ON THE COGNITIVE COMPUTING: PERSPECTIVES*

Madan M. Gupta, Intelligent Systems Research Laboratory, College of Engineering, University of Saskatchewan, Saskatoon, Saskatchewan,

1. Introduction

It was a cold New Year's eve. After cleaning the clutters of 1987 from my office and arranging certain tasks for 1988, I was driving home. Light snow was falling and the roads were icy, but not too busy. Suddenly, my hands steered the car towards the side lane and my foot worked the brake rendering the car motionless. I soon realized that a speeding car, chased by the police, was coming towards me in my lane and would have collided with my car had I not steered it to the side lane. I took a long breath of relief and thanked the Almighty for giving us such a wonderful sensory system and cognitive computational organ, the brain, which can perform many urgent tasks, such as this collision avoidance, at an ultra high speed. The *natural sensors* (in this case my eyes and ears) were acquiring the information continuously and relaying it through the sensory neurons to the cognitive processor (my brain) which perceived the environment and the danger associated with it just in time. The *cognitive processor* then synthesized the control signals and transmitted them through the motor neurons to my hands and foot, which activated the steering and braking mechanisms to avoid the collision. I was left alone on the road and the experience created a number of emotional feelings in my mind: thoughts of drunk drivers on the road, on modern technology, on a government which encourages the selling of liquor in order to collect revenue and then spends the same revenue to curb drunk drivers, and so on.

This incident upset me so greatly that a magnitude of thoughts appeared momentarily keeping the *cognitive processor* busy in various types of *reasoning* and *perception*. After having supper and sitting down in my study, I recalled a thought: the Almighty has given many wonderful attributes to humans. The attributes of 3 **h** which I described in one of the earlier papers need special mention here.

The attributes of 3 **h** are associated with the **h***and*, the **h***ead* and the **h***eart*. We have sucessfully mimiced the functions of the **h***and*, and have created many mighty machines. Now we are working on the emulation of some of the important attributes of the **h***ead* (brain) such as thinking, reasoning, or in general cognition and perception, on a silicon chip and the creation of an intelligent machine. The **h***eart* is associated with the attribute 'emotions', and this is the attribute which is mainly responsible for the 'survival' of humanity. Perhaps this is the subject which must be considered very seriously for future research because a *mighty thinking* machine

*To Professor Arnold Kaufmann

without *emotions* (**heart**) may become the cause for the destruction of humanity.

2. Mentation, Cognition and Fuzzy Logic

In biomedical engineering we apply the principles of the natural sciences and engineering to the benefit of the health sciences. Here, we shall take an inverse biomedical engineering [(biomedical engineering $)^{-1}$] approach and shall try to apply the biological principles to the solution of some engineering problems. In particular, engineers are investigating the problem of creating *intelligence* in a robotic system. The thought of the creation of intelligence on a silicon chip (machine) creates some strange feelings in our minds.

Intelligence implies the ability to think, reason, learn and memorize, or, in general, it refers to the human mentation and cognition process. One of the last frontiers of science, perhaps its ultimate challenge, is understanding the biological basis of mentation and cognition: how we think, reason, learn, remember, perceive and act. I still cannot understand how the brain perceived the dangerous driving situation and acted instantaneously while it might take several seconds to multiply two three-digit numbers. How do the genes contribute to the process of mentation and cognition and how do they develop with the environment?

Here we have two computational tools: the carbon based organic brain which has existed in humans and animals for several billions of years, and the silicon based modern computers which have evolved only over the last three decades. Recent technological advances in computer hardware have made it possible to carry a very powerful computer in a brief case which is ultra fast and efficient in numerical computations. However, the *'cognitive information'* the information which our natural sensors acquire, is *not numerical,* but the *'mentation process'* can process such information very efficiently and act upon it accordingly. The modern day computers fail to process such cognitive information.

The fact that the human mentation and cognition process is so marvelously efficient and effective poses a question for scientists and engineers: *Can some of the functions and attributes of the human sensory system, mentation and the cognitive processor, and motor neurons be emulated in a robotic system?*

For such an emulation process, it is necessary to understand the biological and physiological functions of the brain. It is a difficult question to answer. However, it is felt that if we examine some of the 'mathematical aspects' of our thinking process and 'hardware aspects' of the 'neurons,' the principle element of the brain, we may succeed to some extent in our emulation process.

The mentation and cognitive activity of the brain, unlike the computational function of the binary computer, is based upon the *relative grades* of the information acquired by the natural sensory system. The conventional mathematical tools, whether deterministic or probabilistic, are based upon some absolute measure of the information. Our natural sensors acquire information in the form of *relative grades* rather than absolute numbers. The perception and 'action' of the cognitive process also appear in the form of *relative grades.* While driving on an icy road, for example, we perceive the driving environment in a *relatively graded* sense and act accordingly.

