Chaos in a Single Recurrent Artificial Neuron

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Abstract. A simple artificial neuron can represent a very complex behavior, inclusive chaotic one. Apparently, it is possible to control this behavior by means of the parameters that constitute this artificial neuron. This paper presents a single recurrent neuron which can generate different periodic pattern of activation. The results indicate a variety of the behavior since a constant behavior, a cyclic one and a chaotic behavior.

1 Introduction

The brain is a complex structure and a complex behavior can be generated from this structure including recognition, short temporal and long temporal memory, complex coordination and learning [1, 2, 3, 4, 5]. It is desirable to generate a similar structure to emulate this complex behavior and control them to generate entities with superior abilities. Nowadays it is very difficult to build entities which can emulate the complex activities of the brain; how-ever, recurrent artificial neural network is an approach to this objective. Usually there are several studies about the behavior of complex recurrent neural networks; however, our study is focused to handle single neurons. It has been proposed structures with few neurons, commonly no more than four neurons. It is applied a recurrence to generate different periodic patterns of activation, inclusive chaos [6, 7, 8, 9, 10, 11].

A single neuron can be defined as a single processing element which it emulate the behavior of a natural neuron in a simplified form. It is presented a single recurrent neuron where the activation function is a Gaussian function. The recurrence is applied when the output of this neuron is used as an input. This simple feedback makes a neuron to exhibit some times a set of well-defined periodic patters including chaos. The two parameters of the activation function change the periodic patters of activation. This paper shows the behavior of this neuron when there is a change of these two parameters.

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2 Neuron with a Gaussian activation function

The architecture of a single neuron is shown in several books where neural networks are introduced. It is make an analogy between a natural neuron and an artificial neuron to get a simplistic model (figure 1). The artificial neuron is called a processing element because makes simple operations to integrate the input signals and it is generated an output using an activation function. Usually no linear activation functions are used, like sigmoid and hyperbolic tangential activation function. In this work a Gaussian activation function is used instead. The Gaussian activation function has a bell-like form. This function has two parameters, the width of the bell where it is called lambda and the center of mass called cm (equation1). Both parameters control the behavior of the activation function and consequently the behavior of the neuron is altered.

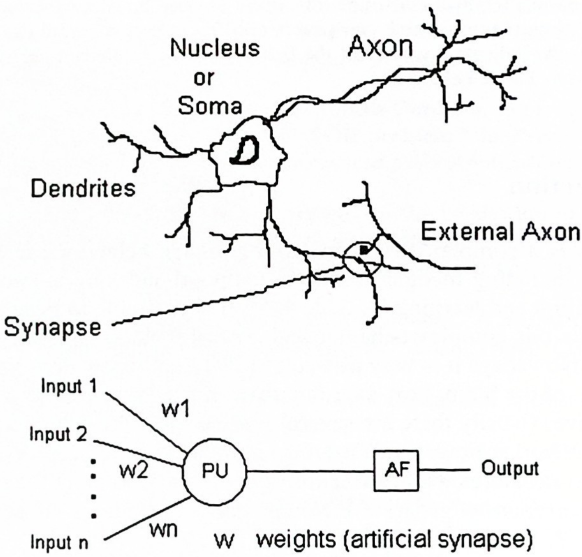

Fig. 1. There are some analogies between a natural neuron and an artificial neuron. Synapse is equivalent to a weight (W) and the activation output of the neuron through the Axon is determined by the activation function (AF).

$$Gauss(x.\lambda, cm) = e^{-(\frac{x-cm}{\lambda})^2} \tag{1}$$

The behavior of this single neuron can be modified including a feed-back of the output to the input. Figure 2 shows the recurrent neuron. The use of a Gaussian activation function is the difference with the artificial neuron shown in figure 1. The implementation of the model is shown where it is generated every pattern through a time unit t.

Step 1: Initialization: oa=0; epoch = 50;
Step 2: Define parameters Lambda and cm
Step 3: Calculate on = gauss (oa, lambda, cm);
Step 4: oa = on;
Step 5: if epoch <= 0 then end; else epoch <- epoch – 1; go to step (3)

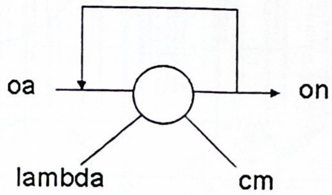

Fig. 2. Single recurrent neuron.

Specific parameters makes that the recurrent neuron exhibit a well defined periodic pattern (figure 3). Other parameters makes that the recurrent neuron exhibits a chaotic pattern (figure 4) and finally there are parameters that make a stable exhibition of the recurrent neuron (figure 5). Chaos is a complex behavior so it is necessary to elaborate a bifurcation diagram to show the possible fixed points of this recurrent neuron as a function of parameters of its activation function [12].

