

# VLSI Implementation of Neural Networks

B. M. Wilamowski, J. Binfet, and M. O. Kaynak

## Abstract

Currently, fuzzy controllers are the most popular choice for hardware implementation of complex control surfaces because they are easy to design. Neural controllers are more complex and hard to train, but provide an outstanding control surface with much less error than that of a fuzzy controller. There are also some problems that have to be solved before the networks can be implemented on VLSI chips. First, an approximation function needs to be developed because CMOS neural networks have an activation function different than any function used in neural network software. Next, this function has to be used to train the network. Finally, the last problem for VLSI designers is the quantization effect caused by discrete values of the channel length ( $L$ ) and width ( $W$ ) of MOS transistor geometries.

Two neural networks were designed in 1.5  $\mu\text{m}$  technology. Using adequate approximation functions solved the problem of activation function. With this approach, trained networks were characterized by very small errors. Unfortunately, when the weights were quantized, errors were increased by an order of magnitude. However, even though the errors were enlarged, the results obtained from neural network hardware implementations were superior to the results obtained with fuzzy system approach.

## I. INTRODUCTION

The analog approach is an attractive alternative for nonlinear signal processing. It provides parallel processing with a speed limited only by the delay of signals through the network. In recent years, a significant amount of research has been devoted in the development of fuzzy controllers [1]. In hardware, fuzzy systems dominate current trends in both microprocessor applications [2] and in custom designed VLSI chips [3]. Fuzzy controllers are especially useful for nonlinear systems, which are difficult to describe by mathematical models. Fuzzy controllers are also easier to implement [4][5][6][7]. Membership functions and fuzzy rules are chosen arbitrarily and therefore, fuzzy controllers are often good but not optimal.

Even though neural networks are primarily implemented in software, their good approximation properties make them an attractive alternative in hardware [8][9]. One concern in hardware implementation is related to the quantized values for the weights enforced by hardware [10][11][12]. Another difficulty is caused by fact that the activation functions obtained in VLSI implementation are different from these used in neural network software. Traditionally, neurons use sigmoidal type activation

functions. Granted, other types of functions can be used, but sigmoidal type functions allow simple networks the ability to describe complex surfaces. This is due to the bell shaped derivative characteristics of a sigmoidal function. In the case presented, the neuron has a sigmoidal type activation. However, the function to describe this is not readily apparent such as the tangent hyperbolic commonly used in neural network software. This means that standard neural network training software cannot be used because it will produce incorrect solutions for the circuit realization.

In the presented approach, the difficulty with VLSI neural network implementation was overcome in the following way. The "measured" activation function is used for neural network training (Section III) and the training algorithm was adapted to quantized values of weights (Section IV).

## II. NEURAL NETWORK CIRCUIT

Nonlinear activation functions of neurons are essential for neural network operation. Such sigmoidal functions can be created in the differential pair shown in Fig. 1.

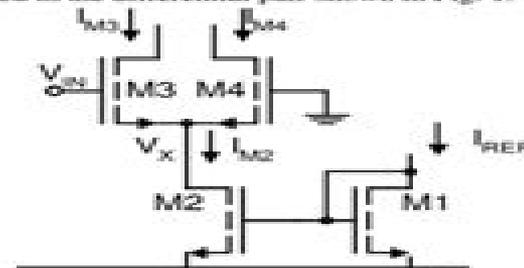


Fig. 1. Sigmoidal function generated by differential pair. Using a simple Shichman-Hodges MOS transistor model for strong inversion, the output currents for the MOS differential pair M3-M4 operating in strong inversion is given by:

