
Information technology — Programming languages, their environments and system software interfaces — Extensions for the programming language C++ to support decimal floating-point arithmetic

Technologies de l'information — Langages de programmation, leurs environnements et interfaces de logiciel système — Extensions pour le langage de programmation C++ pour supporter l'arithmétique flottante décimale

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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

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

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

In exceptional circumstances, when the joint technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide to publish a Technical Report. A Technical Report is entirely informative in nature and shall be subject to review every five years in the same manner as an International Standard.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

ISO/IEC TR 24733 was prepared jointly by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 22, *Programming languages, their environments and system software interfaces*.

Introduction

0.1 General

Most of today's general purpose computing architectures provide binary floating-point arithmetic in hardware. Binary float-point is an efficient representation that minimizes memory use, and is simpler to implement than floating-point arithmetic using other bases. It has therefore become the norm for scientific computations, with almost all implementations following the IEEE-754 standard for binary floating-point arithmetic.

However, human computation and communication of numeric values almost always uses decimal arithmetic, and decimal notations. Laboratory notes, scientific papers, legal documents, business reports and financial statements all record numeric values in decimal form. When numeric data are given to a program or are displayed to a user, binary to-and-from decimal conversion is required. There are inherent rounding errors involved in such conversions; decimal fractions cannot, in general, be represented exactly by floating-point values. These errors often cause usability and efficiency problems, depending on the application.

These problems are minor when the application domain accepts, or requires results to have, associated error estimates (as is the case with scientific applications). However, in business and financial applications, computations are required either to be exact (with no rounding errors) unless explicitly rounded, or to be supported by detailed analyses that are auditable to be correct. Such applications therefore have to take special care in handling any rounding errors introduced by the computations.

The most efficient way to avoid conversion error is to use decimal arithmetic. Recognizing this, the IEEE 754-2008 Standard for Floating-Point Arithmetic specifies decimal floating-point encodings and arithmetic. This technical report specifies extensions to the International Standard for the C++ programming language to permit the use of decimal arithmetic in a manner consistent with the IEEE 754-2008 standard.

0.2 Arithmetic model

This Technical Report is based on a model of decimal arithmetic which is a formalization of the decimal system of numeration (algorithm) as further defined and constrained by the relevant standards, IEEE 854, ANSI X3-274, and IEEE 754-2008.

There are three components to the model:

- *data*— numbers and NaNs, which can be manipulated by, or be the results of, the core operations defined in the model
- *operations*— (such as addition, multiplication, etc.) which can be carried out on data
- *context* - the status of operations (namely, exceptions flags), and controls to govern the results of operations (for example, rounding modes).

The model defines these components in the abstract. It defines neither the way in which operations are expressed (which might vary depending on the computer language or other interface being used), nor the concrete representation (specific layout in storage, or in a processor's register, for example) of data or context.

From the perspective of the C++ language, *data* are represented by data types, *operations* are defined within expressions, and *context* is the floating environment specified in `<cfenv>` and `<fenv.h>`. This Technical Report specifies how the C++ language implements these components.

0.3 The formats

In the C++ International Standard, the representation of a floating-point number is specified in an abstract form where the constituent components of the representation are defined (sign, exponent, significand) but the internals of these components are not. 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.

This approach was inherited from the C programming language. At the time that C was first standardized, there were already various hardware implementations of floating-point arithmetic in common use. Specifying the exact details of a representation would make most of the existing C implementations at the time not conforming.

This Technical Report specifies decimal floating-point arithmetic according to the IEEE 754-2008 standard, with the constituent components of the representation defined. This is more stringent than the approach taken for the floating-point types in the C++ standard. Since it is expected that all decimal floating-point hardware implementations will conform to the IEEE 754-2008 standard, binding to this standard directly benefits both implementers and programmers.

Information technology — Programming languages, their environments and system software interfaces — Extensions for the programming language C++ to support decimal floating-point arithmetic

1 Scope

This Technical Report specifies an extension to the programming language C++, specified by ISO/IEC 14882:2003. The extension provides support for decimal floating-point arithmetic that is consistent with the specification in IEEE 754-2008. Any conflict between the requirements described here and that specification is unintentional.

The binary floating-point arithmetic specified in IEEE 754-2008 is not considered in this Technical Report.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 14882:2003, *Programming languages — C++*

ISO/IEC TR 19768:2007, *Information technology — Programming languages — Technical Report on C++ Library Extensions*

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*

IEEE 754-2008, *IEEE Standard for Floating-Point Arithmetic*

3 Conventions

3.1 General

This Technical Report is non-normative; the extensions that it describes may be considered for inclusion in a future revision of the International Standard for C++, but they are not currently required for conformance to that standard. Furthermore, it is conceivable that a future revision of the International Standard will include facilities that are similar and not identical to the extensions described in this report,

Although this report describes extensions to the *C++ standard library*, vendors may choose to implement these extensions in the C++ language translator itself. This practice is permitted so long as all well-formed programs are accepted by the implementation, and the semantics of those programs which do not have undefined or implementation-defined behavior are as if the extensions had taken the form of a library. [Note: This allows, for instance, an implementation to produce a different result when the extension is implemented in the C++ language translator, for programs that are ill-formed when the extension is implemented as a library.]

The result of deriving a user-defined type from `std::decimal::decimal32`, `std::decimal::decimal64`, or `std::decimal::decimal128` is undefined.

3.2 Relation to C++ Standard Library Introduction

Unless otherwise specified, the whole of the ISO C++ Standard Library introduction [lib.library] as specified in ISO/IEC 14882 is included into this Technical Report by reference.

This Technical Report introduces the following elements to supplement those described in [lib.structure.specifications] as specified in ISO/IEC 14882:

Expansion: the semantics of a macro's expansion text

Library Overload Set: an overload set for a given function name or overloaded operator. Each library overload set specifies the parameter types for the required overloads, and can be implemented as a suitably constrained function template, a set of overloaded non-template functions, or a combination of both.

[Example:

Consider a library overload set with the following specification:

```
decimal128 foo(decimal128 d, RHS rhs);
```

Library Overload Set: *RHS* may be any of the decimal floating-point types.

Returns: *d*.

A possible implementation of this library overload set is:

```
decimal128 foo(decimal128 d, decimal128) { return d; }
decimal128 foo(decimal128 d, decimal64) { return d; }
decimal128 foo(decimal128 d, decimal32) { return d; }
```

Another possible implementation of this library overload set is:

```
template <typename RHS>
decimal128 foo(decimal128 d, RHS) { return d; }
```

In the latter implementation, the template type parameter *RHS* must be constrained to the decimal floating-point types.

--end example]

3.3 Relation to "Technical Report on C++ Library Extensions"

Unless otherwise specified, the following sections of ISO/IEC Technical Report 19768: "Technical Report on C++ Library Extensions" are included into this Technical Report by reference:

- General [tr.intro]
- Metaprogramming and type traits [tr.meta]
- Additions to header <functional> synopsis [tr.unord.fun.syn]
- Class template hash [tr.unord.hash]
- C compatibility [tr.c99]

3.4 Categories of extensions

This technical report describes 4 categories of library extensions:

- New library components (types and functions) that are declared entirely in new headers, such as the type `decimal::decimal32` in the <decimal> header.
- New library components declared as additions to existing standard headers, such as the functions added to the headers <cmath> and <math.h> in subclause 4.6.
- New library components declared as additions to TR1 headers, such as the template `is_decimal_floating_point` added to the header <type_traits> in subclause 4.11.
- Additions to standard library components, such as the specializations of `std::numeric_limits` in subclause 4.3.

New headers are distinguished from extensions to existing headers by the title of the *synopsis* clause. In the first case the title is of the form "Header <foo> synopsis," and the synopsis includes all namespace scope declarations contained in the header. In the second case the title is of the form "Additions to header <foo> synopsis" and the synopsis includes only the extensions, *i.e.* those namespace scope declarations that are not present in ISO/IEC 14882 or ISO/IEC 19768.

3.5 Namespaces and headers

The extensions described in this technical report are declared within the namespace `decimal`, which is nested inside the namespace `std`.

Unless otherwise specified, references to other entities described in this technical report are assumed to be qualified with `std::decimal::`, references to entities described in the C++ standard library are assumed to be qualified with `std::`, and references to entities described in TR1 are assumed to be qualified with `std::tr1::`.

Even when an extension is specified as additions to standard headers (the second and third categories in section 3.4), vendors should not simply add declarations to standard headers in a way that would be visible to users by default [*Note:* That would fail to be standard conforming, because the new names, even within a namespace, could conflict with user macros. --end note] Users should be required to take explicit action to have access to library extensions. It is recommended either that additional declarations in standard headers be protected with a macro that is not defined by default, or else that all extended headers, including both new headers and parallel versions of standard headers with nonstandard declarations, be placed in a separate directory that is not part of the default search path.

4 Decimal floating-point types

4.1 Characteristics of decimal floating-point types

This Technical Report introduces three *decimal floating-point types*, named decimal32, decimal64, and decimal128. The set of values of type decimal32 is a subset of the set of values of type decimal64; the set of values of the type decimal64 is a subset of the set of values of the type decimal128. These types supplement the standard C++ types `float`, `double`, and `long double`, which are collectively described as the *basic floating types*.

