TS 18661-4,5 REVISIONS

N3173 (updates N3165)
WG 14 – virtual meeting
October 16 – 20, 2023

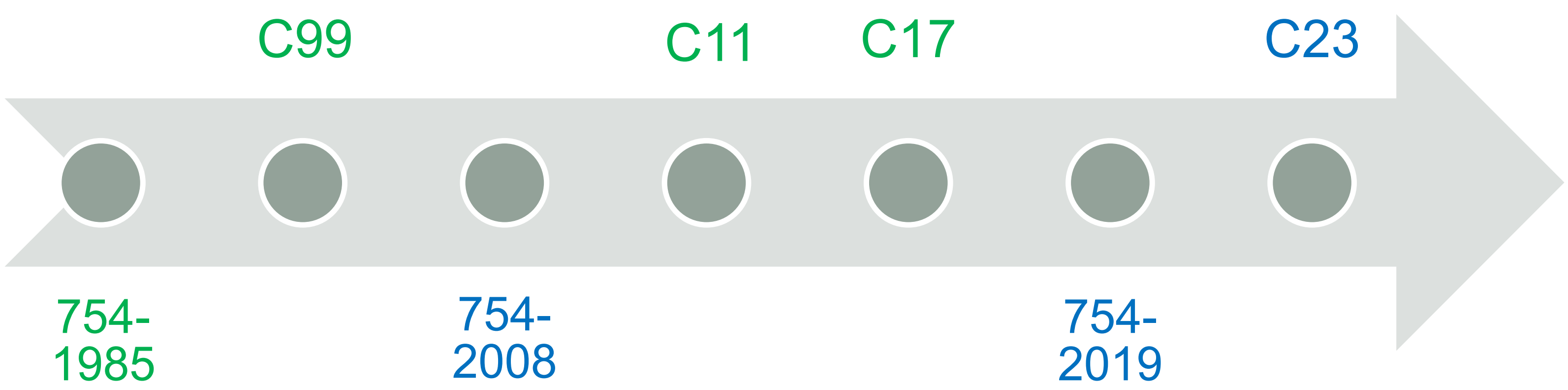
C FP group

Latest drafts

- N3163 draft ISO/IEC TS 18661-4, 2nd ed
- N3164 draft ISO/IEC TS 18661-5, 2nd ed

Background (1)

- C99 was first C to support IEEE 754/IEC 60559.
- 754-2008 was a major revision.
- C17 still based on 754-1985.
- C23 supports 754-2008 and minor revision in 2019, mostly.

