ESANN'1998 proceedings - European Symposium on Artificial Neural Networks
Bruges (Belgium), 22-23-24 April 1998, D-Facto public., ISBN 2-9600049-8-1, pp. 291-296

The CNN Computer - a tutorial

Tamas Roska

Computer and Automation Institute of the Hungarian Academy of Sciences, Budapest and the University of California at Berkeley

Abstract. The Cellular Neural/nonlinear Network (CNN) paradigm defines a framework for continuous spatiotemporal operations via nonlinear array dynamics. The architecture of the CNN Universal Machine as well as the CNN chip set is described. The computational infrastructure of the CNN computer consists of the following parts: high level language, compiler, operating system, physical interface, as well as application development system. Some key applications will illustrate this new computing paradigm with its physical implementation parameters.

1. Introduction

The Cellular Neural /nonlinear Network (CNN) was invented in 1988 by L.O.Chua and L.Yang [1,2]. In the CNN Universal Machine (CNNUM) architecture [4], invented in 1992-93, the CNN dynamics is embedded in an array computer framework where analog array dynamics is combined by logic, locally and globally. The algorithms running on these computers are called analogic, reflecting the latter property.

Recently, the first physical implementations of the CNNUM chips has been fabricated [14-17], their computing power is about TeraOPS per cm^2. A new step in building a computer system is the Chip set architecture [36] and the construction of its physical implementation , the CNN Engine Board [39]. To prototype the CNNUM chips as the visual microprocessors, we need a CNN Chip Prototyping System [35] including a high level language with a compiler [40], an operating system , and a physical interface to the CNNUM chip. All these elements are now operational.

The world of analogic spatiotemporal CNN algorithms, hence, became practical. Indeed, the image processing implications of partial differential equations, the pattern formation properties, the propagation failure, and a few other very complex nonlinear phenomena can now be implemented and tested in a few microseconds.

In this tutorial, we summarize these results and illustrate them by practical examples.

2. Physical implementations

The CNN Universal Machine can be implemented in different ways. There ara three main directions

- analog and mixed signal CMOS [e.g. 14-17]
- emulated digital CMOS [e.g. 41] and
- optical implementations [e.g. 37].

Each implementations has its own advantage. Three typical case studies will be shown.

3. Computational infrastructure

The main elements of the computational infrastructure are

- CNN Application Development Environment and Toolkit [33]
- CNN Chip Prototyping System [34,35]

These systems will be reviewed with special emphasis on the Alpha language [40] used for describing complex spatiotemporal algorithms.

4. Algorithmic aspects and Applications

In principle, the CNN computational framework is broader than the world of partial differential equations (PDEs) in the continuous domain and than the cellular automata in the Boolean domain. To exploit these inherent potential, several projects have been carried out to solve real life problems. The application of detecting inner boundaries in Echocardiograms, fax applications, and mammogram diagnostics will be shown.

References

[1] L. O. Chua and L. Yang, "Cellular Neural Networks: Theory", *IEEE Trans. on Circuits and Systems*, Vol. 35, pp. 1257-1272, Oct. 1988.

[2] L. O. Chua and L. Yang, "Cellular Neural Networks: Applications", *IEEE Trans. on Circuits and Systems*, Vol. 35, pp. 1273-1290, Oct. 1988.

[3] L. O. Chua, T. Roska, T. Kozek, and Á. Zarándy, "The CNN Paradigm", *IEEE Trans. on Circuits and Systems*, Vol. 40, pp.147-156, March 1993.

[4] T. Roska and L. O. Chua, "The CNN Universal Machine: an Analogic Array Computer", *IEEE Trans. on Circuits and Systems*, Vol. 40, pp. 163-173, March 1993.

[5] L. O. Chua and T. Roska, "Cellular Neural Networks: Foundations and Primer", Lecture Notes, Electronics Research Laboratory, University California at Berkeley, 1997.

ESANN'1998 proceedings - European Symposium on Artificial Neural Networks
Bruges (Belgium), 22-23-24 April 1998, D-Facto public., ISBN 2-9600049-8-1, pp. 291-296

[6] F.Werblin, T.Roska and L.O.Chua, "The Analogic Cellular Neural Network as a Bionic Eye", *International Journal of Circuit Theory and Applications*, Vol. 23, pp. 541-549,

[7] B. J. Sheu and J. Choi, *Neural Information Processing and VLSI*, Kluwer Academic Publishers, 1995.