The three decimal encoding formats defined in IEEE 754-2008 correspond to the three decimal floating types as follows:

- decimal32 is a *decimal32* number, which is encoded in four consecutive octets (32 bits)
- decimal64 is a *decimal64* number, which is encoded in eight consecutive octets (64 bits)
- decimal128 is a *decimal128* number, which is encoded in 16 consecutive octets (128 bits)

The value of a finite number is given by $(-1)^{\text{sign}} \times \text{coefficient} \times 10^{\text{exponent}}$. Refer to IEEE 754-2008 for details of the format.

These formats are characterized by the length of the coefficient, and the maximum and minimum exponent. The coefficient is not normalized, so trailing zeros are significant; i.e. 1.0 is equal to but can be distinguished from 1.00. Table 1 shows these characteristics by format.

Table 1 -- Format Characteristics

Format	decimal32	decimal64	decimal128
Coefficient length in digits	7	16	34
Maximum Exponent ($E^{\max}$)	97	385	6145
Minimum Exponent ($E^{\min}$)	-94	-382	-6142

4.2 Decimal Types

4.2.1 Header <decimal> synopsis

```
#include <iosfwd>

namespace std {
namespace decimal {

    // 4.2.2 class decimal32:
    class decimal32;

    // 4.2.3 class decimal64:
    class decimal64;

    // 4.2.4 class decimal128:
    class decimal128;

    // 4.2.5 initialization from coefficient and exponent:
    decimal32 make_decimal32 (long long coeff, int exponent);
    decimal32 make_decimal32 (unsigned long long coeff,
                              int exponent);
    decimal64 make_decimal64 (long long coeff, int exponent);
    decimal64 make_decimal64 (unsigned long long coeff,
                              int exponent);
    decimal128 make_decimal128 (long long coeff, int exponent);
    decimal128 make_decimal128 (unsigned long long coeff,
                                int exponent);

    // 4.2.6 conversion to generic floating-point type:
    float decimal32_to_float (decimal32 d);
    float decimal64_to_float (decimal64 d);
    float decimal128_to_float (decimal128 d);
    float decimal_to_float (decimal32 d);
    float decimal_to_float (decimal64 d);
    float decimal_to_float (decimal128 d);

    double decimal32_to_double (decimal32 d);
    double decimal64_to_double (decimal64 d);
    double decimal128_to_double (decimal128 d);
    double decimal_to_double (decimal32 d);
    double decimal_to_double (decimal64 d);
    double decimal_to_double (decimal128 d);

    long double decimal32_to_long_double (decimal32 d);
    long double decimal64_to_long_double (decimal64 d);
    long double decimal128_to_long_double (decimal128 d);
    long double decimal_to_long_double (decimal32 d);
    long double decimal_to_long_double (decimal64 d);
    long double decimal_to_long_double (decimal128 d);

    // 4.2.7 unary arithmetic operators:
    decimal32 operator+(decimal32 rhs);
```

```

decimal64 operator+(decimal64 rhs);
decimal128 operator+(decimal128 rhs);
decimal32 operator-(decimal32 rhs);
decimal64 operator-(decimal64 rhs);
decimal128 operator-(decimal128 rhs);

// 4.2.8 binary arithmetic operators:
/* see 4.2.8 */ operator+(LHS lhs, decimal32 rhs);
/* see 4.2.8 */ operator+(LHS lhs, decimal64 rhs);
decimal128 operator+(LHS lhs, decimal128 rhs);

decimal32 operator+(decimal32 lhs, RHS rhs);
decimal64 operator+(decimal64 lhs, RHS rhs);
decimal128 operator+(decimal128 lhs, RHS rhs);

/* see 4.2.8 */ operator-(LHS lhs, decimal32 rhs);
/* see 4.2.8 */ operator-(LHS lhs, decimal64 rhs);
decimal128 operator-(LHS lhs, decimal128 rhs);

decimal32 operator-(decimal32 lhs, RHS rhs);
decimal64 operator-(decimal64 lhs, RHS rhs);
decimal128 operator-(decimal128 lhs, RHS rhs);

/* see 4.2.8 */ operator*(LHS lhs, decimal32 rhs);
/* see 4.2.8 */ operator*(LHS lhs, decimal64 rhs);
decimal128 operator*(LHS lhs, decimal128 rhs);

decimal32 operator*(decimal32 lhs, RHS rhs);
decimal64 operator*(decimal64 lhs, RHS rhs);
decimal128 operator*(decimal128 lhs, RHS rhs);

/* see 4.2.8 */ operator/(LHS lhs, decimal32 rhs);
/* see 4.2.8 */ operator/(LHS lhs, decimal64 rhs);
decimal128 operator/(LHS lhs, decimal128 rhs);

decimal32 operator/(decimal32 lhs, RHS rhs);
decimal64 operator/(decimal64 lhs, RHS rhs);
decimal128 operator/(decimal128 lhs, RHS rhs);

// 4.2.9 comparison operators:
bool operator==(LHS lhs, decimal32 rhs);
bool operator==(LHS lhs, decimal64 rhs);
bool operator==(LHS lhs, decimal128 rhs);

bool operator==(decimal32 lhs, RHS rhs);
bool operator==(decimal64 lhs, RHS rhs);
bool operator==(decimal128 lhs, RHS rhs);

bool operator!=(LHS lhs, decimal32 rhs);
bool operator!=(LHS lhs, decimal64 rhs);
bool operator!=(LHS lhs, decimal128 rhs);

bool operator!=(decimal32 lhs, RHS rhs);

```

```

bool operator!=(decimal64 lhs, RHS rhs);
bool operator!=(decimal128 lhs, RHS rhs);

bool operator<(LHS lhs, decimal32 rhs);
bool operator<(LHS lhs, decimal64 rhs);
bool operator<(LHS lhs, decimal128 rhs);

bool operator<(decimal32 lhs, RHS rhs);
bool operator<(decimal64 lhs, RHS rhs);
bool operator<(decimal128 lhs, RHS rhs);

bool operator<=(LHS lhs, decimal32 rhs);
bool operator<=(LHS lhs, decimal64 rhs);
bool operator<=(LHS lhs, decimal128 rhs);

bool operator<=(decimal32 lhs, RHS rhs);
bool operator<=(decimal64 lhs, RHS rhs);
bool operator<=(decimal128 lhs, RHS rhs);

bool operator>(LHS lhs, decimal32 rhs);
bool operator>(LHS lhs, decimal64 rhs);
bool operator>(LHS lhs, decimal128 rhs);

bool operator>(decimal32 lhs, RHS rhs);
bool operator>(decimal64 lhs, RHS rhs);
bool operator>(decimal128 lhs, RHS rhs);

bool operator>=(LHS lhs, decimal32 rhs);
bool operator>=(LHS lhs, decimal64 rhs);
bool operator>=(LHS lhs, decimal128 rhs);

bool operator>=(decimal32 lhs, RHS rhs);
bool operator>=(decimal64 lhs, RHS rhs);
bool operator>=(decimal128 lhs, RHS rhs);

// 4.2.10 Formatted input:
template <class charT, class traits>
    std::basic_istream<charT, traits> &
        operator>>(std::basic_istream<charT, traits> & is,
                    decimal32 & d);

template <class charT, class traits>
    std::basic_istream<charT, traits> &
        operator>>(std::basic_istream<charT, traits> & is,
                    decimal64 & d);

template <class charT, class traits>
    std::basic_istream<charT, traits> &
        operator>>(std::basic_istream<charT, traits> & is,
                    decimal128 & d);

// 4.2.11 Formatted output:
template <class charT, class traits>

```

```
std::basic_ostream<charT, traits> &
operator<<(std::basic_ostream<charT, traits> & os,
          decimal32 d);

template <class charT, class traits>
std::basic_ostream<charT, traits> &
operator<<(std::basic_ostream<charT, traits> & os,
          decimal64 d);

template <class charT, class traits>
std::basic_ostream<charT, traits> &
operator<<(std::basic_ostream<charT, traits> & os,
          decimal128 d);
}
}
```

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4.2.2 Class decimal32

4.2.2.1 Class summary

```

namespace std {
namespace decimal {
class decimal32 {
public:
    // 4.2.2.2 construct/copy/destroy:
    decimal32();

    // 4.2.2.3 conversion from floating-point type:
    explicit decimal32(decimal64 d64);
    explicit decimal32(decimal128 d128);
    explicit decimal32(float r);
    explicit decimal32(double r);
    explicit decimal32(long double r);

    // 4.2.2.4 conversion from integral type:
    decimal32(int z);
    decimal32(unsigned int z);
    decimal32(long z);
    decimal32(unsigned long z);
    decimal32(long long z);
    decimal32(unsigned long long z);

    // 4.2.2.5 conversion to integral type:
    operator long long() const;

    // 4.2.2.6 increment and decrement operators:
    decimal32 & operator++();
    decimal32 & operator++(int);
    decimal32 & operator--();
    decimal32 & operator--(int);

    // 4.2.2.7 compound assignment:
    decimal32 & operator+=(RHS rhs);
    decimal32 & operator-=(RHS rhs);
    decimal32 & operator*=(RHS rhs);
    decimal32 & operator/=(RHS rhs);
};
}

```

4.2.2.2 Construct/copy/destroy

```
decimal32();
```

Effects: Constructs an object of type `decimal32` with the value equivalent to `+0` and quantum equal to `-101`.