The mentation and cognitive process thus acts upon the graded information. Information may appear in a numerical form (temperature of the body is 38.4^0C), however, during the process of cognition we perceive this temperature as *near normal,* in the form of a *relative grade.* Thus, the cognitive process acts upon the different forms of information and this leads to 'formless' uncertainty: *temperature is near normal.* This 'formless uncertainty' provides us with a new scientific challenge. Recently, scientists have started to think of giving a morophology to this amorphous uncertainty. In the past, mathematicians have distained this challenge and have chosen to avoid natural mentation by devising theories unrelated to human perception and the cognitive process.

It was in 1965 when Lotfi A. Zadeh published his first celebrated paper on *fuzzy sets.* It is also now almost two decades since he first introduced to me this new type of information and uncertainty and showed me the path which leads to somewhat beautiful gardens full of immortal and ever increasing fragrance. Though I was taught the notion of cognition and perception at school, I was very ignorant about this uncertainty and its pervasiveness around these notions.

No one had seen the beauty of *fuzzy sets* before Lotfi Zadeh and it was he who first showed the promise of consolidating this beauty into an organized field full of rich theories and promising applications.

The theory of fuzzy logic is based upon the notion of *relative graded membership* and so is the function of the mentation and cognitive process. In the past, studies of cognitive uncertainty and its cognate, the cognitive information, were hindered by the lack of suitable tools for modeling such information. However, with the introduction of the theory of fuzzy logic, it is possible now to expand studies in this important field of cognitive information, neural networks, and cognitive-neural computing tools.

My own laboratory is heavily committed to studies in the field of cognitive information processing, cognitive vision fields, vision perception, cognitive-neural computing tools, and cognitive feedback controllers with promising applications to intelligent robotic systems and medical image processing. Most of these studies make use of the theory of fuzzy logic.

3. Perspectives

Recent progress in information-based technology has significantly broadened the capabilities and application of computers. Today's computers are merely being used for the storage and processing of numerical data (information). Should we not re-examine the functions of these computing tools in view of the increasing interests in subjects such as knowledge-based systems, expert systems and intelligent robotic systems and for solving problems related to decision and control? Human mentation acts upon cognitive information and the cognitive information is characterized by using relative grades: *"Although it is snowing, it is not very cold".* Human mentation and cognition function by using fresh information (acquired from the environment by our natural sensors) and the information (experience, knowlege-base) stored in the memory.

Shannon's definition of *'information'* was based upon certain physical measurements of random activities in systems, in particular, in communication channels. This definition of information was restricted only to a class of information arising from physical systems.

If we want to emulate some of the cognitive functions (learning, remembering, reasoning, intelligence and perceiving, etc.) of humans in a machine, we have to generalize the definition of information and to develop new mathematical tools and hardware. These new mathematical tools and hardware must deal with the simulation and processing of cognitive information. Many new notions, although still at a primitive stage, are springing up around the mathematics of fuzzy logic and, hopefully, we will be able to nurture some interesting studies in the not too distance future.

Bibliography

1. R.E. Bellman, and L.A. Zadeh, "Decision Making in a Fuzzy Environment", *Management Science,* (1970), 17, B.141-B.164.
2. M. Black, "Vagueness: An Exercise in Logical Analysis", *Philosophy of Science,* 4, (1937), 427-455.
3. L. Brillouin, "Science and Information Theory", *Academic Press,* New York, (1956).
4. R.C. Conant, "Law of Information Which Govern Systems", *IEEE Trans. Systems, Man. and Cybernetics,* Vol. 6, (1976), 334-338.
5. I.R. Goodman and H.T. Nguyen, "Uncertainty Models for Knowledge-Based Systems", *North-Holland,* New York, 1985.
6. M.M. Gupta, "Fuzzy Automata and Decision Processes: The First Decade", *Sixth Trienniel World IFAC Congress,* Boston, Cambridge, August 24-30, (1975).
7. M.M. Gupta, "Cognition, Perception and Uncertainty", in Fuzzy Logic in Knowledge-Based Systems, Decision and Control, North Holland, (1988).
8. A. Kaufmann, "Introduction to the Theory of Fuzzy Subsets", Vol. 1, *Academic Press,* New York, (1975).
9. A. Kaufmann and M.M. Gupta, "Introduction to Fuzzy Arithemtic: Theory and Applications", *Van Nostrand Reinhold,* New York, 1985.
10. G.J. Klir, "Where Do We Stand on Measures of Uncertainty, Ambiguity, Fuzziness and the Like", *Fuzzy Sets and Systems,* Special Issue on Measure of Uncertainty, Vol. 24, No. 2, November 1987, 141-160.
11. K. Kornwachs and W. von Lucadou, "Pragmatic Information as a Nonclassical Concept to Describe Cognitive Processes", *Cognive Systems,* 1, (1985), 79-84.
12. F.M. Reza, "An Introduction to Information Theory", *McGraw-Hill,* New York, (1961).
13. L.A. Zadeh, "Fuzzy Sets", *Information and Control,* 8, (1965), 338-353.