Information Technology — Programming languages, their environments, and system software interfaces — Floating-point extensions for C — Part 3: Interchange and extended types

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO/IEC TS 18661 was prepared by Technical Committee ISO/IEC JTC 1, Information Technology, Subcommittee SC 22, Programming languages, their environments, and system software interfaces.

ISO/IEC TS 18661 consists of the following parts, under the general title Floating-point extensions for C:

— Part 1: Binary floating-point arithmetic
— Part 2: Decimal floating-point arithmetic
— Part 3: Interchange and extended types
— Part 4: Supplementary functions
— Part 5: Supplementary attributes


Part 2 supersedes ISO/IEC TR 24732:2009 (Information technology — Programming languages, their environments and system software interfaces — Extension for the programming language C to support decimal floating-point arithmetic).

Introduction

Background

IEC 60559 floating-point standard

The IEEE 754-1985 standard for binary floating-point arithmetic was motivated by an expanding diversity in floating-point data representation and arithmetic, which made writing robust programs, debugging, and moving programs between systems exceedingly difficult. Now the great majority of systems provide data formats and arithmetic operations according to this standard. The IEC 60559:1989 international standard was equivalent to the IEEE 754-1985 standard. Its stated goals were:

1. Facilitate movement of existing programs from diverse computers to those that adhere to this standard.

2. Enhance the capabilities and safety available to programmers who, though not expert in numerical methods, may well be attempting to produce numerically sophisticated programs. However, we recognize that utility and safety are sometimes antagonists.

3. Encourage experts to develop and distribute robust and efficient numerical programs that are portable, by way of minor editing and recompilation, onto any computer that conforms to this standard and possesses adequate capacity. When restricted to a declared subset of the standard, these programs should produce identical results on all conforming systems.

4. Provide direct support for
   a. Execution-time diagnosis of anomalies
   b. Smoother handling of exceptions
   c. Interval arithmetic at a reasonable cost

5. Provide for development of
   a. Standard elementary functions such as exp and cos
   b. Very high precision (multiword) arithmetic
   c. Coupling of numerical and symbolic algebraic computation

6. Enable rather than preclude further refinements and extensions.

To these ends, the standard specified a floating-point model comprising:

- **formats** – for binary floating-point data, including representations for Not-a-Number (NaN) and signed infinities and zeros
- **operations** – basic arithmetic operations (addition, multiplication, etc.) on the format data to compose a well-defined, closed arithmetic system; also specified conversions between floating-point formats and decimal character sequences, and a few auxiliary operations
- **context** – status flags for detecting exceptional conditions (invalid operation, division by zero, overflow, underflow, and inexact) and controls for choosing different rounding methods

The IEC 60559:2011 international standard is equivalent to the IEEE 754-2008 standard for floating-point arithmetic, which is a major revision to IEEE 754-1985.

The revised standard specifies more formats, including decimal as well as binary. It adds a 128-bit binary format to its basic formats. It defines extended formats for all of its basic formats. It specifies data interchange
formats (which may or may not be arithmetic), including a 16-bit binary format and an unbounded tower of wider formats. To conform to the floating-point standard, an implementation must provide at least one of the basic formats, along with the required operations.

The revised standard specifies more operations. New requirements include – among others – arithmetic operations that round their result to a narrower format than the operands (with just one rounding), more conversions with integer types, more classifications and comparisons, and more operations for managing flags and modes. New recommendations include an extensive set of mathematical functions and seven reduction functions for sums and scaled products.

The revised standard places more emphasis on reproducible results, which is reflected in its standardization of more operations. For the most part, behaviors are completely specified. The standard requires conversions between floating-point formats and decimal character sequences to be correctly rounded for at least three more decimal digits than is required to distinguish all numbers in the widest supported binary format; it fully specifies conversions involving any number of decimal digits. It recommends that transcendental functions be correctly rounded.

The revised standard requires a way to specify a constant rounding direction for a static portion of code, with details left to programming language standards. This feature potentially allows rounding control without incurring the overhead of runtime access to a global (or thread) rounding mode.

Other features recommended by the revised standard include alternate methods for exception handling, controls for expression evaluation (allowing or disallowing various optimizations), support for fully reproducible results, and support for program debugging.

The revised standard, like its predecessor, defines its model of floating-point arithmetic in the abstract. It neither defines the way in which operations are expressed (which might vary depending on the computer language or other interface being used), nor does it define the concrete representation (specific layout in storage, or in a processor's register, for example) of data or context, except that it does define specific encodings that are to be used for data that may be exchanged between different implementations that conform to the specification.

IEC 60559 does not include bindings of its floating-point model for particular programming languages. However, the revised standard does include guidance for programming language standards, in recognition of the fact that features of the floating-point standard, even if well supported in the hardware, are not available to users unless the programming language provides a commensurate level of support. The implementation's combination of both hardware and software determines conformance to the floating-point standard.

C support for IEC 60559

The C standard specifies floating-point arithmetic using an abstract model. The representation of a floating-point number is specified in an abstract form where the constituent components (sign, exponent, significand) of the representation are defined but not the internals of these components. In particular, the exponent range, significand size, and the base (or radix) are implementation-defined. This allows flexibility for an implementation to take advantage of its underlying hardware architecture. Furthermore, certain behaviors of operations are also implementation-defined, for example in the area of handling of special numbers and in exceptions.

The reason for this approach is historical. At the time when C was first standardized, before the floating-point standard was established, there were various hardware implementations of floating-point arithmetic in common use. Specifying the exact details of a representation would have made most of the existing implementations at the time not conforming.


ISO/IEC Technical Report 24732:2009 introduced partial C support for the decimal floating-point arithmetic in IEC 60559:2011. TR 24732, for which technical content was completed while IEEE 754-2008 was still in the later stages of development, specifies decimal types based on IEC 60559:2011 decimal formats, though it does not include all of the operations required by IEC 60559:2011.

Purpose

The purpose of this Technical Specification is to provide a C language binding for IEC 60559:2011, based on the C11 standard, that delivers the goals of IEC 60559 to users and is feasible to implement. It is organized into five Parts.

Part 1 provides changes to C11 that cover all the requirements, plus some basic recommendations, of IEC 60559:2011 for binary floating-point arithmetic. C implementations intending to support IEC 60559:2011 are expected to conform to conditionally normative Annex F as enhanced by the changes in Part 1.

Part 2 enhances TR 24732 to cover all the requirements, plus some basic recommendations, of IEC 60559:2011 for decimal floating-point arithmetic. C implementations intending to provide an extension for decimal floating-point arithmetic supporting IEC 60559:2011 are expected to conform to Part 2.

Part 3 (Interchange and extended types), Part 4 (Supplementary functions), and Part 5 (Supplementary attributes) cover recommended features of IEC 60559:2011. C implementations intending to provide extensions for these features are expected to conform to the corresponding Parts.

Additional background on formats

The 2011 revision of the ISO/IEC 60559 standard for floating-point arithmetic introduces a variety of new formats, both fixed and extendable. The new fixed formats include

- a 128-bit basic binary format (the 32 and 64 bit basic binary formats are carried over from ISO/IEC 60559:1989)
- 64 and 128 bit basic decimal formats
- interchange formats, whose precision and range are determined by the width $k$, where
  - for binary, $k = 16, 32, 64$, and $k \geq 128$ and a multiple of 32, and
  - for decimal, $k \geq 32$ and a multiple of 32
- extended formats, for each basic format, with minimum range and precision specified

Thus IEC 60559 defines five basic formats - binary32, binary64, binary128, decimal64, and decimal128 - and five corresponding extended formats, each with somewhat more precision and range than the basic format it extends. IEC 60559 defines an unlimited number of interchange formats, which include the basic formats.

Interchange formats may or may not be supported as arithmetic formats. If not, they may be used for the interchange of floating-point data but not for arithmetic computation. IEC 60559 provides conversions between non-arithmetic interchange formats and arithmetic formats which can be used for computation.

Extended formats are intended for intermediate computation, not input or output data. The extra precision often allows the computation of extended results which when converted to a narrower output format differ from the ideal results by little more than a unit in the last place. Also, the extra range often avoids any intermediate overflow or underflow that might occur if the computation were done in the format of the data. The essential property of extended formats is their sufficient extra widths, not their specific widths. Extended formats for any given basic format may vary among implementations.

Extendable formats, which provide user control over range and precision, are not covered in Technical Specification 18661.

The 32 and 64 bit binary formats are supported in C by types `float` and `double`. If a C implementation defines the macro `__STDC_IEC_60559_BFP__` (see Part 1 of Technical Specification 18661) signifying that it
supports Annex F of the C Standard, then its float and double formats must be IEC 60559 binary32 and binary64.

Part 2 of Technical Specification 18661 defines types _Decimal32, _Decimal64, and _Decimal128 with IEC 60559 formats decimal32, decimal64, and decimal128. Although IEC 60559 does not require arithmetic support (other than conversions) for its decimal32 interchange format, Part 2 of Technical Specification 18661 has full arithmetic and library support for _Decimal32, just like for _Decimal64 and _Decimal128.

The C Standard provides just three standard floating types (float, double, and long double) that are required of all implementations. Annex F of the C Standard requires the standard floating types to be binary. The long double type must be at least as wide as double, but C does not further specify details of its format, even in Annex F.

Part 3 of Technical Specification 18661, this document, provides nomenclatures for types with IEC 60559 arithmetic interchange formats and extended formats. The nomenclatures allow portable use of the formats as envisioned in IEC 60559. This document covers these aspects of the types:

- names
- characteristics
- conversions
- constants
- function suffixes
- character sequence conversion interfaces

This specification includes interchange and extended nomenclatures for formats that, in some cases, already have C nomenclatures. For example, types with the IEC 60559 double format may include double, _float64 (the type for the binary64 interchange format), and maybe _float32x (the type for the binary32-extended format). This redundancy is intended to support the different programming models appropriate for the types with arithmetic interchange formats and extended formats and C standard floating types.

This document also supports the IEC 60559 non-arithmetic interchange formats with functions that convert among encodings and between encodings and character sequences, for all interchange formats.
Information Technology — Programming languages, their environments, and system software interfaces — Floating-point extensions for C — Part 3: Interchange and extended types

1 Scope

This document, Part 3 of Technical Specification 18661, extends programming language C to include types with the arithmetic interchange and extended floating-point formats specified in ISO/IEC/IEEE 60559:2011, and to include functions that support the non-arithmetic interchange formats in that standard.

2 Conformance

An implementation conforms to Part 3 of Technical Specification 18661 if

a) It meets the requirements for a conforming implementation of C11 with all the changes to C11 as specified in Parts 1-3 of Technical Specification 18661;

b) It conforms to Part 1 or Part 2 (or both) of Technical Specification 18661; and

c) It defines __STDC_IEC_60559_TYPES__ to 201.8mm.

3 Normative references

The following referenced documents are indispensable for the application of this document. Only the editions cited apply.

ISO/IEC 9899:2011, Information technology — Programming languages, their environments and system software interfaces — Programming Language C

ISO/IEC 9899:2011/Cor.1:2012, Technical Corrigendum 1


ISO/IEC 18661-1:yyyy, Information Technology — Programming languages, their environments, and system software interfaces — Floating-point extensions for C — Part 1: Binary floating-point arithmetic

ISO/IEC 18661-2:yyyy, Information Technology — Programming languages, their environments, and system software interfaces — Floating-point extensions for C — Part 2: Decimal floating-point arithmetic


4 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 9899:2011 and ISO/IEC/IEEE 60559:2011 and the following apply.

5 C standard conformance

5.1 Freestanding implementations

The specification in C11 + TS18661-1 + TS18661-2 allows freestanding implementations to conform to this Part of Technical Specification 18661.

5.2 Predefined macros

Change to C11 + TS18661-1 + TS18661-2:

In 6.10.8.3#1, add:

```c
__STDC_IEC_60559_TYPES__
```

The integer constant 201ymml, intended to indicate support of interchange and extended floating types according to IEC 60559.

5.3 Standard headers

The new identifiers added to C11 library headers by this Part of Technical Specification 18661 are defined or declared by their respective headers only if __STDC_WANT_IEC_60559_TYPES_EXT__ is defined as a macro at the point in the source file where the appropriate header is first included. The following changes to C11 + TS18661-1 + TS18661-2 list these identifiers in each applicable library subclause.