4.2.2.3 Conversion from floating-point type

```
explicit decimal32(decimal64 d64);
```

Effects: Constructs an object of type `decimal32` by converting from type `decimal64`. Conversion is performed in accordance with IEEE 754-2008.

```
explicit decimal32(decimal128 d128);
```

Effects: Constructs an object of type `decimal32` by converting from type `decimal128`. Conversion is performed in accordance with IEEE 754-2008.

```
explicit decimal32(float r);
```

Effects: Constructs an object of type `decimal32` by converting from type `float`. If `std::numeric_limits<float>::is_iec559 == true` then the conversion is performed in accordance with IEEE 754-2008. Otherwise, the result of the conversion is implementation-defined.

```
explicit decimal32(double r);
```

Effects: Constructs an object of type `decimal32` by converting from type `double`. If `std::numeric_limits<double>::is_iec559 == true` then the conversion is performed in accordance with IEEE 754-2008. Otherwise, the result of the conversion is implementation-defined.

```
explicit decimal32(long double r);
```

Effects: Constructs an object of type `decimal32` by converting from type `long double`. If `std::numeric_limits<long double>::is_iec559 == true` then the conversion is performed in accordance with IEEE 754-2008. Otherwise, the result of the conversion is implementation-defined.

4.2.2.4 Conversion from integral type

```
decimal32(int z);
decimal32(unsigned int z);
decimal32(long z);
decimal32(unsigned long z);
decimal32(long long z);
decimal32(unsigned long long z);
```

Effects: Constructs an object of type `decimal32` by converting from the type of `z`. Conversion is performed in accordance with IEEE 754-2008. If the value being converted is in the range of values that can be represented but cannot be represented exactly, the result shall be correctly rounded with exceptions raised in accordance with IEEE 754-2008.

4.2.2.5 Conversion to integral type

```
operator long long() const;
```

Effects: Returns the result of the conversion of **this* to the type `long long` by discarding the fractional part (i.e., the value is truncated toward zero). If the value of the integral part cannot be represented by the integer type or **this* has infinite value or is NAN, the “invalid” floating-point exception shall be raised and the result of the conversion is unspecified.

4.2.2.6 Increment and decrement operators

```
decimal32 & operator++();
```

Effects: Adds 1 to **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal32 operator++(int);
```

Effects:

```
decimal32 tmp = *this;
*this += 1;
return tmp;
```

```
decimal32 & operator--();
```

Effects: Subtracts 1 from **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal32 operator--(int);
```

Effects:

```
decimal32 tmp = *this;
*this -= 1;
return tmp;
```

4.2.2.7 Compound assignment

```
decimal32 & operator+=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Adds *rhs* to **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal32 & operator-=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Subtracts *rhs* from **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal32 & operator*=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Multiplies **this* by *rhs*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal32 & operator/=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Divides **this* by *rhs*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

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4.2.3 Class `decimal64`

4.2.3.1 Class summary

```

namespace std {
namespace decimal {
class decimal64 {
public:
    // 4.2.3.2 construct/copy/destroy:
    decimal64();

    // 4.2.3.3 conversion from floating-point type:
    decimal64(decimal32 d32);
    explicit decimal64(decimal128 d128);
    explicit decimal64(float r);
    explicit decimal64(double r);
    explicit decimal64(long double r);

    // 4.2.3.4 conversion from integral type:
    decimal64(int z);
    decimal64(unsigned int z);
    decimal64(long z);
    decimal64(unsigned long z);
    decimal64(long long z);
    decimal64(unsigned long long z);

    // 4.2.3.5 conversion to integral type:
    operator long long() const;

    // 4.2.3.6 increment and decrement operators:
    decimal64 & operator++();
    decimal64 operator++(int);
    decimal64 & operator--();
    decimal64 operator--(int);

    // 4.2.3.7 compound assignment:
    decimal64 & operator+=(RHS rhs);
    decimal64 & operator-=(RHS rhs);
    decimal64 & operator*=(RHS rhs);
    decimal64 & operator/=(RHS rhs);
};
}
}

```

4.2.3.2 Construct/copy/destroy

```
decimal64();
```

Effects: Constructs an object of type `decimal64` with the value equivalent to +0 and quantum equal to -398.

4.2.3.3 Conversion from floating-point type

```
decimal64(decimal32 d32);
```

Effects: Constructs an object of type `decimal64` by converting from type `decimal32`. Conversion is performed in accordance with IEEE 754-2008.

```
explicit decimal64(decimal128 d128);
```

Effects: Constructs an object of type `decimal64` by converting from type `decimal128`. Conversion is performed in accordance with IEEE 754-2008.

```
explicit decimal64(float r);
```

Effects: Constructs an object of type `decimal64` by converting from type `float`. If `std::numeric_limits<float>::is_iec559 == true` then the conversion is performed in accordance with IEEE 754-2008. Otherwise, the result of the conversion is implementation-defined.

```
explicit decimal64(double r);
```

Effects: Constructs an object of type `decimal64` by converting from type `double`. If `std::numeric_limits<double>::is_iec559 == true` then the conversion is performed in accordance with IEEE 754-2008. Otherwise, the result of the conversion is implementation-defined.

```
explicit decimal64(long double r);
```

Effects: Constructs an object of type `decimal64` by converting from type `long double`. If `std::numeric_limits<long double>::is_iec559 == true` then the conversion is performed in accordance with IEEE 754-2008. Otherwise, the result of the conversion is implementation-defined.

4.2.3.4 Conversion from integral type

```
decimal64(int z);
decimal64(unsigned int z);
decimal64(long z);
decimal64(unsigned long z);
decimal64(long long z);
decimal64(unsigned long long z);
```

Effects: Constructs an object of type `decimal64` by converting from the type of `z`. Conversion is performed in accordance with IEEE 754-2008. If the value being converted is in the range of values that can be represented but cannot be represented exactly, the result shall be correctly rounded with exceptions raised in accordance with IEEE 754-2008.

4.2.3.5 Conversion to integral type

```
operator long long() const;
```

Effects: Returns the result of the conversion of `*this` to the type `long long` by discarding the fractional part (i.e., the value is truncated toward zero). If the value of the integral part cannot be represented by the integer type or `*this` has infinite value or is NAN, the “invalid” floating-point exception shall be raised and the result of the conversion is unspecified.

4.2.3.6 Increment and decrement operators

```
decimal64 & operator++();
```

Effects: Adds 1 to `*this`, in accordance with IEEE 754-2008, and assigns the result to `*this`.

Returns: `*this`

```
decimal64 operator++(int);
```

Effects:

```
decimal64 tmp = *this;
*this += 1;
return tmp;
```

```
decimal64 & operator--();
```

Effects: Subtracts 1 from **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal64 operator--(int);
```

Effects:

```
decimal64 tmp = *this;
*this -= 1;
return tmp;
```

4.2.3.7 Compound assignment

```
decimal64 & operator+=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Adds *rhs* to **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal64 & operator-=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Subtracts *rhs* from **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal64 & operator*=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Multiplies **this* by *rhs*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal64 & operator/=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Divides **this* by *rhs*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

4.2.4 Class `decimal128`

4.2.4.1 Class summary

```

namespace std {
namespace decimal {
class decimal128 {
public:
    // 4.2.4.2 construct/copy/destroy:
    decimal128();

    // 4.2.4.3 conversion from floating-point type:
    decimal128(decimal32 d32);
    decimal128(decimal64 d64);
    explicit decimal128(float r);
    explicit decimal128(double r);
    explicit decimal128(long double r);

    // 4.2.4.4 conversion from integral type:
    decimal128(int z);
    decimal128(unsigned int z);
    decimal128(long z);
    decimal128(unsigned long z);
    decimal128(long long z);
    decimal128(unsigned long long z);

    // 4.2.4.5 conversion to integral type:
    operator long long() const;

    // 4.2.4.6 increment and decrement operators:
    decimal128 & operator++();
    decimal128 operator++(int);
    decimal128 & operator--();
    decimal128 operator--(int);

    // 4.2.4.7 compound assignment:
    decimal128 & operator+=(RHS rhs);
    decimal128 & operator-=(RHS rhs);
    decimal128 & operator*=(RHS rhs);
    decimal128 & operator/=(RHS rhs);
};
}
}

```

4.2.4.2 Construct/copy/destroy

```
decimal128();
```

Effects: Constructs an object of type `decimal128` with the value equivalent to +0 and quantum equal to -6176.

4.2.4.3 Conversion from floating-point type

```
decimal128(decimal32 d32);
```

Effects: Constructs an object of type `decimal128` by converting from type `decimal32`. Conversion is performed as in IEEE 754-2008.

```
decimal128(decimal64 d64);
```

Effects: Constructs an object of type `decimal128` by converting from type `decimal64`. Conversion is performed in accordance with IEEE 754-2008.

```
explicit decimal128(float r);
```

Effects: Constructs an object of type `decimal128` by converting from type `float`. If `std::numeric_limits<float>::is_iec559 == true` then the conversion is performed in accordance with IEEE 754-2008. Otherwise, the result of the conversion is implementation-defined.

```
explicit decimal128(double r);
```

Effects: Constructs an object of type `decimal128` by converting from type `double`. If `std::numeric_limits<double>::is_iec559 == true` then the conversion is performed in accordance with IEEE 754-2008. Otherwise, the result of the conversion is implementation-defined.

