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An Artificial Tongue for Taste sensor based on Neural Network

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Abstract— A taste sensor, namely an artificial tongue, with global selectivity is composed of several kinds of lipid/polymer membranes for transforming information about substances producing taste into electrical signals, which are input to neural network. This artificial tongue composed of five sensors are able to distinguish easily the five basic tastes (salty, sour, sweet, bitter and umami), The sensor output exhibits different patterns for chemical substances which have different taste qualities such as saltiness, sourness and bitterness, whereas it exhibits similar patterns for chemical substances with similar tastes. The sensor responds to the taste itself, as can be understood from the fact that taste interactions such as the suppression effect, which appears for mixtures of sweet and bitter substances, can be reproduced well. The suppression of the bitterness of quinine and a drug substance by sucrose can be quantified. The tastes of foodstuffs such as beer, coffee, mineral water, milk, sake, rice, soybean paste and vegetables can be discussed quantitatively using the artificial tongue, which provides the objective scale for the human sensory expression.

Index Terms—Taste Sensor, Artificial Tongue, Neural Network (NN), Chemical Substances.

1 INTRODUCTION

NOW-a-days, neural network based agents are becoming smarter day by day. They can drive a car, perceive an object by its scent, detect and solve the problem, take responsibility as a human being and realize the emotion of human being [1]. Even emotion is being included to agent. Therefore, an artificial tongue is proposed to sense taste in this paper.

Smell depends on sensory receptors that respond to airborne chemicals. In humans, these chemoreceptors are located in the olfactory epithelium — a patch of tissue about the size of a postage stamp located high in the nasal cavity. The olfactory epithelium is made up of three kinds of cells:

- **Sensory neurons** each with a primary cilium
- Supporting cells between them
- **Basal cells** that divide regularly producing a fresh crop of sensory neurons to replace those that die (and providing an exception to the usual rule that neurons seldom are replaced).

There are several reasons to choose NN based on artificial tongue. NN neurons are much faster than human brain's neurons. Hence NN can make any decision as like as human brain [7].

In some cases especially for pattern classification, Human Brain Neuron (HBN) shows poor performance however NN can perform very efficiently [8].

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2 ARTIFICIAL NEURAL NETWORK

Neural networks are used to allow computers to learn and adapt to different tasks that they are presented with. It can be seen as a computer representation of the human brain. In the human brain, there are neurons interconnected to each other, and depending on an impulse the neurons receive, a response will occur. This impulse that neurons in the human brain receive is equivalent to the input that is given to a neural network, so as the response that follows an impulse is similar to a decision the neural network outputs. Fig. 1 describes how NN process input X and send the out A.

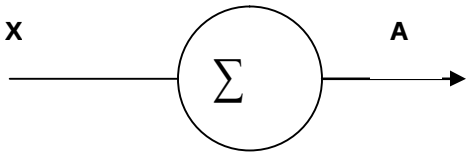

Fig. 1. A single neuron for a neural network taking input x with an output A

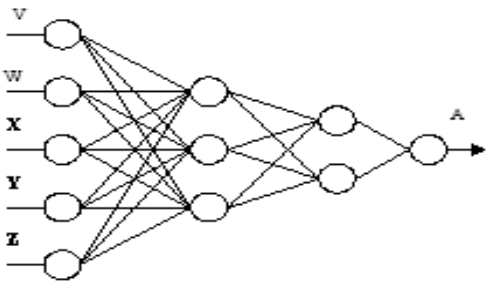

Fig. 2. Graphical representation of neurons interconnected receiving many inputs and producing single output.

Similarly fig. 2 describes the NN interconnectivity and producing a single output from many inouts.

NN is a very simple model and consists of a single 'trainable' neuron. Trainable means that its threshold and input weights are modifiable. Inputs are presented to the neuron and each input has a desired output. If the neuron does not give the desired output, then it has made a mistake. To rectify this, its threshold and/or input weights must be changed. How this change is to be calculated is determined by the learning algorithm.