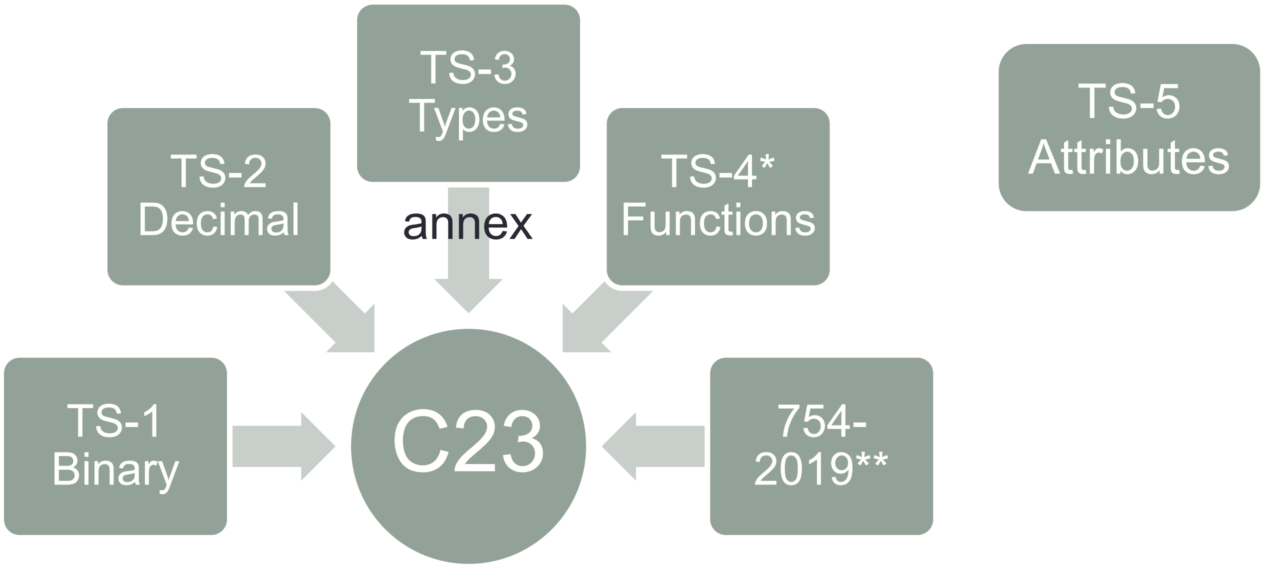


Background (2)

- CFP formed in 2009 to develop a C binding for major revision IEEE 754-2008 aka IEC 60559:2011.
- Developed ISO/IEC TS 18661, in five parts:
  - 1: Binary floating-point arithmetic (2014)
  - 2: Decimal floating-point arithmetic (2015)
  - 3: Interchange and extended types (2015)
  - 4: Supplementary functions (2015)
  - 5: Supplementary attributes (2016)

Background (3)

Incorporation into C23



* Not reduction functions

** Not augmented arithmetic

TS-4 & TS-5 revisions - purpose

Specify C extensions for IEC 60559 features not in C23.

TS-4 Supplementary functions

- Reduction functions from TS-4 v1
- Augmented arithmetic from IEC 60559: 2020

TS-5 Supplementary attributes

- All of TS-5 v1

Changes from 1st versions

- Written in the style of an annex for C extensions, not as changes to C.
- Based on C23.
- Based on IEC 60559-2020.
- Includes new augmented arithmetic feature from IEC 60559-2020.
- Offers conformance to separate features in the TSes.
- Changes most pragma prefixes from **`FENV_`** to **`FP_`** and headers from **`<fenv.h>`** to **`<math.h>`**.
- Includes new evaluation method macros that reflect the effective evaluation method.
- Includes examples for use of scaled products and augmented arithmetic.
- Changes scaled product output type from **`long long int`** to **`long int`** to work with **`scalbln`**.

TS-4 V2

SUPPLEMENTARY FUNCTIONS

TS-4 revision

Two features, with separate feature macros …

1. Reduction functions
   - `__STDC_IEC_60559_FUNCS_REDUCTION__`
   - Sum reductions
   - Scaled products

2. Augmented arithmetic
   - `__STDC_IEC_60559_FUNCS_AUGMENTED_ARITHMETIC__`

Both are `<math.h>` extensions, interfaces guarded by

`__STDC_WANT_IEC_60559_FUNCS_EXT__`

Sum reductions

IEC 60559:2011 specifies and recommends sum reduction operations on vectors p and q of length n:

sum(p, n)	$\sum_{i=1}^{n} p_i$
dot(p, q, n)	$\sum_{i=1}^{n} p_i \times q_i$
sumSquare(p, n)	$\sum_{i=1}^{n} p_i^2$
sumAbs(p, n)	$\sum_{i=1}^{n} \lvert p_i \rvert$

Scaled products

IEC 60559 specifies and recommends scaled product reduction operations: compute without over/underflow

pr = scaled product and sf = scale factor

such that

result product = pr × radix^{sf}

scaledProd(p, n)	$\prod_{i=1}^{n} p_i$
scaledProdSum(p, q, n)	$\prod_{i=1}^{n} (p_i + q_i)$
scaledProdDiff(p, q, n)	$\prod_{i=1}^{n} (p_i - q_i)$

Reduction function names

IEC 60559	TS 16881-4
sum	**`reduc_sum`**
dot	**`reduc_sumprod`**
sumSquare	**`reduc_sumsq`**
sumAbs	**`reduc_sumabs`**
scaledProd	**`scaled_prod`**
scaledProdSum	**`scaled_prodsum`**
scaledProdDiff	**`scaled_proddiff`**