```
explicit decimal128(long double r);
```

Effects: Constructs an object of type `decimal128` by converting from type `long double`. If `std::numeric_limits<long double>::is_iec559 == true` then the conversion is performed in accordance with IEEE 754-2008. Otherwise, the result of the conversion is implementation-defined.

4.2.4.4 Conversion from integral type

```
decimal128(int z);
decimal128(unsigned int z);
decimal128(long z);
decimal128(unsigned long z);
decimal128(long long z);
decimal128(unsigned long long z);
```

Effects: Constructs an object of type `decimal128` by converting from the type of `z`. Conversion is performed in accordance with IEEE 754-2008. If the value being converted is in the range of values that can be represented but cannot be represented exactly, the result shall be correctly rounded with exceptions raised in accordance with IEEE 754-2008.

4.2.4.5 Conversion to integral type

```
operator long long() const;
```

Effects: Returns the result of the conversion of `*this` to the type `long long` by discarding the fractional part (i.e., the value is truncated toward zero). If the value of the integral part cannot be represented by the integer type or `*this` has infinite value or is NaN, the “invalid” floating-point exception shall be raised and the result of the conversion is unspecified.

4.2.4.6 Increment and decrement operators

```
decimal128 & operator++();
```

Effects: Adds 1 to `*this`, in accordance with IEEE 754-2008, and assigns the result to `*this`.

Returns: `*this`

```
decimal128 operator++(int);
```

Effects:

```
decimal128 tmp = *this;
*this += 1;
return tmp;
```

```
decimal128 & operator--();
```

Effects: Subtracts 1 from **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal128 operator--(int);
```

Effects:

```
decimal128 tmp = *this;
*this -= 1;
return tmp;
```

4.2.4.7 Compound assignment

```
decimal128 & operator+=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Adds *rhs* to **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal128 & operator-=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Subtracts *rhs* from **this*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal128 & operator*=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Multiplies **this* by *rhs*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

```
decimal128 & operator/=(RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types, or any of the decimal floating-point types.

Effects: Divides **this* by *rhs*, in accordance with IEEE 754-2008, and assigns the result to **this*.

Returns: **this*

4.2.5 Initialization from coefficient and exponent

```
decimal32  make_decimal32 (long long coeff, int exponent);
decimal32  make_decimal32 (unsigned long long coeff,
                           int exponent);
decimal64  make_decimal64 (long long coeff, int exponent);
decimal64  make_decimal64 (unsigned long long coeff,
                           int exponent);
decimal128 make_decimal128(long long coeff, int exponent);
decimal128 make_decimal128(unsigned long long coeff,
                           int exponent);
```

Effects: Returns an object of the appropriate decimal floating-point type with the value $\text{coeff} \times 10^{\text{exponent}}$, rounded in accordance with IEEE-754, if necessary. If an overflow condition occurs, then the value of the macro `ERANGE` is stored in `errno`.

[*Note:* In cases where the desired coefficient is greater than `ULLONG_MAX` or less than `LLONG_MIN`, it will be preferable to initialize an object of decimal floating-point type by extracting its value from a string literal using one of the `strtod` functions or `iostreams`. -- *end note.*]

4.2.6 Conversion to generic floating-point type

```
float decimal32_to_float (decimal32 d);
float decimal64_to_float (decimal64 d);
float decimal128_to_float(decimal128 d);
float decimal_to_float(decimal32 d);
float decimal_to_float(decimal64 d);
float decimal_to_float(decimal128 d);
```

Returns: If `std::numeric_limits<float>::is_iec559 == true`, returns the result of the conversion of *d* to `float`, performed in accordance with IEEE 754-2008. Otherwise, the returned value is implementation-defined. See 5.3.

```
double decimal32_to_double (decimal32 d);
double decimal64_to_double (decimal64 d);
double decimal128_to_double(decimal128 d);
double decimal_to_double(decimal32 d);
double decimal_to_double(decimal64 d);
double decimal_to_double(decimal128 d);
```

Returns: If `std::numeric_limits<double>::is_iec559 == true`, returns the result of the conversion of *d* to `double`, performed in accordance with IEEE 754-2008. Otherwise, the returned value is implementation-defined. See 5.3.

```
long double decimal32_to_long_double (decimal32 d);
long double decimal64_to_long_double (decimal64 d);
long double decimal128_to_long_double(decimal128 d);
long double decimal_to_long_double(decimal32 d);
long double decimal_to_long_double(decimal64 d);
long double decimal_to_long_double(decimal128 d);
```

Returns: If `std::numeric_limits<long double>::is_iec559 == true`, returns the result of the conversion of *d* to `long double`, performed in accordance with IEEE 754-2008. Otherwise, the returned value is implementation-defined. See 5.3.

4.2.7 Unary arithmetic operators

```
decimal32 operator+(decimal32 lhs);
decimal64 operator+(decimal64 lhs);
decimal128 operator+(decimal128 lhs);
```

Returns: Adds *lhs* to 0, in accordance with IEEE 754-2008, and returns the result.

```
decimal32 operator-(decimal32 lhs);
decimal64 operator-(decimal64 lhs);
decimal128 operator-(decimal128 lhs);
```

Returns: the result of inverting the sign of *lhs*.

[*Note:* because of the possibility that *lhs* may equal -0, this is not the same as subtracting *lhs* from 0 --end note.]

4.2.8 Binary arithmetic operators

The return type of each binary arithmetic operator in this section is determined according to the following algorithm:

- if one or both of the parameters of the overloaded operator is `decimal128`, then the return type is `decimal128`,
- otherwise, if one or both of the parameters is `decimal64`, then the return type is `decimal64`,
- otherwise, the return type is `decimal32`.

```
/* see above */ operator+(LHS lhs, decimal32 rhs);
/* see above */ operator+(LHS lhs, decimal64 rhs);
decimal128 operator+(LHS lhs, decimal128 rhs);
```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: Adds *rhs* to *lhs*, in accordance with IEEE 754-2008, and returns the result.

```
decimal32 operator+(decimal32 lhs, RHS rhs);
decimal64 operator+(decimal64 lhs, RHS rhs);
decimal128 operator+(decimal128 lhs, RHS rhs);
```

Library Overload Set: *RHS* may be any of the integral types.

Returns: Adds *rhs* to *lhs*, in accordance with IEEE 754-2008, and returns the result.

```
/* see above */ operator-(LHS lhs, decimal32 rhs);
/* see above */ operator-(LHS lhs, decimal64 rhs);
decimal128 operator-(LHS lhs, decimal128 rhs);
```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: Subtracts *rhs* from *lhs*, in accordance with IEEE 754-2008, and returns the result.

```

decimal32 operator-(decimal32 lhs, RHS rhs);
decimal64 operator-(decimal64 lhs, RHS rhs);
decimal128 operator-(decimal128 lhs, RHS rhs);

```

Library Overload Set: *RHS* may be any of the integral types.

Returns: Subtracts *rhs* from *lhs*, in accordance with IEEE 754-2008, and returns the result.

```

/* see above */ operator*(LHS lhs, decimal32 rhs);
/* see above */ operator*(LHS lhs, decimal64 rhs);
decimal128 operator*(LHS lhs, decimal128 rhs);

```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: Multiplies *lhs* by *rhs*, in accordance with IEEE 754-2008, and returns the result.

```

decimal32 operator*(decimal32 lhs, RHS rhs);
decimal64 operator*(decimal64 lhs, RHS rhs);
decimal128 operator*(decimal128 lhs, RHS rhs);

```

Library Overload Set: *RHS* may be any of the integral types.

Returns: Multiplies *lhs* by *rhs*, in accordance with IEEE 754-2008, and returns the result.

```

/* see above */ operator/(LHS lhs, decimal32 rhs);
/* see above */ operator/(LHS lhs, decimal64 rhs);
decimal128 operator/(LHS lhs, decimal128 rhs);

```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: Divides *lhs* by *rhs*, in accordance with IEEE 754-2008, and returns the result.

```

decimal32 operator/(decimal32 lhs, RHS rhs);
decimal64 operator/(decimal64 lhs, RHS rhs);
decimal128 operator/(decimal128 lhs, RHS rhs);

```

Library Overload Set: *RHS* may be any of the integral types.

Returns: Divides *lhs* by *rhs*, in accordance with IEEE 754-2008, and returns the result.

4.2.9 Comparison operators

```

bool operator==(LHS lhs, decimal32 rhs);
bool operator==(LHS lhs, decimal64 rhs);
bool operator==(LHS lhs, decimal128 rhs);

```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: `true` if *lhs* is exactly equal to *rhs* according to IEEE 754-2008, `false` otherwise.

```

bool operator==(decimal32 lhs, RHS rhs);
bool operator==(decimal64 lhs, RHS rhs);
bool operator==(decimal128 lhs, RHS rhs);

```

Library Overload Set: *RHS* may be any of the integral types.

Returns: *true* if *lhs* is exactly equal to *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator!=(LHS lhs, decimal32 rhs);
bool operator!=(LHS lhs, decimal64 rhs);
bool operator!=(LHS lhs, decimal128 rhs);

```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: *true* if *lhs* is not exactly equal to *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator!=(decimal32 lhs, RHS rhs);
bool operator!=(decimal64 lhs, RHS rhs);
bool operator!=(decimal128 lhs, RHS rhs);

```

Library Overload Set: *RHS* may be any of the integral types.