$$I_{M3} = \frac{K}{2} (V_{IN} - V_X - V_{TN})^2 \quad (1)$$

$$I_{M4} = \frac{K}{2} (0 - V_X - V_{TN})^2 \quad (2)$$

and from Kirchhoff's Law

$$I_{M2} = I_{M3} + I_{M4} \quad (3)$$

# Vlsi Design Of Neural Networks

**Tao Wei**



## **Vlsi Design Of Neural Networks:**

VLSI Design of Neural Networks Ulrich Ramacher, Ulrich Rückert, 2013-01-21 The early era of neural network hardware design starting at 1985 was mainly technology driven. Designers used almost exclusively analog signal processing concepts for the recall mode. Learning was deemed not to cause a problem because the number of implementable synapses was still so low that the determination of weights and thresholds could be left to conventional computers. Instead, designers tried to directly map neural parallelity into hardware. The architectural concepts were accordingly simple and produced the so-called interconnection problem which in turn made many engineers believe it could be solved by optical implementation in adequate fashion only. Furthermore, the inherent fault tolerance and limited computation accuracy of neural networks were claimed to justify that little effort is to be spent on careful design but most effort be put on technology issues. As a result, it was almost impossible to predict whether an electronic neural network would function in the way it was simulated to do. This limited the use of the first neuro chips for further experimentation, not to mention that real world applications called for much more synapses than could be implemented on a single chip at that time. Meanwhile, matters have matured. It is recognized that isolated definition of the effort of analog multiplication for instance would be just as inappropriate on the part of the chip designer as determination of the weights by simulation without allowing for the computing accuracy that can be achieved on the part of the user.

VLSI for Neural Networks and Artificial Intelligence Jose G. Delgado-Frias, W.R. Moore, 2013-06-29 Neural network and artificial intelligence algorithms and computing have increased not only in complexity but also in the number of applications. This in turn has posed a tremendous need for a larger computational power that conventional scalar processors may not be able to deliver efficiently. These processors are oriented towards numeric and data manipulations. Due to the neurocomputing requirements such as non-programming and learning and the artificial intelligence requirements such as symbolic manipulation and knowledge representation, a different set of constraints and demands are imposed on the computer architectures. Organizations for these applications. Research and development of new computer architectures and VLSI circuits for neural networks and artificial intelligence have been increased in order to meet the new performance requirements. This book presents novel approaches and trends on VLSI implementations of machines for these applications. Papers have been drawn from a number of research communities; the subjects span analog and digital VLSI design, computer design, computer architectures, neurocomputing, and artificial intelligence techniques. This book has been organized into four subject areas that cover the two major categories of this book: the areas are analog circuits for neural networks, digital implementations of neural networks, neural networks on multiprocessor systems and applications, and VLSI machines for artificial intelligence. The topics that are covered in each area are briefly introduced below.

VLSI for Artificial Intelligence and Neural Networks Jose G. Delgado-Frias, W.R. Moore, 2012-12-06 This book is an edited selection of the papers presented at the International Workshop on VLSI for Artificial Intelligence and Neural Networks which was held at

the University of Oxford in September 1990 Our thanks go to all the contributors and especially to the programme committee for all their hard work Thanks are also due to the ACM SIGARCH the IEEE Computer Society and the IEE for publicizing the event and to the University of Oxford and SUNY Binghamton for their active support We are particularly grateful to Anna Morris Maureen Doherty and Laura Duffy for coping with the administrative problems Jose Delgado Frias Will Moore April 1991 vii PROLOGUE Artificial intelligence and neural network algorithms computing have increased in complexity as well as in the number of applications This in tum has posed a tremendous need for a larger computational power than can be provided by conventional scalar processors which are oriented towards numeric and data manipulations Due to the artificial intelligence requirements symbolic manipulation knowledge representation non deterministic computations and dynamic resource allocation and neural network computing approach non programming and learning a different set of constraints and demands are imposed on the computer architectures for these applications

**Towards the Visual Microprocessor** Tamás Roska, Ángel Rodríguez-Vázquez, 2001-01-17 VLSIs Very Large Scale Integration are highly complex integrated circuits with thousands of semiconductors resting on a single substrate chip These circuits can be programmed to perform as cellular neural networks CNNs

**VLSI Design of Neural Networks Using Pulse Coded Weights with On-chip Learning Capability** Gyu Moon, 1993 **Developments in Digital VLSI Design for Artificial Neural Networks** International Computer Science Institute, Nelson Morgan, K. Asanovic, B. Kingsbury, J. Wawrzynek, 1990 **VLSI Design of Functional Artificial Neural Networks Using Semistate Theory with a Robotics Application** Sanjeev Kumar Singh, 1998

