Processing of Logical Functions in the Human Brain

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Abstract: - The human brain has ability to process logical functions. However, the human brain does not process logical functions same way as digital computers do it. The digital computers use double-state logic, whereas the human brain uses multi-state logic to process basic logical decisions. Human thinking is based on the principles of fuzzy logic. The fuzziness in the human brain function is caused by the function of neurons and their ability to switch depending on input values in dendrites. The paper shows how the human brain processes fuzziness using the soft logical functions.

Key Words: - Logical Function, logical AND function, logical OR function, SoftAND function and SoftOR function, general logical function, fuzzy logic, fuzzy sets, fuzzy systems.

1 Introduction

This is the fourth paper in the series of papers called Human Brain. The previous paper called Memorising and Forgetting in the Human Brain was introduced on the NNA02 congress held in Interlaken 2002 organised by WSEAS.

The human brain has ability to process logical functions using neural structures. There are differences between processing logical function in the neural structures and in the digital circuits based on silicon.

Logical circuits based on silicon are built using digital gates. The neural logical functions are done by neurons and dendrites.

There exist very different principles of processing the logical functions using digital logic and using the neural structures.

The digital gates are controlled by the electric voltage in the range from 0 to 5 Volts. The switching threshold level is typically about 0.5 Volts. When the input is set to the value of below 0.5V, the input is considered to be logical 0 or false. When the input is set to the value of above 0.5V, the input is considered to be logical 1 or true.

The input values are processed using logical rules and result is set either to 0 or 1 according to the truth tables depicted in the following text.

The neurons and dendrites process logical functions different way. Each neuron can have one or more inputs bringing charged ions to the neuron body. These input dendrites can be considered as inputs of logical gate having specific characteristics not similar to the electronic gates.

The stream of ions fills neuron body with electric charge. When the voltage inside the neuron body exceeds a threshold level, the output impulse train is fired.

The firing of the impulses depends on the speed of charging via input dendrites and on the threshold level in the axon-hillock. (The axon-hillock is the place where the axon is connected to the neuron body. The axon is an only one output of neuron.)

More inputs can potentially bring more charge at certain time interval.

Smaller the stream of charged ions and higher threshold level in the axon-hillock gives character of AND function to the neuron.

Bigger the stream of charged ions and lower threshold level in the axon-hillock gives character of OR function to the neuron.

There are two basic levels in which the human brain processes the logical functions.

The first level is processed in neural structures. The second level of processing is done by the whole brain on the highest functional level.

The first level of thinking affects the second level but not strictly the same way for similar cases.

The paper shows differences of processing logical functions using electronic gates versus processing in the neural structures as neurons, dendrites axons and synapses are. How the human brain processes the basic logical functions and how this processing influences the function of the human brain.

2 Logical Function

Mathematics defines the set of few logical functions. However, for explanation of the human brain function
only two basic functions will be used as an example of processing logical function in the brain.
The first two of them are AND function and OR function. We could describe more than these two functions but it is not the purpose of this paper to describe logical function that we can find in many mathematical schoolbooks for universities.
The Table 1 is the truth table for these two functions for two input variables. These 2 functions are shown here only for the purpose of describing differences between the logical functions and the brain logical functions.

### Table 1

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<tr>
<th>A</th>
<th>B</th>
<th>AND</th>
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This is the simple example of logical processing in digital systems. As one can see we have only 2 states for each variable.

All rules created using such functions are strong rules. It means that we can make only strong decisions. No soft rules decisions can be applied using such rules.

Everything is strongly defined for such functions. Let us have two assertions. The A assertion is true and the B assertion is also true. Then the result is also true for both functions.

But when we need something like the A assertion is maybe true or the B assertion is nearly true, we cannot use this logic.

For such cases we can derive some functions that can help us to understand the function of the human brain.

### 3 Decision Processing

In the real life we have to make many decisions. These decisions cannot be strong as well as the digital logic is.

We have to take many different input values into account. We cannot act upon some conditions when all input conditions are fulfilled. We must make correct decisions depending on values that are not very reliable and in most cases they are non-precise.

