PHYSICAL LIMITS FOR SELF-CONTAINED SYSTEMS: AN EXAMPLE OF THE HUMAN BRAIN AS A COGNITIVE SYSTEM

S. Seker and J. Dikun

***Abstract*—** This study presents the calculation of information rate using the Bremermann's limit for human-brain. In this manner, the information rate of the brain can be approximately calculated. This is the physical limit of the natural system as an example of the human-brain or a cognitive system.

***Keywords*—** *Self Contained Systems, Information Processing, Bremermann's limit, Brain and Launder's Limit*

1. INTRODUCTION

INFORMATION processing is executed by information processors or computer hardware's. Most important information processor is human brain. In life, the human brain system uses some mathematical models of the objects or things in the real life to recognize the reality and hence, it tries to get some matching between the models and objects. The Objects which carry meaning are represented by patterns called as symbols. As a result, to form the symbolic expressions, that constitute inputs to or outputs, from information processes, they are stored in the processor memory. And also, the memory stores the symbolic expressions. In an information processing system like the human-brain, the mathematical or abstract model is provided by the ability of its processing units.

Since 1980, the increasing attention has been focused on the study of the human brain as an information processor of the parallel type. This is related with the cognitive science and cognitive engineering which can be accepted as a further step of the Machine learning and Artificial Intelligence. From these different viewpoints, natural or artificial ones need to the processing or computing speed as a system capacity. For this reason, an upper limit of the computing speed is described and presented in this study [1,2].

2. BREMERMANN'S LIMIT FOR MAXIMUM COMPUTATION SPEED

Bremermann's limit for maximum computation speed is based upon the Shannon's channel capacity concept under the combination of quantum and relativity theories [3-8].The Shannon's formula that is related with the channel capacity. *C* for noisy channels is described as:

$$C = BW.log_2(1+\frac{S}{N}) \quad (1)$$

Where *BW*: Band width, $^S/_N$: Signal to Noise Power ratio. *C* is also channel capacity or maximum rate in bits per second [3]. Here, the band width is defined as maximum frequency in most cases and it becomes υ_{max}. In quantum physics, it is represented in the maximum energy formula as given by below:

$$E_{max} = h\upsilon_{max} \ . \quad (2)$$

Where *h* is Planck's constant.

Also another concept of the quantum physics is Heisenberg's uncertainty principle, where the uncertainty of the energy ΔE is measured in the time interval or uncertainty of time Δt depending on the following inequality.

$$\Delta E.\Delta t \geq h \quad (3)$$

Hence the equation (1), namely the Shannon's formula, can be written for $S = N$ and then it defines the maximum channel chapacity as below:

$$C_{max} = \upsilon_{max} log_2(1+1) = \upsilon_{max} \quad (4)$$

And using the Equations (2), the maximum channel capacity becomes

$$C_{max} = \upsilon_{max} = \frac{E_{max}}{h}. \quad (5)$$

Hence it means the maximum bit speed to be presented to the channel depending on the Shannon's opinion.

In quantum theory the continuouty of the energy interval of (0, E_{max}) can be represented by the interval of ΔE, hence, it is divided by *n* and defined as

$$\Delta E = \frac{E_{max}}{n} \quad (6)$$

Here it means that the same energy is distributed to *n*-channels if the first one of the Eq. (6) is substituted in the Equation (5), the channel capacity is written as follows:

$$C_{max} = \frac{n.\Delta E}{h}. \quad (7)$$

Also, using the Einstein's formula for the Energy,

$$E_{max} = mc^2, \quad (8)$$

where m is total mass and c is also speed of the light in vacumm. From this view point C_{max} is redefined for the equation (8) and it becomes

$$C_{max} = \frac{mc^2}{h}. \quad (9)$$

Getting the quality of the Equations (7) and (9), it is written as

Serhat Seker, is with Department of Electrical Engineering, Istanbul Technical University, Istanbul, Turkey, (e-mail: sekers@itu.edu.tr).

Jelena Dikun, is with Ship Energy Department, Lithuanian Maritime Academy, Klaipeda, Lithuania, (e-mail: jeldik@bk.ru).

Manuscript received Jun 17, 2018; accepted Sep 19, 2018.
Digital Object Identifier:

$$\frac{n.\Delta E}{h} = \frac{mc^2}{h}. \quad (10)$$

In this equality, ΔE is changed, through the Equation (3), with the inequality of $\Delta E \geq \frac{h}{\Delta t}$

And, finally

$$\frac{n.(h/\Delta t)}{\Delta t} \leq \frac{mc^2}{h},$$

or it is

$$\frac{n}{\Delta t} \leq \frac{mc^2}{h}. \quad (11)$$

Here $(\frac{mc^2}{h})$ is in the unit of bit/sec depending on the left side of the inequality (11). Whereas c^2/h is in the unit of bit/sec/kg and it is known with the name of Hens-Joorchim Bremermann, so-called Bremermann's limit, as maximum computational speed of a self-contained system in the material universe.

Numerical value of the Bremermann's limit is $c^2/h = 1.36 \times 10^{50}\ bit/sec/kg$ where, $c = 3.10^8\ m/sec$, $h = 6.626.\times 10^{-34}\ m^2kg/sec$.