Reduction function interfaces

```
#define __STDC_WANT_IEC_60559_FUNCS_EXT__
#include <math.h>

#ifdef __STDC_IEC_60559_BFP__
#ifdef __STDC_IEC_60559_FUNCS_REDUCTION__
double reduc_sum(size_t n, const double p[static n]);
...
double scaled_prod (size_t n, const double p[static n],
       long int * restrict sfptr );
...
```

Arrays indexed 0 to **`n`** - 1

IEC 60559 reductions

- Result values not fully specified like other IEC 60559 operations.
- Implementation can (re)order operations and use extra range and precision, for speed and accuracy.
- Must avoid over/underflow, except if final result of a sum reduction deserves over/underflow.
- Scaled products allow computing quotients of huge products whose numerator and denominator products would overflow.

Reduction special cases (1)

Follows general principles for special cases, e.g.

`reduc_sum(n, p)`

- Returns a NaN if any member of array **`p`** is a NaN.
- Returns a NaN and raises the “invalid” floating-point exception if any two members of array **`p`** are infinities with different signs.
- Otherwise, returns $\pm\infty$ if the members of **`p`** include one or more infinities $\pm\infty$ (with the same sign).

Reduction special cases (2)

`scaled_prod(n, p, sfptr)`

- Returns a NaN if any member of array **`p`** is a NaN.
- Returns a NaN and raises the “invalid” floating-point exception if any two members of array **`p`** are a zero and an infinity.
- Otherwise, returns an infinity if any member of array **`p`** is an infinity.
- Otherwise, returns a zero if any member of array **`p`** is a zero.
- Otherwise, returns a NaN and raises the “invalid” floating-point exception if the scale factor is outside the range of the **`long int`** type.

TS-5 V2

SUPPLEMENTARY ATTRIBUTES

TS-5 revision (1)

Four features, with separate feature macros …

Evaluation formats

- **`__STDC_IEC_60559_ATTRIB_EVALUATION_FORMAT__`**

Optimization controls

- **`__STDC_IEC_60559_ATTRIB_OPTIMIZATION__`**

Reproducibility

- **`__STDC_IEC_60559_ATTRIB_REPRODUCIBLE__`**

Alternate exception handling

- **`__STDC_IEC_60559_ATTRIB_ALTERNATE_EXCEPTION_HANDLING__`**

Interfaces guarded by

`__STDC_WANT_IEC_60559_ATTRIBS_EXT__`

TS-5 revision (2)

- IEC 60559 recommends that language standards provide block-scope attributes to control expression evaluation, value-changing optimizations, reproducibility, and alternate exception handling.
- TS 18661-5 provides these attributes as standard pragmas, like existing FP pragmas.
- The attributes are intended to address four problem areas in FP programming …

Problem area 1

Porting floating-point code between platforms and tool sets, including debugging ported code

- Program development tools typically provide controls to manage optimizations and evaluation methods.
- These controls are implementation specific, both in syntax and semantics, and are often vaguely defined.
- It's difficult to impossible to map controls on one system to equivalent ones on another.
- Standard pragmas for evaluation methods and optimizations are intended to address this problem.

Problem area 2

Balancing performance against precision and reliability

- Current implementation-specific controls are usually compiler options that apply to the whole translation unit.
- However, many programs need aggressive optimizations only for relatively small performance-critical blocks.
- Applying value-changing optimizations where they aren't needed unnecessarily risks floating-point anomalies.
- Similarly, extra precision might be needed only in relatively small precision-critical blocks.
- Using extra precision throughout the program might unnecessarily degrade performance.
- The block-scope semantics of the pragmas address this problem.

Evaluation methods (1)

The following pragmas provide the preferredWidth attributes recommended for language standards by IEC 60559:

`#pragma STDC FP_FLT_EVAL_METHOD` *width*

- *width* indicates a supported evaluation method for which macro **`FLT_EVAL_METHOD`** has the value *width*.
- Requires support for *width* equal -1 (indeterminable), 0 (evaluate to wider of **`float`** and type), and **`DEFAULT`**.
- Allows support for other values of *width*.