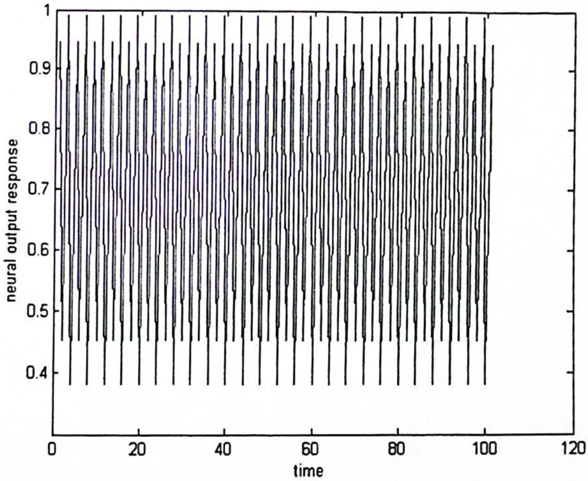

Fig. 3. Periodic pattern of a single neuron with Gaussian activation function (lambda = 0.5, cm =0.5).

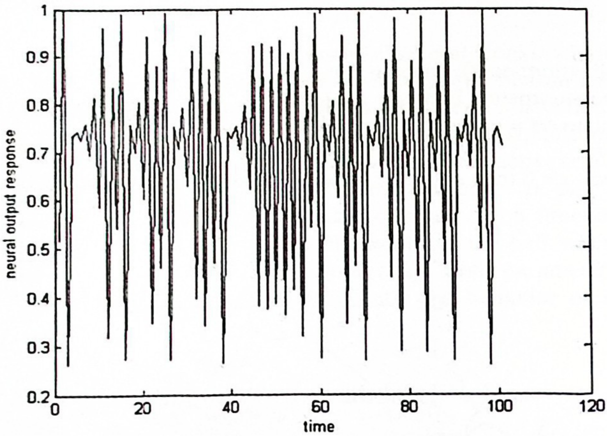

Fig. 4. A periodic pattern of a single neuron with Gaussian activation function (lambda = 0.43.

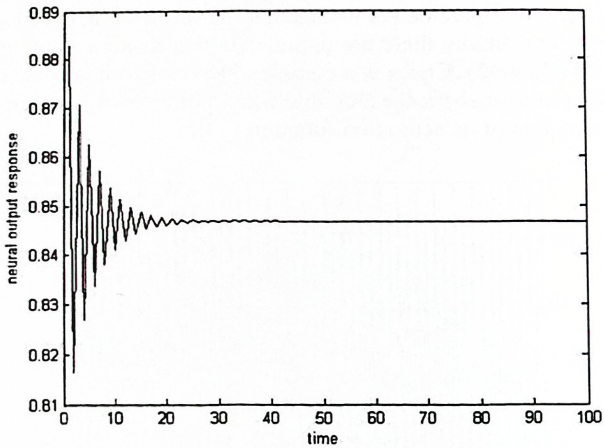

Fig. 5. One A periodic pattern of a single neuron with Gaussian activation function (lambda = 0.85, cm =0.5).

3 Description results

To illustrate a complete behavior of the neuron it is necessary to generate a bifurcation diagram common used when there is a chaotic behavior. In this diagram it is plotted a change of one parameter (i. e. lambda) and the other parameter is set fixed. All the possible values of the neuron activation are plotter in y axis versus the changing parameter. It is used a normalized information, this means between 0 and 1.

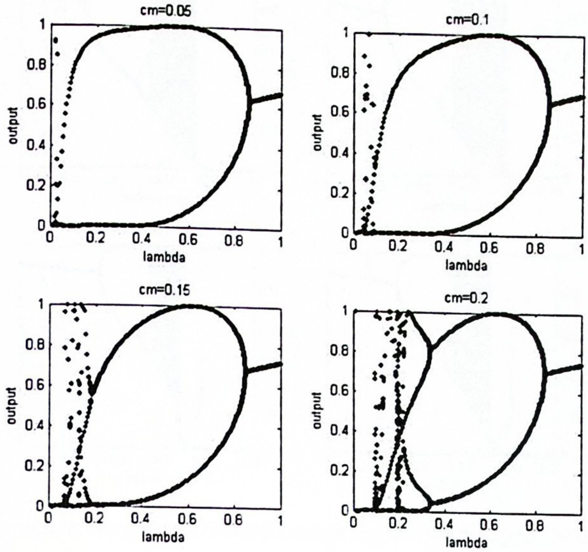

Fig. 6. One Bifurcation diagram of a single recurrent neuron using parameter cm from 0.05 to 0.2.

