Proceedings of 1993 International Joint Conference on Neural Networks

NEURITE NETWORKS
The Genetic Programming of Cellular Automata Based Neural Nets Which GROW

Hugo de Garis

Brain Builder Group, Evolutionary Systems Department,
ATR Human Information Processing Research Laboratories,
2-2 Hikari-dai, Seika-cho, Soraku-gun,
Kansai Science City, Kyoto, 619-02, Japan.
tel : + 81 7749 5 1079, fax : + 81 7749 5 1408,
email : degaris@hip.atr.co.jp

Keywords :

Neurite Networks, Genetic Programming (GP), Genetic Algorithms (GAs), GenNets (Genetically Programmed Neural Network Modules), Cellular Automata (CAs), CA Networks, Artificial Nervous Systems, Incremental GP, Biots (Biological Robots), Darwinian Robotics, 1000-GenNet Biots, GenNet Accelerators, GenNet Shaping, CA Neurons, CA Machines, Darwin Machines, CREEPER.

Abstract :

This paper proposes the introduction of a new branch of neural networks, called "Neurite Networks", where the distinction between the two is that with "Neurite Networks", the neural network gets GROWN, i.e. it has an embryological component. A "neurite" is a neurobiological term meaning a "baby neuron which grows connections with other neurites". The artificial neurite network introduced in this paper is based on a cellular automata (CA) network whose branchings are genetically programmed (i.e. they are grown under the control of a Genetic Algorithm). A sequence of CA signals is sent down the middle of a CA "trail" (see the photo at the end of this paper). When a signal hits the end of a trail, it can make the trail extend, turn left, turn right, branch left, branch right, split, etc., depending upon the state of the CA signal. These signal sequences are treated as the chromosomes of a Genetic Algorithm. Once the CA network is formed, a second set of CA state transition rules is switched on to make it behave like a neural network. The fitness of this CA based neural network is measured in terms of how well it controls some behavior of a biological robot (biot). ATR's "Brain Builder Group" hopes to use such ideas to build Darwin Machines (i.e. machines which evolve) as a tool to build an artificial brain.

1. Introduction

One of the research aims of ATR's new Evolutionary Systems Department is to build an artificial brain by 2001. The very title of the department reflects one of its fundamental assumptions, i.e. that hyper complex systems (such as biological brains or embryos) will probably have to be built using an evolutionary approach rather than using design. Complexity levels will be so high, that no human being will be able to predict or even analyze how the system will function. The author has given the concept of "evolutionary building of complex systems" a label. He calls it "Genetic

Programming (GP)" [de Garis 1990, 1991, 1992, 1993]. This paper shows how an artificial neural network, based on cellular automata can be grown, using GP techniques. It is hoped that the ideas and results of this paper will serve as the conceptual basis for the construction of what the author calls "Darwin Machines" [de Garis 1991]. A Darwin Machine is a special hardware device used to perform GP in parallel. For example, Cellular Automata Machines could function in parallel to evolve the neurite networks described below. Each CAM would have a conventional programmable processor to measure the fitness of the evolved neurite network. A central processor could then perform the GA aspects of the evolution (e.g. calculate the next generation of chromosomes etc). Alternatively, a more distributed GA could be performed, where each CAM and its processor communicates only with its neighbors. It is hoped that using these Darwin Machines, it will be possible to build/evolve/GP a large number of neurite network modules and their connections to build an artificial brain capable of giving a biological robot (biot) some 100 "behaviors".

This paper consists of the following sections. Section 2 gives a brief introduction to cellular automata and how cellular automata trails can be evolved into cellular automata networks. Section 3 expands on the initial ideas of section 2, especially in explaining how CA trails can be made to behave like neural networks. Section 4 presents ideas for future research.

2. The Genetic Programming of Cellular Automata Trails

A cellular automata is a set of "cells" (e.g. squares in a 2D grid, or cubes in a 3D grid) each of which can be in a finite number of states. State transition rules (applying to all cells in the grid) determine how a cell updates (synchronously) its state depending upon its present state and the states of its neighbors. Fig. 1 shows an example of a state transition rule.