The typical example can be shown on decisions made by the medical doctors while they analyse the disease from which a patient suffers.

Let us have some disease for which there are 5 basic symptoms that characterise it. The medical doctor cannot make logical AND function while deciding about presence of this disease. The doctor cannot say: “I found that this patient has all these 5 symptoms. Therefore he/she suffers from this disease. And/or the patient has only 4 of these symptoms. Therefore he/she does not suffer from this disease.

Logical functions are not able to simulate thinking of a doctor or any other person about some problem.

When we try to analyse how medical doctors think about existence or absence of some disease or symptom of disease, we realise that typical logical AND logical OR functions are not very useful and/or useable.

The people doing theirs daily work must think the similar way as the medical doctors. They also must use the natural logic and not the digital logic.

But the thinking of medical doctors allows us to understand better the way the human brain works.

When we must think about technical problems we use more logical functions AND, OR. But when we think about diseases we must think about much more variations and that can complicate diagnose. Diseases have the same nature as the human brain.

The diseases occur in the human body and brain. They have also fuzzy character as the brain has. For detection of concrete disease the doctor must take many non-precise symptoms into account.

Therefore the thinking of medical doctors is different to the thinking of people working in industry.

Medical doctors before they set correct diagnose must be able to work with hypothesises about presence of symptoms leading to the correct diagnose. Many serious diseases have practically same or very similar symptoms as illnesses that are not serious. Therefore, diagnoses must be defined correctly.

The input information for setting diagnose is very unclear. In spite of that the final decision must be correct and precise.

On the one side the brain must be able to solve such complex problems as is diagnose, on the other hand the nature was not able to create complex devices that would help to process complex functions.

The neuron is very simple device to create the logical functions. Therefore, I tried to develop function that would simulate function of the neuron with its simplicity.

The explanation of the human thinking can be shown on the function described in the next chapters.

### 4 Majority Function

The majority function is shown in the Table 2. There can be seen 3 inputs and one output.

We have circuit with 3 inputs and internal threshold of 0.5 of maximum value.
For output value holds. If majority of inputs are set to 1, the output is set to 1. If majority of inputs are set to 0, then the output is set to 0.

If the number of inputs is even, the output value is not defined for logical functions. But in the biological systems the values are not precise, therefore there exists always some concrete solution.

Table 2

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<tr>
<th>A</th>
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The Table 2 shows the truth table of Majority function for three-input function.

The most of neurons have big number of inputs. The big number of inputs can give better statistical results. However, it is not so easy to describe truth table of the typical neuron. Moreover the threshold level for impulse generating in the neuron is not typically 0.5 of the maximum generated impulse voltage.

5 SoftAND Function

The brain is not able to build logical AND function, as we know it from the mathematical definitions. The AND function can be realised in the brain using rules of probability.

Table 3

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<th>A</th>
<th>B</th>
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<th>SoftAND (0.7)</th>
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When we increase the threshold level of the Majority function we decrease probability of generating the output impulse. We can suppose that such function can work as SoftAND function that is shown in Table 3.

The Table 3 shows the typical truth table for logical AND function. When we decrease threshold level to 0.6, we get different results.

Table 4

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The results are the same as for the Majority function. It means the for threshold values of 0.5 to 0.66666666 we get Majority function whereas for the higher threshold values we get SoftAND function shown is Table 3.

6 SoftOR Function

The brain is not able to build logical OR function, as well as it holds for the logical AND function.

The similar way as for she SoftAND function we define the SoftOR function using the decrease of the threshold level instead of the increase in case of SoftAND function.

The SoftOR function is generated in the case when the probability to generate impulses increases. This happens if the threshold level for impulse generating decreases.

So let us have Table 5 defining the SoftOR function using truth table. It is clear that when at least one input is activated in the SoftOR function, the result value is 1. Then the result of the function is typical logical OR function.
However, when the threshold level for the SoftOR function increases to the value of 0.3, the result values change. The result is shown in the Table 6.