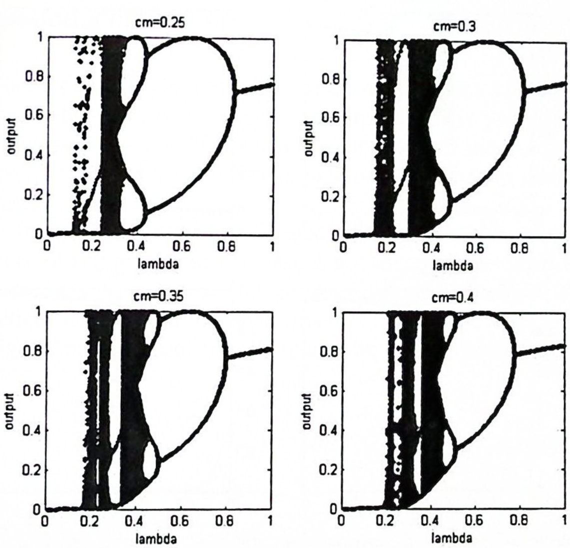

Fig. 7. Bifurcation diagram of a single recurrent neuron using parameter cm from 0.25 to 0.4.

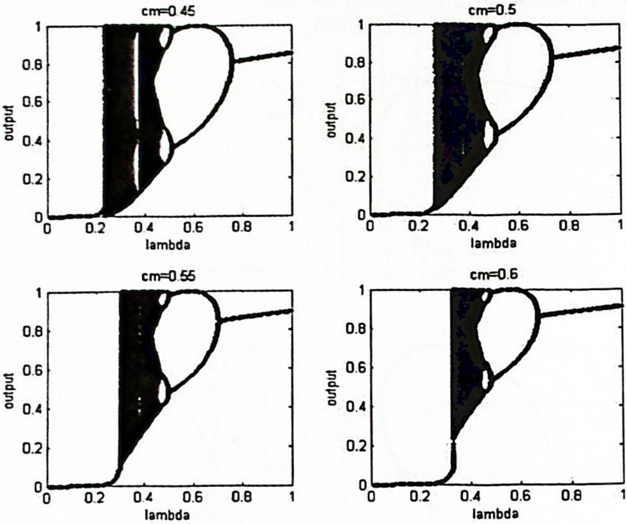

Fig. 8. Bifurcation diagram of a single recurrent neuron using parameter cm from 0.45 to 0.6.

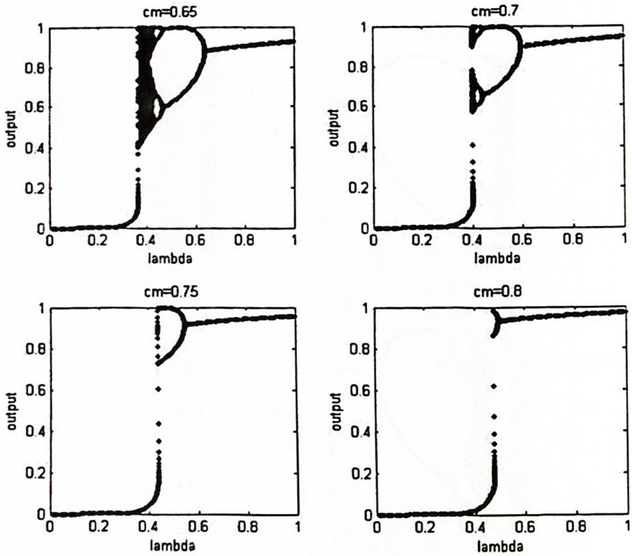

Fig. 9. Bifurcation diagram of a single recurrent neuron using parameter cm from 0.65 to 0.8

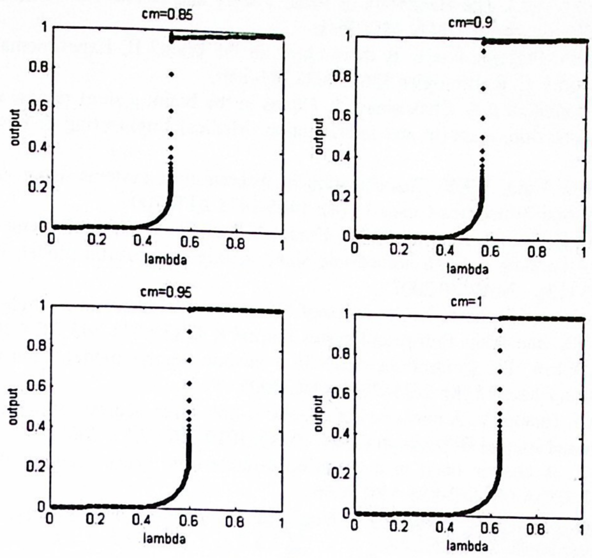

Fig. 10. Bifurcation diagram of a single recurrent neuron using parameter cm from 0.85 to 1.0.

4 Discussion and Conclusion

The interaction of several neurons of this kind could express a diversity of periodic patterns activities with a set of controllable parameters. It is possible to generate a variety of periodic patterns activities when it is used a rich interconnection of these neurons; however, it is necessary to realize new investigations to control all the parameters involved.

There is an implicit property of self organization where it is possible to store a complex sequence of actions and its response is not altered by the input sequence; that means, there is an attractor presence. This property is desirable because it is possible to store several action sequences in the same structure. The future work includes the use of a genetic algorithm to control this parameter an exhibit several desirable patters activities.

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Image Processing Applications