Changes to C11 + TS18661-1 + TS18661-2:

After 5.2.4.2.2#6b, insert the paragraph:

```
[6c] The following identifiers are defined only if __STDC_WANT_IEC_60559_TYPES_EXT__ is defined as a macro at the point in the source file where <float.h> is first included:
```

for supported types _FloatN:

```
FLT\N\_MANT\_DIG   FLT\N\_MIN\_10\_EXP   FLT\N\_EPSILON
FLT\N\_DECIMAL\_DIG FLT\N\_MAX\_EXP   FLT\N\_MIN
FLT\N\_DIG         FLT\N\_MAX\_10\_EXP  FLT\N\_TRUE\_MIN
FLT\N\_MIN\_EXP    FLT\N\_MAX
```

for supported types _FloatNx:

```
FLT\NX\_MANT\_DIG   FLT\NX\_MIN\_10\_EXP  FLT\NX\_EPSILON
FLT\NX\_DECIMAL\_DIG FLT\NX\_MAX\_EXP   FLT\NX\_MIN
FLT\NX\_DIG         FLT\NX\_MAX\_10\_EXP  FLT\NX\_TRUE\_MIN
FLT\NX\_MIN\_EXP    FLT\NX\_MAX
```

for supported types _DecimalN, where N ≠ 32, 64, and 128:

```
DEC\N\_MANT\_DIG   DEC\N\_MAX   DEC\N\_TRUE\_MIN
DEC\N\_MIN\_EXP    DEC\N\_EPSILON
DEC\N\_MAX\_EXP    DEC\N\_MIN
```
for supported types _DecimalNx:

\[
\begin{array}{ccc}
\text{DEC\text{\textunderscore}N\text{\textunderscore}MANT\_DIG} & \text{DEC\text{\textunderscore}N\text{\textunderscore}MAX} & \text{DEC\text{\textunderscore}N\text{\textunderscore}TRUE\_MIN} \\
\text{DEC\text{\textunderscore}N\text{\textunderscore}MIN\_EXP} & \text{DEC\text{\textunderscore}N\text{\textunderscore}EPSILON} & \\
\text{DEC\text{\textunderscore}N\text{\textunderscore}MAX\_EXP} & \text{DEC\text{\textunderscore}N\text{\textunderscore}MIN} \\
\end{array}
\]

5 After 7.3#2, insert the paragraph:

[2a] The following identifiers are declared or defined only if __STDC_WANT_IEC_60559_TYPES_EXT__ is defined as a macro at the point in the source file where <complex.h> is first included:

for supported types _FloatN:

\[
\begin{align*}
\text{cacosfN} & \quad \text{catanhfN} & \quad \text{csqrtfN} \\
\text{casinfN} & \quad \text{ccoshfN} & \quad \text{cargfN} \\
\text{catanfN} & \quad \text{csinhfN} & \quad \text{cinagfN} \\
\text{ccosfN} & \quad \text{ctanhfN} & \quad \text{CMPLXFN} \\
\end{align*}
\]

10 \text{csinfN} \quad \text{cexpfN} \quad \text{conjfN} \\
15 \text{ctanfN} \quad \text{cloqfN} \quad \text{cprojfN} \\
\text{ccoshfN} \quad \text{cabsfN} \quad \text{crealfN} \\
\text{casinhfN} \quad \text{cpowfN}

20 for supported types _FloatN\text{\textunderscore}X:

\[
\begin{align*}
\text{cacosfN} & \quad \text{catanhfN} & \quad \text{csqrtfN} \\
\text{casinfN} & \quad \text{ccoshfN} & \quad \text{cargfN} \\
\text{catanfN} & \quad \text{csinhfN} & \quad \text{cinagfN} \\
\text{ccosfN} & \quad \text{ctanhfN} & \quad \text{CMPLXFN} \\
\end{align*}
\]

\[
\begin{align*}
\text{csinfN} & \quad \text{cexpfN} & \quad \text{conjfN} \\
\text{ctanfN} & \quad \text{cloqfN} & \quad \text{cprojfN} \\
\text{ccoshfN} & \quad \text{cabsfN} & \quad \text{crealfN} \\
\text{casinhfN} & \quad \text{cpowfN}
\end{align*}
\]

25

25 After 7.12#1c, insert the paragraph:

[1d] The following identifiers are defined or declared only if __STDC_WANT_IEC_60559_TYPES_EXT__ is defined as a macro at the point in the source file where <math.h> is first included:
for supported types `_FloatN`:

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>modffN</td>
<td>trunctfN</td>
</tr>
<tr>
<td>scalbnfN</td>
<td>llrintfN</td>
</tr>
<tr>
<td>cbrtfN</td>
<td>lroundfN</td>
</tr>
<tr>
<td>fabsfN</td>
<td>totalorderfN</td>
</tr>
<tr>
<td>hypotfN</td>
<td>totalordermagfN</td>
</tr>
<tr>
<td>powfN</td>
<td>fmaxfN</td>
</tr>
<tr>
<td>sqrtfN</td>
<td>fminfN</td>
</tr>
<tr>
<td>erfN</td>
<td>getpayloadfN</td>
</tr>
<tr>
<td>erfcfN</td>
<td>setpayloadfN</td>
</tr>
<tr>
<td>lgammafN</td>
<td>canonicalizefN</td>
</tr>
<tr>
<td>tgammafN</td>
<td>decodefN</td>
</tr>
<tr>
<td>floorfN</td>
<td>fdimfN</td>
</tr>
<tr>
<td>nearbyintfN</td>
<td>fmaxmagfN</td>
</tr>
<tr>
<td>ceilfN</td>
<td>fminmagfN</td>
</tr>
<tr>
<td>roundfN</td>
<td>fmafN</td>
</tr>
<tr>
<td>lroundfN</td>
<td>totalorderfN</td>
</tr>
<tr>
<td>lroundfN</td>
<td>totalordermagfN</td>
</tr>
<tr>
<td>truncfN</td>
<td>getpayloadfN</td>
</tr>
<tr>
<td>roundevenfN</td>
<td>setpayloadfN</td>
</tr>
<tr>
<td>fromfpfN</td>
<td>setpayloadfN</td>
</tr>
</tbody>
</table>

for supported types `_FloatNx`:

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>modffNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>scalbnfNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>cbrtfNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>fabsfNx</td>
<td>fromfpfNx</td>
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<tr>
<td>hypotfNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>powfNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>sqrtfNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>erfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>erfcfNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>lgammafNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>tgammafNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>floorfNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>nearbyintfN</td>
<td>fromfpfNx</td>
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<td>roundfNx</td>
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<td>fromfpfNx</td>
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<tr>
<td>truncfNx</td>
<td>fromfpfNx</td>
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<tr>
<td>roundevenfNx</td>
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<tr>
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<td>roundfNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
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<td>fromfpfNx</td>
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<tr>
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<td>fromfpfNx</td>
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<tr>
<td>totalorderfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>getpayloadfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>setpayloadfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>fmaxmagfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>fminmagfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>fmafN</td>
<td>fromfpfNx</td>
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<tr>
<td>totalorderfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>totalordermagfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>getpayloadfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>setpayloadfN</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>fminfN</td>
<td>fromfpfNx</td>
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<tr>
<td>fromfpfNx</td>
<td>fromfpfNx</td>
</tr>
<tr>
<td>fromfpfNx</td>
<td>fromfpfNx</td>
</tr>
</tbody>
</table>

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for supported types \_FloatM and \_FloatN where M < N:

\[ fMaddfN \quad fMmulfN \quad fMsqrtfN \]
\[ fMsubfN \quad fMdivfN \quad fMfmafN \]

for supported types \_FloatM and \_FloatNx where M ≤ N:

\[ fMaddfNx \quad fMmulfNx \quad fMsqrtfNx \]
\[ fMsubfNx \quad fMdivfNx \quad fMfmafNx \]

for supported types \_FloatMx and \_FloatN where M < N:

\[ fMxaddfN \quad fMxmulfN \quad fMxsqrtfN \]
\[ fMxsubfN \quad fMxdivfN \quad fMxfmafN \]

for supported types \_FloatMx and \_FloatNx where M < N:

\[ fMxaddfNx \quad fMxmulfNx \quad fMxsqrtfNx \]
\[ fMxsubfNx \quad fMxdivfNx \quad fMxfmafNx \]

for supported IEC 60559 arithmetic or non-arithmetic binary interchange formats of widths M and N:

\[ fMencfN \]

for supported types \_DecimalN, where N ≠ 32, 64, and 128:

\[ \text{HUGE\_VAL\_DN} \quad \text{scalblndN} \quad \text{remquodN} \]
\[ \text{SNAND} \quad \text{cbrtdN} \quad \text{copysigndN} \]
\[ \text{FP\_FAST\_FMADN} \quad \text{fabsdN} \quad \text{nandN} \]
\[ \text{acosdN} \quad \text{hypotdN} \quad \text{nextafterdN} \]
\[ \text{asindN} \quad \text{powdN} \quad \text{nextupdN} \]
\[ \text{atanandN} \quad \text{sqrtN} \quad \text{nextdowndN} \]
\[ \text{atan2dN} \quad \text{erfdN} \quad \text{canonicalizedN} \]
\[ \text{cosdN} \quad \text{ercfdN} \quad \text{quantizedN} \]
\[ \text{sindN} \quad \text{lgammaandN} \quad \text{samequantumN} \]
\[ \text{tandN} \quad \text{tgammaandN} \quad \text{quantumN} \]
\[ \text{acoshdN} \quad \text{ceildN} \quad \text{lquantexpdN} \]
\[ \text{asinhdN} \quad \text{floordN} \quad \text{encodedcNd} \]
\[ \text{atanhdN} \quad \text{nearbyintdN} \quad \text{decodedcNd} \]
\[ \text{expdN} \quad \text{rintdN} \quad \text{encodebindN} \]
\[ \text{exp2dN} \quad \text{lrintdN} \quad \text{decodebindN} \]
\[ \text{expmlN} \quad \text{llrintdN} \quad \text{fdimdN} \]
\[ \text{frexpN} \quad \text{rounddN} \quad \text{fmadN} \]
\[ \text{i1ogbdN} \quad \text{lrounddN} \quad \text{fmindN} \]
\[ \text{ilogbdN} \quad \text{lrounddN} \quad \text{fmaxmagdN} \]
\[ \text{idexpdN} \quad \text{truncdN} \quad \text{fminmagdN} \]
\[ \text{logdN} \quad \text{roundevendN} \quad \text{fmadN} \]
\[ \text{log10dN} \quad \text{fromfpdN} \quad \text{totalorderdN} \]
\[ \text{log1pdN} \quad \text{ufromfpdN} \quad \text{totalordermagdN} \]
\[ \text{log2dN} \quad \text{fromfpxdN} \quad \text{getpayloaddN} \]
\[ \text{logbdN} \quad \text{ufromfpxdN} \quad \text{setpayloaddN} \]
\[ \text{modfN} \quad \text{fmoddN} \quad \text{setpayloadsigdN} \]
\[ \text{scalbndN} \quad \text{remainderdN} \]
for supported types _DecimalNx:

```plaintext
HUGE_VAL_DNx scalbnNx fmoddNx
SNANDNx scalblndNx remainderdNx
FP_FAST_FMADNx cbrtdNx remquodNx
5 acosdNx fabsdNx copysigndNx
asindNx hypotdNx nandNx
atandNx powdNx nextafterdNx
atan2dNx sqrtldNx nextupdNx
cosdNx erfdNx nextdowndNx
10 sindNx erfcdNx canonicalizedNx
tandNx lgammadNx quantizedNx
acoshdNx tgammaNdNx samequantumdNx
asinhdNx ceilNdNx quantumdNx
atanhdNx fmoddNx llquantexpdNx
15 expdNx nearbyintdNx fdimdNx
exp2dNx rintdNx fmaedxNx
expmdNx lrintdNx fmindNx
frexpddNx llrintdNx fmaxmagdNx
ilogbdNx rounddNx fminmagdNx
llogbdNx lrounddNx fmadNx
ldeexpdNx llrounddNx totalorderdNx
logdNx truncated Nx totalordermagdNx
log10dNx roundevenNdNx getpayloadNdNx
log1pdNx fromfpdNx setpayloadNdNx
25 log2dNx ufromfpdNx setpayloadsigdNx
logbdNx fromfpxdNx
modfdNx ufromfpxdNx
```

for supported types _DecimalM and _DecimalN where M < N and M and N are not both one of 32, 64, and 128:

```plaintext
30 FP_FAST_DADDNN FP_FAST_DMSQRTDN dMmuldN
FP_FAST_DMSUBDNN FP_FAST_DFMADNN dMdivdN
FP_FAST_DMMULDN dMaddN dMsqrdN
FP_FAST_DMDIVDN dMsubdN dMfmadN
```

for supported types _DecimalM and _DecimalNx where M ≤ N:

```plaintext
35 FP_FAST_DADDNX FP_FAST_DMSQRTDNX dMmuldNx
FP_FAST_DMSUBNX FP_FAST_DFMADNX dMdivdNx
FP_FAST_DMMULNX dMaddNx dMsqrdNx
FP_FAST_DDIVNX dMsubdNx dMfmadNx
```

for supported types _DecimalMx and _DecimalN where M < N:

```plaintext
40 FP_FAST_DXADDN FP_FAST_DXSQRTDN dMxmuldN
FP_FAST_DXSUBDNN FP_FAST_DXFADNX dMxdivdN
FP_FAST_DXMSUBDNN dMxadddN dMxsqrdN
FP_FAST_DXDIVDN dMxsubdN dMxfmadN
```
for supported types \_DecimalMx and \_DecimalNx where $M < N$:

\[
\begin{align*}
\text{FP\_FAST\_D}M\text{X} & \text{ADD}\_D & \text{FP\_FAST\_D}M\text{X} & \text{SQRT}\_D & dM\text{xmul}\_D \\
\text{FP\_FAST\_D}M\text{X} & \text{SUB}\_D & \text{FP\_FAST\_D}M\text{X} & \text{FMAD}\_D & dM\text{xdiv}\_D \\
\text{FP\_FAST\_D}M\text{X} & \text{MUL}\_D & dM\text{xadd}\_D & dM\text{xsq}\_D & dM\text{xsqrt}\_D \\
\text{FP\_FAST\_D}M\text{X} & \text{DIV}\_D & dM\text{xsub}\_D & dM\text{xdiv}\_D & dM\text{xfmad}\_D
\end{align*}
\]

for supported IEC 60559 arithmetic and non-arithmetic decimal interchange formats of widths $M$ and $N$:

\[
\begin{align*}
dM\text{enc}\_\text{d} & \text{d} & dM\text{enc}\_\text{bind} & \text{N} \\
\end{align*}
\]

After 7.22#1b, insert the paragraph:

[1c] The following identifiers are declared only if \_\_STDC\_WANT\_IEC\_60559\_TYPES\_EXT\_ is defined as a macro at the point in the source file where <stdlib.h> is first included:

for supported types \_Float\_N:

\[
\begin{align*}
\text{strfrom} & \text{f} \_N & \text{strto} & \text{f} \_N \\
\end{align*}
\]

for supported types \_Float\_Nx:

\[
\begin{align*}
\text{strfrom} & \text{f} \_N \_x & \text{strto} & \text{f} \_N \_x \\
\end{align*}
\]

for supported types \_Decimal\_N, where $N \neq 32, 64, \text{ and } 128$:

\[
\begin{align*}
\text{strfrom} & \text{d} \_N & \text{strtod} & \_N \\
\end{align*}
\]

for supported types \_Decimal\_Nx:

\[
\begin{align*}
\text{strfrom} & \text{d} \_N \_x & \text{strtod} & \_N \_x \\
\end{align*}
\]

for supported IEC 60559 arithmetic and non-arithmetic binary interchange formats of width $N$:

\[
\begin{align*}
\text{strfrom} & \text{enc} & \text{f} \_N \_x & \text{strto} & \text{enc} \_f \_N \_x \\
\text{strfrom} & \text{enc} & \text{bind} \_N & \text{strto} & \text{enc} \_\text{bind} \_N \\
\end{align*}
\]

6 Types

This clause specifies changes to C11 + TS18661-1 + TS18661-2 to include types that support the arithmetic interchange formats and extended formats specified in IEC 60559. The encoding conversion functions (11.3) and numeric conversion functions for encodings (12) support the non-arithmetic interchange formats specified in IEC 60559.

