (base sixteen) begins with 0x or 0X and consists of a sequence of hexadecimal digits, which include the decimal digits and the letters a through f and A through F with decimal values ten through fifteen. [Example: the number twelve can be written 12, 014, or 0XC.]
- 2 The type of an integer literal depends on its form, value, and suffix. If it is decimal and has no suffix, it has the first of these types in which its value can be represented: int, long int; if the value cannot be represented as a long int, the behavior is undefined. If it is octal or hexadecimal and has no suffix, it has the first of these types in which its value can be represented: int, unsigned int, long int, unsigned long int. If it is suffixed by u or U, its type is the first of these types in which its value can be represented: unsigned int, unsigned long int. If it is suffixed by l or L, its type is the first of these types in which its value can be represented: long int, unsigned long int. If it is suffixed by ul, lu, uL, Lu, UL, lU, UL, or LU, its type is unsigned long int.
- 3 A program is ill-formed if one of its translation units contains an integer literal that cannot be represented by any of the allowed types.

2.13.2 Character literals

[lex.ccon]

character-literal:

'c-char-sequence'
 L' c-char-sequence'

c-char-sequence:

c-char
 c-char-sequence c-char

c-char:

any member of the source character set except
 the single-quote ' , backslash \ , or new-line character
 escape-sequence
 universal-character-name

²²⁾ The digits 8 and 9 are not octal digits.

escape-sequence:

simple-escape-sequence
octal-escape-sequence
hexadecimal-escape-sequence

simple-escape-sequence: one of

`\'` `\"` `\?` `\\`
`\a` `\b` `\f` `\n` `\r` `\t` `\v`

octal-escape-sequence:

`\` *octal-digit*
`\` *octal-digit* *octal-digit*
`\` *octal-digit* *octal-digit* *octal-digit*

hexadecimal-escape-sequence:

`\x` *hexadecimal-digit*
hexadecimal-escape-sequence *hexadecimal-digit*

- 1 A character literal is one or more characters enclosed in single quotes, as in `'x'`, optionally preceded by the letter `L`, as in `L'x'`. A character literal that does not begin with `L` is an ordinary character literal, also referred to as a narrow-character literal. An ordinary character literal that contains a single *c-char* has type `char`, with value equal to the numerical value of the encoding of the *c-char* in the execution character set. An ordinary character literal that contains more than one *c-char* is a *multicharacter literal*. A multicharacter literal has type `int` and implementation-defined value.
- 2 A character literal that begins with the letter `L`, such as `L'x'`, is a wide-character literal. A wide-character literal has type `wchar_t`.²³⁾ The value of a wide-character literal containing a single *c-char* has value equal to the numerical value of the encoding of the *c-char* in the execution wide-character set. The value of a wide-character literal containing multiple *c-chars* is implementation-defined.
- 3 Certain nongraphic characters, the single quote `'`, the double quote `"`, the question mark `?`, and the backslash `\`, can be represented according to Table 5.

Table 5—escape sequences

new-line	NL (LF)	<code>\n</code>
horizontal tab	HT	<code>\t</code>
vertical tab	VT	<code>\v</code>
backspace	BS	<code>\b</code>
carriage return	CR	<code>\r</code>
form feed	FF	<code>\f</code>
alert	BEL	<code>\a</code>
backslash	<code>\</code>	<code>\\</code>
question mark	<code>?</code>	<code>\?</code>
single quote	<code>'</code>	<code>\'</code>
double quote	<code>"</code>	<code>\"</code>
octal number	<i>ooo</i>	<code>\ooo</code>
hex number	<i>hhh</i>	<code>\xhhh</code>

The double quote `"` and the question mark `?`, can be represented as themselves or by the escape sequences `\"` and `\?` respectively, but the single quote `'` and the backslash `\` shall be represented by the escape sequences `\'` and `\\` respectively. If the character following a backslash is not one of those specified, the behavior is undefined. An escape sequence specifies a single character.

²³⁾ They are intended for character sets where a character does not fit into a single byte.

- 4 The escape `\ooo` consists of the backslash followed by one, two, or three octal digits that are taken to specify the value of the desired character. The escape `\xhhh` consists of the backslash followed by `x` followed by one or more hexadecimal digits that are taken to specify the value of the desired character. There is no limit to the number of digits in a hexadecimal sequence. A sequence of octal or hexadecimal digits is terminated by the first character that is not an octal digit or a hexadecimal digit, respectively. The value of a character literal is implementation-defined if it falls outside of the implementation-defined range defined for `char` (for ordinary literals) or `wchar_t` (for wide literals).
- 5 A universal-character-name is translated to the encoding, in the execution character set, of the character named. If there is no such encoding, the universal-character-name is translated to an implementation-defined encoding. [Note: in translation phase 1, a universal-character-name is introduced whenever an actual extended character is encountered in the source text. Therefore, all extended characters are described in terms of universal-character-names. However, the actual compiler implementation may use its own native character set, so long as the same results are obtained.]