Evaluation methods (2)

`#pragma STDC FP_DEC_EVAL_METHOD` *width*

- Like **`FP_FLT_EVAL_METHOD`**, but for decimal.
- *width* indicates a supported evaluation method for which macro **`DEC_EVAL_METHOD`** has the value *width*.
- Requires support for *width* equal -1 (indeterminant), 1 (evaluate to wider of **`_Decimal64`** and type), and **`DEFAULT`**.
- Allows support for other values of *width*.

TS-5 also specifies a user definable macro

`__STDC_TGMATH_OPERATOR_EVALUATION__`

to have tgmath macros follow the evaluation method like operators do -- to allow wide evaluation that is consistent for all FP operations.

Evaluation methods (3)

TS-5 clarifies that the macros **`FLT_EVAL_METHOD`** and **`DEC_EVAL_METHOD`**

- Characterize the default evaluation methods
- Are not affected by evaluation method pragmas
- Can be used in **`#if`**/**`elif`** directives

Adds similar macros **`FLT_EVAL_METHOD_EFFECTIVE`** and **`DEC_EVAL_METHOD_EFFECTIVE`** that

- Characterize the effective evaluation methods
- Are affected by the evaluation method pragmas
- Cannot be used in **`#if`**/**`elif`** directives

Optimizations (1)

The following pragmas provide value-changing-optimization attributes recommended for language standards by IEC 60559:

`#pragma STDC FP_ALLOW_ASSOCIATIVE_LAW` *on-off-switch*

- $x + (y + z) = (x + y) + z$
- $x * (y * z) = (x * y) * z$

`#pragma STDC FP_ALLOW_DISTRIBUTIVE_LAW` *on-off-switch*

- $x *(y + z) = (x * y) + (x * z)$
- $x *(y - z) = (x * y) - (x * z)$
- $(x + y) / z = (x / z) + (y / z)$
- $(x - y) / z = (x / z) - (y / z)$

Optimizations (2)

`#pragma STDC FP_ALLOW_MULTIPLY_BY_RECIPROCAL` *on-off-switch*

- x / y = x *(1 / y)

`#pragma STDC FP_ALLOW_CONTRACT_FMA` *on-off-switch*

- Contract (compute with just one rounding) floating-point multiply and add or subtract (with the result of the multiply).
- x * y + z   x * y − z
- x + y * z   x − y * z

`#pragma STDC FP_ALLOW_CONTRACT_OPERATION_CONVERSION` *on-off-switch*

- Contract a floating-point operation and a conversion (of the result of the operation), e.g., **`flt_var = dbl_var * dbl_var`**.

Optimizations (3)

`#pragma STDC FP_ALLOW_CONTRACT` *on-off-switch*

- Includes effects of two "contract" pragmas above.
- Equivalent to C's **`FP_CONTRACT`** pragma.

`#pragma STDC FP_ALLOW_ZERO_SUBNORMAL` *on-off-switch*

- Replace subnormal operands and results by zero.

`#pragma STDC FP_ALLOW_VALUE_CHANGING_OPTIMIZATION` *on-off-switch*

- Equivalent to all the optimization pragmas above.

➢ Optimization pragmas allow but do not require the optimizations.

Problem area 3

Obtaining reproducible results (on same or different platforms)

- Some users want results that are the same on different platforms and that remain the same after tool set updates.
- Variations in floating-point results are usually harmless, but not always. The cost to determine whether a difference is the result of insignificant roundoff errors or the result of a serious instability or bug can be great.
- Potential causes of differences in floating-point results are many, and difficult for most programmers to avoid.
- A pragma and guidance for reproducible results is intended to help with this problem.

