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The Human Brain, Entropy and Language Learning

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Abstract: According to one of the most basic laws of physics, known as "the second law of thermodynamics", the amount of disorder - or "entropy" - in the universe is constantly increasing. Modern thermodynamics teaches that there are three basic kinds of systems: *isolated*, *closed*, and *open*. Most dynamic systems, and all living systems, are open. Our body and brain, for example, are open systems. Open systems, such as the brain, have both internal entropy production and external production associated with energy or mass transformations to or from the environment. When the brain exchanges energy and matter with its environment, it maintains itself for periods of time in a state far from thermal equilibrium as well as at a locally reduced entropy state. The brain has three basic input channels and one output channel. Information comes into the brain by way of the five physical senses and/or memory (All Input). However, a second input (orderly or rational) is shown coming through the cortex. Also a third input (chaotic or irrational) coming through the brain stem. Essentially, the inputs of order and chaos represent the sense of order and disorder that is present in virtually all brain activity. For this reasons principle of net entropy applies to language learning, because the brain operates via rate-limited biochemical and electrochemical functions subject to the laws of physics. Learning requires information transfer at key points in time. The brain must first process and store short-term memories. Transfer of short-term memory to intermediate memory occurs between 20 to 40 minutes following initial formation of memory. Significant transfer of intermediate memory to long-term memory occurs at 24 to 48 hours. We would make time available in our schedule for periodic review within the next day or two. We would not wait until the night before the examination to 'cram' as much information as possible, only to encounter increasing entropy during the examination period.

Key words: Human Brain, Entropy, language learning

INTRODUCTION

According to one of the most basic laws of physics, known as "the second law of thermodynamics", the amount of disorder - or "entropy" - in the universe is constantly increasing. However, this does not mean that order or organization or complexity cannot increase anywhere in the universe - it *can*, but only at the expense of a yet greater net increase in disorder in the universe as a whole. Thus the net entropy of the universe as a whole always increases, even for processes which cause a local increase of order and complexity.

This means that the entropy of the universe was at a minimum at the big bang, and has increased since then. However, looking at the universe at its different stages, one is struck by the increase in order and complexity, rather than in the increase in chaos.

Living organisms grow in complexity as they proceed from seed to plant, or by turning plant food into complex cells, or developing from sperm and egg to beings with brains. Our planet, due to the life on it, seems therefore to be tending towards increase in order rather than the reverse. However, the earth and the life on it is no less bound by the laws of entropy than any other entity; all the order they experience through growth is due to energy pumped from the sun, and the sun provides this energy from its tremendous hydrogen fusion explosions, explosions which tremendously increase the entropy, totaling an entropy increase far greater than the seeming decrease of entropy which it gives rise to on earth.

Some have compared the universe to a wound-up clock which is slowly running down, having started with a tremendous supply of order which it is granting to its present constituent parts. It would seem, however, that since there was no complex structure to the big bang, but rather a uniform one, the initial state of the universe

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was not one of order, of a 'wound-up clock', but rather of chaos, disorder, a 'run-down clock'. It thus seems paradoxical that it should contain all the potential for complex order in the universe as it exists today. However, one can see the process of universal development from the big bang to today, and onward, as that of a continual increase in complexity, accompanied by an increase in the total entropy.

The Human Brain:

By far the most complex entity known to humanity is the human brain itself. The human brain contains approximately ten billion nerve cells - called "neurons" - and each neuron is connected to very many other neurons. To get an idea of this amount, we quote the following figures: There are twice as many neurons in each human brain than there are humans on this planet. Every day, in each human brain, 10,000 neurons die and are not replaced - a total of 300 million in a lifetime of 90 years - but this is only three percent of the total amount of neurons in the brain. For these 10 billion neurons to form in a human brain in the nine months between conception and birth, on the average one and a half million must form every hour of those nine months - 25,000 every minute[1]!

Modern thermodynamics teaches that there are three basic kinds of systems: *isolated*, *closed*, and *open* (Çambel, 1993). Isolated systems are those which are totally independent of their environment (these exist only in the laboratory). Closed systems are closed to matter (no matter may pass through the boundaries of the system) but are open to energy and information. Open systems are dependent on environment. Matter, energy, and information may pass through the boundaries of open systems.