30 Changes to C11 + TS18661-1 + TS18661-2:

Replace 6.2.5#10a-10b:

[10a] There are three decimal floating types, designated as \_Decimal32, \_Decimal64, and \_Decimal128. Respectively, they have the IEC 60559 formats: decimal32, decimal64, and decimal128. Decimal floating types are real floating types.
[10b] Together, the standard floating types and the decimal floating types comprise the real floating types.

with:

[10a] IEC 60559 specifies interchange formats, identified by their width, which can be used for the exchange of floating-point data between implementations. The two tables below give parameters for the IEC 60559 interchange formats.

**Table 1 – Binary interchange format parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>binary16</th>
<th>binary32</th>
<th>binary64</th>
<th>binary128</th>
<th>binaryN (N ≥ 128)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N, storage width in bits</td>
<td>16</td>
<td>32</td>
<td>64</td>
<td>128</td>
<td>multiple of 32</td>
</tr>
<tr>
<td>p, precision in bits</td>
<td>11</td>
<td>24</td>
<td>53</td>
<td>113</td>
<td>N (\text{round}(4\times\log_2(N)) + 13)</td>
</tr>
<tr>
<td>emax, maximum exponent e</td>
<td>15</td>
<td>127</td>
<td>1023</td>
<td>16383</td>
<td>(2^{(e_{\text{max}}-1)} - 1)</td>
</tr>
</tbody>
</table>

**Encoding parameters**

| bias, E=e                  | 15       | 127      | 1023     | 16383      | emax              |
| sign bit                   | 1        | 1        | 1        | 1          | 1                 |
| w, exponent field width in bits | 5       | 8        | 11       | 15         | \(\text{round}(4\times\log_2(N)) - 13\) |
| t, trailing significand field width in bits | 10      | 23       | 52       | 112        | \(N - w - 1\)     |
| N, storage width in bits   | 16       | 32       | 64       | 128        | 1 + w + t         |

The function round() in the table above rounds to the nearest integer. For example, binary256 would have \(p = 237\) and \(emax = 262143\).

**Table 2 – Decimal interchange format parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>decimal32</th>
<th>decimal64</th>
<th>decimal128</th>
<th>decimalN (N ≥ 32)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N, storage width in bits</td>
<td>32</td>
<td>64</td>
<td>128</td>
<td>multiple of 32</td>
</tr>
<tr>
<td>p, precision in digits</td>
<td>7</td>
<td>16</td>
<td>34</td>
<td>(9 \times N/32 - 2)</td>
</tr>
<tr>
<td>emax, maximum exponent e</td>
<td>96</td>
<td>384</td>
<td>6144</td>
<td>(3 \times 2^{(e_{\text{max}}/16 - 3)})</td>
</tr>
</tbody>
</table>

**Encoding parameters**

| bias, E=e                  | 101       | 398       | 6176        | emax + p - 2      |
| sign bit                   | 1         | 1         | 1           | 1                  |
| w, exponent field width in bits | 11       | 13        | 17          | \(N/16 + 9\)      |
| t, trailing significand field width in bits | 20      | 50        | 110         | \(15 \times N/16 - 10\) |
| N, storage width in bits   | 32        | 64        | 128         | 1 + 5 + w + t     |

For example, decimal256 would have \(p = 70\) and \(emax = 1572864\).
[10b] Types designated

```plaintext
_FloatN, where N is 16, 32, 64, or ≥ 128 and a multiple of 32
```

and types designated

```plaintext
_DecimalN, where N ≥ 32 and a multiple of 32
```

are collectively called the interchange floating types. Each interchange floating type has the IEC 60559 interchange format corresponding to its width (N) and radix (2 for _FloatN, 10 for _DecimalN). Interchange floating types are not compatible with any other types.

[10c] An implementation that defines `__STDC_IEC_60559_BFP__` and `__STDC_IEC_60559_TYPES__` shall provide _Float32 and _Float64 as interchange floating types with the same representation and alignment requirements as float and double, respectively. If the implementation’s `long double` type supports an IEC 60559 interchange format of width N > 64, then the implementation shall also provide the type _FloatN as an interchange floating type with the same representation and alignment requirements as long double. The implementation may provide other binary interchange floating types.

[10d] An implementation that defines `__STDC_IEC_60559_DFP__` shall provide the types _Decimal32, _Decimal64, and _Decimal128. If the implementation also defines `__STDC_IEC_60559_TYPES__`, it may provide other decimal interchange floating types.

[10e] Note that providing an interchange floating type entails supporting it as an IEC 60559 arithmetic format. An implementation supports IEC 60559 non-arithmetic interchange formats by providing the associated encoding-to-encoding conversion functions (7.12.11.7c), string-to-encoding functions (7.22.1.3c), and string-from-encoding functions (7.22.1.3d). An implementation that defines `__STDC_IEC_60559_TYPES__` shall support the IEC 60559 binary16 format, at least as a non-arithmetic interchange format.

[10f] For each of its basic formats, IEC 60559 specifies an extended format whose maximum exponent and precision exceed those of the basic format it is associated with. The table below gives the minimum values of these parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>binary32</th>
<th>binary64</th>
<th>binary128</th>
<th>decimal64</th>
<th>decimal128</th>
</tr>
</thead>
<tbody>
<tr>
<td>p digits ≥</td>
<td>32</td>
<td>64</td>
<td>128</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>emax ≥</td>
<td>1023</td>
<td>16383</td>
<td>65535</td>
<td>6144</td>
<td>24576</td>
</tr>
</tbody>
</table>

[10g] Types designated _Float32x, _Float64x, _Float128x, _Decimal64x, and _Decimal128x support the corresponding IEC 60559 extended formats and are collectively called the extended floating types. Extended floating types are not compatible with any other types. An implementation that defines `__STDC_IEC_60559_BFP__` and `__STDC_IEC_60559_TYPES__` shall provide _Float32x, which may have the same set of values as `double`, and may provide any of the other two binary extended floating types. An implementation that defines `__STDC_IEC_60559_DFP__` and `__STDC_IEC_60559_TYPES__` shall provide: _Decimal64x, which may have the same set of values as _Decimal128, and may provide _Decimal128x.

[10h] The standard floating types, interchange floating types, and extended floating types are collectively called the real floating types.

[10i] The interchange floating types designated _FloatN and the extended floating types designated _FloatNx are collectively called the binary floating types. The interchange floating types designated
_DecimalN and the extended floating types designated _DecimalNx are collectively called the decimal floating types. Thus the binary floating types and the decimal floating types are real floating types.

Replace 6.2.5#11:

5 [11] There are three complex types, designated as float _Complex, double _Complex, and long double _Complex.43) (Complex types are a conditional feature that implementations need not support; see 6.10.8.3.) The real floating and complex types are collectively called the floating types.

with:

10 [11] For the standard real types float, double, and long double, the interchange floating types _FloatN, and the extended floating types _FloatNx, there are complex types designated respectively as float _Complex, double _Complex, long double _Complex, _FloatN _Complex, and _FloatNx _Complex. 43) (Complex types are a conditional feature that implementations need not support; see 6.10.8.3.) The real floating and complex types are collectively called the floating types.

In the list of keywords in 6.4.1, replace:

    _Decimal32
    _Decimal64
    _Decimal128

with:

    _FloatN, where N is 16, 32, 64, or ≥ 128 and a multiple of 32
    _Float32x
    _Float64x
    _Float128x

25 _DecimalN, where N ≥ 32 and a multiple of 32
    _Decimal64x
    _Decimal128x

In the list of type specifiers in 6.7.2, replace:

30 _Decimal32
    _Decimal64
    _Decimal128

with:

35 _FloatN, where N is 16, 32, 64, or ≥ 128 and a multiple of 32
    _Float32x
    _Float64x
    _Float128x
    _DecimalN, where N ≥ 32 and a multiple of 32
    _Decimal64x
    _Decimal128x
In the list of constraints in 6.7.2#2, replace:

- _Decimal32
- _Decimal64
- _Decimal128

with:

- _Float$N$, where $N$ is 16, 32, 64, or $\geq 128$ and a multiple of 32
- _Float32x
- _Float64x
- _Float128x

10 - _Decimal$N$, where $N$ $\geq$ 32 and a multiple of 32
- _Decimal64x
- _Decimal128x
- _Float$N$ _Complex, where $N$ is 16, 32, 64, or $\geq 128$ and a multiple of 32
- _Float32x _Complex

15 - _Float64x _Complex
- _Float128x _Complex

Replace 6.7.2#3a:

[3a] The type specifiers _Decimal32, _Decimal64, and _Decimal128 shall not be used if the implementation does not support decimal floating types (see 6.10.8.3).

20 with:

[3a] The type specifiers _Float$N$ (where $N$ is 16, 32, 64, or $\geq 128$ and a multiple of 32), _Float32x, _Float64x, _Float128x, _Decimal$N$ (where $N$ $\geq$ 32 and a multiple of 32), _Decimal64x, and _Decimal128x shall not be used if the implementation does not support the corresponding types (see 6.10.8.3).

25 Replace 6.5#8a:

[8a] Operators involving decimal floating types are evaluated according to the semantics of IEC 60559, including production of results with the preferred quantum exponent as specified in IEC 60559.

with:

30 [8a] Operators involving operands of interchange or extended floating type are evaluated according to the semantics of IEC 60559, including production of decimal floating-point results with the preferred quantum exponent as specified in IEC 60559 (see 5.2.4.2.2b).
Replace G.2#2:

[2] There are three imaginary types, designated as float _Imaginary, double _Imaginary, and long double _Imaginary. The imaginary types (along with the real floating and complex types) are floating types.

with:

[2] For the standard floating types float, double, and long double, the interchange floating types _FloatN, and the extended floating types _FloatNx, there are imaginary types designated respectively as float _Imaginary, double _Imaginary, long double _Imaginary, _FloatN _Imaginary, and _FloatNx _Imaginary. The imaginary types (along with the real floating and complex types) are floating types.

7 Characteristics

This clause specifies new <float.h> macros, analogous to the macros for standard floating types, that characterize the interchange and extended floating types. Some specification for decimal floating types introduced in Part 2 of Technical Specification 18661 is subsumed under the general specification for interchange floating types.

Changes to C11 + TS18661-1 + TS18661-2:

Renumber and rename 5.2.4.2.2a:

5.2.4.2.2a Characteristics of decimal floating types in <float.h>

to:

5.2.4.2.2b Alternate model for decimal floating-point numbers

and remove paragraphs 1-3:

[1] This subclause specifies macros in <float.h> that provide characteristics of decimal floating types in terms of the model presented in 5.2.4.2.2. The prefixes DEC32_, DEC64_, and DEC128_ denote the types _Decimal32, _Decimal64, and _Decimal128 respectively.

[2] DEC_EVAL_METHOD is the decimal floating-point analogue of FLT_EVAL_METHOD (5.2.4.2.2). Its implementation-defined value characterizes the use of evaluation formats for decimal floating types:

-1 indeterminable;
0 evaluate all operations and constants just to the range and precision of the type;
1 evaluate operations and constants of type _Decimal32 and _Decimal64 to the range and precision of the _Decimal64 type, evaluate _Decimal128 operations and constants to the range and precision of the _Decimal128 type;
2 evaluate all operations and constants to the range and precision of the _Decimal128 type.

[3] The integer values given in the following lists shall be replaced by constant expressions suitable for use in #if preprocessing directives:

— radix of exponent representation, b(=10)

For the standard floating types, this value is implementation-defined and is specified by the macro FLT_RADIX. For the decimal floating types there is no corresponding macro, since the value 10
is an inherent property of the types. Wherever \texttt{FLT\_RADIX} appears in a description of a function that has versions that operate on decimal floating point types, it is noted that for the decimal floating-point versions the value used is implicitly 10, rather than \texttt{FLT\_RADIX}.

- number of digits in the coefficient
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC32_MANT_DIG</td>
<td>7</td>
</tr>
<tr>
<td>DEC64_MANT_DIG</td>
<td>16</td>
</tr>
<tr>
<td>DEC128_MANT_DIG</td>
<td>34</td>
</tr>
</tbody>
</table>

- minimum exponent
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC32_MIN_EXP</td>
<td>-94</td>
</tr>
<tr>
<td>DEC64_MIN_EXP</td>
<td>-382</td>
</tr>
<tr>
<td>DEC128_MIN_EXP</td>
<td>-6142</td>
</tr>
</tbody>
</table>

- maximum exponent
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC32_MAX_EXP</td>
<td>97</td>
</tr>
<tr>
<td>DEC64_MAX_EXP</td>
<td>385</td>
</tr>
<tr>
<td>DEC128_MAX_EXP</td>
<td>6145</td>
</tr>
</tbody>
</table>

- maximum representable finite decimal floating-point number (there are 6, 15 and 33 9's after the decimal points respectively)
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC32_MAX</td>
<td>9.999999999999999996DF</td>
</tr>
<tr>
<td>DEC64_MAX</td>
<td>9.99999999999999999999999999999999E384DD</td>
</tr>
<tr>
<td>DEC128_MAX</td>
<td>9.999999999999999999999999999999999999999999999E6144DL</td>
</tr>
</tbody>
</table>

- the difference between 1 and the least value greater than 1 that is representable in the given floating type
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC32_EPSILON</td>
<td>1E-6DF</td>
</tr>
<tr>
<td>DEC64_EPSILON</td>
<td>1E-15DD</td>
</tr>
<tr>
<td>DEC128_EPSILON</td>
<td>1E-33DL</td>
</tr>
</tbody>
</table>

- minimum normalized positive decimal floating-point number
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC32_MIN</td>
<td>1E-95DF</td>
</tr>
<tr>
<td>DEC64_MIN</td>
<td>1E-383DD</td>
</tr>
<tr>
<td>DEC128_MIN</td>
<td>1E-6143DL</td>
</tr>
</tbody>
</table>

- minimum positive subnormal decimal floating-point number
  
<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC32_TRUE_MIN</td>
<td>0.000001E-95DF</td>
</tr>
<tr>
<td>DEC64_TRUE_MIN</td>
<td>0.0000000000000000000000000000000000000001E-383DD</td>
</tr>
<tr>
<td>DEC128_TRUE_MIN</td>
<td>0.000000000000000000000000000000000000000000000000000001E-6143DL</td>
</tr>
</tbody>
</table>

After 5.2.4.2.2, insert:

**5.2.4.2.2a Characteristics of interchange and extended floating types in \texttt{<float.h>**

[1] This subclause specifies macros in \texttt{<float.h>} that provide characteristics of interchange floating types and extended floating types in terms of the model presented in 5.2.4.2.2. The prefix \texttt{FLT\_N\_} indicates a binary interchange floating type of width \(N\). The prefix \texttt{FLT\_N\_X\_} indicates a binary extended floating type that extends a basic format of width \(N\). The prefix \texttt{DEC\_N\_} indicates a decimal interchange floating type of width \(N\). The prefix \texttt{DEC\_N\_X\_} indicates a decimal extended floating type that extends a basic format of width \(N\). The type parameters \(p\), \(\theta_{\text{max}}\), and \(\theta_{\text{min}}\) for extended floating types are for the extended floating type itself, not for the basic format that it extends. For each
interchange or extended floating type that the implementation provides, `<float.h>` shall define the associated macros in the following lists. Conversely, for each such type that the implementation does not provide, `<float.h>` shall not define the associated macros in the following lists.

