ADAPTIVE RESONANCE THEORY

Abstract

Adaptive Resonance Theory (ART) is a competitive neural network. ART has been used in biological applications, such as medical diagnoses and examining patterns of brain waves in certain psychological conditions. Neural Networks alone are very similar to the biological nervous system, hence its application in medicine. A neural net takes into account all of the ideas that govern the nervous system. For instance, the connection between neurons and the way in which the signal is carried out is quite similar to the nervous system. ART is a type of neural network that can be trained to recognize certain patterns. For instance in a biological aspect one would want to see if the signal processing for muscular movement for paraplegics is the same. Another idea is to analyze the brain waves of a person with a normal brain and a person afflicted with schizophrenia. Then if there is a difference, what treatments will be most effective in normalizing the brain waves? ART has had much success with electronics and modeling circuits, however, as the field of computers and medicine expands, the most important question becomes is ART successful in modeling the brain accurately and in particular is it successful in its application to medicine.

Introduction

Many individuals learn certain tasks by repetition, which would indicate that they memorize the task, others learn by watching, which would indicate that they learn from examples. A neural network is a model that that processes information almost the same way the human brain processes information. The neural net consists of neurons that are connected to other neurons [1]. The connections are distinguished by a weight, which represents the data that will be used to perform the task assigned. There are two ways to train a neural net, supervised and unsupervised. Supervised training occurs by giving examples that correspond to an output. Unsupervised training occurs by the data being given but no corresponding output being assigned. The weights are instead grouped according to similarity [2]. Adaptive Resonance Theory works in this fashion. ART1 in particular is an ART network that learns by examples. The architecture of ART1 consists of three layers, an input layer, the cluster units, and reset mechanism that will control the degree of similarity of patterns [3]. An interesting aspect of ART1 is that the there is no need for the patterns to be inputted in any order. The connections of the units in the layers are arranged in such a way that the input layer is connected to the interface layer, each unit in the input and interface layer are connected to the reset unit, which in turn is connected to every cluster unit. Each unit in the interface layer is also connected to each unit in the cluster layer by two pathways, forming a cycle. [4]. This is all seems arbitrary until an algorithm is provided detailing how these layers work together.

The algorithm of an ART1 network begins by initializing a binary input vector called s, this is then presented to the input layer, and this data is sent to the corresponding interface layer, x. The interface layer then send signals to the clustering layer over connection pathways. Each clustering unit computes its net input and the units compete for right to be active. This is why ART is called a competitive learning method. Since the values are binary, active units are set to 1 and the rest to 0. The "winning unit" or unit that has the largest net input, can then learn the input pattern. A signal is sent from the clustering layer back down to the interface layer. The units in the interface layer remain active only if they receive nonzero signals from both the input and clustering units. The unit can only learn the pattern if the quantity of the user-defined vigilance parameter, degree of similarity required for patterns to be assigned to the same cluster unit, is less than the ratio of all x units to all s units. If the opposite is true than this original winning unit becomes inhibited and all the activations of the input and interface layer are set to zero. The process is then repeated until all units are inhibited or a winning unit is found that fits the rule. When a winning unit fits the criteria to learn then all the units within that cluster are adjusted. A very important part of the algorithm of ART1 is that at the end of each presentation of a pattern all cluster units are set back to zero [5]. If the case exists that all the units are inhibited one must specify what should be done.

The ART1 network has many uses. For instance it has been used in pattern recognition, pitch perception, modeling electronic noses that can detect different smells, this application is for chemical purposes but uses the biology of smell. The biological aspect of ART has been used in simulating brain waves this in turn is used to understand certain neurological diseases such as Alzheimer's, Parkinson's, and also schizophrenia. Though schizophrenia is labeled a psychological disorder, research has found that the brain of a schizophrenic person differs from that of a non- afflicted individual.

Methods

All of the techniques used for detecting patterns in schizophrenic brain waves and observing relatedness between the brain and schizophrenic behavior will demonstrate the use of ART. Stephen Grossberg , the father of Adaptive Resonance Theory, illustrates that when certain signals in the brain that control emotion are altered they can produce symptoms that are characteristic of schizophrenia [6].

Grossberg agrees with other researchers that the major characteristic symptoms of schizophrenia are psychomotor poverty, disorganization, and hallucinations. Many of these symptoms are directly related to the defects of the frontal lobe of the brain [7]. Other symptoms of schizophrenia that are related to the way in which the brain processes information include attention. These symptoms are classified as negative symptoms [8]. Grossberg tries to show how the brain is directly related to behavior and in particular related to the symptoms of schizophrenia.

The biology of attention is quite different than the biology of the sense organs. For instance attention is controlled by sensory and emotional expectations, but also linked to previously learned information. Schizophrenia is not the only disorder in which attention is modeled. Alzheimer's, Parkinson's, and depression are also disorders in which the circuits of the brain directly influence the symptoms of the disease.