[8] J. P. Keener, "Propagation and its Failure in Coupled Systems of Discrete Excitable Cells", *SIAM J. Appl. Math.*, 47, 556-572.

[9] B. E. Shi, *Spatio-temporal Image Filtering with Cellular Neural Networks*, PhD Thesis, University of California at Berkeley, 1994.

[10] K. R. Crounse and L. O. Chua, "Methods for Image Processing in Cellular Neural Networks: A Tutorial", *IEEE Trans. on Circuits and Systems*, Vol. 42, No. 10, pp. 583-601, October 1995.

[11] B. E. Shi, T. Roska and L. O. Chua, "Design of Linear Cellular Neural Networks for Motion Sensitive Filtering", *IEEE Trans. on Circuits and Systems*, Vol. 40, No. 5, pp. 320-331, October 1993.

[12] Á. Zarándy, A. Stoffels, T. Roska, and L. O. Chua, "Implementation of Binary and Gray-Scale Morphology on the CNN Universal Machine", *Memorandum UCB/ERL M96/19*, Electronics Research Laboratory, University California at Berkeley, April 1996.

[13] J. M. Cruz, L. O. Chua, T. Roska, "A Fast, Complex and Efficient Test Implementation of the CNN Universal Machine", in *Proceedings of 3rd International Workshop on Cellular Neural Networks and Their Applications*, pp. 61-66, Rome, 1994.

[14] S. Espejo, R. Carmona, R. Domingúez-Castro, and A. Rodrigúez-Vázquez, "CNN Universal Chip in CMOS Technology", *International Journal of Circuit Theory and Applications*, Special Issue on CNN II: Part I, Vol. 24, pp. 93-111, 1996.

[15] R. Dominguez-Castro, S. Espejo, A. Rodriguez-Vazquez, R.Carmona, P.Földesy, Á.Zarándy, P.Szolgay, T.Szirányi, and T. Roska "A 0.8 μm CMOS 2-D Programmable Mixed-Signal Focal-Plane Array Processor with On-Chip Binary Imaging and Instructions Storage", *IEEE J. Solid State Circuits*, pp. 103-1026, July, 1997.

[16] J. M. Cruz and L.O. Chua, "A 16x16 Cellular Neural Network Universal Chip: the First Complete Single-chip Dynamic Computer Array with Distributed Memory and with Gray-scale Input-output", *Journal Analog Integrated Circuits and Signal Processing*, in Press, 1997

[17] Ari Paasio, Adam Dawidziuk, Kari Halonen and Veikko Porra, "Minimum Size 0.5 Micron CMOS Programmable 48 by 48 CNN Test Chip", *in Proceedings of the ECCTD '97*, pp. 154-156, Budapest 1997.

[18] J. Canny, "A Computational Approach to Edge Detection", *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. PAMI-8, pp. 679-698, November 1986.

[19] P. Perona and J. Malik, "Scale-Space and Edge Detection Using Anisotropic Diffusion", *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. 12, pp. 629-639, July 1990.

[20] N. Nordström, "Biased Anisotropic Diffusion - A Unified Regularization and Diffusion Approach to Edge Detection", *Image Vision Computers*, Vol. 8, No 4, pp. 318-327, July 1990.

[21] F. Catté, P. L. Lions, J. M. Morel, and T. Coll, "Image Selective Smoothing and Edge Detection by Nonlinear Diffusion", *SIAM Journal on Numerical Analysis*, Vol. 29, No. 1, pp. 182-193, 1992.

[22] L. Alvarez, P. L. Lions, and J. M. Morel, "Image Selective Smoothing and Edge Detection by Nonlinear Diffusion. II", *SIAM Journ. on Num. Analysis*, Vol. 29, No. 3, pp. 845-866, 1992.

[23] A. Schultz, "A Nonlinear Diffusion method for Image Segmentation", Report, Radar Devision, Naval Research Laboratory, 1993

[24] T. Roska and T. Szirányi, "Classes of Analogic Algorithms and Their Practical Use in Complex Image Processing Tasks", *in Proceedings of the NSIP'95*, pp. 767-770, Halkidiki, June, 1995.