**Neural Information Processing and VLSI** Bing J. Sheu, Joongho Choi, 2012-12-06 Neural Information Processing and VLSI provides a unified treatment of this important subject for use in classrooms industry and research laboratories in order to develop advanced artificial and biologically inspired neural networks using compact analog and digital VLSI parallel processing techniques Neural Information Processing and VLSI systematically presents various neural network paradigms computing architectures and the associated electronic optical implementations using efficient VLSI design methodologies Conventional digital machines cannot perform computationally intensive tasks with satisfactory performance in such areas as intelligent perception including visual and auditory signal processing recognition understanding and logical reasoning where the human being and even a small living animal can do a superb job Recent research advances in artificial and biological neural networks have established an important foundation for high performance information processing with more efficient use of computing resources The secret lies in the design optimization at various levels of computing and communication of intelligent machines Each neural network system consists of massively paralleled and distributed signal processors with every processor performing very simple operations thus consuming little power Large computational capabilities of these systems in the range of some hundred giga to several tera operations per second are derived from collectively parallel processing and efficient data routing through well structured interconnection networks Deep submicron very large scale

integration VLSI technologies can integrate tens of millions of transistors in a single silicon chip for complex signal processing and information manipulation The book is suitable for those interested in efficient neurocomputing as well as those curious about neural network system applications It has been especially prepared for use as a text for advanced undergraduate and first year graduate students and is an excellent reference book for researchers and scientists working in the fields covered

Neural Network Solutions to Two VLSI Design Problems Ran Libeskind-Hadas,1989 VLSI Design for a Neural Network Damian HEGARTY,1993 **Analog CMOS VLSI Design of Neural Networks** ,1993 *VLSI Design of an Adaptive Neural Network* Fawzy Ibrahim Hamama,1990 VLSI Implementation of a Digital Neural Network with On-chip Learning Darrell Gates,1990 The Industrial Electronics Handbook J. David Irwin,1997-05-09 From traditional topics that form the core of industrial electronics to new and emerging concepts and technologies The Industrial Electronics Handbook in a single volume has the field covered Nowhere else will you find so much information on so many major topics in the field For facts you need every day and for discussions on topics you have only dreamed of The Industrial Electronics Handbook is an ideal reference

*Very Large Scale Integration Design of Feed Forward Fully Connected Neural Network* Bo Liu (M.S.),2005 *Adaptive Analog VLSI Neural Systems* M. Jabri,R.J. Coggins,B.G. Flower,2012-12-06 Adaptive Analog VLSI Neural Systems is the first practical book on neural networks learning chips and systems It covers the entire process of implementing neural networks in VLSI chips beginning with the crucial issues of learning algorithms in an analog framework and limited precision effects and giving actual case studies of working systems The approach is systems and applications oriented throughout demonstrating the attractiveness of such an approach for applications such as adaptive pattern recognition and optical character recognition Dr Jabri and his co authors from AT T Bell Laboratories Bellcore and the University of Sydney provide a comprehensive introduction to VLSI neural networks suitable for research and development staff and advanced students

Analog VHDL Andrzej T. Rosinski,Alain Vachoux,2012-12-06 Analog VHDL brings together in one place important contributions and up to date research results in this fast moving area Analog VHDL serves as an excellent reference providing insight into some of the most challenging research issues in the field VLSI and Hardware Implementations using Modern Machine Learning Methods Sandeep Saini,Kusum Lata,G.R. Sinha,2021-12-30 Machine learning is a potential solution to resolve bottleneck issues in VLSI via optimizing tasks in the design process This book aims to provide the latest machine learning based methods algorithms architectures and frameworks designed for VLSI design The focus is on digital analog and mixed signal design techniques device modeling physical design hardware implementation testability reconfigurable design synthesis and verification and related areas Chapters include case studies as well as novel research ideas in the given field Overall the book provides practical implementations of VLSI design IC design and hardware realization using machine learning techniques Features Provides the details of state of the art machine learning methods used in VLSI design Discusses hardware implementation and device modeling pertaining to machine learning algorithms