Reproducibility (1)

The following pragma provides the reproducible-results attribute recommended for language standards by IEC 60559:

`#pragma STDC FP_REPRODUCIBLE` *on-off-switch*

Implies effects of

- **`#pragma STDC FENV_ACCESS ON`**
- **`#pragma STDC FP_ALLOW_VALUE_CHANGING_OPTIMIZATION OFF`**

and if **`__STDC_IEC_60559_BFP__`** is defined

- **`#pragma STDC FP_FLT_EVAL_METHOD 0`**

and if **`__STDC_IEC_60559_DFP__`** is defined

- **`#pragma STDC FP_DEC_EVAL_METHOD 1`**

Reproducibility (2)

- Recommends a diagnostic message if the source code uses a language or library feature whose results may not be reproducible.
- Includes guidelines for code intended to be reproducible, e.g.
  - The code does not contain any use that may result in undefined behavior. The code does not depend on any behavior that is unspecified, implementation-defined, or locale-specific.
  - The code does not use the **`long double`** type.
  - The code does not depend on the payloads (F.10.13) or sign bits of quiet NaNs.
  - The code does not use signaling NaNs.

  etc.

Conformance note

- A low-quality or initial implementation of the features for evaluation methods, optimizations and reproducibility could have a conformance mode where only **`FLT_EVAL_METHOD`** equal 0 is supported, optimizations are disabled, and pragmas are ignored.

Problem area 4

Where default exception handling is not what a user wants

- Floating-point exceptions occur when there is no generally best result
- IEC 60559 default exception handling:
  - recognizes five kinds of exceptions (invalid operation, division by zero, overflow, underflow, and inexact)
  - sets an exception flag
  - provides well-defined results
  - provides results that are intended to be at least as generally useful as any others
  - does not stop or change the flow of execution
- A pragma for alternate exception handling provides other ways to handle exceptions

Exceptions

They're called exceptions because no matter what default you choose, somebody will take exception to it.

~ *W. Kahan*

Alternate exception handling (1)

`#pragma STDC FENV_EXCEPT` *except-list action*

except-list a comma-separated list of exception macro names:

`FE_DIVBYZERO`, **`FE_INVALID`**, …

and **`FE_ALL_EXCEPT`**

and optional sub-exception designations:

`FE_INVALID_ADD`	$+\infty + (-\infty)$
`FE_INVALID_MUL`	$\infty * 0$
`FE_INVALID_SNAN`	signaling NaN operand
`FE_DIVBYZERO_LOG`	log(0)

etc.

Alternate exception handling (2)

action one of

- **DEFAULT**

  IEC 60559 default exception handling.
- **NOEXCEPT**

  like default but no flags set.
- **OPTEXCEPT**

  like default but flags may be set.
- **ABRUPT**

  only for “underflow”, IEC 60559-defined abrupt underflow shall occur, unlike **ALLOW_ZERO_SUBNORMAL** where zeroing may occur.

Alternate exception handling (3)

The following actions change flow of control

action one of (cont.)

- **`BREAK`**

  terminate compound statement associated with pragma, ASAP*.

  *ASAP – for performance, the objects, flags, dynamic modes, and library states that would be changed at any point if the compound statement ran to completion are indeterminate or unspecified.

Alternate exception handling (4)

action one of (cont.)

These work together

- **`TRY`**

  A designated exception may be handled (ASAP) by a compound statement associated with a **`CATCH`** action.

- **`CATCH`**

  Code to handle designated exceptions.

Alternate exception handling (5)

action one of (cont.)

These work together

- **`DELAYED_TRY`**

  After associated compound statement completes, a designated exception may be handled by a compound statement associated with a **`DELAYED_CATCH`** action.

- **`DELAYED_CATCH`**

  Code to handle designated exceptions.

Alternate exception handling (6)

```
double d[n]; float f[n];
…
#pragma STDC FENV_EXCEPT TRY FE_DIVBYZERO,  FE_OVERFLOW
{

        for (i=0; i<n; i++) {
                f[i] = 1.0 / d[i];
        }
}
#pragma STDC FENV_EXCEPT CATCH FE_DIVBYZERO
{
        printf(“divide-by-zero\n”); }
}
#pragma STDC FENV_EXCEPT CATCH FE_OVERFLOW
{
        printf(“overflow\n”);
}
```

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Questions?

TS 18661-4,5 REVISIONS

Thank you!