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A New Neuron Model Based on Dendritic Mechanism and Its Applications
(樹状突起のメカニズムに基づく新型ニューロンモデルとその応用)

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By

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Abstract

In the past 600 million years, the organisms have evolved into a large number of neurons linked to each other by the formation of the neural network to solve the problems how the human brains handle a variety of complex information in a complex and changing environment. Brain is an organ that serves as the center of the nervous system and aims to perceive outside environment by its own advanced information processing ability. It not only abstracts the characteristics from the information of outside but also makes judgments on the basis of the abstraction being gotten from the sound lights, etc. from outside environment

All along, in order to clarify the functions of human brain, many scientists, one after another, make a lot of effort. From the appearance of the artificial neural networks to the research on brain waves, the study of brain has never stopped. With the development of science and technology, more and more new technologies are being used in the research of brain. Research in this area has attracted more and more attention. In order to understand the process of brain, the principle of this complex neural system, many researchers shift the attention to the neurons, the basic building blocks of the nervous system.

In chapter1, the functions, features and the relationship of brain, neural networks and neurons are introduced. With the support of the latest technologies, the computing power of the brain is found to be far underestimated. Many experiments show that single neurons as well as the dendrites hold very powerful computing capability. However, previous neuron model just possesses simple computing capabilities and

can’t solve complex nonlinear problems. Furthermore, the dendrites just transmit signals and don’t participate in the specific computations. In addition, the neuron model adopted to this thesis and a brief introduction of its structure are performed.

In chapter 2, two types of neuron model are described in detail. They are McCulloch-Pitts Model and Koch-Poggio-Torre model. For McCulloch-Pitts Model, the neuron is simply treated as a computing unit, and doesn’t take into account of the computational capacity in dendrites. Although the dendritic computation is realized on paper in Koch-Poggio-Torre model, there is no specific mathematical realization to be created. Therefore, it can’t be used in practice.

In chapter 3, a very detailed description of the new neuron model which is called Neuron Model with Dendritic Mechanism and can be also called Neuron Model with Dendritic Nonlinearity (NMDN) is carried out. NMDN is proposed on the basis of Koch-Poggio-Torre model by Professor Tang. In order to reflect the physiological morphology and the functions of neurons in NMDN, the logical AND (owing to the soft-minimum function) are used to realize the switch function and the logical OR (owing to the soft-maximum function) are used to deal with when there are two or more inputs and switches in parallel. Furthermore, a logical NOT (owing to the sigmoid function) is also required when a signal is transmitted in the dendrites. Thus, a nonlinear interaction belonging to the dendrites can be expressed by logic operation AND, OR and NOT. Moreover, NMDN can heighten and fix the practical dendrites and synapses, filter out the worthless ones by training and form a mature dendrites shape to preserve the valuable synapses. And, in order to simplify the computation in dendrites, the authors have proposed to use the simple addition and multiplication in place of soft-maximum function and soft-minimum function to improve the algorithm. After optimization, not only is the computation simplified, but also all the features of the original model can be maintained.

In chapter 4, NMDN is used for the detection of breast cancer and compared to traditional back-propogation neural networks (BPNNs) for the first time. Breast cancer is one of the leading causes of unnatural deaths of women in the world. How to detect breast cancer correctly has become one of the topics that scientists are most concerned about. In this thesis, NMDN are trained according to the different branches of dendrites. And the comparison is performed on the accuracy, stability, convergence speed and AUC. The result discloses that the performance of NMDN is more superior than BPNNs. Additional, due to the NMDN's particular dendritic structures, a kind of stable dendritic structure evolves to distinguish cancer cells through learning. Moreover, the 0-connection existing branches after evolving can be eliminated from the dendrite morphology to release computation load, and don't influence the performance of classification.

In chapter 5, NMDN is also for the first time to be proposed to predict the change trends of the overreaction on Shanghai stock market on the basis of the trading data from January 2004 to October 2014. In this thesis, the first n-months' data is treated as input data to predict the following month's data. The result shows that the neuron model possesses huge computational ability and successes in predicting the tendency. Moreover, with the growth of input data, the correlation between the data of first n-month and following month improves. In addition, NMDN provides another new approach for the researchers.

In chapter 6, I summarize the results of two applications on classification and prediction to prove that a single neuron has a very superior computing power.

【論文審査の結果の要旨】

当学位論文審査委員会は，標記の博士学位申請論文を詳細に査読し，また論文発表会を平成27年2月4日(水)に公開で開催し，詳細な質疑を行って論文の審査を行った。以下に審査結果の要旨を記す。

脳の優れた情報処理能力は、脳における神経細胞（ニューロン）がシナプスを相互結合、相互作用することによって実現されている。1943 年に McCulloch と Pitts は神経細胞の最も代表的なモデルを提唱した。このモデルはニューラルネットワークの基本的なニューロンモデルとしてよく知られている。しかし、このモデルは神経細胞の空間的加算と閾値作用しか考慮していない。近年の研究によって神経細胞の詳細な性質が明らかにされている。それらの研究によって神経細胞はそれぞれ個性的な形をしていることが解明され、樹状突起上でのチャネルが反応することによって起こるシナプス結合の作用やチャネル自体が演算プロセスに関与していることがわかってきた。そこで、本研究は、樹状突起のメカニズムに基づく新型ニューロンモデルを提案し、実験結果により、提案したモデルおよびその学習アルゴリズムの有効性を示した。

学位申請論文は 6 章で構成される。各章の概要を以下に示す。

第 1 章では、研究の背景、論文の概要について簡単に説明した。

第2章では神経細胞の最も代表的なモデルの種類、特徴、動作原理とその問題点について明確に記述した。

第3章では、樹状突起のメカニズムに基づく新型ニューロンモデルとその学習アルゴリズムを提案し、その詳細について述べた。

第4章では、提案の新型ニューロンモデルとその学習アルゴリズムを乳癌検出に適用し、従来のニューラルネットワーク方法との比較を行った。その結果により、提案法が従来のニューラルネットワーク方法より精度、安定性、収束速度などいずれの面においても優れていることを示した。更に、学習によって無駄な樹枝状構造を除去し，癌細胞を検出できる安定した樹枝突起構造が形成できることも確認した。

第5章では、提案の新型ニューロンモデルとその学習アルゴリズムを中国上海株式市場過剰反応の予測に適用し、2004年 1 月から2014年10月までの11年間の間に上海A株市場からランダムで抽出された200銘柄の終値データに基ついて、過剰反応現象の変化動向を予測した。その結果から提案法が予測能力を持ち、時間帯区分が大きければ大きいほど予測結果がよくなることを示した。

第 6 章では、本研究で得られた成果を総括している。

学位申請論文で提案したモデルとその学習アルゴリズムは非常に有効で，工学的応用のみならず，学術的にも価値が高い。

よって，当博士論文審査委員会は本博士学位申請論文が博士の学位を授与することに十分に値するものと認め，合格と判断した。