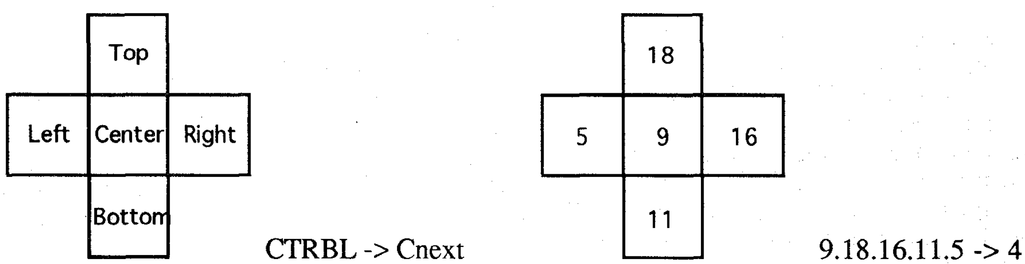

Fig. 1 A Cellular Automata State Transition Rule

A 3 cell wide CA "trail" as shown in Fig. 2 can be fed a sequence of CA signals which propagate down the trail until they hit the end. When they do, CA state transition rules can be defined so that the trail is extended by one square, or made to turn left, turn right, split, branch left, branch right etc (e.g. [Codd 1968]). One then evolves the sequence of CA signals using a conventional Genetic Algorithm [e.g. Goldberg 1989]. When one trail collides with another, a "synapse" is formed, as shown in Fig. 3. The two cells of the synapse then absorb signals passing through, thus keeping the configuration of the intersecting trails constant. The photo at the end of this paper shows the result of a CA network evolution. The fitness in this case was simply the number of synapses formed (25). There were 4 "CA neurons" (not shown). The chromosome was split into 4 and fed simultaneously into the starting points of the 4 CA trails.

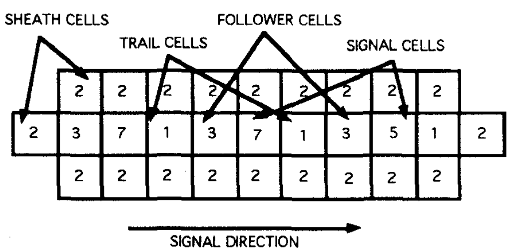

Fig. 2 A Cellular Automata Trail

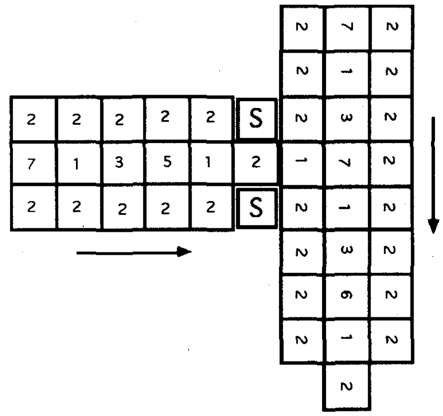

Fig. 3 A Synapse Between 2 CA Trails

3. Cellular Automata Based Neurite Networks

One can then evolve CA networks. There is too little space in this 4 page paper to go into the many details, but CA rules can be defined to repair and clean up "destroyed" trails. Some collision circumstances make synapse formation impossible, in which case no CA rule is defined, so by default the background (black, zero) state becomes the next state, which can destroy the trail. Usually the network stabilizes after several hundred clock cycles, i.e. all signal sequences get absorbed at synapses. Once this happens, a second set of CA rules gets switched on which makes the CA network behave like a neural network. For example, there are two kinds of sheath cells, one for "axons" and one for "dendrites". Signals in axons remain at the same strength as at emission (at CA neurons), but once the axon signal passes through an axon-dendrite synapse (created in the CA net growth phase), it becomes a dendrite signal, which drops off in strength as it advances. Thus the dendrite signal strength is dependent on its distance from the synapse. These distances are evolvable, hence the distances behaves like the weights of conventional neural networks. Axon-axon or dendrite-dendrite synapses simply absorb the oncoming signal.

Two merging dendrites can add their incoming signal strengths. CA rules can be defined which allow this. Similarly, the axon output signal strength at a CA neuron can be a non linear function of the sum of its incoming dendritic signal strengths.

4. Future Research

A lot of work remains to be done. Hopefully however, the reader can see the potential of neurite networks. Not only can they be evolved, but they can be GROWN. Therefore it will probably be possible to grow connections incrementally between one neurite module (i.e. a GenNet = Genetically Programmed Neural Network [de Garis 1990]) and another, and thus build/evolve/GP an artificial brain with hundreds of GenNets. This would be a kind of incremental evolution. Building an artificial brain is one of the long term dreams of ATR's Brain Builder Group. We hope also to design Darwin Machines to use as tools to perform this GenNet (neurite network) evolution at high speed. In the near future, a 3D CA neurite network will be grown on ATR's CM5 supercomputer.

References :

[Codd 1968] "Cellular Automata", E.F. Codd, Academic Press, 1968.

[de Garis 1990] "Genetic Programming : Modular Evolution for Darwin Machines", Hugo de Garis, IJCNN-90-WASH-DC, (Int. Joint Conf. on Neural Networks), January 1990, Washington DC, USA.

[de Garis 1991] "Genetic Programming", Hugo de Garis, Ch. 8 in book "Neural and Intelligent Systems Integration", ed. Branko Soucek, WILEY, 1991.

[de Garis 1992] "Artificial Embryology : The Genetic Programming of an Artificial Embryo", Hugo de Garis, Ch. 14 in book "Dynamic, Genetic, and Chaotic Programming", ed. Branko Soucek and the IRIS Group, WILEY, 1992.

[de Garis 1993] "Genetic Programming : GenNets, Artificial Nervous Systems, Artificial Embryos", Hugo de Garis, WILEY manuscript.

[Goldberg 1989] "Genetic Algorithms in Search, Optimization, and Machine Learning", D.E. Goldberg, Addison-Wesley, 1989.