[2] If `FLT_RADIX` is 2, the value of the macro `FLT_EVAL_METHOD` (5.2.4.2.2) characterizes the use of evaluation formats for standard floating types and for binary interchange and extended floating types:

-1 indeterminable;

0 evaluate all operations and constants, whose semantic type has at most the range and precision of `float`, to the range and precision of `float`; evaluate all other operations and constants to the range and precision of the semantic type;

1 evaluate operations and constants, whose semantic type has at most the range and precision of `double`, to the range and precision of `double`; evaluate all other operations and constants to the range and precision of the semantic type;

2 evaluate operations and constants, whose semantic type has at most the range and precision of `long double`, to the range and precision of `long double`; evaluate all other operations and constants to the range and precision of the semantic type;

`N`, where `_FloatN` is a supported interchange floating type
evaluate operations and constants, whose semantic type has at most the range and precision of the `_FloatN` type, to the range and precision of the `_FloatN` type; evaluate all other operations and constants to the range and precision of the semantic type;

`N + 1`, where `_FloatNx` is a supported extended floating type
evaluate operations and constants, whose semantic type has at most the range and precision of the `_FloatNx` type, to the range and precision of the `_FloatNx` type; evaluate all other operations and constants to the range and precision of the semantic type.

If `FLT_RADIX` is not 2, the use of evaluation formats for operations and constants of binary interchange and extended floating types is implementation-defined.

[3] The implementation-defined value of the macro `DEC_EVAL_METHOD` characterizes the use of evaluation formats (see analogous `FLT_EVAL_METHOD` in 5.2.4.2.2) for decimal interchange and extended floating types:

-1 indeterminable;

0 evaluate all operations and constants just to the range and precision of the type;

1 evaluate operations and constants, whose semantic type has at most the range and precision of the `_Decimal64` type, to the range and precision of the `_Decimal64` type; evaluate all other operations and constants to the range and precision of the semantic type;

2 evaluate operations and constants, whose semantic type has at most the range and precision of the `_Decimal128` type, to the range and precision of the `_Decimal128` type; evaluate all other operations and constants to the range and precision of the semantic type;

`N`, where `_DecimalN` is a supported interchange floating type
evaluate operations and constants, whose semantic type has at most the range and precision of the `_DecimalN` type, to the range and precision of the `_DecimalN` type; evaluate all other operations and constants to the range and precision of the semantic type;
$N + 1$, where \_Decimal\N is a supported extended floating type
evaluate operations and constants, whose semantic type has at most the range and
precision of the \_Decimal\N type, to the range and precision of the \_Decimal\N type;
evaluate all other operations and constants to the range and precision of the semantic type;

[4] The integer values given in the following lists shall be replaced by constant expressions suitable
for use in \#if preprocessing directives:

— radix of exponent representation, $b$ (= 2 for binary, 10 for decimal)

For the standard floating types, this value is implementation-defined and is specified by the macro
FLT\_RADIX. For the interchange and extended floating types there is no corresponding macro,
since the radix is an inherent property of the types.

— number of decimal digits, $n$, such that any floating-point number with $p$ bits can be rounded to a
floating-point number with $n$ decimal digits and back again without change to the value,

\[ N + 1 \]

FLTN\_DECIMAL\_DIG
FLTN\_X\_DECIMAL\_DIG

— number of bits in the floating-point significand, $p$

FLTN\_MANT\_DIG
FLTN\_X\_MANT\_DIG

— number of digits in the coefficient, $p$

DECN\_MANT\_DIG
DECN\_X\_MANT\_DIG

— number of decimal digits, $n$, such that any floating-point number with $p$ bits can be rounded to a
floating-point number with $n$ decimal digits and back again without change to the value,

\[ 1 + p \log_{10} 2 \]

FLTN\_DECIMAL\_DIG
FLTN\_X\_DECIMAL\_DIG

— number of decimal digits, $q$, such that any floating-point number with $q$ decimal digits can be
rounded into a floating-point number with $p$ bits and back again without change to the $q$ decimal
digits, \[
\left\lfloor (p - 1) \log_{10} 2 \right\rfloor
\]

FLTN\_DIG
FLTN\_X\_DIG

— minimum negative integer such that the radix raised to one less than that power is a normalized
floating-point number, $e_{\text{min}}$

FLTN\_MIN\_EXP
FLTN\_X\_MIN\_EXP
DECN\_MIN\_EXP
DECN\_X\_MIN\_EXP

— minimum negative integer such that 10 raised to that power is in the range of normalized floating-
point numbers, \[
\left\lfloor \log_{10} 2^{e_{\text{min}} - 1} \right\rfloor
\]

FLTN\_MIN\_10\_EXP
FLTN\_X\_MIN\_10\_EXP
— maximum integer such that the radix raised to one less than that power is a representable finite floating-point number, \( e_{\text{max}} \)

\[
\begin{align*}
\text{FLT}_N\text{ MAX}_\text{ EXP} \\
\text{FLT}_N\text{ MAX}_\text{ EXP} \\
\text{DEC}_N\text{ MAX}_\text{ EXP} \\
\text{DEC}_N\text{ MAX}_\text{ EXP}
\end{align*}
\]

— maximum integer such that 10 raised to that power is in the range of representable finite floating-point numbers, \( \left\lfloor \log_{10}((1 - 2^{-p})2^{e_{\text{max}}}) \right\rfloor \)

\[
\begin{align*}
\text{FLT}_N\text{ MAX}_\text{ 10}_\text{ EXP} \\
\text{FLT}_N\text{ MAX}_\text{ 10}_\text{ EXP}
\end{align*}
\]

— maximum representable finite floating-point number, \((1 - b^{-p})b^{e_{\text{max}}}\)

\[
\begin{align*}
\text{FLT}_N\text{ MAX} \\
\text{FLT}_N\text{ MAX} \\
\text{DEC}_N\text{ MAX} \\
\text{DEC}_N\text{ MAX}
\end{align*}
\]

— the difference between 1 and the least value greater than 1 that is representable in the given floating-point type, \( b^{e_{\text{min}}-p} \)

\[
\begin{align*}
\text{FLT}_N\text{ EPSILON} \\
\text{FLT}_N\text{ EPSILON} \\
\text{DEC}_N\text{ EPSILON} \\
\text{DEC}_N\text{ EPSILON}
\end{align*}
\]

— minimum normalized positive floating-point number, \( b^{e_{\text{min}}-1} \)

\[
\begin{align*}
\text{FLT}_N\text{ MIN} \\
\text{FLT}_N\text{ MIN} \\
\text{DEC}_N\text{ MIN} \\
\text{DEC}_N\text{ MIN}
\end{align*}
\]

— minimum positive subnormal floating-point number, \( b^{e_{\text{min}}-p} \)

\[
\begin{align*}
\text{FLT}_N\text{ TRUE}_\text{ MIN} \\
\text{FLT}_N\text{ TRUE}_\text{ MIN} \\
\text{DEC}_N\text{ TRUE}_\text{ MIN} \\
\text{DEC}_N\text{ TRUE}_\text{ MIN}
\end{align*}
\]

With the following change, `DECIMAL_DIG` characterizes conversions of supported IEC 60559 encodings, which may be wider than supported floating types.

**Change to C11 + TS18661-1 + TS18661-2:**

In 5.2.4.2.2#11, change the bullet defining `DECIMAL_DIG` from:

— number of decimal digits, \( n \), such that any floating-point number in the widest supported floating type with …
to:

— number of decimal digits, \( n \), such that any floating-point number in the widest of the supported floating types and the supported IEC 60559 encodings with …

8 Conversions

The following change to C11 + TS18661-1 + TS18661-2 enhances the usual arithmetic conversions to handle interchange and extended floating types. IEC 60559 recommends against allowing implicit conversions of operands to obtain a common type where the conversion is between types where neither is a subset of (or equivalent to) the other. The following change supports this restriction.

Changes to C11 + TS18661-1 + TS18661-2:

Replace 6.3.1.4#1a:

- When a finite value of decimal floating type is converted to an integer type other than _Bool, the fractional part is discarded (i.e., the value is truncated toward zero). If the value of the integral part cannot be represented by the integer type, the “invalid” floating-point exception shall be raised and the result of the conversion is unspecified.

with:

- When a finite value of interchange or extended floating type is converted to an integer type other than _Bool, the fractional part is discarded (i.e., the value is truncated toward zero). If the value of the integral part cannot be represented by the integer type, the “invalid” floating-point exception shall be raised and the result of the conversion is unspecified.

Replace 6.3.1.4#2a:

- When a value of integer type is converted to a decimal floating type, if the value being converted can be represented exactly in the new type, it is unchanged. If the value being converted cannot be represented exactly, the result shall be correctly rounded with exceptions raised as specified in IEC 60559.

with:

- When a value of integer type is converted to an interchange or extended floating type, if the value being converted can be represented exactly in the new type, it is unchanged. If the value being converted cannot be represented exactly, the result shall be correctly rounded with exceptions raised as specified in IEC 60559.

In 6.3.1.8#1, replace the following items after “This pattern is called the usual arithmetic conversions:”:

If one operand has decimal floating type, the other operand shall not have standard floating, complex, or imaginary type.

First, if the type of either operand is _Decimal128, the other operand is converted to _Decimal128.

Otherwise, if the type of either operand is _Decimal64, the other operand is converted to _Decimal64.

Otherwise, if the type of either operand is _Decimal32, the other operand is converted to _Decimal32.

If there are no decimal floating types in the operands:
First, if the corresponding real type of either operand is \texttt{long double}, the other operand is converted, without change of type domain, to a type whose corresponding real type is \texttt{long double}.

Otherwise, if the corresponding real type of either operand is \texttt{double}, the other operand is converted, without change of type domain, to a type whose corresponding real type is \texttt{double}.

Otherwise, if the corresponding real type of either operand is \texttt{float}, the other operand is converted, without change of type domain, to a type whose corresponding real type is \texttt{float}.

with:

If one operand has decimal floating type, the other operand shall not have standard floating, complex, or imaginary type, nor shall it have a floating type of radix 2.

If both operands have floating types and neither of the sets of values of their corresponding real types is a subset of (or equivalent to) the other, the behavior is undefined.

Otherwise, if both operands are floating types and the sets of values of their corresponding real types are equivalent, then the following rules are applied:

If both operands have the same corresponding real type, no further conversion is needed.

Otherwise, if the corresponding real type of either operand is an interchange floating type, the other operand is converted, without change of type domain, to a type whose corresponding real type is that same interchange floating type.

Otherwise, if the corresponding real type of either operand is a standard floating type, the other operand is converted, without change of type domain, to a type whose corresponding real type is that same standard floating type.

Otherwise, if both operands have floating types, the operand, whose set of values of its corresponding real type is a (proper) subset of the set of values of the corresponding real type of the other operand, is converted, without change of type domain, to a type with the corresponding real type of that other operand.

Otherwise, if one operand has a floating type, the other operand is converted to the corresponding real type of the operand of floating type.

9 Constants

The following changes to C11 + TS18661-1 + TS18661-2 provide suffixes that designate constants of interchange and extended floating types.

Changes to C11 + TS18661-1 + TS18661-2:

Change \texttt{floating-suffix} in 6.4.4.2 from:

\begin{verbatim}
floating-suffix: one of
   f l F L df dd dl DF DD DL
\end{verbatim}

to:

\begin{verbatim}
floating-suffix: one of
   f l F L df dd dl DF DD DL fN FN fNx FNx dN DN dNx DNx
\end{verbatim}
Replace 6.4.4.2#2a:

[2a] A floating-suffix df, dd, dl, DF, DD, or DL shall not be used in a hexadecimal-floating-constant.

with:

[2a] A floating-suffix df, dd, dl, DF, DD, DL, dN, DN, dNx, or DNx shall not be used in a hexadecimal-floating-constant.

[2b] A floating-suffix shall not designate a type that the implementation does not provide.

Replace 6.4.4.2#4a:

[4a] If a floating constant is suffixed by df or DF, it has type _Decimal32. If suffixed by dd or DD, it has type _Decimal64. If suffixed by dl or DL, it has type _Decimal128.

with:

[4a] If a floating constant is suffixed by fN or FN, it has type _FloatN. If suffixed by fNx or FNx, it has type _FloatN. If suffixed by df or DF, it has type _Decimal32. If suffixed by dd or DD, it has type _Decimal64. If suffixed by dl or DL, it has type _Decimal128. If suffixed by dN or DN, it has type _DecimalN. If suffixed by dNx or DNx, it has type _DecimalN.

Replace the second sentence of 6.4.4.2#5a:

The quantum exponent is specified to be the same as for the corresponding strtod32, strtod64, or strtod128 function for the same numeric string.

with:

The quantum exponent is specified to be the same as for the corresponding strtodN or strtodNx function for the same numeric string.

10 Expressions

The following changes to C11 + TS18661-1 + TS18661-2 specify operator constraints for interchange and extended floating types.