2.13.3 Floating literals

[lex.fcon]

floating-literal:
$$\text{fractional-constant } \text{exponent-part}_{\text{opt}} \text{floating-suffix}_{\text{opt}}$$

$$\text{digit-sequence } \text{exponent-part } \text{floating-suffix}_{\text{opt}}$$
fractional-constant:
$$\text{digit-sequence}_{\text{opt}} . \text{digit-sequence}$$

$$\text{digit-sequence} .$$
exponent-part:
$$\text{e } \text{sign}_{\text{opt}} \text{digit-sequence}$$

$$\text{E } \text{sign}_{\text{opt}} \text{digit-sequence}$$
sign: one of

+ -

digit-sequence:
$$\text{digit}$$

$$\text{digit-sequence } \text{digit}$$
floating-suffix: one of

f l F L

- 1 A floating literal consists of an integer part, a decimal point, a fraction part, an `e` or `E`, an optionally signed integer exponent, and an optional type suffix. The integer and fraction parts both consist of a sequence of decimal (base ten) digits. Either the integer part or the fraction part (not both) can be omitted; either the decimal point or the letter `e` (or `E`) and the exponent (not both) can be omitted. The integer part, the optional decimal point and the optional fraction part form the *significant part* of the floating literal. The exponent, if present, indicates the power of 10 by which the significant part is to be scaled. If the scaled value is in the range of representable values for its type, the result is the scaled value if representable, else the larger or smaller representable value nearest the scaled value, chosen in an implementation-defined manner. The type of a floating literal is `double` unless explicitly specified by a suffix. The suffixes `f` and `F` specify `float`, the suffixes `l` and `L` specify `long double`. If the scaled value is not in the range of representable values for its type, the program is ill-formed.

2.13.4 String literals

[lex.string]

string-literal:

"*s-char-sequence*_{opt}"
 L"*s-char-sequence*_{opt}"

s-char-sequence:

s-char
s-char-sequence s-char

s-char:

any member of the source character set except
 the double-quote " , backslash \ , or new-line character
escape-sequence
universal-character-name

- 1 A string literal is a sequence of characters (as defined in 2.13.2) surrounded by double quotes, optionally beginning with the letter L, as in "... " or L"... ". A string literal that does not begin with L is an ordinary string literal, also referred to as a narrow string literal. An ordinary string literal has type “array of *n* `const char`” and *static* storage duration (3.7), where *n* is the size of the string as defined below, and is initialized with the given characters. A string literal that begins with L, such as L"asdf", is a wide string literal. A wide string literal has type “array of *n* `const wchar_t`” and has static storage duration, where *n* is the size of the string as defined below, and is initialized with the given characters.

- 2 Whether all string literals are distinct (that is, are stored in nonoverlapping objects) is implementation-defined. The effect of attempting to modify a string literal is undefined.

- 3 In translation phase 6 (2.1), adjacent narrow string literals are concatenated and adjacent wide string literals are concatenated. If a narrow string literal token is adjacent to a wide string literal token, the behavior is undefined. Characters in concatenated strings are kept distinct. [Example:

```
"\xA" "B"
```

contains the two characters ' \xA ' and ' B ' after concatenation (and not the single hexadecimal character ' \xAB ').]

- 4 After any necessary concatenation, in translation phase 7 (2.1), ' \0 ' is appended to every string literal so that programs that scan a string can find its end.
- 5 Escape sequences and universal-character-names in string literals have the same meaning as in character literals (2.13.2), except that the single quote ' is representable either by itself or by the escape sequence \ ' , and the double quote " shall be preceded by a \ . In a narrow string literal, a universal-character-name may map to more than one `char` element due to *multibyte encoding*. The size of a wide string literal is the total number of escape sequences, universal-character-names, and other characters, plus one for the terminating L' \0 '. The size of a narrow string literal is the total number of escape sequences and other characters, plus at least one for the multibyte encoding of each universal-character-name, plus one for the terminating ' \0 '.

2.13.5 Boolean literals

[lex.bool]

boolean-literal:

false
 true

- 1 The Boolean literals are the keywords `false` and `true`. Such literals have type `bool`. They are not lvalues.

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