The output of the perceptron is constrained to Boolean values - (true, false), (1, 0), (1, -1) or whatever. This is not a limitation because if the output of the neural network were to be the input for something else, then the output edge could be made to have a weight. Then the output would be dependent on this weight. The neural network (fig. 3) looks like:

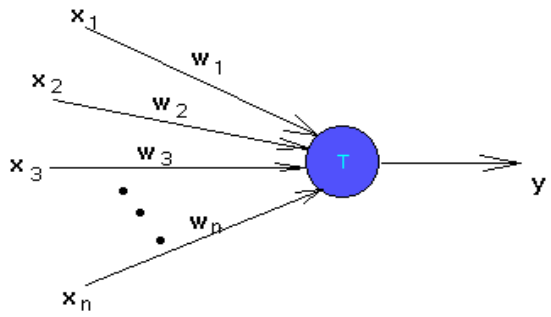

Fig. 3. Architecture of Neural Network

1. $x_1, x_2, ..., x_n$ are inputs. These could be real numbers or Boolean values depending on the problem.
2. y is the output and is Boolean.
3. $w_1, w_2, ..., w_n$ are weights of the edges and are real valued.
4. T is the threshold and is real valued.

$$w_1 x_1 + w_2 x_2 + ... + w_n x_n \quad \text{.....(1)}$$

The output y is 1 if the net input is greater than the threshold T. Otherwise the output is zero. The idea is that we should be able to train this neural network to respond to certain inputs with certain desired outputs. After the training period, it should be able to give reasonable outputs for any kind of input. If it wasn't trained for that input, then it should try to find the best possible output depending on how it was trained.

3 SENSE OF TASTE

Taste is the ability to respond to dissolved molecules and ions called tastants. Humans detect taste with taste receptor cells. These are clustered in taste buds. Each taste bud has a pore that opens out to the surface of the tongue enabling molecules and ions taken into the mouth to reach the receptor cells inside. There are 5 (five) primary taste sensations:

1. Salty
2. Sour
3. Sweet
4. Bitter
5. Umami

3.1. Properties of the Taste System

A single taste bud contains 50–100 taste cells representing all 5 (five) taste sensations (so the classic textbook pictures showing separate taste areas on the tongue are wrong). Each taste cell has receptors on its apical surface. These are transmembrane proteins which

- admit the ions that give rise to the sensations of salty and sour;
- bind to the molecules that give rise to the sensations of sweet, bitter and umami.

A single taste cell seems to be restricted to expressing only a single type of receptor (except for bitter receptors). Taste receptor cells are connected, through an ATP-releasing synapse, to a sensory neuron leading back to the brain.

However, a single sensory neuron can be connected to several taste cells in each of several different taste buds. The sensation of taste like all sensations resides in the brain [1].

3.1.1. Salty

At least one of the receptors for salty substances (e.g., table salt, NaCl), is an ion channel that allows sodium ions (Na+) to enter directly into the cell. This depolarizes it allowing calcium ions (Ca2+) to enter [4] triggering the release of ATP at the synapse to the attached sensory neuron and generating an action potential in it.

In lab animals, and perhaps in humans, the hormone aldosterone increases the number of these salt receptors. This makes good biological sense:

- The main function of aldosterone is to maintain normal sodium levels in the body.
- An increased sensitivity to sodium in its food would help an animal suffering from sodium deficiency (often a problem for ungulates, like cattle and deer).

3.1.2. Sour

Sour receptors are transmembrane ion channels that admit the protons (H+) liberated by sour substances (acids) into the cell.

3.1.3. Sweet

Sweet substances (like table sugar — sucrose) bind to G-

protein-coupled receptors (GPCRs) at the cell surface.

- Each receptor contains 2 subunits designated T1R2 and T1R3 and is
- Coupled to G proteins.
- The complex of G proteins has been named gustducin because of its similarity in structure and action to the transducin that plays such an essential role in rod vision.
- Activation of gustducin triggers a cascade of intracellular reactions:
    a. Activation of adenylyl cyclase
    b. Formation of cyclic AMP (cAMP)
    c. The closing of K+ channels that leads to depolarization of the cell.
    d. The mechanism is similar to that used by our odor receptors [4].

The hormone leptin inhibits sweet cells by opening their K+ channels. This hyperpolarizes the cell making the generation of action potentials more difficult. Could leptin, which is secreted by fat cells, be a signal to cut down on sweets?

3.1.4. Bitter

The binding of substances with a bitter taste, e.g., quinine, phenyl thiocarbamide [3], also takes place on G-protein-coupled receptors that are coupled to gustducin [2].

In this case, however, cyclic AMP acts to release calcium ions from the endoplasmic reticulum [5], which triggers the release of neurotransmitter at the synapse to the sensory neuron.