Changes to C11 + TS18661-1 + TS18661-2:

Replace 6.5.5#2a:

[2a] If either operand has decimal floating type, the other operand shall not have standard floating type, complex type, or imaginary type.

with:

[2a] If either operand has decimal floating type, the other operand shall not have standard floating type, binary floating type, complex type, or imaginary type.

Replace 6.5.6#3a:

[3a] If either operand has decimal floating type, the other operand shall not have standard floating type, complex type, or imaginary type.
with:

[3a] If either operand has decimal floating type, the other operand shall not have standard floating type, binary floating type, complex type, or imaginary type.

Replace 6.5.8#2a:

[2a] If either operand has decimal floating type, the other operand shall not have standard floating type.

with:

[2a] If either operand has decimal floating type, the other operand shall not have standard floating type or binary floating type.

Replace 6.5.9#2a:

[2a] If either operand has decimal floating type, the other operand shall not have standard floating type, complex type, or imaginary type.

with:

[2a] If either operand has decimal floating type, the other operand shall not have standard floating type, binary floating type, complex type, or imaginary type.

In 6.5.15#3, replace the bullet:

— one operand has decimal floating type, and the other has arithmetic type other than standard floating type, complex type, and imaginary type;

with:

— one operand has decimal floating type, and the other has arithmetic type other than standard floating type, binary floating types, complex type, and imaginary type;

Replace 6.5.16#2a:

[2a] If either operand has decimal floating type, the other operand shall not have standard floating type, complex type, or imaginary type.

with:

[2a] If either operand has decimal floating type, the other operand shall not have standard floating type, binary floating type, complex type, or imaginary type.

In F.9.2#1, replace the first sentence:

[1] The equivalences noted below apply to expressions of standard floating types.

with:

[1] The equivalences noted below apply to expressions of standard floating types and binary floating types.

11 Non-arithmetic interchange formats

An implementation supports IEC 60559 arithmetic interchange formats by providing the corresponding interchange floating types. An implementation supports IEC 60559 non-arithmetic formats by providing the encoding-to-encoding conversion functions in <math.h> and the string-to-encoding and string-from-encoding
functions in `<stdlib.h>`. See 6.2.5. These functions, together with functions required for interchange floating types, provide conversions between any two of the supported IEC 60559 arithmetic and non-arithmetic interchange formats and between character sequences and any supported IEC 60559 arithmetic or non-arithmetic format.

### 12 Mathematics `<math.h>`

This clause specifies changes to C11 + TS18661-1 + TS18661-2 to include functions and macros for interchange and extended floating types. The binary types are supported by functions and macros corresponding to those specified for standard floating types (`float`, `double`, and `long double`) in C11 + TS18661-1, including Annex F. The decimal types are supported by functions and macros corresponding to those specified for decimal floating types in TS18661-2.

All classification (7.12.3) and comparison (7.12.14) macros specified in C11 + TS18661-1 + TS18661-2 naturally extend to handle interchange and extended floating types.

This clause also specifies encoding conversion functions that are part of support for the non-arithmetic interchange formats in IEC 60559 (see 6.2.5).

### Changes to C11 + TS18661-1 + TS18661-2:

In 7.12#1, change the second sentence from:

> Most synopses specify a family of functions consisting of a principal function with one or more `double` parameters, a `double` return value, or both; and other functions with the same name but with `f` and `l` suffixes, which are corresponding functions with `float` and `long double` parameters, return values, or both.

...to:

> Most synopses specify a family of functions consisting of:

- a principal function with one or more `double` parameters, a `double` return value, or both; and,
- other functions with the same name but with `f`, `l`, `fn`, `fnx`, `dN`, and `dNx` suffixes, which are corresponding functions whose parameters, return values, or both are of types `float`, `long double`, `_FloatN`, `_FloatN`, `_DecimalN`, and `_DecimalN`, respectively.

Add after 7.12#1d:

> [1e] For each interchange or extended floating type that the implementation provides, `<math.h>` shall define the associated macros and declare the associated functions. Conversely, for each such type that the implementation does not provide, `<math.h>` shall not define the associated macros or declare the associated functions unless explicitly specified otherwise.

### 12.1 Macros

### Changes to C11 + TS18661-1 + TS18661-2:

Replace 7.12#3a:

> [3a] The macro

```
HUGE_VAL_D32
```

expands to a constant expression of type `_Decimal64` representing positive infinity. The macros...
HUGE_VAL_D64
HUGE_VAL_D128

are respectively _Decimal64 and _Decimal128 analogues of HUGE_VAL_D32.

with:

[3a] The macros

HUGE_VAL_FN
HUGE_VAL_DN
HUGE_VAL_FN/10
HUGE_VAL_DN/10

expand to constant expressions of types _FloatN, _DecimalN, _FloatNx, and _DecimalNx, respectively, representing positive infinity.

Replace 7.12#5b:

[5b] The decimal signaling NaN macros

SNAND32
SNAND64
SNAND128

each expands to a constant expression of the respective decimal floating type representing a signaling NaN. If a signaling NaN macro is used for initializing an object of the same type that has static or thread-local storage duration, the object is initialized with a signaling NaN value.

with:

[5b] The signaling NaN macros

SNANFN
SNANDN
SNANFN/10
SNANDN/10

expand to constant expressions of types _FloatN, _DecimalN, _FloatNx, and _DecimalNx, respectively, representing a signaling NaN. If a signaling NaN macro is used for initializing an object of the same type that has static or thread-local storage duration, the object is initialized with a signaling NaN value.

Replace 7.12#7b:

[7b] The macros

FP_FAST_FMAD32
FP_FAST_FMAD64
FP_FAST_FMAD128

are, respectively, _Decimal32, _Decimal64, and _Decimal128 analogues of FP_FAST_FMA.

with:

[7b] The macros

FP_FAST_FMAFN
FP_FAST_FMADN
FP_FAST_FMAFN\times
FP_FAST_FMADN\times

are, respectively, _FloatN, _DecimalN, _FloatN\times, and _DecimalN\times analogues of FP_FAST_FMA.

Replace 7.12#7c:

[7c] The macros

FP_FAST_D32ADDD64
FP_FAST_D32ADDD128
FP_FAST_D64ADDD128
FP_FAST_D32SUBD64
FP_FAST_D32SUBD128
FP_FAST_D64SUBD128
FP_FAST_D32MULD64
FP_FAST_D32MULD128
FP_FAST_D64MULD128
FP_FAST_D32DIVD64
FP_FAST_D32DIVD128
FP_FAST_D64DIVD128
FP_FAST_D32FMAD64
FP_FAST_D32FMAD128
FP_FAST_D64FMAD128
FP_FAST_D32SQRTD64
FP_FAST_D32SQRTD128
FP_FAST_D32SQRTD128

are decimal analogues of FP_FAST_FADD, FP_FAST_FADDL, FP_FAST_DADDL, etc.

with:

[7c] The macros in the following lists are interchange and extended floating type analogues of FP_FAST_FADD, FP_FAST_FADDL, FP_FAST_DADDL, etc.

[7d] For M < N, the macros

FP_FAST_FMAFFN
FP_FAST_FMSUBFN
FP_FAST_FMULFN
FP_FAST_FMDIVFN
FP_FAST_FMFMAPFN
FP_FAST_FMSQRTFN
FP_FAST_DMAFFFN
FP_FAST_DMSUBDN
FP_FAST_DMULDN
FP_FAST_DDIVDN
FP_FAST_DFMADN
FP_FAST_DMSQRTDN

characterize the corresponding functions whose arguments are of an interchange floating type of width N and whose return type is an interchange floating type of width M.
[7e] For $M \leq N$, the macros

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP_FAST_FMADDFN</td>
<td>MADDFN</td>
</tr>
<tr>
<td>FP_FAST_FMSUBFN</td>
<td>MSUBFN</td>
</tr>
<tr>
<td>FP_FAST_FMMULFN</td>
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<tr>
<td>FP_FAST_FMADDNFN</td>
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<tr>
<td>FP_FAST_FMSUBFN</td>
<td>MSUBFN</td>
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<td>FP_FAST_FMULFN</td>
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<tr>
<td>FP_FAST_FMXDIVFN</td>
<td>MDIVFN</td>
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<td>FP_FAST_FMSQRTFN</td>
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<tr>
<td>FP_FAST_DADDN</td>
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<td>FP_FAST_DSUBN</td>
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<td>FP_FAST_DMULN</td>
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<td>FP_FAST_DADDN</td>
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<td>FP_FAST_DMULN</td>
<td>MULN</td>
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<tr>
<td>FP_FAST_DDIVN</td>
<td>DIVN</td>
</tr>
<tr>
<td>FP_FAST_DMSQRTN</td>
<td>MSQRTN</td>
</tr>
</tbody>
</table>

characterize the corresponding functions whose arguments are of an extended floating type that extends a format of width $N$ and whose return type is an interchange floating type of width $M$.

[7f] For $M < N$, the macros

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP_FAST_FMADDFN</td>
<td>MADDFN</td>
</tr>
<tr>
<td>FP_FAST_FMSUBFN</td>
<td>MSUBFN</td>
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<td>FP_FAST_DMULN</td>
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<tr>
<td>FP_FAST_DDIVN</td>
<td>DIVN</td>
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<tr>
<td>FP_FAST_DMSQRTN</td>
<td>MSQRTN</td>
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</tbody>
</table>

characterize the corresponding functions whose arguments are of an interchange floating type of width $N$ and whose return type is an extended floating type that extends a format of width $M$.

[7g] For $M < N$, the macros

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP_FAST_FMADDFN</td>
<td>MADDFN</td>
</tr>
<tr>
<td>FP_FAST_FMSUBFN</td>
<td>MSUBFN</td>
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<tr>
<td>FP_FAST_FMMULFN</td>
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<td>FP_FAST_FMADDNFN</td>
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<td>DIVN</td>
</tr>
<tr>
<td>FP_FAST_DMSQRTN</td>
<td>MSQRTN</td>
</tr>
</tbody>
</table>

characterize the corresponding functions whose arguments are of an extended floating type that extends a format of width $N$ and whose return type is an extended floating type that extends a format of width $M$.

### 12.2 Floating-point environment

Changes to C11 + TS18661-1 + TS18661-2:
In 7.6.1a#2, change the first sentence from:

The **FENV_ROUND** pragma provides a means to specify a constant rounding direction for floating-point operations for standard floating types within a translation unit or compound statement.

to:

The **FENV_ROUND** pragma provides a means to specify a constant rounding direction for floating-point operations for standard and binary floating types within a translation unit or compound statement.

In 7.6.1a#3, change the first sentence from:

*direction* shall be one of the names of the supported rounding direction macros for operations for standard floating types (7.6), or **FE_DYNAMIC**.

to:

*direction* shall be one of the names of the supported rounding direction macros for use with **fegetround** and **fesetround** (7.6), or **FE_DYNAMIC**.

In 7.6.1a#4, change the first sentence from:

The **FENV_ROUND** directive affects operations for standard floating types. Within the scope of an **FENV_ROUND** directive establishing a mode other than **FE_DYNAMIC**, floating-point operators, …

to:

The **FENV_ROUND** directive affects operations for standard and binary floating types. Within the scope of an **FENV_ROUND** directive establishing a mode other than **FE_DYNAMIC**, floating-point operators, …

In 7.6.1a#4, change the table title from:

**Functions affected by constant rounding modes – for standard floating types**

to:

**Functions affected by constant rounding modes – for standard and binary floating types**

In 7.6.1a#4, replace the sentence following the table:

Each `<math.h>` function listed in the table above indicates the family of functions of all standard floating types (for example, `acosf` and `acosl` as well as `acos`).

with:

Each `<math.h>` function listed in the table above indicates the family of functions of all standard and binary floating types (for example, `acosf`, `acosl`, `acosfN`, and `acosfNx` as well as `acos`).

After 7.6.1a#4, add:

[4a] The `fMencfN`, `strfromencfN`, and `strtoencfN` functions for binary interchange types are also affected by constant rounding modes.

In 7.6.1b#2 after the table, add:

Each `<math.h>` function listed in the table above indicates the family of functions of all decimal floating types (for example, `acosdNx`, as well as `acosdN`).
After 7.6.1b#2, add:

[3] The $dMencbindN$, $dMencdecN$, $strfromencbindN$, $strfromencdecN$, $strtoencbindN$, and $strtoencdecN$ functions for decimal interchange types are also affected by constant rounding modes.

Change 7.6.3 from:

The $fegetround$ and $fesetround$ functions provide control of rounding direction modes.

to:

The functions in this subclause provide control of rounding direction modes.

Change 7.6.3.1#2 from:

The $fegetround$ function gets the current rounding direction.

to:

The $fegetround$ function gets the current rounding direction for operations for standard and binary floating types.

In 7.6.3.2#2, change the first sentence from:

The $fesetround$ function establishes the rounding direction represented by its argument $round$.

to:

The $fesetround$ function establishes the rounding direction represented by its argument $round$ for operations for standard and binary floating types.