### Table 6

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### 7 General Definition of the Soft Logic

Comparing Table 6, Table 4 and Table 2 we can see that all three tables are the same.

We can also notice that for the threshold values between 0.333333 to 0.666666 we have Majority function.

For the values below the 0.333333 value we have logical OR function and for the values above 0.666666 we have the logical AND function.

For the 3 input values is this definition trivial. But for neurons with the big amount of inputs we get very complex logic functions that can solve many complex needs of the human brain.

Changes of the threshold level that enables to generate impulses allow to change the logic of processing from the AND function up to the OR function.

The soft logic comparing to the ordinary logic has character of statistical functions. It means that instead of saying when all inputs are set to 1, the result is 1 for logical AND function we say that if weighs of all inputs in the SoftAND function exceed the threshold level the result is set to 1.

The threshold level can be exceeded using many different ways. Either one of inputs is set to 0 and others are set to 1, or all are set to the value little less than 1, or any combination of values that can cause the internal value exceeds the threshold level.

Such processing is typical fuzzy process that works on principles of non-precise values in the system.

### 8 Real Logic in the Human Brain

The soft logic described in this paper shows real natural logic realised in the brain only partially.

In the definitions described above we suppose that all inputs have value of 1, which is not true. If it really was true, all dendrites would have to have the same diameter and the flow speed of ions through the axon would have to be the same.

Biological tissues do not allow such equality in all parameters of the system, which would be an only very special case. In biological systems we have to always suppose inequality of all parameters and attributes.

As the each dendrite and/or axon has different diameter, the input values are not the same. The diameter of dendrite or axon changes during life, moreover.

The threshold level for generating an impulse in the neuron is also different for each neuron. The threshold value is not equal during the whole life of neuron, either. It changes during life.

However, the output value remains the same for the whole life. The size of the output value is given by the concentration of ions of sodium, potassium, chloride and calcium. It does not depend on the growth of neural structures.

Because of these variations in the brain tissue we get highly variable brain, which is not possible to describe in details so far. Probably, the people will not be able to describe the human brain in details in the future.

In the real brain we cannot define concrete threshold levels at which majority function changes to the AND function and/or to the OR function.

As the input values have different sizes or weighs, the threshold levels are different for each combination of these input values.

When we realise how many neurons the human brain has, we can imagine how complex problem it would be to describe the function of the human brain in all details.

We could also imagine how complex problem is to build the human brain as a computer.
We do not have technologies that would allow us to build devices like the human brain is so far. All effort to build the brain is directed to build the massively parallel systems having similar characteristics as the brain has. The similarities of the artificial and the real brains are meant only in some special functions. The artificial brain is not able to fully emulate function of the real brain.

The main difference between artificial brain computers and the real brain is ability of the brain to grow, to change its structure completely and to die. The neural structures are added to the brain or they are removed when they die.

9 Fuzzy Logic and the Human Brain

The variability of the brain structures was the base for creation of terms as Fuzzy Logic, Fuzzy Sets, Fuzzy Systems, etc.

The human brain is the fuzzy system. The artificial fuzzy systems invented by Prof. Zadeh can help us to describe macrostructures of the human brain. We can show only something of the human brain function and logic.

The artificial fuzzy systems are distant from the real function of the brain. However, they are probably the best approximation of the brain function in terms of logical thinking.

This paper shows how the real brain processes fuzzy logic in the biological tissue.

10 Soft Logic in the Real Life

The idea of the soft logic corresponds with the real thinking of people. When people think about concrete problem they use majority function in the most cases. It means that they compare between two or more cases. The case having higher weight wins. People just use weighing the chances according to their impact on themselves. The real life depends on economy. Therefore, people select new job or other valuables just according to the amount of money that this decision will bring them.

In most situations people do not need to use logic of AND, OR functions for their decisions. The majority function is the sufficient logical for the most of simple decisions made in the life.

With the development of science and other complex activities the brain is pushed to process functions requiring solving many details of many different kinds. But when the scientific thinking is processed the brain must use more complex logic.