Returns: *true* if *lhs* is not exactly equal to *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator<(LHS lhs, decimal32 rhs);
bool operator<(LHS lhs, decimal64 rhs);
bool operator<(LHS lhs, decimal128 rhs);

```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: *true* if *lhs* is less than *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator<(decimal32 lhs, RHS rhs);
bool operator<(decimal64 lhs, RHS rhs);
bool operator<(decimal128 lhs, RHS rhs);

```

Library Overload Set: *RHS* may be any of the integral types.

Returns: *true* if *lhs* is less than *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator<=(LHS lhs, decimal32 rhs);
bool operator<=(LHS lhs, decimal64 rhs);
bool operator<=(LHS lhs, decimal128 rhs);

```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: *true* if *lhs* is less than or equal to *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator<=(decimal32 lhs, RHS rhs);
bool operator<=(decimal64 lhs, RHS rhs);
bool operator<=(decimal128 lhs, RHS rhs);

```

Library Overload Set: *RHS* may be any of the integral types.

Returns: *true* if *lhs* is less than or equal to *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator>(LHS lhs, decimal32 rhs);
bool operator>(LHS lhs, decimal64 rhs);
bool operator>(LHS lhs, decimal128 rhs);

```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: *true* if *lhs* is greater than *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator>(decimal32 lhs, RHS rhs);
bool operator>(decimal64 lhs, RHS rhs);
bool operator>(decimal128 lhs, RHS rhs);

```

Library Overload Set: *RHS* may be any of the integral types.

Returns: *true* if *lhs* is greater than *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator>=(LHS lhs, decimal32 rhs);
bool operator>=(LHS lhs, decimal64 rhs);
bool operator>=(LHS lhs, decimal128 rhs);

```

Library Overload Set: *LHS* may be any of the integral types or any of the decimal floating-point types.

Returns: *true* if *lhs* is greater than or equal to *rhs* according to IEEE 754-2008, *false* otherwise.

```

bool operator>=(decimal32 lhs, RHS rhs);
bool operator>=(decimal64 lhs, RHS rhs);
bool operator>=(decimal128 lhs, RHS rhs);

```

Library Overload Set: *RHS* may be any of the integral types.

Returns: *true* if *lhs* is greater than or equal to *rhs* according to IEEE 754-2008, *false* otherwise.

4.2.10 Formatted input

```
template <class charT, class traits>
    std::basic_istream<charT, traits> &
        operator>>(std::basic_istream<charT, traits> & is,
                    decimal32 & d);

template <class charT, class traits>
    std::basic_istream<charT, traits> &
        operator>>(std::basic_istream<charT, traits> & is,
                    decimal64 & d);

template <class charT, class traits>
    std::basic_istream<charT, traits> &
        operator>>(std::basic_istream<charT, traits> & is,
                    decimal128 & d);
```

Effects: This function constructs an object of class `std::basic_istream<charT, traits>::sentry`. If the `sentry` object returns `true` when converted to a value of type `bool`, input is extracted as if by the following code fragment:

```
typedef extended_num_get<charT,
    std::istreambuf_iterator<charT, traits> > extnumget;
std::ios_base::iostate err = 0;
std::use_facet<extnumget>(is.getloc()).get(*this, 0, *this, err, d);
setstate(err);
```

If an exception is thrown during input then `std::ios::badbit` is set in the error state of the input stream *is*. If `(is.exceptions() & std::ios_base::badbit) != 0` then the exception is rethrown. In any case, the formatted input function destroys the `sentry` object.

Returns: *is*.

4.2.11 Formatted output

```
template <class charT, class traits>
    std::basic_ostream<charT, traits> &
        operator<<(std::basic_ostream<charT, traits> & os,
                    decimal32 d);

template <class charT, class traits>
    std::basic_ostream<charT, traits> &
        operator<<(std::basic_ostream<charT, traits> & os,
                    decimal64 d);

template <class charT, class traits>
    std::basic_ostream<charT, traits> &
        operator<<(std::basic_ostream<charT, traits> & os,
                    decimal128 d);
```

Effects: This function constructs an object of class `std::basic_ostream<charT, traits>::sentry`. If the sentry object returns true when converted to a value of type `bool`, output is generated as if by the following code fragment:

```
typedef extended_num_put<charT,
    std::ostreambuf_iterator<charT, traits> > extnumput;
bool failed =
    std::use_facet<extnumput>(os.getloc()).put(*this,
        *this, os.fill(), d).failed();
if (failed)
    { os.setstate(std::ios_base::failbit); }
```

If an exception is thrown during output then `std::ios::badbit` is set in the error state of the input stream `os`. If `(os.exceptions() & std::ios_base::badbit) != 0` then the exception is rethrown. In any case, the formatted output function destroys the sentry object.

Returns: `os`.

4.3 Additions to header <limits>

The standard template `std::numeric_limits` shall be specialized for the `decimal32`, `decimal64`, and `decimal128` types.

[Example:

```
namespace std {
    template<> class numeric_limits<decimal::decimal32> {
    public:
        static const bool is_specialized = true;
        static decimal::decimal32 min() throw()
            { return DEC32_MIN; }
        static decimal::decimal32 max() throw()
            { return DEC32_MAX; }

        static const int digits = 7;
        static const int digits10 = digits;
        static const int max_digits10 = digits;

        static const bool is_signed = true;
        static const bool is_integer = false;
        static const bool is_exact = false;

        static const int radix = 10;
        static decimal::decimal32 epsilon() throw()
            { return DEC32_EPSILON; }
        static decimal::decimal32 round_error() throw();

        static const int min_exponent = -94;
        static const int min_exponent10 = min_exponent;
        static const int max_exponent = 97;
        static const int max_exponent10 = max_exponent;

        static const bool has_infinity = true;
        static const bool has_quiet_NaN = true;
        static const bool has_signaling_NaN = true;
        static const float_denorm_style has_denorm =
            denorm_present;
        static const bool has_denorm_loss = true;

        static decimal::decimal32 infinity() throw();
        static decimal::decimal32 quiet_NaN() throw();
        static decimal::decimal32 signaling_NaN() throw();
        static decimal::decimal32 denorm_min() throw()
            { return DEC32_DEN; }

        static const bool is_iec559 = false;
        static const bool is_bounded = true;
        static const bool is_modulo = false;
        static const bool traps = true;
        static const bool tinyness_before = true;
        static const float_round_style round_style =
            round_indeterminate;
    };
};
```

```

template<> class numeric_limits<decimal::decimal64> {
public:
    static const bool is_specialized = true;

    static decimal::decimal64 min() throw()
        { return DEC64_MIN; }
    static decimal::decimal64 max() throw()
        { return DEC64_MAX; }

    static const int digits          = 16;
    static const int digits10       = digits;
    static const int max_digits10   = digits;

    static const bool is_signed     = true;
    static const bool is_integer    = false;
    static const bool is_exact      = false;

    static const int radix = 10;
    static decimal::decimal64 epsilon() throw()
        { return DEC64_EPSILON; }
    static decimal::decimal64 round_error() throw()
        { return ...; }

    static const int min_exponent    = -382;
    static const int min_exponent10 = min_exponent;
    static const int max_exponent    = 385;
    static const int max_exponent10 = max_exponent;

    static const bool has_infinity      = true;
    static const bool has_quiet_NaN     = true;
    static const bool has_signaling_NaN = true;
    static const float_denorm_style has_denorm =
        denorm_present;
    static const bool has_denorm_loss    = true;

    static decimal::decimal64 infinity() throw()
        { return ...; }
    static decimal::decimal64 quiet_NaN() throw()
        { return ...; }
    static decimal::decimal64 signaling_NaN() throw()
        { return ...; }
    static decimal::decimal64 denorm_min() throw()
        { return DEC64_DEN; }

    static const bool is_iec559        = false;
    static const bool is_bounded       = true;
    static const bool is_modulo        = false;
    static const bool traps            = true;
    static const bool tinyness_before = true;

    static const float_round_style round_style =
        round_indeterminate;
};

```

```

template<> class numeric_limits<decimal::decimal128> {
public:
    static const bool is_specialized = true;

    static decimal::decimal128 min() throw()
        { return DEC128_MIN; }
    static decimal::decimal128 max() throw()
        { return DEC128_MAX; }

    static const int digits          = 34;
    static const int digits10       = digits;
    static const int max_digits10   = digits;

    static const bool is_signed     = true;
    static const bool is_integer    = false;
    static const bool is_exact      = false;

    static const int radix = 10;
    static decimal::decimal128 epsilon() throw()
        { return DEC128_EPSILON; }
    static decimal::decimal128 round_error() throw()
        { return ...; }

    static const int min_exponent    = -6142;
    static const int min_exponent10 = min_exponent;
    static const int max_exponent    = 6145;
    static const int max_exponent10 = max_exponent;

    static const bool has_infinity          = true;
    static const bool has_quiet_NaN         = true;
    static const bool has_signaling_NaN     = true;
    static const float_denorm_style has_denorm =
        denorm_present;
    static const bool has_denorm_loss       = true;

    static decimal::decimal128 infinity() throw()
        { return ...; }
    static decimal::decimal128 quiet_NaN() throw()
        { return ...; }
    static decimal::decimal128 signaling_NaN() throw()
        { return ...; }
    static decimal::decimal128 denorm_min() throw()
        { return DEC128_DEN; }

    static const bool is_iec559          = false;
    static const bool is_bounded         = true;
    static const bool is_modulo           = false;
    static const bool traps               = true;
    static const bool tinyness_before    = true;

    static const float_round_style round_style =
        round_indeterminate;
};
} --end example]

```

4.4 Headers `<cfloat>` and `<float.h>`

4.4.1 General

The header `<cfloat>` is described in [tr.c99.cfloat] as specified in ISO/IEC 19768. The header `<float.h>` is described in [tr.c99.float.h] as specified in ISO/IEC 19768. These headers are extended by this Technical Report to define characteristics of the decimal floating-point types `decimal32`, `decimal64`, and `decimal128`. As well, `<float.h>` is extended to define the convenience typedefs `_Decimal32`, `_Decimal64`, and `_Decimal128` for compatibility with the C programming language.

4.4.2 Additions to header `<cfloat>` synopsis