Grossberg's model is called the CogEM model. This model is designed to show data about interacting cognitive, emotional, and motor learning properties [9]. The model itself is based on ART1. The model shows that there are three types of internal representation interacting during learning, sensory and cognitive, drive, and motor. Each of the learning properties is controlled by different parts of the brain. Sensory and cognitive are controlled by the thalamocortex or the brainstem. Drive is controlled by the hypothalamus and amygdala. Motor is controlled by the cortex and cerebellum [10]. An ART network then represents the model. There are three types of learning each controlled by the aforementioned parts of the brain. Conditioned reinforcer learning; which links a conditioned stimulus to an unconditioned stimulus, strengthens the weights in a sensory to drive pathway. As these weights are being adjusted, the drive to sensory pathways forms simultaneously. This type of learning is known as incentive motivational learning. The sensory to motor pathways, or habit learning allows the sensory-motor vectors to be adaptively measured. This network allows the sensory representations to store activities that retain their sensitivity to the relative size of their inputs, while also conserving the total activity among the active representations [11]. With this model, Grossberg and other researchers have been able to predict what would happen when certain types of arousal become imbalanced.

Another model, similar to Grossberg's CogEM model, also looks at the symptoms of schizophrenia and its relatedness to behavior [12]. The model designed by Marcia Rozenthal, Eliasz Engelhardt, and Luis Alfredo Vidal de Carvalho examines the same symptoms however tries to illustrate specific patterns of the brain circuits that are damaged. The model used 53 schizophrenic patients, subjected the patients to many neurocognitive tests that illustrate how well their memory is, how well they can determine patterns between objects. From these tests, certain defining parameters were assigned. For instance, their IQ, their scores on the maze tests, measure of learning ability, etc [13]. All of these parameters were chosen because they have a connection to the frontal sub cortex and bilateral cortex circuits of the brain. This data was then applied to the ART network. The ART network clustered the patients into similar groups and then the researchers developed a conclusion based on these clusters.

Both the above models use ART to detect patterns in schizophrenia. Other researchers have used ART for other medical purposes. Researchers in China have used ART to diagnose cardiac irregularities. ART is used here to detect different wave shape features for different subjects or different beats of the same subject [14].

ART1 has also been used to detect signal pattern recognition and limb function determination and control of stimulation levels in paraplegics [15].

Data and Results

Grossberg's CogEm model showed that the combination of conditioned reinforced learning and incentive motivational learning form a loop that is only on when sensory is activated on by its stimulus [16]. Also when unattended sensory representations lose activation due to competition from attended representations, their output signals are reduced or completely destroyed. Therefore learning proceeds very slow. The signals from drive to sensory enable the weights in their cluster to learn also; this in turn allows drive to motivate the sensory representations. Then the active S representations can learn sensory-motor associations with motor representations [17]. The model suggests that one cause of decreased pre-frontal lobe activity may be due to a reduction in the incentive motivational signals from the amygdala circuits that connect to the prefrontal cortex [18]. This was illustrated by decreasing the inputs to the drive representations. This then illustrates depression found in some schizophrenic patients and ultimately in depressed patients. The reason is that the prefrontal cortex will not be able to perform efficiently and motivation will decrease along with goals, causing depression. Contrarily when drive representations are overly stimulated then some characteristic symptoms of schizophrenia are likely to occur [19]. This is biologically consistent with the notion that the neurotransmitter dopamine in excess is sent to the amygdale and is the major biochemical cause of hallucinations in schizophrenia. This is also modeled for Parkinson's disease. Parkinson's disease symptoms, such as uncontrollable motor function, are due to the lack of dopamine sent to the amygdala. The CogEM model is a good model for showing how certain amounts inputs to the brain can lead to symptoms associated with schizophrenia.

Similarly, the model from Rozenthal, Engelhardt, and Carvalho shows that certain aspects of the person's intelligence and/or learning capacity are related to their brain deficiencies. After processing the data from the neurocognitive tests into the ART network, first cluster contained patients with lower IQ, with a compatible global memory, showing homogeneity between verbal and visual memory levels [20]. The learning capacity of these individuals is also low. This leads to the conclusion that these patients don't show disturbances in the primary processes of memory consolidation. The planning capacity of the patient is also low. This is consistent with the damages of the frontal cortex. The second cluster contained patients with higher IQ and the same compatibility between verbal and visual memory levels. Their learning ability is also low, as well as their planning skills. This is also suggests damage of the frontal cortex but instead the disturbances concentrate in the dominant hemisphere of the brain not both as in the first group of patients.