Humans have genes encoding 25 different bitter receptors ("T2Rs"). However, each taste cell responsive to bitter expresses many of these genes. (This is in sharp contrast to the system in olfaction where a single odor-detecting cell expresses only a single type of odor receptor.)

Despite this and still unexplained a single taste cell seems to respond to certain bitter-tasting molecules in preference to others.

The sensation of taste like all sensations resides in the brain. Transgenic mice that

- Express T2Rs in cells that normally express T1Rs (sweet) respond to bitter substances as though they were sweet;
- Express a receptor for a tasteless substance in cells that normally express T2Rs (bitter) are repelled by the tasteless compound.

So it is the activation of hard-wired neurons that determines the sensation of taste, not the molecules nor the receptors themselves.

3.1.5. Umami

Umami is the response to salts of glutamic acid like monosodium glutamate (MSG) a flavor enhancer used in many processed foods and in many Asian dishes. Processed meats and cheeses (proteins) also contain glutamate.

The binding of amino acids, including glutamic acid, takes place on G-protein-coupled receptors that are coupled to heterodimers of the protein subunits T1R1 and T1R3.

Another umami receptor (at least in the rat's tongue) is a modified version of the glutamate receptors found at excitatory synapses in the brain.

3.2. Discrimination of odor

How can one kind of cell enable us to discriminate among so many different odors? Humans can discriminate between hundreds, perhaps thousands, of different odorant molecules, each with its own structure. How can one kind of cell provide for this?

- The mammalian genome contains a family of about 1000 related but separate genes encoding different odor receptors. (No more than 40% of these are functional in humans, the rest are pseudogenes which may help to explain why dogs are better at detecting odors than we are.)
    a. The olfactory epithelium of rats (which is more convenient to study than that of humans) expresses several hundred genes not expressed in other tissues.
    b. Each gene encodes a transmembrane protein that resembles but is not identical to the others.
    c. Each protein contains 7 regions of hydrophobic alpha helix that allow the molecule to pass back and forth 7 times through the plasma membrane.
    d. In some cases, the portion of the molecule exposed outside the cell may be responsible for binding the odorant molecule.
    e. However, many odorant molecules are hydrophobic and could easily enter the lipid bilayer and bind to the receptor there. This possibility is supported by the finding that much of the sequence variability from one receptor to another is found in the alpha helices.
- **Each olfactory neuron expresses only a single type of receptor**. Some evidence:
    a. Gene probes for a single type of receptor bind to only 1 in a 1000 sensory neurons in a normal olfactory epithelium.
    b. However, rats made to express a single type of receptor in large numbers of their olfactory neurons responded much more vigorously to a single type of odorant than to any of the other 73 tested. Solutions containing a recombinant

virus carrying the receptor gene were inserted into the nasal cavities of living rats. Many of their olfactory neurons became infected and expressed that receptor gene.

c. Cells taken from these rats and placed in tissue culture also responded to only that one type of odorant molecule.

3.3. Olfactory of neuron

Although a single olfactory neuron contains over a thousand receptor genes, there is only a single enhancer capable of binding to the promoters of these genes and turning them on. (There are, of course, two alleles of the enhancer but only one is active [one is methylated; the other is not]. Presumably, when the active enhancer encounters the promoter of an olfactory gene, it turns it on and ceases its search. Thus only one olfactory receptor gene gets to be expressed in a single cell, but which one is a matter of chance.

In mice, the enhancer is on chromosonme 11. Although several olfactory genes are also on that chromosome, many others are scattered over several other chromosomes. Nonetheless, it has been demonstrated (e.g., by FISH analysis) that the enhancer on chromosome 11 can find and bind to the promoter of an olfactory gene on other chromosomes not just those on #11.

Now we have a mechanism for discriminating among a thousand or so odorants. However,

- Each receptor is probably capable of binding to several different odorants — some more tightly than others. (The cells described above also responded — although more weakly — to 3 related odorants.)
- Each odorant is capable of binding to several different receptors.

This provides the basis for combinatorial diversity. Assume that it would work like this:

- Odorant A binds to receptors on neurons #3, #427 and #886.
- Odorant B binds to receptors on neurons #2, #427 and #743.

The brain then would interpret the two different patterns of impulses as separate odors. So now we have a mechanism capable of discriminating among millions of different odorants.