Most dynamic systems, and all living systems, are open. Our body and brain , for example, are open systems (Atkins, 1984). Modern chaos theory addresses complex systems, which are systems with a large number of interrelated parts. It also addresses dynamic systems. There are two main types of dynamic systems: discrete and continuous. Every complex system and especially every living system (living systems are usually referred to as self-organizing systems) is also a dissipative structure. Ilya Prigogine won the Nobel Prize for chemistry in 1977 for his work on dissipative structures, which he defined as any structure that takes on and dissipates energy as it interacts with its environment. A dissipative system, unlike one that conserves energy, gives rise to irreversible processes (Nicolis & Prigogine, 1989). All systems that exhibit disequilibrium and self-organization are dissipative and have a dissipative structure (Briggs and Peat, 1989). Thus, not only our physical body itself is such a structure but every organ including the brain. The term itself expresses a paradox because *dissipative* suggests falling apart or chaos while *structure* suggests organization and order. Dissipative systems are those which are able to maintain identity only because they are open to flows of energy, matter, or information from their environments (Prigogine and Stengers, 1984). For example, living systems dissipate entropy by taking in low-entropy energy in the form of food and oxygen, and giving off high-entropy energy in the form of heat, carbon dioxide, and excreta (Penose, 1989).

Models of the Human Brain:

There are numerous working models today that attempt to simulate how consciousness arises from the human brain. In general, brain models can be divided into four main areas or types:

a. Physical and neurophysical systems such as the reticular formation activating system.
b. Models of biochemical and neurochemical systems (bottom up).
c. Cognitive models (top down).
d. Complex systems models using chaos theory.

The Complex Systems Model of the Brain:
Mainzer (1994) Writes:

The complex system approach is an interdisciplinary methodology to deal with nonlinear complex systems like the cellular organ known as the brain. The emergence of mental states (for instance pattern recognition, feelings, thoughts) is explained by the evolution of (macroscopic) order parameters of cerebral assemblies which are caused by nonlinear (microscopic) interactions of neural cells in learning strategies far from thermal equilibrium. Cell assemblies with mental states are interpreted as attractors (fixed points, periodic, quasi-periodic, or chaotic) of phase transitions. (p. 7)

By addressing the brain as a complex system of neural cells, we can assume that its dynamics follow the nonlinear mathematics of neural networks. For example, the standard evolution equations used for pattern emergence in physics, chemistry, and biology, should carry over to the brain's ability to compare and recognize patterns. Although neurons are the cerebral parts of the brain, the complex systems model suggests that the whole is more than the sum of its parts. The nonlinear interactions of cells and molecules causes phase transitions when conditions are far from equilibrium. Due to the slaving principle of macrocosmic ordering parameters, the (healthy) brain as a whole changes over time in a linear and predictable fashion. The complex systems model "does not explain what life is, but it can model how forms of life can arise under certain conditions" (Mainzer, 1994, p. 73).

Open systems, such as the brain, have both internal entropy production and external production associated with energy or mass transformations to or from the environment. When the brain exchanges energy and matter with its environment, it maintains itself for periods of time in a state far from thermal equilibrium as well as at a locally reduced entropy state. Under these conditions, small fluctuations lead to irreversible bifurcations, and thus to increasing complexity of possible behavior. In this way, the brain increases its entropy production so that its control parameter can maintain a certain threshold level. When production goes too far, feedback mechanisms allow the control parameter to change. This induces instabilities which cause increased dissipation which, in turn, influences the threshold level. In short, the brain is a self-regulating system where,

A mental disposition is understood as a global state of a complex system which is caused by the local nonlinear interactions of its parts, but which cannot be reduced to its parts. (Mainzer, 1994, p. 107).

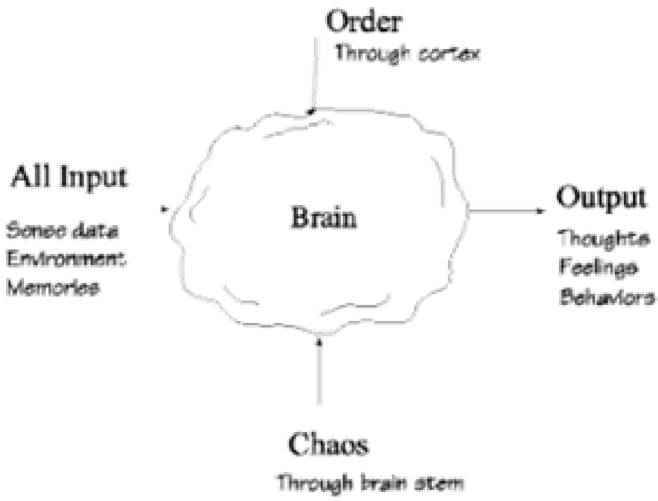

Fig. 1:

Figure 1 shows a very simplified model for brain activity. The brain has three basic input channels and one output channel. Information comes into the brain by way of the five physical senses and/or memory, as shown on the left under All Input. However, at the top of the brain, a second input (orderly or rational) is shown coming through the cortex. Also, at the bottom of the brain, a third input (chaotic or irrational) is shown coming through the brain stem. Essentially, the inputs of order and chaos represent the sense of order and disorder that is present in virtually all brain activity. The inputs of order and chaos cause a tension throughout the brain that is mandatory for proper and healthy growth. Without the input from order, the brain would fall into insanity and irrationality. It would dream too much. Without the input from chaos, the brain would fall into stereotyped "grooves" or habitual modes of thinking, and would function like an automaton or robot, without any real creativity. It would no longer dream at all. The output, our thoughts, feelings, and behaviors, depends upon a proper blending of chaos and order. "The psyche is made up of processes whose energy springs from the equilibration of all kinds of opposites" (Jung, 1973, p. 117).