12.3 Functions

Changes to C11 + TS18661-1 + TS18661-2:

Add the following list of function prototypes to the synopsis of the respective subclauses:

7.12.4 Trigonometric functions

```c
_FloatN acosfN(_FloatN x);
_FloatNx acosfNx(_FloatNx x);
DecimalN acosdN(_DecimalN x);
DecimalNx acosdNx(_DecimalNx x);

_FloatN asinfN(_FloatN x);
_FloatNx asinfNx(_FloatNx x);
DecimalN asindN(_DecimalN x);
DecimalNx asindNx(_DecimalNx x);

_FloatN atanfN(_FloatN x);
_FloatNx atanfNx(_FloatNx x);
DecimalN atandN(_DecimalN x);
DecimalNx atandNx(_DecimalNx x);

_FloatN atan2fN(_FloatN y, _FloatN x);
_FloatNx atan2fNx(_FloatNx y, _FloatNx x);
```
7.12.5 Hyperbolic functions

20

_FloatN acoshfN(_FloatN x);
_FloatNx acoshNx(_FloatNx x);
_HalfN  acoshdH(_HalfN x);
_FloatNx acosdhNx(_HalfNx x);

25

_FloatN asinhfN(_FloatN x);
_FloatNx asinhNx(_FloatNx x);
_HalfN  asinhdH(_HalfN x);
_FloatNx asinhdNx(_HalfNx x);

30

_FloatN atanhfN(_FloatN x);
_FloatNx atanhNx(_FloatNx x);
_HalfN  atanhdH(_HalfN x);
_FloatNx atanhdNx(_HalfNx x);

35

_FloatN coshfN(_FloatN x);
_FloatNx coshNx(_FloatNx x);
_HalfN  coshdH(_HalfN x);
_FloatNx coshdNx(_HalfNx x);

40

_FloatN sinhfN(_FloatN x);
_FloatNx sinhNx(_FloatNx x);
_HalfN  sinhdH(_HalfN x);
_FloatNx sinhdNx(_HalfNx x);

45

_FloatN tanhfN(_FloatN x);
_FloatNx tanhNx(_FloatNx x);
_HalfN  tanhdH(_HalfN x);
_FloatNx tanhdNx(_HalfNx x);

50

7.12.6 Exponential and logarithmic functions

_FloatN expfN(_FloatN x);
_FloatNx expfNx(_FloatNx x);
_HalfN  expdH(_HalfN x);
_FloatNx expdNx(_HalfNx x);
_DecimalNx expdNx(_DecimalNx x);
_FloatN exp2fN(_FloatN x);
_FloatNx exp2fNx(_FloatNx x);
_DecimalN exp2dN(_DecimalN x);
_DecimalNx exp2dNx(_DecimalNx x);

_FloatN expmlfN(_FloatN x);
_FloatNx expmlfNx(_FloatNx x);
_DecimalN expmldN(_DecimalN x);
_DecimalNx expmldNx(_DecimalNx x);

_FloatN frexpN(_FloatN value, int *exp);
_FloatNx frexpN(_FloatNx value, int *exp);
_DecimalN frexpD(_DecimalN value, int *exp);
_DecimalNx frexpDx(_DecimalNx value, int *exp);

int ilogbfN(_FloatN x);
int ilogbfNx(_FloatNx x);
int ilogbdN(_DecimalN x);
int ilogbdNx(_DecimalNx x);

_FloatN ldexpfN(_FloatN value, int exp);
_FloatNx ldexpfN(_FloatNx value, int exp);
_DecimalN ldexpD(_DecimalN value, int exp);
_DecimalNx ldexpDx(_DecimalNx value, int exp);

long int ilogbfN(_FloatN x);
long int ilogbfNx(_FloatNx x);
long int ilogbdN(_DecimalN x);
long int ilogbdNx(_DecimalNx x);

_FloatN logfN(_FloatN x);
_FloatNx logfNx(_FloatNx x);
_DecimalN logdN(_DecimalN x);
_DecimalNx logdxN(_DecimalNx x);

_FloatN log10fN(_FloatN x);
_FloatNx log10fNx(_FloatNx x);
_DecimalN log10dN(_DecimalN x);
_DecimalNx log10dNx(_DecimalNx x);

_FloatN log1pfN(_FloatN x);
_FloatNx log1pfNx(_FloatNx x);
_DecimalN log1pdN(_DecimalN x);
_DecimalNx log1pdNx(_DecimalNx x);

_FloatN log2fN(_FloatN x);
_FloatNx log2fNx(_FloatNx x);
_DecimalN log2dN(_DecimalN x);
_DecimalNx log2dNx(_DecimalNx x);

_FloatN logbfN(_FloatN x);
_FloatNx logbfNx(_FloatNx x);
_DecimalN logbdN(_DecimalN x);
_DecimalNx logbdNx(_DecimalNx x);
7.12.7 Power and absolute-value functions

_FloatN cbrtfN(_FloatN x);  
_FloatN cbrtfNx(_FloatNx x);  
_DecimalN cbrtdN(_DecimalN x);  
_DecimalNx cbrtdNx(_DecimalNx x);

_FloatN fabsfN(_FloatN x);   
_FloatN fabsfNx(_FloatNx x);  
_DecimalN fabsdN(_DecimalN x);  
_DecimalNx fabdNx(_DecimalNx x);

_FloatN hypotfN(_FloatN x, _FloatN y); 
_FloatN hypotfNx(_FloatNx x, _FloatNx y);  
_DecimalN hypotdN(_DecimalN x, _DecimalN y); 
_DecimalNx hypotdNx(_DecimalNx x, _DecimalNx y);

_FloatN powfN(_FloatN x, _FloatN y);  
_FloatN powfNx(_FloatNx x, _FloatNx y);  
_DecimalN powdN(_DecimalN x, _DecimalN y); 
_DecimalNx powdNx(_DecimalNx x, _DecimalNx y);

_FloatN sqrtfN(_FloatN x);    
_FloatN sqrtfNx(_FloatNx x);  
_DecimalN sqrtdN(_DecimalN x);  
_DecimalNx sqrtdNx(_DecimalNx x);

7.12.8 Error and gamma functions

_FloatN erffN(_FloatN x);     
_FloatN erffNx(_FloatNx x);    
_DecimalN erfdN(_DecimalN x);  
_DecimalNx erfdNx(_DecimalNx x);

_FloatN erfcfN(_FloatN x);    
_FloatN erfcfNx(_FloatNx x);    
_DecimalN erfcdfN(_DecimalN x);  
_DecimalNx erfcdfNx(_DecimalNx x);

_FloatN lgammafN(_FloatN x);  
_FloatN lgammafNx(_FloatNx x);  
_FloatN lgammalN(_FloatN x);   
_FloatN lgammalN(_FloatNx x);  
_DecimalN lgammalN(_DecimalN x); 
_DecimalNx lgammalN(_DecimalNx x);
7.12.9 Nearest integer functions

\texttt{\_FloatN\ ceilfN(\_FloatN x);} \\
\texttt{\_FloatN\ ceilfN(\_FloatN x);} \\
\texttt{\_DecimalN\ ceildN(\_DecimalN x);} \\
\texttt{\_DecimalN\ ceildN(\_DecimalN x);} \\
\texttt{\_FloatN\ floorfN(\_FloatN x);} \\
\texttt{\_FloatN\ floorfN(\_FloatN x);} \\
\texttt{\_DecimalN\ floordN(\_DecimalN x);} \\
\texttt{\_DecimalN\ floordN(\_DecimalN x);} \\
\texttt{\_FloatN\ nearbyintfN(\_FloatN x);} \\
\texttt{\_FloatN\ nearbyintfN(\_FloatN x);} \\
\texttt{\_DecimalN\ nearbyintdN(\_DecimalN x);} \\
\texttt{\_DecimalN\ nearbyintdN(\_DecimalN x);} \\
\texttt{\_FloatN\ rintfN(\_FloatN x);} \\
\texttt{\_FloatN\ rintfN(\_FloatN x);} \\
\texttt{\_DecimalN\ rintdN(\_DecimalN x);} \\
\texttt{\_DecimalN\ rintdN(\_DecimalN x);} \\
\texttt{\texttt{\_}\texttt{long}\ \texttt{int}\ \texttt{lrintfN(\_FloatN x);} \\
\texttt{\texttt{\_}\texttt{long}\ \texttt{int}\ \texttt{lrintfN(\_FloatN x);} \\
\texttt{\texttt{\_}\texttt{long}\ \texttt{int}\ \texttt{lrintdN(\_DecimalN x);} \\
\texttt{\texttt{\_}\texttt{long}\ \texttt{int}\ \texttt{lrintdN(\_DecimalN x);} \\
\texttt{\_FloatN\ roundfN(\_FloatN x);} \\
\texttt{\_FloatN\ roundfN(\_FloatN x);} \\
\texttt{\_DecimalN\ rounddN(\_DecimalN x);} \\
\texttt{\_DecimalN\ rounddN(\_DecimalN x);} \\
\texttt{\texttt{\_}\texttt{long}\ \texttt{int}\ \texttt{lroundfN(\_FloatN x);} \\
\texttt{\texttt{\_}\texttt{long}\ \texttt{int}\ \texttt{lroundfN(\_FloatN x);} \\
\texttt{\texttt{\_}\texttt{long}\ \texttt{int}\ \texttt{lrounddN(\_DecimalN x);} \\
\texttt{\texttt{\_}\texttt{long}\ \texttt{int}\ \texttt{lrounddN(\_DecimalN x);} \\
\texttt{\_FloatN\ roundevenfN(\_FloatN x);} \\
\texttt{\_FloatN\ roundevenfN(\_FloatN x);}
_FloatN roundevenfN(_FloatN x);
_DecimalN roundevenD(_DecimalN x);
_DecimalN roundevenDx(_DecimalN x);

_FloatN truncfN(_FloatN x);
_FloatN truncfNx(_FloatN x);
_DecimalN trunclD(_DecimalN x);
_DecimalNx trunclDx(_DecimalN x);

intmax_t fromfpfN(_FloatN x, int round, unsigned int width);
intmax_t fromfpfxN(_FloatN x, int round, unsigned int width);
intmax_t fromfpD(_DecimalN x, int round, unsigned int width);
intmax_t fromfpDx(_DecimalN x, int round, unsigned int width);
uintmax_t ufomfpfN(_FloatN x, int round, unsigned int width);
uintmax_t ufomfpfxN(_FloatN x, int round, unsigned int width);
uintmax_t ufomfpD(_DecimalN x, int round, unsigned int width);
uintmax_t ufomfpDx(_DecimalN x, int round, unsigned int width);

intmax_t fromfpfxN(_FloatN x, int round, unsigned int width);
intmax_t fromfpfxN(_FloatN x, int round, unsigned int width);
intmax_t fromfpDx(_DecimalN x, int round, unsigned int width);
intmax_t fromfpDx(_DecimalN x, int round, unsigned int width);
uintmax_t ufomfpfxN(_FloatN x, int round, unsigned int width);
uintmax_t ufomfpfxN(_FloatN x, int round, unsigned int width);
uintmax_t ufomfpDx(_DecimalN x, int round, unsigned int width);
uintmax_t ufomfpDx(_DecimalN x, int round, unsigned int width);

7.12.10 Remainder functions

_FloatN fmodfN(_FloatN x, _FloatN y);
_FloatN fomodfN(_FloatN x, _FloatN y);
_DecimalN fmodD(_DecimalN x, _DecimalN y);
_DecimalNx fmodDx(_DecimalN x, _DecimalN y);

_FloatN remainderrfN(_FloatN x, _FloatN y);
_FloatNx remainderrfNx(_FloatN x, _FloatN y);
_DecimalN remainderD(_DecimalN x, _DecimalN y);
_DecimalNx remainderDx(_DecimalN x, _DecimalN y);

_FloatN remquofN(_FloatN x, _FloatN y, int *quo);
_FloatNx remquotEfx(_FloatN x, _FloatN y, int *quo);

7.12.11 Manipulation functions

_FloatN copiesignfN(_FloatN x, _FloatN y);
_FloatN copiesignfNx(_FloatN x, _FloatN y);
_DecimalN copiesignD(_DecimalN x, _DecimalN y);
_DecimalNx copiesignDx(_DecimalN x, _DecimalN y);

_FloatN nanfN(const char *tagp);
_FloatNx nanfNx(const char *tagp);
_DecimalN nandN(const char *tagp);
_DecimalNx nandNx(const char *tagp);

_FloatN nextafterfN(_FloatN x, _FloatN y);
_FloatNx nextafterfNx(_FloatN x, _FloatN y);

7.12.12 Maximum, minimum, and positive difference functions

```c
_FLOATN nextupf(_FLOATN x);
_FLOATN nextupfN(_FLOATNx x);
_FLOATN nextupd(_DECIMALN x);
_FLOATN nextupdN(_DECIMALNx x);

_FLOATN nextdownf(_FLOATN x);
_FLOATN nextdownfN(_FLOATNx x);
_FLOATN nextdownd(_DECIMALN x);
_FLOATN nextdowndN(_DECIMALNx x);

void encodebind( unsigned char * restrict encptr, const unsigned char * restrict xptr);
void decodedcd( _DECIMALN * restrict cx, const _DECIMALN * restrict xptr);
void encodedcd( _DECIMALN * restrict cx, const _DECIMALN * restrict xptr);
void encodebindN( unsigned char * restrict encptr, const _DECIMALN * restrict xptr);
void decodedcdN( _DECIMALN * restrict cx, const _DECIMALN * restrict xptr);
void encodedcdN( _DECIMALN * restrict cx, const _DECIMALN * restrict xptr);

_INTN fmaxfN(_FLOATN x, _FLOATN y);
_FLOATN fmaxfN(_FLOATNx x, _FLOATNx y);
_DECIMALN fmaxd(_DECIMALN x, _DECIMALN y);
_DECIMALNx fmaxdN(_DECIMALNx x, _DECIMALNx y);

_FLOATN fminfN(_FLOATN x, _FLOATN y);
_FLOATN fminfN(_FLOATNx x, _FLOATNx y);
_DECIMALN fmind(_DECIMALN x, _DECIMALN y);
_DECIMALNx fmindN(_DECIMALNx x, _DECIMALNx y);

_FLOATN fmaxmagf(_FLOATN x, _FLOATN y);
_FLOATN fmaxmagf(_FLOATNx x, _FLOATNx y);
_DECIMALN fmaxmagd(_DECIMALN x, _DECIMALN y);
_DECIMALNx fmaxmagdN(_DECIMALNx x, _DECIMALNx y);
```

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Functions that round result to narrower format

7.12.13 Floating multiply-add

7.12.14 Functions that round result to narrower format

FloatN fmaxmagfNx(_FloatNx x, _FloatNx y);
DecimalN fmaxmagdN(_DecimalN x, _DecimalN y);
DecimalN fmaxmagdNx(_DecimalNx x, _DecimalNx y);

_FloatN fminmagfN(_FloatN x, _FloatN y);
_FloatNx fminmagfNx(_FloatNx x, _FloatNx y);
DecimalN fminmagdN(_DecimalN x, _DecimalN y);
DecimalN fminmagdNx(_DecimalNx x, _DecimalNx y);

_FloatN fmafN(_FloatN x, _FloatN y, _FloatN z);
_FloatN fmafNx(_FloatNx x, _FloatNx y, _FloatNx z);
DecimalN fmadN(_DecimalN x, _DecimalN y, _DecimalN z);
DecimalN fmadNx(_DecimalNx x, _DecimalNx y, _DecimalNx z);