Explores machine learning for various VLSI architectures and reconfigurable computing Illustrates the latest techniques for device size and feature optimization Highlights the latest case studies and reviews of the methods used for hardware implementation This book is aimed at researchers professionals and graduate students in VLSI machine learning electrical and electronic engineering computer engineering and hardware systems *Innovations in Bio-Inspired Computing and Applications* Ajith Abraham,Mrutyunjaya Panda,Subhrajit Pradhan,Laura Garcia-Hernandez,Kun Ma,2020-08-05 This book highlights recent research on bio inspired computing and its various innovative applications in information and communication technologies It presents 38 high quality papers from the 10th International Conference on Innovations in Bio Inspired Computing and Applications IBICA 2019 and 9th World Congress on Information and Communication Technologies WICT 2019 which was held at GIET University Gunupur India on December 16 18 2019 As a premier conference IBICA WICT brings together researchers engineers and practitioners whose work involves bio inspired computing computational intelligence and their applications in information security real world contexts etc Including contributions by authors from 18 countries the book offers a valuable reference guide for all researchers students and practitioners in the fields of Computer Science and Engineering *Analog VLSI Implementation of Neural Systems* Carver Mead,Mohammed Ismail,1989-08-31 This volume contains the proceedings of a workshop on Analog Integrated Neural Systems held May 8 1989 in connection with the International Symposium on Circuits and Systems The presentations were chosen to encompass the entire range of topics currently under study in this exciting new discipline Stringent acceptance requirements were placed on contributions 1 each description was required to include detailed characterization of a working chip and 2 each design was not to have been published previously In several cases the status of the project was not known until a few weeks before the meeting date As a result some of the most recent innovative work in the field was presented Because this discipline is evolving rapidly each project is very much a work in progress Authors were asked to devote considerable attention to the shortcomings of their designs as well as to the notable successes they achieved In this way other workers can now avoid stumbling into the same traps and evolution can proceed more rapidly and less painfully The chapters in this volume are presented in the same order as the corresponding presentations at the workshop The first two chapters are concerned with finding solutions to complex optimization problems under a predefined set of constraints The first chapter reports what is to the best of our knowledge the first neural chip design In each case the physics of the underlying electronic medium is used to represent a cost function in a natural way using only nearest neighbor connectivity

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## Table of Contents Vlsi Design Of Neural Networks

1. Understanding the eBook Vlsi Design Of Neural Networks
  - The Rise of Digital Reading Vlsi Design Of Neural Networks
  - Advantages of eBooks Over Traditional Books
2. Identifying Vlsi Design Of Neural Networks
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Vlsi Design Of Neural Networks
  - User-Friendly Interface
4. Exploring eBook Recommendations from Vlsi Design Of Neural Networks
  - Personalized Recommendations
  - Vlsi Design Of Neural Networks User Reviews and Ratings
  - Vlsi Design Of Neural Networks and Bestseller Lists
5. Accessing Vlsi Design Of Neural Networks Free and Paid eBooks
  - Vlsi Design Of Neural Networks Public Domain eBooks
  - Vlsi Design Of Neural Networks eBook Subscription Services
  - Vlsi Design Of Neural Networks Budget-Friendly Options
6. Navigating Vlsi Design Of Neural Networks eBook Formats
  - ePub, PDF, MOBI, and More
  - Vlsi Design Of Neural Networks Compatibility with Devices
  - Vlsi Design Of Neural Networks Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Vlsi Design Of Neural Networks
  - Highlighting and Note-Taking Vlsi Design Of Neural Networks
  - Interactive Elements Vlsi Design Of Neural Networks
8. Staying Engaged with Vlsi Design Of Neural Networks

- Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Vlsi Design Of Neural Networks
9. Balancing eBooks and Physical Books Vlsi Design Of Neural Networks
- Benefits of a Digital Library
  - Creating a Diverse Reading Collection Vlsi Design Of Neural Networks
10. Overcoming Reading Challenges
- Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Vlsi Design Of Neural Networks
- Setting Reading Goals Vlsi Design Of Neural Networks
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Vlsi Design Of Neural Networks
- Fact-Checking eBook Content of Vlsi Design Of Neural Networks
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
- Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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