Jung (1973) wrote that "all knowledge is the result of imposing some kind of order upon the reactions of the psychic system as they flow into our consciousness" (p. 81). Thus the imposition of order upon the chaotic flow of our sensory impressions, gives rise to meaningful information.

Language Learning and Entropy of Brain:

James Clerk Maxwell was a 19th century mathematician and physicist. He described 'Maxwell's Demon' -- a mythical creature that strives to increase the order of a system (thus decreasing entropy) without a concomitant increase in total net entropy (disorder). However, this defies the second law of thermodynamics, a fundamental law of physics, which states that entropy in a system must increase. Although order can be increased in one place for a short period of time, disorder must also eventually increase. Hence, the demon defies the laws of physics. We should avoid invoking this demon in systematic processes that we develop, including language learning processes.[McClare CW,1971].

This principle of net entropy applies to language learning, because the brain operates via rate-limited biochemical and electrochemical functions subject to the laws of physics. Most learning models are completely oblivious to this principle. Learning requires modification of synaptic interfaces at the dendritic level.[Bhatt DH, Zhang S, Gan WB ,2009] There are cell and tissue based regulatory pathways for learning that are subject to gene regulation with protein synthesis.[Kandel ER,2001]

There are both deterministic and stochastic aspects of the learning process. The deterministic aspect of learning indicates how much information can be retained. For learning to occur, only a finite number of synaptic modifications can be established per unit time. These synaptic modifications cannot be increased by increasing the rate of information delivery.[Cartling B,1996] The stochastic aspect of learning involves a decay of learning over time. However, the loss of learned data elements is random, just like another stochastic process -- radioactive decay. One cannot tell precisely what data will be lost over time, but some loss will inevitably occur.[. Hastings HM, Pekelney R,1982]

Learning requires information transfer at key points in time. The brain must first process and store short-term memories. The important paleocortical regions involved with short-term memory are the medial temporal lobe structures that include the hippocampus, amygdala, and adjacent cerebral cortex.[Pasquier F, Hamon M, Lebert F, Jacob B, Pruvo JP, Petit H,1997] Transfer of short-term memory to intermediate memory occurs between 20 to 40 minutes following initial formation of memory, through axonal projections from hippocampus to cerebral neocortex. Significant transfer of intermediate memory to long-term memory occurs at 24 to 48 hours. The memories stored in the neocortex eventually become independent of the medial temporal lobe system.[Squire LR, Zola-Morgan S,1991]

The process of forming memory requires synaptic modification through a process known as long-term potentiation (LTP) in which a long-lasting enhancement of synaptic transmission occurs with repetitive stimulation of excitatory synapses. LTP is a biochemical process that occurs in the hippocampus and is mediated by N-methyl-D-aspartate (NMDA) receptors as well as cyclic AMP-responsive element binding protein (CREB). Aging has been shown to alter the expression and distribution of N-methyl-D-aspartate (NMDA) receptors in many different brain regions, including the hippocampus, and may explain the diminished learning capacity and dementia seen in the elderly [Clayton DA, Grosshans DR, Browning MD,2002].

Short-term memory retention begins to decay at 20 to 40 minutes. There is a finite amount of information that can be transferred from short term to long-term memory per unit time, but some of that information will be lost. A reduction in the stochastic process will facilitate long-term retention of information. There are key branch points in learning where reinforcement can reduce the stochastic process. These branch points occur at 20 to 40 minutes (transfer to intermediate memory) and at 24 to 48 hours (transfer to long-term memory). Review of the information in the learning process at these critical branch points will reduce the loss of information.

There is a finite learning rate that is bounded by entropy-driven molecular processes, and this cannot be exceeded, just as Maxwell's demon cannot create order without simultaneously creating disorder. Optimal teaching occurs when increasing order (decreased entropy) in the brain occurs over a short time, so that overall disorder (increased entropy) is also allowed to occur.

In most institutions of higher learning, including medical schools, the timing of teaching exercises is determined by convenient clock intervals and by tradition, subject to those eight fateful words, 'But we have always done it that way.' Thus, a lecture mode of teaching is governed in most institutions by a rigid schedule of one-hour intervals. The lecturer has set amount of material that must be delivered, and if there is an hour available, then an hour will be used. Within that hour, the lecturer may race through the material, oblivious to the deterministic aspect of the learning process. The stochastic aspect is probably recognized, at least in part, as a price to pay in this educational system, though any given lecturer's bias is typically that someone else's material will be the part that is forgotten.