```
#include <decimal>

// number of digits in the coefficient:
#define DEC32_MANT_DIG 7
#define DEC64_MANT_DIG 16
#define DEC128_MANT_DIG 34

// minimum exponent:
#define DEC32_MIN_EXP -94
#define DEC64_MIN_EXP -382
#define DEC128_MIN_EXP -6142

// maximum exponent:
#define DEC32_MAX_EXP 97
#define DEC64_MAX_EXP 385
#define DEC128_MAX_EXP 6145

// 4.4.4 maximum finite value:
#define DEC32_MAX implementation-defined
#define DEC64_MAX implementation-defined
#define DEC128_MAX implementation-defined

// 4.4.5 epsilon:
#define DEC32_EPSILON implementation-defined
#define DEC64_EPSILON implementation-defined
#define DEC128_EPSILON implementation-defined

// 4.4.6 minimum positive normal value:
#define DEC32_MIN implementation-defined
#define DEC64_MIN implementation-defined
#define DEC128_MIN implementation-defined

// 4.4.7 minimum positive subnormal value:
#define DEC32_SUBNORMAL_MIN implementation-defined
#define DEC64_SUBNORMAL_MIN implementation-defined
#define DEC128_SUBNORMAL_MIN implementation-defined

// 4.4.8 evaluation format:
#define DEC_EVAL_METHOD implementation-defined
```

4.4.4 Maximum finite value

Expansion: an rvalue of type `decimal32` equal to the maximum finite number that can be represented by an object of type `decimal32`; exactly equal to 9.999999×10^{96} (there are six 9's after the decimal point)

Expansion: an rvalue of type `decimal64` equal to the maximum finite number that can be represented by an object of type `decimal64`; exactly equal to $9.99999999999999 \times 10^{384}$ (there are fifteen 9's after the decimal point)

Expansion: an rvalue of type decimal128 equal to the maximum finite number that can be represented by an object of type decimal128; exactly equal to $9.999999999999999999999999999999 \times 10^{6144}$ (there are thirty-three 9's after the decimal point)

Expansion: an rvalue of type `decimal32` equal to the difference between 1 and the least value greater than 1 that can be represented by an object of type `decimal32`; exactly equal to 1×10^{-6}

Expansion: an rvalue of type `decimal64` equal to the difference between 1 and the least value greater than 1 that can be represented by an object of type `decimal64`; exactly equal to 1×10^{-15}

Expansion: an rvalue of type `decimal128` equal to the difference between 1 and the least value greater than 1 that can be represented by an object of type `decimal128`; exactly equal to 1×10^{-33}

4.4.6 Minimum positive normal value

```
#define DEC32_MIN implementation-defined
```

Expansion: an rvalue of type `decimal32` equal to the minimum positive normal number that can be represented by an object of type `decimal32`; exactly equal to 1×10^{-95}

```
#define DEC64_MIN implementation-defined
```

Expansion: an rvalue of type `decimal64` equal to the minimum positive normal number that can be represented by an object of type `decimal64`; exactly equal to 1×10^{-383}

```
#define DEC128_MIN implementation-defined
```

Expansion: an rvalue of type `decimal128` equal to the minimum positive normal number that can be represented by an object of type `decimal128`; exactly equal to 1×10^{-6143}

4.4.7 Minimum positive subnormal value

```
#define DEC32_SUBNORMAL implementation-defined
```

Expansion: an rvalue of type `decimal32` equal to the minimum positive finite number that can be represented by an object of type `decimal32`; exactly equal to 0.000001×10^{-95}

```
#define DEC64_SUBNORMAL implementation-defined
```

Expansion: an rvalue of type `decimal64` equal to the minimum positive finite number that can be represented by an object of type `decimal64`; exactly equal to $0.0000000000000001 \times 10^{-383}$

```
#define DEC128_SUBNORMAL implementation-defined
```

Expansion: an rvalue of type `decimal128` equal to the minimum positive finite number that can be represented by an object of type `decimal128`; exactly equal to $0.000000000000000000000000000001 \times 10^{-6143}$

4.4.8 Evaluation format

```
#define DEC_EVAL_METHOD implementation-defined
```

Except for assignment and casts, the values of operations with decimal floating operands and values subject to the usual arithmetic conversions are evaluated to a format whose range and precision may be greater than required by the type. The use of evaluation formats is characterized by the implementation-defined value of `DEC_EVAL_METHOD`:

- 1 indeterminate;
- 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.

All other negative values for `DEC_EVAL_METHOD` characterize implementation-defined behavior.

4.5 Additions to `<cfenv>` and `<fenv.h>`

4.5.1 General

The header `<cfenv>` is described in [tr.c99.cfenv]. The header `<fenv.h>` is described in [tr.c99.fenv]. The floating point environment specified in these subclauses is extended by this Technical Report to apply to decimal floating-point types.

4.5.2 Additions to `<cfenv>` synopsis

```
// 4.5.3 rounding direction macros:
#define FE_DEC_DOWNWARD          implementation-defined
#define FE_DEC_TONEAREST        implementation-defined
#define FE_DEC_TONEARESTFROMZERO implementation-defined
#define FE_DEC_TOWARD_ZERO      implementation-defined
#define FE_DEC_UPWARD           implementation-defined

namespace std {
namespace decimal {

    // 4.5.4 fe_dec_getround function:
    int fe_dec_getround();

    // 4.5.5 fe_dec_setround function:
    int fe_dec_setround(int round);
}
}
```

4.5.3 Rounding modes

Macros are added to `<cfenv>` and `<fenv.h>`:

Table 2 -- DFP rounding direction macros

Additional DFP rounding direction macros introduced by this Technical Report	Equivalent TR1 macro for generic floating types	IEEE-754
FE_DEC_DOWNWARD	FE_DOWNWARD	Towards minus infinity
FE_DEC_TONEAREST	FE_TONEAREST	To nearest, ties even
FE_DEC_TONEARESTFROMZERO	n/a	To nearest, ties away from zero
FE_DEC_TOWARD_ZERO	FE_TOWARD_ZERO	Toward zero
FE_DEC_UPWARD	FE_UPWARD	Toward plus infinity

These macros are used by the `fe_dec_getround` and `fe_dec_setround` functions for getting and setting the rounding mode to be used in decimal floating-point operations.

4.5.4 The `fe_dec_getround` function

```
int fe_dec_getround();
```

Effects: gets the current rounding direction for decimal floating-point operations.

Returns: the value of the rounding direction macro representing the current rounding direction for decimal floating-point operations, or a negative value if there is no such rounding macro or the current rounding direction is not determinable.

4.5.5 The `fe_dec_setround` function

```
int fe_dec_setround(int round);
```

Effects: establishes *round* as the rounding direction for decimal floating-point operations. If *round* is not equal to the value of a DFP rounding direction macro, the rounding direction is not changed.

If `FLT_RADIX` is not 10, the rounding direction altered by the `fesetround` function is independent of the rounding direction altered by the `fe_dec_setround` function; otherwise, if `FLT_RADIX` is 10, whether the `fesetround` and `fe_dec_setround` functions alter the rounding direction of both generic floating type and decimal floating type operations is implementation defined.

Returns: a zero value if and only if the argument is equal to one of the rounding direction macros introduced in 4.6.2.

4.5.6 Changes to `<fenv.h>`

Each name placed into the namespace `decimal` by `<cfenv>` is placed into both the namespace `decimal` and the global namespace by `<fenv.h>`.

4.6 Additions to `<cmath>` and `<math.h>`

4.6.1 General

The elementary mathematical functions declared in the standard C++ header `<cmath>` are overloaded by this Technical Report to support the decimal floating-point types. The macros `HUGE_VAL_D32`, `HUGE_VAL_D64`, `HUGE_VAL_D128`, `DEC_INFINITY`, and `DEC_NAN` are defined for use with these functions. The following math functions are completely specified by 754-2008 and are correctly rounded:

`sqrt`, `fma`, `fabs`, `fmax`, `fmin`, `ceil`, `floor`, `trunc`, `round`, `rint`, `lround`, `llround`, `ldexp`, `frexp`, `ilogb`, `logb`, `scalbn`, `scalbln`, `copysign`, `nextafter`, `remainder`, `isnan`, `isinf`, `isfinite`, `isnormal`, `signbit`, `fpclassify`, `isunordered`, `isgreater`, `isgreaterequal`, `isless`, `islessequal`, `quantize`, and `samequantum`.

The accuracy of other math functions is implementation defined and the implementation may state that the accuracy is unknown. The TR1 function templates `signbit`, `fpclassify`, `isinf`, `isfinite`, `isnormal`, `isgreater`, `isgreaterequal`, `isless`, `islessequal`, `islessgreater`, and `isunordered` are also extended by this Technical Report to handle the decimal floating-point types.

4.6.2 Additions to header `<cmath>` synopsis