[25] M. Csapodi and T. Roska, "Dynamic Analogic Algorithms for Complex Recognition Task - A First Step Towards the Bionic Eyeglass", *International Journal of Circuit Theory and Applications*, Special Issue on CNN II: Part I, Vol. 24, No. 1, pp. 127-145, 1996.

[26] T. Szirányi and J. Zerubia, "Markov Random Field Image Segmentation Using Cellular Neural Network", *IEEE Transactions on Circuits and Systems*, Vol. 44, pp. 86-69, January 1997.

[27] P. Szolgay, I. Szatmári and K. László, "A Fast Fixed Point Learning Method to Implement Assocative Memory on CNNs", *IEEE Transactions on Circuits and Systems*, Vol. 44, No. 4, pp. 362-366, April 1997.

[28] Á. Zarándy, T. Roska, Gy. Liszka, J. Hegyesi, L. Kék and C. Rekeczky, "Design of Analogic CNN Algorithms for Mammogram Analysis", in *Proceedings of 3rd International Workshop on Cellular Neural Networks and Their Applications*, pp. 255-260, Rome, 1994.

[29] Á. Zarándy, F.Werblin, T. Roska and L. O. Chua, "Spatial-logic Algorithms Using Basic Morphological Analogic CNN Operations", *Int. Journ. of Circuit Theory and Applications,* Vol. 24, pp. 283-300, 1996.

[30] Cs. Rekeczky, A. Ushida, and T. Roska, "Rotation Invariant Detection of Moving and Standing objects Using Analogic Cellular Neural Network Algorithms Based on Ring-Codes", *IEICE Transactions on Fundamentals and Information Sciences*, Vol. E78-A, No. 10, pp. 1316-1330, October 1995

[31] Cs. Rekeczky, Á. Tahy, Z. Végh, T. Roska, "The Use of CNN Technology in Echocardiography: Spatio-temporal Nonlinear Filtering and Contour Detection", *DNS-7-1997, Technical Report, Analogical and Neural Computing Systems Laboratory, Computer and Automation Institute of the Hungarian Academy of Sciences,* Budapest, May 1997(also accepted for publication in *Int. Journ. of Circuit Theory and Apllications*),.

[32] T. Roska, L. Kék, Á. Zarándy, and L. Nemes, ed. "Analogic CNN Program Library", Version 7.0, Analogical and Neural Computing Laboratory, Computer and Automation Institute, Hung. Academy of Sciences, 1997.

[33] CADETWin, CNN Application Development Environment and Toolkit, V.2.1, MTA SzTAKI, Budapest, 1997

[34] CCPS-97, CNN Chip Prototyping System, V. 2.1, MTA SzTAKI, Budapest, 1997

[35] T. Roska, P.Szolgay, Á.Zarándy,P.Venetianer, A.Radványi, and T.Szirányi, "The CNN Chip Prototyping System", *Proceedings of 3rd International Workshop on Cellular Neural Networks and Their Applications*, pp. 375-380, Rome, 1994

[36] T. Roska, "The CNN Chip set architecture and the Visual Mouse", ", *Proceedings of 4th International Workshop on Cellular Neural Networks and Their Applications*, pp. 369-374, Seville, 1994

[37] S.I.Andersson, "Optical Cellular Neural Networs for PDE solver", Proc. Design Automation Day at ECCTD-97, pp.198, Budapest , 1997

[38] T. Roska, "Space variant adaptive CNN - fault tolerance and plasticity", Proc. NOLTA 97, Hawaii, 1997

[39] P.Földesy and P.Szolgay, " A CNN Engine board", ", Proc. Design Automation Day at ECCTD-97, pp.198, Budapest , 1997

[40] S.Zöld, "The Alpha language and compiler for CNN computers", *DNS-10-1997, Technical Report, Analogical and Neural Computing Systems Laboratory, Computer and Automation Institute of the Hungarian Academy of Sciences,* Budapest, 1997

[41] Á.Zarándy, P.Keresztes, T. Roska, and P. Szolgay, "An emulated digital architecture implementing the CNN Universal Machine, *Proceedings of 5th International Workshop on Cellular Neural Networks and Their Applications, London 1998* (submitted)