If we were to proactively exclude Maxwell's demon from the learning process, we would break up delivery of information into smaller segments of no more than 20 minutes. We would present the material at a constant pace, without trying to overwhelm ourselves with information. We would stop at intervals to reinforce the material that had been presented. We would make time available in our schedule for periodic review within the next day or two. We would not wait until the night before the examination to 'cram' as much information as possible, only to encounter increasing entropy during the examination period.

Conclusion:

It has long been a basic concept in thermodynamics that entropy affects all systems, and causes natural systems to degrade into greater confusion and disorder as time passes. Modern thermodynamics teaches that there are three basic kinds of systems: *isolated*, *closed*, and *open*. Most dynamic systems, and all living systems, are open. Our body and brain, for example, are open systems. Open systems, such as the brain, have both internal entropy production and external production associated with energy or mass transformations to or from the environment. When the brain exchanges energy and matter with its environment, it maintains itself for periods of time in a state far from thermal equilibrium as well as at a locally reduced entropy state. The brain has three basic input channels and one output channel. Information comes into the brain by way of the five physical senses and/or memory (All Input). However, a second input (orderly or rational) is shown coming through the cortex. Also a third input (chaotic or irrational) coming through the brain stem. Essentially, the inputs of order and chaos represent the sense of order and disorder that is present in virtually all brain activity. For this reasons principle of net entropy applies to language learning, because the brain operates via rate-limited biochemical and electrochemical functions subject to the laws of physics. Learning requires information transfer at key points in time. The brain must first process and store short-term memories. Transfer of short-term memory to intermediate memory occurs between 20 to 40 minutes following initial formation of memory. Significant transfer of intermediate memory to long-term memory occurs at 24 to 48 hours. We would make time available in our schedule for periodic review within the next day or two. We would not wait until the night before the examination to 'cram' as much information as possible, only to encounter increasing entropy during the examination period.

REFERENCES

Atkins, P.W., 1984. *The second law*. New York: Scientific American.

Bhatt, D.H., S. Zhang, W.B. Gan, 2009. Dendritic spine dynamics. Annu Rev Physiol., 71: 261-82.

Briggs, J. and F.D. Peat, 1989. *The turbulent mirror: An illustrated guide to chaos theory and the science of wholeness*. New York: Harper & Row.

Cartling, B., 1996. Dynamics control of semantic processes in a hierarchical associative memory. Biol Cybern., 74(4): 385.

Clayton, D.A., D.R. Grosshans, M.D. Browning, 2002. Aging and surface expression of hippocampal NMDA receptors. J Biol Chem., 277(17): 14367-14369.

Hastings, H.M., R. Pekelney, 1982. Stochastic information processing biological systems. Biosystems, 15(2): 155-168.

Jung, C.G., 1991. The development of personality: Papers on child psychology, education, and related subjects.

Jung, C.G., 1973. On the nature of the psyche. Hull, R. F. C. (Trans). from Bollingen Series XX. *The Collected Works of C.G. Jung*. *8*. Princeton, NJ: Princeton University Press. First published in 1960.

Jung, C.G., 1974. Dreams. Hull, R.F.C. (Trans). From Bollingen Series XX. The Collected Works of C. G. Jung. 4, 8, 12, 16. Princeton, NJ: Princeton University Press.

Kandel, E.R., 2001. The molecular biology of memory storage: a dialogue between genes and synapses. Science, 294: 1030-1038.

Kort E. Patterson, 1995. Entropy, Complexity and Life.

Mainzer, K., 1994. *Thinking in complexity: The complex dynamics of matter, mind, and mankind*. Berlin: Springer-Verlag.

McClare, C.W., 1971. Chemical machines, Maxwell's demon and living organisms. J Theor Biol., 30(1): 1-34.

Nicolis, G. and I. Prigogine, 1989. *Exploring complexity: An introduction*. New York: W.H. Freeman.

Pasquier, F., M. Hamon, F. Lebert, B. Jacob, J.P. Pruvo, H. Petit, 1997. Medial temporal lobe atrophy in memory disorders. J. Neurol., 244(3): 175-181.

Penrose, R., 1989. The emperor's new mind: Concerning computers, minds, and the laws of physics. Oxford: Oxford University Press.

Prigogine, I., 1980. *From being to becoming: Time and complexity in the physical sciences*. San Francisco: W.H. Freeman.

Prigogine, I. and I. Stengers, 1984. *Order out of chaos: Man's new dialogue with nature*. Toronto: Bantam.

Squire, L.R., S. Zola-Morgan, 1991. The medial temporal lobe memory system. Science, 253(5026): 1380-1386.

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