```
// 4.6.3 macros:
#define HUGE_VAL_D32      implementation-defined
#define HUGE_VAL_D64      implementation-defined
#define HUGE_VAL_D128     implementation-defined
#define DEC_INFINITY      implementation-defined
#define DEC_NAN            implementation-defined
#define FP_FAST_FMAD32    implementation-defined
#define FP_FAST_FMAD64    implementation-defined
#define FP_FAST_FMAD128   implementation-defined

namespace std {
namespace decimal {
    // 4.6.4 evaluation formats:
    typedef decimal-floating_t decimal32_t;
    typedef decimal-floating_t decimal64_t;

    // 4.6.5 samequantum functions:
    bool samequantum      (decimal32 x, decimal32 y);
    bool samequantumd32   (decimal32 x, decimal32 y);

    bool samequantum      (decimal64 x, decimal64 y);
    bool samequantumd64   (decimal64 x, decimal64 y);

    bool samequantum      (decimal128 x, decimal128 y);
    bool samequantumd128  (decimal128 x, decimal128 y);

    // 4.6.6 quantize functions:
    decimal32 quantize     (decimal32 x, decimal32 y);
    decimal32 quantized32  (decimal32 x, decimal32 y);

    decimal64 quantize     (decimal64 x, decimal64 y);
    decimal64 quantized64  (decimal64 x, decimal64 y);

    decimal128 quantize    (decimal128 x, decimal128 y);
    decimal128 quantized128 (decimal128 x, decimal128 y);

    // 4.6.7 quantexp functions:
    int quantexpd32        (decimal32 x);
    int quantexpd64        (decimal64 x);
    int quantexpd128       (decimal128 x);

    // 4.6.8 elementary functions:
    // trigonometric functions:
    decimal32 acosd32      (decimal32 x);
    decimal64 acosd64      (decimal64 x);
    decimal128 acosd128    (decimal128 x);

    decimal32 asind32      (decimal32 x);
    decimal64 asind64      (decimal64 x);
    decimal128 asind128    (decimal128 x);

    decimal32 atand32      (decimal32 x);
```

```

decimal64  atand64  (decimal64  x);
decimal128 atand128 (decimal128 x);

decimal32  atan2d32 (decimal32  x, decimal32  y);
decimal64  atan2d64 (decimal64  x, decimal64  y);
decimal128 atan2d128 (decimal128 x, decimal128 y);

decimal32  cosd32  (decimal32  x);
decimal64  cosd64  (decimal64  x);
decimal128 cosd128 (decimal128 x);

decimal32  sind32  (decimal32  x);
decimal64  sind64  (decimal64  x);
decimal128 sind128 (decimal128 x);

decimal32  tand32  (decimal32  x);
decimal64  tand64  (decimal64  x);
decimal128 tand128 (decimal128 x);

// hyperbolic functions:
decimal32  acoshd32 (decimal32  x);
decimal64  acoshd64 (decimal64  x);
decimal128 acoshd128 (decimal128 x);

decimal32  asinhd32 (decimal32  x);
decimal64  asinhd64 (decimal64  x);
decimal128 asinhd128 (decimal128 x);

decimal32  atanh32  (decimal32  x);
decimal64  atanh64  (decimal64  x);
decimal128 atanh128 (decimal128 x);

decimal32  coshd32  (decimal32  x);
decimal64  coshd64  (decimal64  x);
decimal128 coshd128 (decimal128 x);

decimal32  sinhd32  (decimal32  x);
decimal64  sinhd64  (decimal64  x);
decimal128 sinhd128 (decimal128 x);

decimal32  tanhd32  (decimal32  x);
decimal64  tanhd64  (decimal64  x);
decimal128 tanhd128 (decimal128 x);

// exponential and logarithmic functions:
decimal32  expd32  (decimal32  x);
decimal64  expd64  (decimal64  x);
decimal128 expd128 (decimal128 x);

decimal32  exp2d32  (decimal32  x);
decimal64  exp2d64  (decimal64  x);
decimal128 exp2d128 (decimal128 x);

decimal32  expm1d32 (decimal32  x);

```

```

decimal64 expmld64 (decimal64 x);
decimal128 expmld128 (decimal128 x);

decimal32 frexpd32 (decimal32 value, int * exp);
decimal64 frexpd64 (decimal64 value, int * exp);
decimal128 frexpd128 (decimal128 value, int * exp);

int ilogbd32 (decimal32 x);
int ilogbd64 (decimal64 x);
int ilogbd128 (decimal128 x);

decimal32 ldexpd32 (decimal32 x, int exp);
decimal64 ldexpd64 (decimal64 x, int exp);
decimal128 ldexpd128 (decimal128 x, int exp);

decimal32 logd32 (decimal32 x);
decimal64 logd64 (decimal64 x);
decimal128 logd128 (decimal128 x);

decimal32 log10d32 (decimal32 x);
decimal64 log10d64 (decimal64 x);
decimal128 log10d128 (decimal128 x);

decimal32 log1pd32 (decimal32 x);
decimal64 log1pd64 (decimal64 x);
decimal128 log1pd128 (decimal128 x);

decimal32 log2d32 (decimal32 x);
decimal64 log2d64 (decimal64 x);
decimal128 log2d128 (decimal128 x);

decimal32 logbd32 (decimal32 x);
decimal64 logbd64 (decimal64 x);
decimal128 logbd128 (decimal128 x);

decimal32 modfd32 (decimal32 value, decimal32 * iptr);
decimal64 modfd64 (decimal64 value, decimal64 * iptr);
decimal128 modfd128 (decimal128 value, decimal128 * iptr);

decimal32 scalbnd32 (decimal32 x, int n);
decimal64 scalbnd64 (decimal64 x, int n);
decimal128 scalbnd128 (decimal128 x, int n);

decimal32 scalblnd32 (decimal32 x, long int n);
decimal64 scalblnd64 (decimal64 x, long int n);
decimal128 scalblnd128 (decimal128 x, long int n);

// power and absolute-value functions:
decimal32 cbrtd32 (decimal32 x);
decimal64 cbrtd64 (decimal64 x);
decimal128 cbrtd128 (decimal128 x);

decimal32 fabsd32 (decimal32 x);
decimal64 fabsd64 (decimal64 x);

```

```

decimal128 fabstd128 (decimal128 x);

decimal32 hypotd32 (decimal32 x, decimal32 y);
decimal64 hypotd64 (decimal64 x, decimal64 y);
decimal128 hypotd128 (decimal128 x, decimal128 y);

decimal32 powd32 (decimal32 x, decimal32 y);
decimal64 powd64 (decimal64 x, decimal64 y);
decimal128 powd128 (decimal128 x, decimal128 y);

decimal32 sqrt32 (decimal32 x);
decimal64 sqrt64 (decimal64 x);
decimal128 sqrt128 (decimal128 x);

// error and gamma functions:
decimal32 erfd32 (decimal32 x);
decimal64 erfd64 (decimal64 x);
decimal128 erfd128 (decimal128 x);

decimal32 erfcd32 (decimal32 x);
decimal64 erfcd64 (decimal64 x);
decimal128 erfcd128 (decimal128 x);

decimal32 lgammad32 (decimal32 x);
decimal64 lgammad64 (decimal64 x);
decimal128 lgammad128 (decimal128 x);

decimal32 tgamma32 (decimal32 x);
decimal64 tgamma64 (decimal64 x);
decimal128 tgamma128 (decimal128 x);

// nearest integer functions:
decimal32 ceild32 (decimal32 x);
decimal64 ceild64 (decimal64 x);
decimal128 ceild128 (decimal128 x);

decimal32 floord32 (decimal32 x);
decimal64 floord64 (decimal64 x);
decimal128 floord128 (decimal128 x);

decimal32 nearbyintd32 (decimal32 x);
decimal64 nearbyintd64 (decimal64 x);
decimal128 nearbyintd128 (decimal128 x);

decimal32 rintd32 (decimal32 x);
decimal64 rintd64 (decimal64 x);
decimal128 rintd128 (decimal128 x);

long int lrintd32 (decimal32 x);
long int lrintd64 (decimal64 x);
long int lrintd128 (decimal128 x);

long long int llrintd32 (decimal32 x);
long long int llrintd64 (decimal64 x);

```

```

long long int llrintd128 (decimal128 x);

decimal32 roundd32 (decimal32 x);
decimal64 roundd64 (decimal64 x);
decimal128 roundd128 (decimal128 x);

long int lroundd32 (decimal32 x);
long int lroundd64 (decimal64 x);
long int lroundd128 (decimal128 x);

long long int llroundd32 (decimal32 x);
long long int llroundd64 (decimal64 x);
long long int llroundd128 (decimal128 x);

decimal32 truncd32 (decimal32 x);
decimal64 truncd64 (decimal64 x);
decimal128 truncd128 (decimal128 x);

// remainder functions:
decimal32 fmodd32 (decimal32 x, decimal32 y);
decimal64 fmodd64 (decimal64 x, decimal64 y);
decimal128 fmodd128 (decimal128 x, decimal128 y);

decimal32 remainderd32 (decimal32 x, decimal32 y);
decimal64 remainderd64 (decimal64 x, decimal64 y);
decimal128 remainderd128 (decimal128 x, decimal128 y);

decimal32 remquod32 (decimal32 x, decimal32 y, int * quo);
decimal64 remquod64 (decimal64 x, decimal64 y, int * quo);
decimal128 remquod128 (decimal128 x, decimal128 y, int * quo);

