



# Advanced Arithmetic for the Digital Computer, Design of Arithmetic Units

Ulrich Kulisch

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## Abstract

Abstract. Advances in computer technology are now so profound that the arithmetic capability and repertoire of computers can and should be expanded. Nowadays the elementary floating-point operations  $+$ ,  $-$ ,  $\times$ ,  $/$  give computed results that coincide with the rounded exact result for any operands. Advanced computer arithmetic extends this accuracy requirement to all operations in the usual product spaces of computation: the real and complex vector spaces as well as their interval correspondents. This enhances the mathematical power of the digital computer considerably. A new computer operation, the scalar product, is fundamental to the development of advanced computer arithmetic.

This paper studies the design of arithmetic units for advanced computer arithmetic. Scalar product units are developed for different kinds of computers like personal computers, workstations, mainframes, super computers or digital signal processors. The new expanded computational capability is gained at modest cost. The units put a methodology into modern computer hardware which was available on old calculators before the electronic computer entered the scene. In general the new arithmetic units increase both the speed of computation as well as the accuracy of the computed result. The circuits developed in this paper show that there is no way to compute an approximation of a scalar product faster than the correct result.

A collection of constructs in terms of which a source language may accommodate advanced computer arithmetic is described in the paper. The development of programming languages in the context of advanced computer arithmetic is reviewed. The simulation of the accurate scalar product on existing, conventional processors is discussed. Finally the theoretical foundation of advanced computer arithmetic is reviewed and a comparison with other approaches to achieving higher accuracy in computation is given. Shortcomings of existing processors and standards are discussed.

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# Advanced Computer Arithmetic Design

**Ulrich W. Kulisch**



## **Advanced Computer Arithmetic Design:**

*Advanced Computer Arithmetic Design* Michael J. Flynn, Stuart F. Oberman, 2001 Innovative techniques and cutting edge research in computer arithmetic design Computer arithmetic is a fundamental discipline that drives many modern digital technologies High performance VLSI implementations of 3 D graphics encryption streaming digital audio and video and signal processing all require fast and efficient computer arithmetic algorithms The demand for these fast implementations has led to a wealth of new research in innovative techniques and designs Advanced Computer Arithmetic Design is the result of ten years of effort at Stanford University under the Sub Nanosecond Arithmetic Processor SNAP project which author Michael Flynn directs Written with computer designers and researchers in mind this volume focuses on design rather than on other aspects of computer arithmetic such as number systems representation or precision Each chapter begins with a review of conventional design approaches analyzes the possibilities for improvement and presents new research that advances the state of the art The authors present new data in these vital areas Addition and the Ling adder Improvements to floating point addition Encoding to reduce execution times for multiplication The effects of technology scaling on multiplication Techniques for floating point division Approximation techniques for high level functions such as square root logarithms and trigonometric functions Assessing cost performance of arithmetic units Clocking to increase computer operation frequency New implementation of continued fractions to the approximation of functions This volume presents the results of a decade s research in innovative and progressive design techniques Covering all the most important research topics in the field Advanced Computer Arithmetic Design is the most up to date and comprehensive treatment of new research currently available

*Advanced Arithmetic for the Digital Computer* Ulrich W. Kulisch, 2012-09-07 The number one requirement for computer arithmetic has always been speed It is the main force that drives the technology With increased speed larger problems can be attempted To gain speed advanced processors and programming languages offer for instance compound arithmetic operations like matmul and dotproduct But there is another side to the computational coin the accuracy and reliability of the computed result Progress on this side is very important if not essential Compound arithmetic operations for instance should always deliver a correct result The user should not be obliged to perform an error analysis every time a compound arithmetic operation implemented by the hardware manufacturer or in the programming language is employed This treatise deals with computer arithmetic in a more general sense than usual Advanced computer arithmetic extends the accuracy of the elementary floating point operations for instance as defined by the IEEE arithmetic standard to all operations in the usual product spaces of computation the complex numbers the real and complex intervals and the real and complex vectors and matrices and their interval counterparts The implementation of advanced computer arithmetic by fast hardware is examined in this book Arithmetic units for its elementary components are described It is shown that the requirements for speed and for reliability do not conflict with each other Advanced computer arithmetic is superior to other arithmetic with

respect to accuracy costs and speed

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**A Practical Introduction to Computer Architecture** Daniel Page, 2009-04-14 It is a great pleasure to write a preface to this book In my view the content is unique in that it blends traditional teaching approaches with the use of mathematics and a mainstream Hardware Design Language HDL as formalisms to describe key concepts The book keeps the machine separate from the application by strictly following a bottom up approach it starts with transistors and logic gates and only introduces assembly language programs once their execution by a processor is clearly defined Using a HDL Verilog in this case rather than static circuit diagrams is a big deviation from traditional books on computer architecture Static circuit diagrams cannot be explored in a hands on way like the corresponding Verilog model can In order to understand why I consider this shift so important one must consider how computer architecture a subject that has been studied for more than 50 years has evolved In the pioneering days computers were constructed by hand An entire computer could just about be described by drawing a circuit diagram Initially such diagrams consisted mostly of analogue components before later moving toward digital logic gates The advent of digital electronics led to more complex cells such as half adders ip ops and decoders being recognised as useful building blocks

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