

## IEEE 754-2008 Decimal Floating-Point for Intel® Architecture Processors

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### Abstract

A brief description is provided of the decimal floating-point support available for Intel® Architecture processors, compliant with the IEEE Standard 754-2008 for Floating-Point Arithmetic [1]. Some performance results are included.

### Introduction

Intel Corporation had a major contribution in the creation and adoption of the first IEEE Standard for Floating-Point Arithmetic, IEEE 754-1985 [2]. The first Intel 16-bit floating-point coprocessor, the Intel 8087 Numerics Processor Extension<sup>1</sup> (NPX), was introduced in 1981 following a fruitful collaboration with Prof. Kahan from U.C. Berkeley. It implemented almost all the arithmetic operations later mandated by IEEE Standard 754-1985<sup>2</sup>. A paper published in the BYTE magazine in April 1983 [3] introduced the Intel® 8087 with these words: “So you have a shiny new 8086/8088-based microcomputer and you want to write some accounting software that will meet the requirements of the fussiest CPA<sup>3</sup>. Let me introduce you to the Intel 8087 Numerics Processor Extension”.

Now we can argue today that the CPA’s requirements could not be easily met then but they can be met now, 26 years later, thanks to the new IEEE Standard 754-2008 and its inclusion of decimal floating-point arithmetic alongside the binary one. Yet, the 18 decimal digits afforded by the Intel® 8087 and/or additional software techniques satisfied for more than 25 years both CPAs and the financial world. The addition of decimal arithmetic was the most important extension going from IEEE 754-1985 to IEEE 754-2008. After being one of the main contributors and promoters for IEEE 754-1985 and more recently a contributor to IEEE 754-

2008, Intel Corporation supports the new standard, including the decimal floating-point arithmetic. The first major step we made toward compliance with the new specification was the design and implementation of a decimal floating-point library for Intel® Architecture processors (actually a portable library). A software implementation was deemed sufficient for the foreseeable future, given the reasonably good performance that could be achieved, and the relatively low frequency of decimal floating-point operations in applications at the present time.

### IEEE 754-2008 Decimal Floating-Point Compliance Library

A software implementation of the IEEE 754-2008 decimal arithmetic is available for free in source format from <http://software.intel.com/en-us/articles/intel-decimal-floating-point-math-library/>. The Intel® Decimal Floating-Point Math Library v1.0 (Update 1 is provided now) supports the Decimal32, Decimal64, and Decimal128 computation and data interchange formats, and implements all the operations and conversions mandated by the standard. The binary encoding format [1] is used for decimal floating-point values, but the decimal encoding [1] is also supported in the library by means of conversion functions between the two encoding formats. For operations involving integer operands or results, the library supports signed and unsigned 8-, 16-, 32-, and 64-bit integers. The techniques used to implement decimal floating-point operations using binary arithmetic on Intel® processors are best described in an ARITH-18 paper [4], an article in IEEE Transactions on Computers [5], and one ARITH-19 paper [6]. This software implementation is aimed at financial applications, especially in cases where legal requirements make it necessary to use decimal, and not binary floating-point arithmetic (binary floating-point operations may introduce small, but unacceptable errors).

The library package contains: an end user license agreement, allowing practically any usage of the library as long as the copyright notice is

<sup>1</sup> I 8231 was an earlier 8-bit coprocessor

<sup>2</sup> The first coprocessor that allowed for easy compliance with IEEE 754-1985 was the Intel® 80387 Coprocessor

<sup>3</sup> Certified Public Accountant

preserved; a README file; a LIBRARY subdirectory with all the source files necessary to build the library in Linux™, Windows™, HP-UX™, Solaris™, or OS/2™; a TESTS subdirectory with source and input files necessary to build and run a set of tests for the library; and finally, an EXAMPLES subdirectory containing several examples of calls to library functions with various combinations of build options.

## IEEE 754-2008 and ISO/IEC TR 24732 Decimal Floating-Point Compliance Library

The ISO/IEC Technical Report 24732 [7] recognizes that human computation and communication of numeric values almost always uses decimal arithmetic and decimal notations. For this reason, the C Standard WG14 working group created Technical Report 24732, which proposes to add decimal floating types and arithmetic to the C programming language specification. It specifies hundreds of new C99-like functions with decimal operands, from simple to rather complex ones including trigonometric, hyperbolic, exponential, logarithmic, power, error, gamma, and other transcendental functions. An augmented version of the Intel® Decimal Floating-Point Math Library, version 1.1, provides support for all the TR 24732 additions. A similar technical report was issued by the C++ Standard working group, WG21. More recently another standard body, the W3C working group for XML, started looking into the possibility of supporting IEEE 754-2008 decimal floating-point.

### Some Results

We ran the Telco benchmark [8] with the Intel® Decimal Floating-Point Math Library. The results when using the 64-bit or 128-bit format to represent decimal floating-point values are shown below.