The research completed on using ART for diagnosing cardiac irregularities, specifically cardiac arrhythmias, shows that ART uses data input as the number of normal beats and the number of premature ventricular contraction beats. After the network was trained with this input the five of the sixteen F2 nodes are deleted from the network [21]. This then allowed the researchers to quantify the measurements of electrocardiograms of patients with cardiac arrhythmias and formulate rules for diagnosis. They concluded that if the QRS complex of the ECG is upward and its magnitude is high and its width is wide then the beat is an abnormal beat and the diagnosis is cardiac arrhythmia or premature ventricular contraction has occurred.

Discussion

As shown by the above research ART has been very successful in diagnosing, and helping to understand relatedness between defects in the brain and schizophrenia, Parkinson's, Alzheimer's and other diseases caused by frontal lobe cortex deficiencies. ART has other applications as well. Besides diagnostic tools, ART has been used to possibly diagnose schizophrenia before symptoms occur. This is accomplished by matching patterns of cerebral blood flow to the brain between healthy subjects and schizophrenic subjects. The model showed 100% accuracy [22]. Most of the research on ART and Schizophrenia has focused on the patterns of damaged brain circuits that cause certain behavior and symptoms. Both Grossberg and Rozenthal's ART models show the relatedness between problems in the frontal lobe of the brain associated with symptoms of schizophrenia particularly the symptoms involving speech, motor retardation, and lack of emotions. Many of these symptoms are also prevalent in patients with Parkinson's, particularly speech and motor control. Therefore this research has led to the establishment of theories suggesting that schizophrenia and Parkinson's, Alzheimer's and other related disorders are caused or most certainly exacerbated by damaged brain circuits to the amygdala and cortex.

ART also has applications in other areas. For instance modeling pitch perception is similar to matching patterns of characters. It is known that no matter how a letter is written, whether it is script or print it is recognized by the human as that letter. This theory is the same in music. For instance think of the letter as a note or pitch, think of the instrument playing it as the type of writing. With this in mind it shows that no matter what instrument is playing a particular note, the pitch is still recognizable as that pitch [23]. The ART network is trained to recognize certain spectral patterns that correspond to a pitch learns to extract the pitch from the signals. The network must not be confused by shape of the spectral and amplitude, or then the network fails to model pitch on all instruments.

Another function of ART was used in a sociological/ psychological application. This interesting use tries to establish patterns found in the work force in connection to the employee's attitudes. The model tries to answer some questions such as, which pattern of work attitudes correlates to a lucrative business [24].

Furthermore, ART has been used in aspects of genetic algorithms. The ART network uses the fitness measures of certain genotypes as the input data; the weights are then adjusted to output which fitness measures will give the best genotypic survivorship [25]. ART has recently been used in chemical and environmental tools. Electronic noses as they are termed are used to distinguish different odors using ART and also using the biology of the olfactory bulb as its architecture. Each odor presented to the network produces a characteristic pattern of the odorant [26]. ART is coupled with a certain chemical sensor such as a gas chromatograph in order to perform accurately. The future advances of electronic noses will be used for detecting environmental conditions that are characterized by certain odors in the air.

It has been proven that ART is a useful tool for medical applications. However, ART is not the only neural network tool used for medicine. Research has been conducted using a three-layer neural network model constructed from an input layer followed by two computational layers to simulate responses of schizophrenic patients to the Rorschach test [27]. Test subjects respond to a set of ambiguous patterns created by inkblots on paper. Schizophrenic patients have different interpretations to the test. The model proposes that the interpretations of schizophrenic patients to the test are caused by altered noise-to-signal ratios in the units of the neural network. Another neural network model concludes that the brain of schizophrenic patients is directly related to how they perform on certain neurocognitive tests. This model uses parallel organizing techniques and comes to the same conclusion that both Grossberg and Rozenthal discovered [28].

The applications of neural networks has been used in image processing of the brain, genetic algorithms, modeling sense organs such as the eye and nose, modeling electronic circuits, detecting bacterial infections, circulation of blood, and also business aspects.

Conclusion

ART is a neural network approach that involves data being processed and then establishing patterns between the data. ART has been used in extensive research of psychological disorders such as schizophrenia, and related disorders such as Parkinson's and Alzheimer's. The patterns found between schizophrenic patients and the way they performed on certain tests showed that schizophrenic patients share a common defect in their frontal lobe; which in turn allows a greater understanding of the characteristic symptoms they exhibit. These symptoms include lack of emotion, speech and motor retardation. Other research using ART has shown that damage to the cortex is directly related to their behavior. ART has also shown to be successful in diagnosing cardiac irregularities such as cardiac arrhythmias. ART has also been successful in other applications as chemical sensing, genetic algorithms, and modeling pitch. ART can be used in any medical application that involves the brain or detecting patterns in symptoms related to the damaged neurons. Perhaps in the near future ART can be used to determine which treatments are more accurate in treating the negative symptoms of schizophrenia. ART may someday be able to allow researchers to fully understand the causes of schizophrenia, Parkinson's and Alzheimer's disease, paralysis, and any neurological disease.

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