As demonstrated in this document, the numbering for sections upper case Arabic numerals, then upper case Arabic numerals, separated by periods. Initial paragraphs after the section title are not indented. Only the initial, introductory paragraph has a drop cap.

4 RESULTS AND DISCUSSION

Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. As in nature, the network function is determined largely by the connections between elements. It can be trained a neural network to perform a particular function by adjusting the values of the connections (weights) between elements.

Commonly neural networks are adjusted, or trained, so that a particular input leads to a specific target output. Such a situation is shown below. There, the network is adjusted, based on a comparison of the output and the target, until the network output matches the target. Typically many such input/target pairs are needed to train a network. Neural networks have been trained to perform complex functions in various fields, including pattern recognition, identification, classification, speech, vision and control systems.

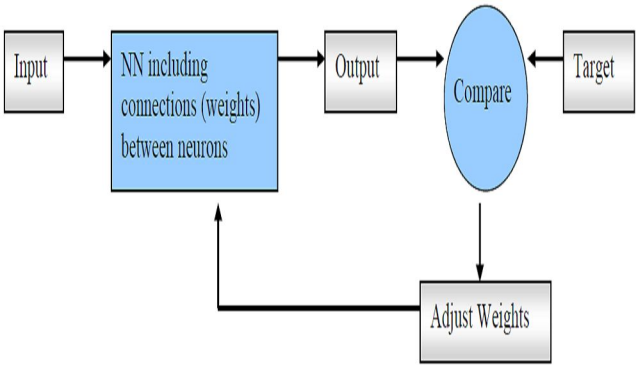

Fig. 4. Trained the neural network

Today neural networks can be trained to solve problems that are difficult for conventional computers or human beings. Throughout the toolbox emphasis is placed on neural network paradigms that build up to or are themselves used in engineering, financial and other practical applications.

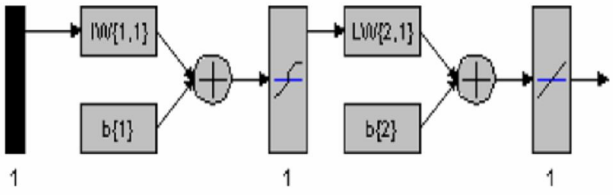

Fig. 5. Processes of NNs

Validation Data:
Inputs: AquariumATP1995
Targets: Salt04WTP1995

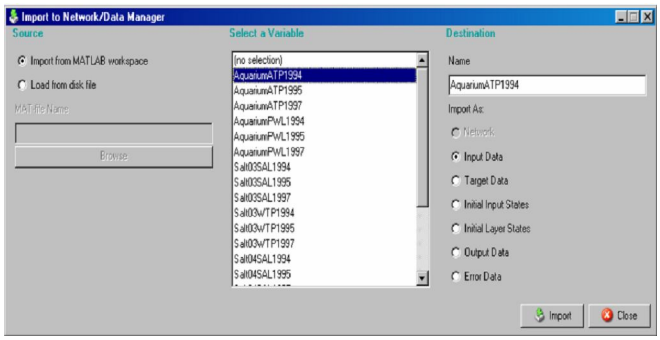

Fig. 6. Input data for NN

Test Data:
Inputs: AquariumATP1997
Targets: Salt04WTP1997

4.2 Discussion (Training, Validation and Testing)

We can adjust the training parameters as well as weights ($W_{i,j}$). For example, by changing the training Parameters, we can adjust the number of hidden layer (fig. 8).

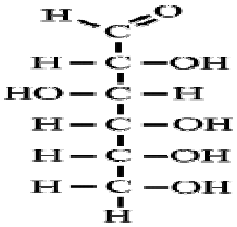

Fig. 7. Bond of Glucose ($C_6H_{12}O_6$)

5 Conclusion

This paper reports on a taste sensor that is able to distinguish tastes. Using lipid or polymer as the principle of detection, we showed how the distinct clusters can be identified for five basic tastes. Distinction can be made with regard to lipid membranes and chemical substances. Furthermore, if the data are treated with ANNs, this "artificial tongue" can identify samples stored under different conditions. It could be recognized with 100% accuracy utilizing proper training patterns and chemical substances. This "artificial tongue" can also be applied to measurements of water pollution. Use of the artificial tongue will lead to a new era of food and environmental sciences.

