Preface

The Cellular Neural Network (CNN), introduced by Chua and Yang from University of California at Berkeley in the late 1980's is an attractive computational structure, particularly form the perspective of implementation in various micro and nanoelectronic technologies. The CNN paradigm includes cellular automata (CAs) as a particular case and in addition it borrows many ideas and techniques from the field of Neural Computation.

Computation in CNNs is brain-like rather than "classic" in the sense of the widespread computing architectures based on microprocessors. Emergent computation, viewed as the class of both dynamic and static patterns of activity emerging in an array of interconnected cells which are meaningful for various information processing tasks, is the equivalent of programming classic computers.

It is thus of a paramount importance to find the equivalent of the "programming rules" for such cellular devices.

The following image can be suggestive to understand the difference between cellular and classic computation: Assume that we have an array of memory cells (i.e. a Random Access Memory). In a classic computer the cells are *sequentially* updated and located by the central processing unit via some external buses while in a cellular computer each memory cell exchanges information locally only with the neighboring cells. A "gene" associated with each cell controls the exchange of information with the cells in a neighborhood. The cells are updated in *parallel* and there is no central processing unit to control the cells.

Like in a classical computer, the array of cells starts from an initial state, which contains the problem, and the solution will be found in the same array of cells after a period of time during which computation emerges. While the designer of a classic computer focuses on the central processing unit, on data coding, address buses and instruction sets, the designer of a cellular computer has to focus mostly on the cell. The "program" is now coded in what Leon Chua called "cells' gene" (i.e. the entire set of parameters defining the cell). Quite often all cells have identical structure and parameters and various tasks can be "programmed" on the same CNN chip by simply changing the genes. The following problems are raised to the cellular computer designer:

- To what degree is a cell capable to perform arbitrary local computations, i.e. the *universality* of a cell?
- What is the choice of the cell parameters such that emergent computation will occur? More sharply, one would like to find the exact values of the parameters for a given information processing task.

This book provides original answers to the above questions. It introduces novel techniques to understand and control better universality and emergence in cellular neural networks. After an introductory chapter and a chapter providing the basics ideas and concepts necessary to understand the remainder of the book, the problem of universal local computation is extensively described in Chapter 3. Our solution, based on the theory of piecewise-linear function approximations, is compact and efficient for both binary and continuous cells. A systematic approach to the second problem, grounded by the very recent theory of local activity [Chua, 1998] is provided in Chapter 4. A set of analytic tools is developed to identify a specific sub-domain called an "edge of chaos" domain in the cell parameter space such that the probability of emergent computation is maximized. Several examples of applying this method are provided. A measure for emergence in discrete time cellular systems is then introduced in Chapter 5 and then exemplified to identify several interesting behaviors in a cellular system, which is a *mutation* of the widely known "Game of Life". The importance of mutations and evolutionary approaches for designing cellular systems with emergent computation is then emphasized in the same chapter for a discrete time cellular system with continuous states. A potential application of emergent dynamic patterns for biometric authentication is presented in Chapter 6.

Why emergent computation in cellular computers when the technology of programming and designing classic computers is so well established and prolific? Here are some possible answers:

(i) The type of computation taking place in a cellular computer is the one used by living entities. Life itself is an emergent phenomenon and several examples in this book will show that simple living-like entities may emerge as a pattern of cellular activities. Brain-like computation could be better mimicked by a compact CNN rather than by a classic computer. Particularly when such computations are required in micro-robotics, or in any circumstance requiring compact yet intelligent sensor systems, the CNN could be a better choice;

(ii) The cellular systems are highly parallel and consequently they perform several orders of magnitudes faster than classic (serial) computing ones. Tera-ops processing speed (10^{12} elementary operation per second) is common for the actual generation of CNNs;

(iii) Recent developments in the area of nanotechnology indicate that cellular structures made of lattices of interconnected active devices (for example, resonant tunneling diodes, quantum dots or single electron transistors) could be easily developed. Characterized by a very high density of cells, they can fully exploit the benefits of emergent computation for various tasks in information processing.

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Dr. Dogaru published more than 60 journal and conference papers, books and research reports in the areas of neural and neuro-fuzzy architectures, cellular neural networks, complex adaptive systems and artificial life. More than 30 papers were published in highly recognized international journals and conference proceedings.

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