11 Associative Thinking

The associative thinking is the type of thinking that allows joining knowledge or information from few different spheres of interest or from few sciences.

The information is received into the human brain via senses (visual, hearing, olfactory, taste, touch and pain.) The information coming from few of senses is joined and processed to create information of the new meaning for the brain. Such information is received and memorised in the brain memory if the person will need such information in the future.

Associative thinking is being built during the whole life. Children do not have developed associations in the brain therefore they can trust everything the adult people say them. During the process of growth the associations in the brain grow as well, therefore young people are able to distinguish the truths from lies, possible from impossible, real from unreal, etc.

Associative thinking is necessary for all beings, people and animals to avoid danger or predators. This thinking is tightly bound with memory, as the association must come from already acquired knowledge or information saved in the brain memory.

The typical use of associative thinking is in case of injuries. When a person hurts itself for example by touching the hot surface, it memorises this information and the next time it avoids touching any surface that is suspicious or looking as hot.

People receive a lot of information during the every day. They have to process it and build associations also in situations of socialising. Teams of people working together on projects must solve not only work problems but they solve also the problems of relations in the team.

People working in a team are typically split into more sub-teams that co-operate but in some cases struggle against other sub-teams or individuals.

The associative thinking helps people to find the best position in any community they must live in.

The associative thinking is based on two basic principles.

The first principle comes from the soft logical functions processing first time defined in [1] and described in this paper.

The second principle is based on the theories similar to the associative memorising that were described in [4]. Soft logical thinking helps to create temporary neural relations that are cleared after these newly built structures are no longer needed.

The principles based on associative memorising are permanent and they help to avoid dangerous situations with the use of experience. The experience is based on
memory records written in the brain during previous life.

Associations are built either as innate connections of neurons in the brain. Complex logical functions are built using simple functions called in this paper as the soft logical functions.

The very complex logical functions are needed to process the highest mental functions as for example language processing, thinking, etc.

12 Language Processing

The language processing and the body movement are two separate problems having one base. Language is processed on both, serial and parallel bases.

The every person must be able to decode sequences of syllables. The sequences of syllables create words. The people are able to decode also sequences of words called sentences. The people are also able to do much more. Let us take an example of translators.

I mean here the people simultaneously translating from one language to another one. They have to be able to memorise one or more sentences and to translate text previously memorized.

Their brainwork like stack memory having ability to translate. Similar ability must have people receiving Morse codes. All these abilities must be trained. Untrained people are not able to do that.

This leads me to convince that the human brain must work also on the serial base. The human brain must be able to memorize chain of information and to process it using parallel structures.

The parallel structures solve grammatical rules. The every grammatical structure needs at least one state in the brain. I called states also as regimes. The term “every grammatical structure” I mean one character or one syllable or one word or one short sentence.

The human language consists of many typical sentences and words those are used most often. People know them very well. They do not make errors to understand them. But there are many sentences less typical. These grammatical structures are then processed with more errors.

13 Serial Processing

The serial processing in the brain is possible because the logical function described above show that the neural structures are able to build chains of neurons that are activated from one neuron. Then the activation goes to the second and other neurons.

The activation can run over the groups of neurons instead of only single neurons. I would compare it to binary counter that create multi-state code that can be used to order regimes of processing.

The brain creates activation waves running over some structures that are activated in the sequences. The logical functions can decode concrete status of the processing. This status is processes by other structures.

The typical algorithmic processing in the brain is body movement. The body movement is controlled by the spinal cord and it is activated from the midbrain.

The logical functions build the sets of sequences that are used for processing of many functions. These sequences activate groups of neurons dedicated to process concrete parallel function in one step.

The brain can process some sequences together with other sequences as a time-sharing process in the digital computers. For example people can walk and think or talk or all of these functions do at one time.

14 Conclusions

The paper describes the logical functions and the soft logical functions and their differences including the processing of logical function in the human brain.

The main result of this paper is description of how the human brain processes the fuzzy logic in the neural structures.

References