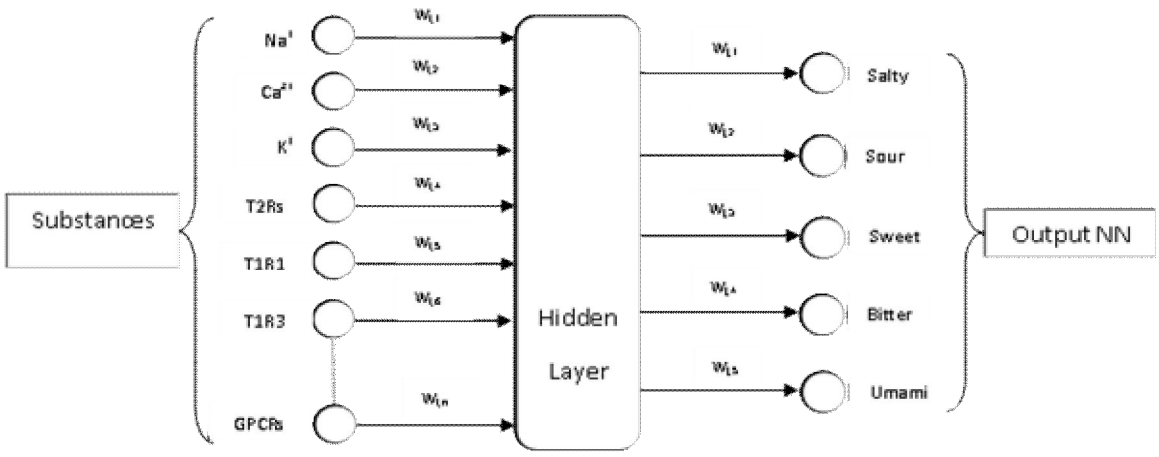

Fig. 8. Design of Artificial Tongue using ANN

We compared here with 5 (five) basic tastes (salty, sour, sweet, bitter and umami). We can distinguish different kind of tastes on basis of different chemical substances (Na^+, Cl^-, Ca^{2+}, K^+, etc), bond (NaCl, H_2O, $C_6H_{12}O_6$, etc), color and size of molecules. For example, where we will get Na^+ and Cl^- as chemical substances there taste should be salty (NaCl). Likewise, Glucose ($C_6H_{12}O_6$) is substances of sweet [9]. We can differentiate it with its chemical substances (Fig. 7). Similarly, mix tastes are available with mixture of different substances. We can also determine the strength of taste from density of substances.

References

[1] "An artificial taste sensor based on conducting polymers" by Riul Júnior, Malmegrim RR, Fonseca FJ, Mattoso LH. EMBRAPA Instrumentação Agropecuária, CP 741, CEP 13560-970 São Carlos, SP, Brazil.

[2] http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/S/Second_messengers.html#calcium_transporters.

[3] "Wine classification by taste sensors made from ultra-thin films and using neural network", by Antonio Riul, Humberto C., de Sousa. Sensors and Actuators B: Chemical, Volume 98, Issue 1, March 1, 2004, Pages 77-82.

[4] "High-Performance Taste Sensor Made from Langmuir–Blodgett Films of Conducting Polymers and a Ruthenium Complex" by Marystela Ferreira, Antonio Riul, Karen Wohnrath. Anal. Chem., January 18, 2003, 75 (4), pp 953–955.

[5] "Artificial taste sensor: Efficient combination of sensors made from Langmuir Blodgett films of conducting polymers and a ruthenium complex and self-assembled films of an azobenzene-containing polymer" by A. Riul, D.S. Dos Santos. ISSN:0743-7463, Journal: Langmuir, Volume: 18.

[6] "Nano-assembled films for taste sensor application" by RIUL Antonio, MALMEGRIM Roger, FONSECA Fernando, MATTOSO Luiz. Journal: Artificial organs, ISSN: 0160-564X, CODEN ARORD7.

[7] "Network-based Intrusion Detection Using Neural Networks" by Chandrika Palagiri, Dept. of CS, Rensselaer Polytechnic Institute, Troy, New York 12180-3590.

[8] "Neural Network Based Online Agent as Human Representative" by K.S. Arefin, A.k. Saha and M.Z. Alom. 2nd ICEESD Conference, Dhaka, Bangladesh, December 19-20th, 2009.

[9] http://creationwiki.org/Glucose

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