_FloatM fMaddfN(_FloatN x, _FloatN y);  // M < N
_FloatM fMaddfNx(_FloatNx x, _FloatNx y);  // M <= N
_FloatM fMaddfN(_FloatN x, _FloatN y);  // M < N
_FloatM fMaddfNx(_FloatNx x, _FloatNx y);  // M < N
DecimalM dMaddN(_DecimalN x, _DecimalN y);  // M < N
DecimalM dMaddN(_DecimalNx x, _DecimalNx y);  // M < N

_FloatM fMsufbN(_FloatN x, _FloatN y);  // M < N
_FloatM fMsufbNx(_FloatNx x, _FloatNx y);  // M <= N
_FloatM fMsufbN(_FloatN x, _FloatN y);  // M < N
_FloatM fMsufbNx(_FloatNx x, _FloatNx y);  // M < N
DecimalM dMsudbN(_DecimalN x, _DecimalN y);  // M < N
DecimalM dMsudbN(_DecimalNx x, _DecimalNx y);  // M <= N

_FloatM fMmulfN(_FloatN x, _FloatN y);  // M < N
_FloatM fMmulfNx(_FloatNx x, _FloatNx y);  // M < N
_FloatM fMmulfN(_FloatN x, _FloatN y);  // M < N
_FloatM fMmulfNx(_FloatNx x, _FloatNx y);  // M < N
DecimalM dMmuldN(_DecimalN x, _DecimalN y);  // M < N
DecimalM dMmuldN(_DecimalNx x, _DecimalNx y);  // M <= N

_FloatM fMdivfN(_FloatN x, _FloatN y);  // M < N
_FloatM fMdivfNx(_FloatNx x, _FloatNx y);  // M < N
_FloatM fMdivfN(_FloatN x, _FloatN y);  // M < N
_FloatM fMdivfNx(_FloatNx x, _FloatNx y);  // M < N
DecimalM dMdivdN(_DecimalN x, _DecimalN y);  // M < N
DecimalM dMdivdN(_DecimalNx x, _DecimalNx y);  // M < N

_FloatM fMsqrtfN(_FloatN x);  // M < N
_FloatM fMsqrtfNx(_FloatNx x);  // M < N
_FloatMx fMxsqrtfN(_FloatN x); // M < N
_FloatMx fMxsqrtfNx(_FloatNx x); // M < N
_FlMx dMsqrtfN(_DecxN x); // M < N
_FlMx dMsqrtfN(_DecxN x); // M <= N
_FlMx dMsqrtfN(_DecxN x); // M < N
_FlMx dMsqrtfN(_DecxN x); // M < N

_FlMx fMxfafN(_FloatN x, _FloatN y, _FloatN z); // M < N
_FlMx fMxfafN(_FloatNx x, _FloatNx y, _FloatNx z); // M <= N
_FlMx fMxfafN(_FloatNx x, _FloatNx y, _FloatNx z); // M < N
_FlMx dMxfafN(_DecxN x, _DecxN y, _DecxN z); // M < N
_FlMx dMxfafN(_DecxN x, _DecxN y, _DecxN z); // M < N
_FlMx dMxfafN(_DecxN x, _DecxN y, _DecxN z); // M < N

F.10.12 Total order functions
int totalorderfN(_FloatN x, _FloatN y);
int totalorderfNx(_FloatNx x, _FloatNx y);
int totalorderdN(_DecxN x, _DecxN y);
int totalorderdNx(_DecxN x, _DecxN y);

int totalordermagfN(_FloatN x, _FloatN y);
int totalordermagfNx(_FloatNx x, _FloatNx y);
int totalordermagdN(_DecxN x, _DecxN y);
int totalordermagdNx(_DecxN x, _DecxN y);

F.10.13 Payload functions
_FlN getpayloadfN(const _FlN *x);
_FlNx getpayloadfNx(const _FlNx *x);
_DecxN getpayloaddN(const _DecxN *x);
_DecxN getpayloaddNx(const _DecxN *x);

int setpayloadfN(_FlN *res, _FlN pl);
int setpayloadfNx(_FlNx *res, _FlNx pl);
int setpayloaddN(_DecxN *res, _DecxN pl);
int setpayloaddNx(_DecxN *res, _DecxN pl);

int setpayloadsigtN(_FlN *res, _FlN pl);
int setpayloadsigtNx(_FlNx *res, _FlNx pl);
int setpayloadsigtN(_DecxN *res, _DecxN pl);
int setpayloadsigtNx(_DecxN *res, _DecxN pl);

If the type of the function is a standard floating type, the exponent is an integral power of 2.

If the type of the function is a standard or binary floating type, the exponent is an integral power of 2.
In 7.12.6.4#3, change the second sentence from:

Otherwise, the \texttt{frexp} functions return the value \(x\), such that: \(x\) has a magnitude in the interval \([1/2, 1)\) or zero, and \texttt{value} equals \(x \times 2^{\text{exp}}\), when the type of the function is a standard floating type; ...

to:

Otherwise, the \texttt{frexp} functions return the value \(x\), such that: \(x\) has a magnitude in the interval \([1/2, 5)\) or zero, and \texttt{value} equals \(x \times 2^{\text{exp}}\), when the type of the function is a standard or binary floating type; ...

In 7.12.6.6#2, change the first sentence from:

The \texttt{ldexp} functions multiply a floating-point number by an integral power of 2 when the type of the function is a standard floating type, or by an integral power of 10 when the type of the function is a decimal floating type.

to:

The \texttt{ldexp} functions multiply a floating-point number by an integral power of 2 when the type of the function is a standard or binary floating type, or by an integral power of 10 when the type of the function is a decimal floating type.

Change 7.12.6.6#3 from:

[3] The \texttt{ldexp} functions return \(x \times 2^{\text{exp}}\) when the type of the function is a standard floating type, or return \(x \times 10^{\text{exp}}\) when the type of the function is a decimal floating type.

to:

[3] The \texttt{ldexp} functions return \(x \times 2^{\text{exp}}\) when the type of the function is a standard or binary floating type, or return \(x \times 10^{\text{exp}}\) when the type of the function is a decimal floating type.

In 7.12.6.11#2, change the second sentence from:

If \(x\) is subnormal it is treated as though it were normalized; thus, for positive finite \(x\),

\[1 \leq x \times b^{-\log_b(x)} < b\]

where \(b = \texttt{FLT\_RADIX}\) if the type of the function is a standard floating type, or \(b = 10\) if the type of the function is a decimal floating type.

to:

If \(x\) is subnormal it is treated as though it were normalized; thus, for positive finite \(x\),

\[1 \leq x \times b^{-\log_b(x)} < b\]

where \(b = \texttt{FLT\_RADIX}\) if the type of the function is a standard floating type, \(b = 2\) if the type of the function is a binary floating type, or \(b = 10\) if the type of the function is a decimal floating type.

In 7.12.6.13#2, change the first sentence from:

The \texttt{scalbn} and \texttt{scalbln} functions compute \(x \times b^n\), where \(b = \texttt{FLT\_RADIX}\) if the type of the function is a standard floating type, or \(b = 10\) if the type of the function is a decimal floating type.
to:

The `scalbn` and `scalbln` functions compute \( x \times b^n \), where \( b = \text{FLT\_RADIX} \) if the type of the function is a standard floating type, \( b = 2 \) if the type of the function is a binary floating type, or \( b = 10 \) if the type of the function is a decimal floating type.

### 12.4 Encoding conversion functions

The functions in this subclause, together with the numerical conversion functions for encodings in clause 13, support the non-arithmetic interchange formats specified by IEC 60559.

**Change to C11 + TS18661-1 + TS18661-2:**

After 7.12.11.7, add:

#### 7.12.11.7a The `encodefN` functions

**Synopsis**

[1]  

```c
#define __STDC_WANT_IEC_60559_TYPES_EXT__
#include <math.h>
void encodefN(unsigned char * restrict encptr, const _FloatN * restrict xptr);
```

**Description**

[2] The `encodefN` functions convert `*xptr` into an IEC 60559 binary\(N\) encoding and store the resulting encoding as an \(N/8\) element array, with 8 bits per array element, in the object pointed to by `encptr`. The order of bytes in the array is implementation-defined. These functions preserve the value of `*xptr` and raise no floating-point exceptions. If `*xptr` is non-canonical, these functions may or may not produce a canonical encoding.

**Returns**


#### 7.12.11.7b The `decodefN` functions

**Synopsis**

[1]  

```c
#define __STDC_WANT_IEC_60559_TYPES_EXT__
#include <math.h>
void decodefN(_FloatN * restrict xptr, const unsigned char * restrict encptr);
```

**Description**

[2] The `decodefN` functions interpret the \(N/8\) element array pointed to by `encptr` as an IEC 60559 binary\(N\) encoding, with 8 bits per array element. The order of bytes in the array is implementation-defined. These functions convert the given encoding into a representation in the type \(_\text{Float}\)\(N\), and store the result in the object pointed to by `xptr`. These functions preserve the encoded value and raise no floating-point exceptions. If the encoding is non-canonical, these functions may or may not produce a canonical representation.

**Returns**

7.12.11.7c Encoding-to-encoding conversion functions

[1] An implementation shall declare a \texttt{fMencfN} function for each \(M\) and \(N\) equal the width of a supported IEC 60559 arithmetic or non-arithmetic binary interchange format. An implementation shall provide both \texttt{dMencdecN} and \texttt{dMencbindN} functions for each \(M\) and \(N\) equal the width of a supported IEC 60559 arithmetic or non-arithmetic decimal interchange format.

7.12.11.7c.1 The \texttt{fMencfN} functions

Synopsis

\begin{verbatim}
#define __STDC_WANT_IEC_60559_TYPES_EXT__
#include <math.h>
void fMencfN(unsigned char * restrict encMptr, const unsigned char * restrict encNptr);
\end{verbatim}

Description

[2] These functions convert between IEC 60559 binary interchange formats. These functions interpret the \(N/8\) element array pointed to by \texttt{encNptr} as an encoding of width \(N\) bits. They convert the encoding to an encoding of width \(M\) bits and store the resulting encoding as an \(M/8\) element array in the object pointed to by \texttt{encMptr}. The conversion rounds and raises floating-point exceptions as specified in IEC 60559. The order of bytes in the arrays is implementation-defined.

Returns

[3] These functions return no value.

7.12.11.7c.2 The \texttt{dMencdecN} and \texttt{dMencbindN} functions

Synopsis

\begin{verbatim}
#define __STDC_WANT_IEC_60559_TYPES_EXT__
#include <math.h>
void dMencdecN(unsigned char * restrict encMptr, const unsigned char * restrict encNptr);
void dMencbindN(unsigned char * restrict encMptr, const unsigned char * restrict encNptr);
\end{verbatim}

Description

[2] These functions convert between IEC 60559 decimal interchange formats that use the same encoding scheme. The \texttt{dMencdecN} functions convert between formats using the encoding scheme based on decimal encoding of the significand. The \texttt{dMencbindN} functions convert between formats using the encoding scheme based on binary encoding of the significand. These functions interpret the \(N/8\) element array pointed to by \texttt{encNptr} as an encoding of width \(N\) bits. They convert the encoding to an encoding of width \(M\) bits and store the resulting encoding as an \(M/8\) element array in the object pointed to by \texttt{encMptr}. The conversion rounds and raises floating-point exceptions as specified in IEC 60559. The order of bytes in the arrays is implementation-defined.

Returns

[3] These functions return no value.

13 Numeric conversion functions in \texttt{<stdlib.h>}

This clause specifies functions to convert between character sequences and the interchange and extended floating types. Conversions from character sequences are provided by functions analogous to the \texttt{strtod}
function in `<stdlib.h>`. Conversions to character sequences are provided by functions analogous to the `strfromd` function in `<stdlib.h>`.

This clause also specifies functions to convert between character sequences and IEC 60559 interchange format encodings.

### Changes to C11 + TS18661-1 + TS18661-2:

After 7.22.1#1, insert:

> [3a] For each interchange or extended floating type that the implementation provides, `<stdlib.h>` shall declare the associated functions. Conversely, for each such type that the implementation does not provide, `<stdlib.h>` shall not declare the associated functions unless specified otherwise.

After 7.22.1.2b, insert:

#### 7.22.1.2c The `strfromN`, `strfromNx`, `strfromdN`, and `strfromdNx` functions

**Synopsis**

```c
#define __STDC_WANT_IEC_60559_TYPES_EXT__
#include <stdlib.h>

int strfromfN(char * restrict s, size_t n, const char * restrict format, _FloatN fp);
int strfromfNx(char * restrict s, size_t n, const char * restrict format, _FloatNx fp);
int strfromdN(char * restrict s, size_t n, const char * restrict format, _DecimalN fp);
int strfromdNx(char * restrict s, size_t n, const char * restrict format, _DecimalNx fp);
```

**Description**

[2] The `strfromfN` and `strfromfNx` functions are similar to the `strfromd` function, except they convert to the types `_FloatN` and `_FloatNx`, respectively. The `strfromdN` and `strfromdNx` functions are similar to the `strfromd64` function, except they convert from the types `_DecimalN` and `_DecimalNx`, respectively.

**Returns**

[3] The `strfromfN` and `strfromfNx` functions return values similar to the `strfromd` function. The `strfromdN` and `strfromdNx` functions return values similar to the `strfromd64` function.

After 7.22.1.3a, insert:

#### 7.22.1.3b The `strtofN`, `strtofNx`, `strtodN`, and `strtodNx` functions

**Synopsis**

```c
#define __STDC_WANT_IEC_60559_TYPES_EXT__
#include <stdlib.h>

_FloatN strtofN(const char * restrict nptr, char ** restrict endptr);
_FloatNx strtofNx(const char * restrict nptr, char ** restrict endptr);
_DecimalN strtodN(const char * restrict nptr, char ** restrict endptr);
```
_DecimalN_x strtodNx(const char * restrict nptr, char ** restrict endptr);

Description

[2] The `strtofN` and `strtofNx` functions are similar to the `strtod` function, except they convert to the types `_FloatN` and `_FloatNx`, respectively. The `strtodN` and `strtodNx` functions are similar to the `strtod64` function, except they convert to the types `_DecimalN` and `_DecimalNx`, respectively.