Also for each bit/sec, it is represented by the amount of heat energy equality of $(kT\ ln\ 2)$ ergs/sec or $10^{-7}(kT\ ln\ 2)$ with Watt/sec T: Temperature in Kelvin.

3. Application of the Bremermann's Limit to Brain and Launder's Limit

Considering the brain mass (weight) as 1350 gr approximately in homogeneous structure, hence, using the inequality (Eq. 11) becomes

$$\frac{n}{\Delta t} \leq \frac{mc^2}{h} = m(\frac{c^2}{h}),$$

$$\frac{n}{\Delta t} \leq (1.35).(1.36) \times 10^{50}\ \frac{bit}{sec},$$

or,

$$\frac{n}{\Delta t} \leq 1.836 \times 10^{50}\ bit/sec\ . \quad (12)$$

Approximately, it becomes $2.10^{50}\ bits/sec$ and at room temperature $T = 273 + 20 = 293 \approx 300°K$ the maximum efficiency of the brain $(EB)_{max}$ becomes:

$$(EB)_{max} = 2.10^{50}.(1.38 \times 10^{-23}.3 \times 10^2.0.693)$$
$$= 5.7 \times 10^{29}\frac{J}{s} = 5.7 \times 10^{29} Watt$$

4. Conclusions

The Bremermann's limit is an upper limit of the information processing, it is restricted by a max-value which is connected with a gram of any matter, in this study, and it was shown for the brain's mass of 1350 gr. But it plays role of (weight) of any material. To determine, the upper limit in this meaning, there is no any importance of the material type, it is just related with the mass-energy relation of the relativity minimum energy spreading, during very short times of the quantum world.

For this reason, the computed value, it is general for any material of 1350 gr. However, the literature says that the processing limit of the brain cannot be greater than this limit. From this viewpoint, the Launder's limit is also became an upper limit in terms of the power or energy. These are the limits of the nature!

Finally, there is no any artificial or living thing can compute more than 2×10^{50} (or 2×10^{47})) of its mass. This is related with a self-contained system because the power (energy) supply is provided in the total mass and the computation is defined as an information transfer through one or more channels (like several Shannon's information channels) within the system.

References

[1] URL1: http://www.alleydog.com, "Information processing model", March 22, 2018.

[2] T. L. Saaty, J. M. Alexander, *Thinking with Models, International Series in Modern Applied Mathematics and Computer Science*, Vol.2, Pegamon Press, 1981, pp.23-25.

[3] C. E. Shannon, A Mathematical Theory of Communication, Bell Systems Technical Journal, Vol. 27, 1948, pp. 623-656.

[4] H. J. Bremermann, The Evolution of Intelligence. The nervous system as a model of its environment. ONR report no. 1, contract Nonr 477(17), University of Washington, Seattle, 1958.

[5] H. J. Bremerman, "Minumun Energy Requirements of Information Transfer and Computing", International Journal of Theoretical Physics, Vol.21, No:3-4, 1982, pp.203-217.

[6] T. Blaszo, "Information Transfer in Quantum Mechanics", Journal for Foundations and Applications of Physics, Vol.2, No.1, 2015, pp.25-34.

[7] F. Hermann and G. B. Schmid, "An analogy between information and energy", European Journal of Physics, Vol.7, No.3, 1986, pp.174-176.

[8] U. Klein, "What is the limit ħ→0 of quantum theory", arXiv:1201.0150v1[quantph] , 2011.

Biographies

Serhat Seker started his education at Mathematics Engineering Department of Istanbul Technical University (ITU) and graduated from Electrical and Electronic Engineering Faculty where he started his career as a research assistant at Electrical Power Engineering Department in 1985. He got his master degree at ITU's Nuclear Energy Institute and his PhD at Electrical Engineering Division of the same university's Science and Technology Institute with his research titled as "Stochastic Signal Processing with Neural Network in Power Plant Monitoring." Dr. Seker studied during his PhD thesis at Energy Research Centre of the Netherlands (ECN) with his scholarship provided from Netherlands Organization for International Cooperation in Higher Education (NUFFIC) and worked on signal analysis techniques there. He was titled as Assistant Professor and Associate Professor at ITU in 1995 and 1996 respectively. Also, he worked on industrial signal processing at Nuclear Engineering Department and Maintenance and Reliability Centre of the University of Tennessee, Knoxville-USA, by getting the scholarship from the Scientific and Technological Research Council of Turkey (NATOTUBITAK B1) in 1997. He had many administrative duties at ITU in the previous years, including his vice dean position at Electrical and Electronic Engineering Faculty during 2001 - 2004. He was a department head in Electrical engineering department between 2004 and 2007. Also, he was dean of Technology Faculty and vice rector as well as the founding dean of Engineering Faculty at Kırklareli University between 2011 and 2013. Dr. Seker is still the Dean of the Electrical and Electronics Engineering Faculty at ITU since 2013.

Jelena Dikun, received the BS Degree in Electrical Engineering Science from Klaipeda University in 2010, the MS Degree in Electrical Engineering Science from Klaipeda University in 2012. Currently she is working as a lecturer in Lithuanian Maritime Academy as well as in Klaipeda State University of Applied Sciences. Her primary research interests include electromagnetic radiation, ships' electrical systems, electrical machines and apparatus, electrical measurements technologies.