Telco: Time / Call (microseconds)	
64-bit	128-bit
0.824 us/call	1.901 us/call
Compiler: Intel® icc 10.1, CFLAGS: -O3 CPU: Intel® Core 2 Quad 2.66Ghz, RAM: 2Gb 667Mhz, FSB: 1066Mhz HD: 2x164GB SATA; OS: RHEL4 2.6.9-42	

When implemented in software on binary hardware, some operations such as conversions

between decimal-floating point and string format can be slightly more efficient if the decimal encoding format is used, because the decimal digits are readily available in the encoding. Others, for example conversions from decimal floating-point to integer or computations such as addition, can perform significantly better if the binary format is used [4] [5]. These are illustrated in the next four figures, with delays shown in clock cycles on the vertical axis, call overhead included (DPD<sup>4</sup> denotes the decimal encoding from the IBM™ decFloats decimal floating-point library [9], and BID<sup>5</sup> the binary encoding from the Intel® Decimal Floating-Point Math Library [10]).

### Conclusion

The implementation of the Intel® Decimal Floating-Point Math Library has been a relative success. Notable uses of Version 1.0 are in GCC on Intel® Architecture processors (starting with GCC 4.3), in the Hewlett-Packard C compiler for the Intel® Itanium® Processor Family, and in the Intuit® QuickBooks™ 2009. Version 1.1 of the library is used in the Intel® C++ Compiler starting with version 11. Widespread usage of the IEEE 754-2008 decimal floating-point arithmetic has yet to materialize, but progress in the first several months after adoption of the new standard is promising.

### References

- [1] IEEE Standard for Floating-Point Arithmetic 754-2008, IEEE, 2008
- [2] ANSI/IEEE Standard for Binary Floating-Point Arithmetic 754-1985, IEEE, 1985
- [3] R. Simington, "The Intel 8087 Numerics Processor Extension," BYTE Publications, 1983
- [4] M. Cornea, C. Anderson, J. Harrison, P.T.P. Tang, E. Schneider, and C. Tsen, "An Implementation of the IEEE 754R Decimal Floating-Point Arithmetic Using the Binary Encoding Format," Proc. 18th IEEE Symp. Computer Arithmetic (ARITH '07), pp. 29-37, 2007
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<sup>4</sup> Densely Packed Decimal

<sup>5</sup> Binary Integer Decimal

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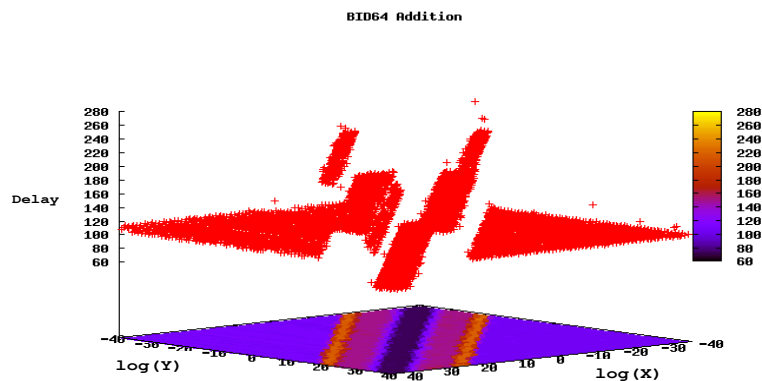
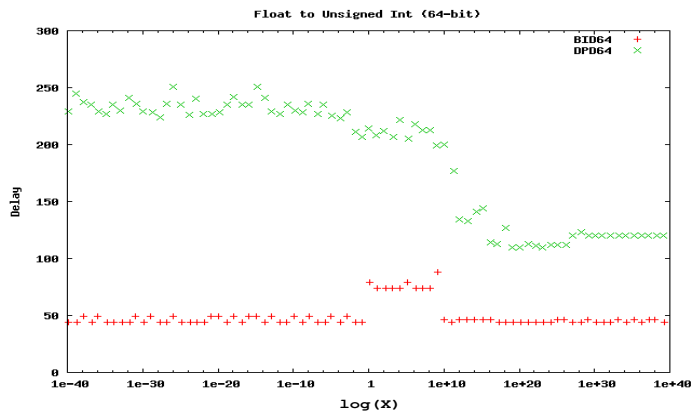
[6] J. Harrison, "Decimal transcendentals via binary," 19th IEEE Symposium on Computer Arithmetic (ARITH '09), 2009

[7] ISO/IEC TR 24732, Extension for the programming language C to support decimal floating-point arithmetic, 2007

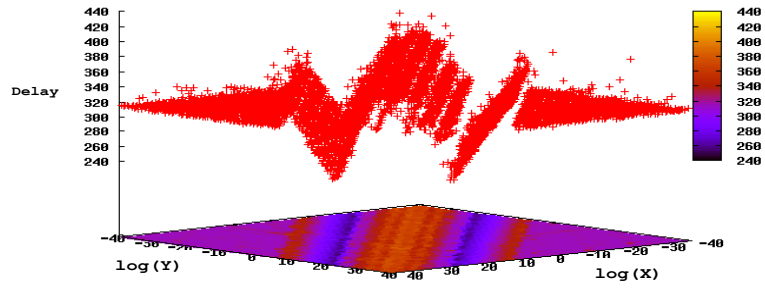
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[9] IBM decFloats Modules, <http://speleotrove.com/decimal/dnfloat.html>, 2008

[10] Intel® Decimal Floating-Point Math Library v1.0, 2008, <http://software.intel.com/en-us/articles/intel-decimal-floating-point-math-library/>.



DPD64 Addition



BID64 - DPD64 Addition