Returns

[3] The `strtofN` and `strtofNx` functions return values similar to the `strtod` function, except in the types `_FloatN` and `_FloatNx`, respectively. The `strtodN` and `strtodNx` functions return values similar to the `strtod64` function, except in the types `_DecimalN` and `_DecimalNx`, respectively.

7.22.1.3c String-to-encoding functions

[1] An implementation shall declare the `strtoencfN` function for each `N` equal the width of a supported IEC 60559 arithmetic or non-arithmetic binary interchange format. An implementation shall declare both the `strtoencdecl` and `strtoencbind` functions for each `N` equal the width of a supported IEC 60559 arithmetic or non-arithmetic decimal interchange format.

7.22.1.3c.1 The `strtoencfN` functions

Synopsis

[1] #define __STDC_WANT_IEC_60559_TYPES_EXT__
    #include <stdlib.h>
    void strtoencfN(unsigned char * restrict encptr, const char * restrict nptr, char ** restrict endptr);

Description

[2] The `strtoencfN` functions are similar to the `strtofN` functions, except they store an IEC 60559 encoding of the result as an `N/8` element array in the object pointed to by `encptr`. The order of bytes in the arrays is implementation-defined.

Returns

[3] These functions return no value.

7.22.1.3c.2 The `strtoencdecl` and `strtoencbind` functions

Synopsis

[1] #define __STDC_WANT_IEC_60559_TYPES_EXT__
    #include <stdlib.h>
    void strtoencdecl(unsigned char * restrict encptr, const char * restrict nptr, char ** restrict endptr);
    void strtoencbind(unsigned char * restrict encptr, const char * restrict nptr, char ** restrict endptr);

Description

[2] The `strtoencdecl` and `strtoencbind` functions are similar to the `strtodN` functions, except they store an IEC 60559 encoding of the result as an `N/8` element array in the object pointed
to by `encptr`. The `strtoencdecN` functions produce an encoding in the encoding scheme based on decimal encoding of the significand. The `strtoencbindN` functions produce an encoding in the encoding scheme based on binary encoding of the significand. The order of bytes in the arrays is implementation-defined.

**Returns**

[3] These functions return no value.

### 7.22.1.3d String-from-encoding functions

[1] An implementation shall declare the `strfromencfN` function for each N equal the width of a supported IEC 60559 arithmetic or non-arithmetic binary interchange format. An implementation shall declare both the `strfromencdecN` and `strfromencbindN` functions for each N equal the width of a supported IEC 60559 arithmetic or non-arithmetic decimal interchange format.

#### 7.22.1.3d.1 The `strfromencfN` functions

**Synopsis**

```c
#include <stdlib.h>

#define __STDC_WANT_IEC_60559_TYPES_EXT__

int strfromencfN(char * restrict s, size_t n, const char * restrict format, const unsigned char * restrict encptr);
```

**Description**

[2] The `strfromencfN` functions are similar to the `strfromfN` functions, except the input is the value of the N/8 element array pointed to by `encptr`, interpreted as an IEC 60559 binary encoding. The order of bytes in the arrays is implementation-defined.

**Returns**

[3] The `strfromencfN` functions return the same values as corresponding `strfromfN` functions.

#### 7.22.1.3d.2 The `strfromencdecN` and `strfromencbindN` functions

**Synopsis**

```c
#include <stdlib.h>

#define __STDC_WANT_IEC_60559_TYPES_EXT__

int strfromencdecN(char * restrict s, size_t n, const char * restrict format, const unsigned char * restrict encptr);

int strfromencbindN(char * restrict s, size_t n, const char * restrict format, const unsigned char * restrict encptr);
```

**Description**

[2] The `strfromencdecN` functions are similar to the `strfromdN` functions except the input is the value of the N/8 element array pointed to by `encptr`, interpreted as an IEC 60559 decimal encoding in the coding scheme based on decimal encoding of the significand. The `strfromencbindN` functions are similar to the `strfromdN` functions except the input is the value of the N/8 element array pointed to by `encptr`, interpreted as an IEC 60559 decimal encoding in the coding scheme based on binary encoding of the significand. The order of bytes in the arrays is implementation-defined.
14 Complex arithmetic \texttt{<complex.h>}

This clause specifies complex functions for corresponding real types that are interchange and extended floating types.

**Changes to C11 + TS18661-1 + TS18661-2:**

Change 7.3.1#3 from:

>[3] Each synopsis specifies a family of functions consisting of a principal function with one or more \texttt{double complex} parameters and a \texttt{double complex} or \texttt{double} return value; and other functions with the same name but with \texttt{f} and \texttt{l} suffixes which are corresponding functions with \texttt{float} and \texttt{long double} parameters and return values.

Add after 7.3.1#3:

>[3a] For each interchange or extended floating type that the implementation provides, \texttt{<complex.h>} shall declare the associated functions. Conversely, for each such type that the implementation does not provide, \texttt{<complex.h>} shall not declare the associated functions.

Add the following list of function prototypes to the synopsis of the respective subclauses:

7.3.5 Trigonometric functions

\begin{verbatim}
_FloatN complex cacosfN(_FloatN complex z);
_FloatNx complex cacosfNx(_FloatNx complex z);
_FloatN complex casinfN(_FloatN complex z);
_FloatNx complex casinfNx(_FloatNx complex z);
_FloatN complex catanfN(_FloatN complex z);
_FloatNx complex catanfNx(_FloatNx complex z);
_FloatN complex ccosfN(_FloatN complex z);
_FloatNx complex ccosfNx(_FloatNx complex z);
_FloatN complex csinfN(_FloatN complex z);
_FloatNx complex csinfNx(_FloatNx complex z);
_FloatN complex ctanfN(_FloatN complex z);
_FloatNx complex ctanfNx(_FloatNx complex z);
\end{verbatim}
7.3.6 Hyperbolic functions

_FloatN complex cacoshfN(_FloatN complex z);
_FloatNx complex cacoshfNx(_FloatNx complex z);

_FloatN complex casinhfN(_FloatN complex z);
_FloatNx complex casinhfNx(_FloatNx complex z);

_FloatN complex catanhfN(_FloatN complex z);
_FloatNx complex catanhfNx(_FloatNx complex z);

_FloatN complex ccoshfN(_FloatN complex z);
_FloatNx complex ccoshfNx(_FloatNx complex z);

_FloatN complex csinhfN(_FloatN complex z);
_FloatNx complex csinhfNx(_FloatNx complex z);

_FloatN complex ctanhfN(_FloatN complex z);
_FloatNx complex ctanhfNx(_FloatNx complex z);

7.3.7 Exponential and logarithmic functions

_FloatN complex cexpfN(_FloatN complex z);
_FloatNx complex cexpfNx(_FloatNx complex z);

_FloatN complex clgpfN(_FloatN complex z);
_FloatNx complex clgpfNx(_FloatNx complex z);

7.3.8 Power and absolute value functions

_FloatN complex cabsfN(_FloatN complex z);
_FloatNx complex cabsfNx(_FloatNx complex z);

_FloatN complex cpowfN(_FloatN complex z, _FloatN complex y);
_FloatNx complex cpowfNx(_FloatNx complex z, _FloatNx complex y);

_FloatN complex csqrtfN(_FloatN complex z);
_FloatNx complex csqrtfNx(_FloatNx complex z);

7.3.9 Manipulation functions

_FloatN complex cargfN(_FloatN complex z);
_FloatNx complex cargfNx(_FloatNx complex z);

_FloatN complex cimagfN(_FloatN complex z);
_FloatNx complex cimagfNx(_FloatNx complex z);

_FloatN complex CMPLXfN(_FloatN x, _FloatN y);
_FloatNx complex CMPLXfNx(_FloatNx x, _FloatNx y);

_FloatN complex conjfN(_FloatN complex z);
_FloatNx complex conjfNx(_FloatNx complex z);

_FloatN complex cprojfN(_FloatN complex z);
15 Type-generic macros `<tgmath.h>`

The following changes to C11 + TS18661-1 + TS18661-2 enhance the specification of type-generic macros in `<tgmath.h>` to apply to interchange and extended floating types, as well as standard floating types.

Changes to C11 + TS18661-1 + TS18661-2:

In 7.25, replace paragraphs [3b]:

[3b] If arguments for generic parameters of a type-generic macro are such that some argument has a corresponding real type that is of standard floating type and another argument is of decimal floating type, the behavior is undefined.

with:

[3b] If arguments for generic parameters of a type-generic macro are such that some argument has a corresponding real type that is a standard floating type or a floating type of radix 2 and another argument is of decimal floating type, the behavior is undefined.

In 7.25#3c, replace the bullets:

— First, if any argument for generic parameters has type `_Decimal128`, the type determined is _Decimal128.

— Otherwise, if any argument for generic parameters has type `_Decimal64`, or if any argument for generic parameters is of integer type and another argument for generic parameters has type `_Decimal32`, the type determined is _Decimal64.

— Otherwise, if any argument for generic parameters has type `_Decimal32`, the type determined is _Decimal32.

— Otherwise, if the corresponding real type of any argument for generic parameters is `long double`, the type determined is `long double`.

— Otherwise, if the corresponding real type of any argument for generic parameters is `double` or is of integer type, the type determined is `double`.

— Otherwise, if any argument for generic parameters is of integer type, the type determined is `double`.

— Otherwise, the type determined is `float`.

with:

— If two arguments have floating types and neither of the sets of values of their corresponding real types is a subset of (or equivalent to) the other, the behavior is undefined.

— If any arguments for generic parameters have type `_DecimalM` where $M \geq 64$ or `_DecimalNx` where $N \geq 32$, the type determined is the widest of the types of these arguments. If `_DecimalM` and `_DecimalNx` are both widest types (with equivalent sets of values) of these arguments, the type determined is `_DecimalM`.
— Otherwise, if any argument for generic parameters is of integer type and another argument for
generic parameters has type _Decimal32, the type determined is _Decimal64.

— Otherwise, if any argument for generic parameters has type _Decimal32, the type determined is
_Decimal32.

— Otherwise, if the corresponding real type of any argument for generic parameters has type long
double, _FloatM where \( M \geq 128 \), or _FloatNx where \( N \geq 64 \), the type determined is the
widest of the corresponding real types of these arguments. If _FloatM and either long double
or _FloatNx are both widest corresponding real types (with equivalent sets of values) of these
arguments, the type determined is _FloatM. Otherwise, if long double and _FloatNx are
both widest corresponding real types (with equivalent sets of values) of these arguments, the type
determined is long double.

— Otherwise, if the corresponding real type of any argument for generic parameters has type
double, _Float64, or _Float32x, the type determined is the widest of the corresponding real
types of these arguments. If _Float64 and either double or _Float32x are both widest
 corresponding real types (with equivalent sets of values) of these arguments, the type determined is
_Float64. Otherwise, if double and _Float32x are both widest corresponding real types
(with equivalent sets of values) of these arguments, the type determined is double.

— Otherwise, if any argument for generic parameters is of integer type, the type determined is
double.

— Otherwise, if the corresponding real type of any argument for generic parameters has type
_Float32, the type determined is _Float32.

— Otherwise, the type determined is float.

In the second bullet 7.25#3c, attach a footnote to the wording:

the type determined is the widest

where the footnote is:

*) The term widest here refers to a type whose set of values is a superset of (or equivalent to) the
sets of values of the other types.

In 7.25#6, replace:

Use of the macro with any argument of standard floating or complex type invokes a complex function.
Use of the macro with an argument of decimal floating type results in undefined behavior.

with:

Use of the macro with any argument of standard floating type, floating type of radix 2, or complex
type, invokes a complex function. Use of the macro with an argument of a decimal floating type
results in undefined behavior.

After 7.25#6c, add the paragraph:

[6d] For an implementation that provides the following real floating types:

<table>
<thead>
<tr>
<th>type</th>
<th>IEC 60559 format</th>
</tr>
</thead>
<tbody>
<tr>
<td>float</td>
<td>binary32</td>
</tr>
<tr>
<td>double</td>
<td>binary64</td>
</tr>
<tr>
<td>long double</td>
<td>binary128</td>
</tr>
</tbody>
</table>
a type-generic macro `cbrt` that conforms to the specification in this clause and that is affected by constant rounding modes could be implemented as follows:

```c
#if defined(__STDC_WANT_IEC_60559_TYPES_EXT__)  
  #define cbrt(X) _Generic((X),  
      _Float128: cbrtf128(X),  
      _Float64: cbrtf64(X),  
      _Float32: cbrtf32(X),  
      _Float64x: cbrtf64x(X),  
      _Float32x: cbrtf32x(X),  
      long double: cbrtl(X),  
      default: _Roundwise_cbrt(X),  
      float: cbrtf(X))
#else  
  #define cbrt(X) _Generic((X),  
      long double: cbrtl(X),  
      default: _Roundwise_cbrt(X),  
      float: cbrtf(X))
#endif
```

where `_Roundwise_cbrt()` is equivalent to `cbrt()` invoked without macro-replacement suppression.

In 7.25#7, insert at the beginning of the example:

```c
#define __STDC_WANT_IEC_60559_TYPES_EXT__
```

In 7.25#7, append to the declarations:

```c
#if __STDC_IEC_60559_TYPES__ >= 201
  _Float32x f32x;
  _Float64 f64;
  _Float128 f128;
  _Float64x complex f64xc;
#endif
```

In 7.25#7, append to the table:

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>cos(f64xc)</code></td>
<td><code>ccosf64x(f64xc)</code></td>
</tr>
<tr>
<td><code>pow(dc, f128)</code></td>
<td><code>cpowf128(dc, f128)</code></td>
</tr>
<tr>
<td><code>fmax(f64, d)</code></td>
<td><code>fmaxf64(f64, d)</code></td>
</tr>
<tr>
<td><code>fmax(d, f32x)</code></td>
<td><code>fmax(d, f32x)</code>, the function, if the set of values of _Float32x is a subset of (or equivalent to) the set of values of double, or <code>fmaxf32x(d, f32x)</code>, if the set of values of double is a proper subset of the set of values of _Float32x, or undefined, if neither of the sets of values of double and _Float32x is a subset of the other (and the sets are not equivalent)</td>
</tr>
<tr>
<td><code>pow(f32x, n)</code></td>
<td><code>powf32x(f32x, n)</code></td>
</tr>
</tbody>
</table>
Bibliography