// manipulation functions:
decimal32 copysignd32 (decimal32 x, decimal32 y);
decimal64 copysignd64 (decimal64 x, decimal64 y);
decimal128 copysignd128 (decimal128 x, decimal128 y);

decimal32 nand32 (const char * tagp);
decimal64 nand64 (const char * tagp);
decimal128 nand128 (const char * tagp);

decimal32 nextafterd32 (decimal32 x, decimal32 y);
decimal64 nextafterd64 (decimal64 x, decimal64 y);
decimal128 nextafterd128 (decimal128 x, decimal128 y);

decimal32 nexttowardd32 (decimal32 x, decimal128 y);
decimal64 nexttowardd64 (decimal64 x, decimal128 y);
decimal128 nexttowardd128 (decimal128 x, decimal128 y);

// maximum, minimum, and positive difference functions:
decimal32 fdimd32 (decimal32 x, decimal32 y);
decimal64 fdimd64 (decimal64 x, decimal64 y);
decimal128 fdimd128 (decimal128 x, decimal128 y);

decimal32 fmaxd32 (decimal32 x, decimal32 y);

```

```

decimal64 fmaxd64 (decimal64 x, decimal64 y);
decimal128 fmaxd128 (decimal128 x, decimal128 y);

decimal32 fmind32 (decimal32 x, decimal32 y);
decimal64 fmind64 (decimal64 x, decimal64 y);
decimal128 fmind128 (decimal128 x, decimal128 y);

// floating multiply-add:
decimal32 fmad32 (decimal32 x, decimal32 y, decimal32 z);
decimal64 fmad64 (decimal64 x, decimal64 y, decimal64 z);
decimal128 fmad128 (decimal128 x, decimal128 y, decimal128 z);

// 4.6.6.1 abs function overloads
decimal32 abs(decimal32 d);
decimal64 abs(decimal64 d);
decimal128 abs(decimal128 d);
}
}

```

4.6.3 <cmath> macros

```
#define HUGE_VAL_D32 implementation-defined
```

Expansion: a positive rvalue of type decimal32 representing infinity.

```
#define HUGE_VAL_D64 implementation-defined
```

Expansion: a positive rvalue of type decimal64 representing infinity.

```
#define HUGE_VAL_D128 implementation-defined
```

Expansion: a positive rvalue of type decimal128 representing infinity.

```
#define DEC_INFINITY implementation-defined
```

Expansion: an rvalue of type decimal32 representing infinity.

```
#define DEC_NAN implementation-defined
```

Expansion: an rvalue of type decimal32 representing quiet NaN.

```
#define FP_FAST_FMA32 implementation-defined
```

```
#define FP_FAST_FMA64 implementation-defined
```

```
#define FP_FAST_FMA128 implementation-defined
```

Effects: these macros are, respectively, decimal32, decimal64, and decimal128 analogs of FP_FAST_FMA in subclause 7.12 of ISO/IEC 9899.

4.6.4 Evaluation formats

```
typedef decimal-floating-type decimal32_t;
```

```
typedef decimal-floating-typedecimal64_t;
```

The types decimal32_t and decimal64_t are decimal floating types at least as wide as decimal32 and decimal64, respectively, and such that decimal64_t is at least as wide as decimal32_t. If DEC_EVAL_METHOD equals 0, decimal32_t and decimal64_t are decimal32 and decimal64, respectively; if DEC_EVAL_METHOD equals 1, they are both decimal64; if DEC_EVAL_METHOD equals 2, they are both decimal128; and for other values of DEC_EVAL_METHOD, they are otherwise implementation-defined.

4.6.5 samequantum functions

```
bool samequantumd32 (decimal32 x, decimal32 y);
bool samequantumd64 (decimal64 x, decimal64 y);
bool samequantumd128 (decimal128 x, decimal128 y);
```

Effects: determines if the quantum exponents of x and y are the same. If both x and y are NaN, or infinity, they have the same quantum exponents; if exactly one operand is infinity or exactly one operand is NaN, they do not have the same quantum exponents. The samequantum functions raise no exception.

Returns: true when x and y have the same representation exponents, false otherwise.

```
bool samequantum (decimal32 x, decimal32 y);
```

Returns: samequantumd32(x , y)

```
bool samequantum (decimal64 x, decimal64 y);
```

Returns: samequantumd64(x , y)

```
bool samequantum (decimal128 x, decimal128 y);
```

Returns: samequantumd128(x , y)

4.6.6 quantexp functions

```
int quantexpd32 (decimal32 x);
int quantexpd64 (decimal64 x);
int quantexpd128 (decimal128 x);
```

Effects: if x is finite, returns its quantum exponent. Otherwise, a domain error occurs and INT_MIN is returned.

```
int quantexp (decimal32 x);
```

Returns: quantexpd32(x)

```
int quantexp (decimal64 x);
```

Returns: quantexpd64(x)

```
int quantexp (decimal128 x);
```

Returns: quantexpd128(x)

4.6.7 quantize functions

```
decimal32 quantized32 (decimal32 x, decimal32 y);
decimal64 quantized64 (decimal64 x, decimal64 y);
decimal128 quantized128 (decimal128 x, decimal128 y);
```

Returns: a number that is equal in value (except for any rounding) and sign to x , and which has an exponent set to be equal to the exponent of y . If the exponent is being increased, the value is correctly rounded according to the current rounding mode; if the result does not have the same value as x , the "inexact" floating-point exception is raised. If the exponent is being decreased and the significand of the result has more digits than the type would allow, the "invalid" floating-point exception is raised and the result is NaN. If one or both operands are NaN the result is NaN. Otherwise if only one operand is infinity, the "invalid" floating-point exception is raised and the result is NaN. If both operands are infinity, the result is DEC_INFINITY, with the same sign as x , converted to the type of x . The quantize functions do not signal underflow.

```
decimal32 quantize (decimal32 x, decimal32 y);
```

Returns: quantized32(x , y)

```
decimal64 quantize (decimal64 x, decimal64 y);
```

Returns: quantized64(x , y)

```
decimal128 quantize (decimal128 x, decimal128 y);
```

Returns: quantized128(x , y)

4.6.8 Elementary functions

For each of the following standard elementary functions from `<cmath>`,

acos	ceil	floor	log	sin	tanh
asin	cos	fmod	log10	sinh	
atan	cosh	frexp	modf	sqrt	
atan2	fabs	ldexp	pow	tan	

and for each of the following TR1 elementary functions from `<cmath>`:

acosh	expm1	llround	nexttoward
asinh	fdim	lrint	remainder
atanh	fma	lround	remquo
cbrt	fmax	log1p	rint
copysign	fmin	log2	round
erf	hypot	logb	scalbn
erfc	ilogb	nan	scalbln
exp	lgamma	nearbyint	tgamma
exp2	llrint	nextafter	trunc

- an additional function is introduced to the namespace `std::decimal` with the name *func*d32, where *func* is the name of the original function; all parameters of type `double` in the original are replaced with type `decimal32` in the new function; all parameters of type `double *` are replaced with type `decimal32 *`; if the return type

of the original function is `double`, the return type of the new function is `decimal32`; the specification of the behavior of the new function is otherwise equivalent to that of the original function

- an additional overload of the original function *func* is introduced to the namespace in which the original is declared; apart from its name and nearest enclosing namespace, this function has the same signature, return type, and behavior as the function *funcd32*, described above
- an additional function is introduced to the namespace `std::decimal` with the name *funcd64*, where *func* is the name of the original function; all parameters of type `double` in the original are replaced with type `decimal64` in the new function; all parameters of type `double *` are replaced with type `decimal64 *`; if the return type of the original function is `double`, the return type of the new function is `decimal64`; the specification of the behavior of the new function is otherwise equivalent to that of the original function
- an additional overload of the original function *func* is introduced to the namespace in which the original is declared; apart from its name and nearest enclosing namespace, this function has the same signature, return type, and behavior as the function *funcd64*, described above
- an additional function is introduced to the namespace `std::decimal` with the name *funcd128*, where *func* is the name of the original function; all parameters of type `double` in the original are replaced with type `decimal128` in the new function; all parameters of type `double *` are replaced with type `decimal128 *`; if the return type of the original function is `double`, the return type of the new function is `decimal128`; the specification of the behavior of the new function is otherwise equivalent to that of the original function
- an additional overload of the original function *func* is introduced to the namespace in which the original is declared; apart from its name and nearest enclosing namespace, this function has the same signature, return type, and behavior as the function *funcd128*, described above

Moreover, there shall be additional overloads of the original function *func*, declared in *func*'s namespace, sufficient to ensure:

- If any argument corresponding to a `decimal64` parameter has type `decimal128`, then all arguments of decimal floating-point type or integer type corresponding to `decimal64` parameters are effectively cast to `decimal128`.
- Otherwise, if any argument corresponding to a `decimal64` parameter has type `decimal64`, then all other arguments of decimal floating-type or integer-type corresponding to `decimal64` parameters are effectively cast to `decimal64`.
- Otherwise, if any argument corresponding to a `decimal64` parameter has type `decimal32`, then all other arguments of decimal floating-type or integer-type corresponding to `decimal64` parameters are effectively cast to `decimal32`.