COGNITION, PERCEPTION AND UNCERTAINTY*

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A beautiful blanket wraps our scientific environment and thoughts, but it is woven with fragile threads of two kinds of uncertainties. The first arises from the physical systems and the second from human thinking, reasoning, cognition and perception. A distainful act towards this wrapper may break the fragile threads and then our thoughts will just be naked, emotionless and impotent. Let us create more respect for this fragile uncertainty and generate intelligible rules for its morphology.

The theory of deterministic systems and stochastic processes has been an integral part of my graduate studies, teaching and research. In fact, I was, and I am still, a member of the school of *determinism* and *stochasticism*. It was in the summer of 1968 that I first had the opportunity to listen to Professor Lotfi A. Zadeh, the exponent and founder of *'Fuzzy-ism,'* at the Symposium on Adaptivity and Sensitivity held under the auspices of the International Federation of Automatic Control (IFAC) at Dubrovnik, Yugoslavia. His lucid exposition on Fuzzy Set Theory, the theory which deals with the information and uncertainty arising from human thinking, reasoning, cognition and perception, aroused my interest in this new class of mathematics and, since then, I have become also a student of the *School of Fuzzy-ism*.

During my studies, I soon realized that the 'lack of uncertainty' or the excess of 'precision and certainty' in our engineering design, decision and control problems are providing us with unrealizable solutions. The certainty (precision) has become an absolute standard in both our teaching and research, and far too often it is introduced into our scientific works without thought or feeling. This is the attribute which does not exist in our cognition, perception, reasoning and thinking. A baby of one week starts recognizing his mother by smiling at her, but the cognition, perception and recognition of his mother and his environment do not take place in the precise sense. This same imprecision or uncertainty will play an important role in thinking and reasoning throughout his life.

In our scientific decision and control studies, we have realized that the path of 'precision' is rapidly leading us towards unrealizable goals, but we still continue to move along that path. Of course, we know that any 'precise' design will be doomed to failure. Behind the curtain of 'precision' we have become impotent, and have lost scientific creativity.

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*To: Professor Peter N. Nikiforuk

There are various classes of uncertainties, however, for the discussion purposes here we classify these uncertainties into two broad categories: *U-Type One*, and *U-Type Two*, where U- stands for uncertainty.

The *U-Type One* uncertainty deals with the information or phenomenon which arises from the random behaviour of physical systems. The pervasiveness of this type of uncertainty can be witnessed in the random vibrations of a machine, randomness of a message, random fluctuations of electrons in a magnetic field, diffusion of gases in a thermal field, random electrical activities of the cardiac muscles, uncertain fluctuations in the weather pattern and the turbulent blood flow through a damaged cardiac valve. The *U-Type One* uncertainty has been studied for centuries, and we have a very rich statistical theory to characterize such a random phenomenon. The calculus of mean and variance is very rich in this respect and is being used very widely.

The *U-Type Two* uncertainty, unlike the *U-Type One*, is the uncertainty that deals with phenomena arising from human thinking, reasoning, cognition and perception processes, or cognitive information in general. This is a subject which has been either neglected or taken very lightly. The cognition and perception of the physical environment through our natural sensors (eyes, ears, nose, etc.), the perception of pain and other similar biological events through our nervous system and neural networks deserve special attention. The 'perception phenomenon' associated with these processes are full of 'uncertainties' and cannot be characterized by conventional statistical theory. We can feel pain: 'the back is *very painful*', but this pain can be neither measured nor characterized using statistical theory. Similarly, we express our perception linguistically, 'this *red* flower is just *beautiful* and is full of *pleasing fragrance*'. This corresponds to the 'perception' of our physical environment where *'red'* and *'beautiful'* describe the visual perception, whereas *'pleasing fragrance'* describes the perception of smell. Again, we cannot characterize these perceptions using the strength of the statistical theory.

The *U-Type Two* uncertainty and its cognate, the *cognitive information*, involve the activities of the neural networks. To non-scientists, it may seem strange that such familiar 'notions' have recently become the focus of intense research. But it is the 'ignorance' of these notions, and their possible technological applications in intelligent man-made systems, and not 'familiarity' with them which has forced scientists to conduct research in the field of *U-Type Two* uncertainty and *cognitive information*.

The development of the human cognitive process and the perception of his environment starts taking shape with the development of imaginative power in a baby's brain. A baby in the cradle can recognize the human face long before it is conscious of any visual physical attributes of humans or its environment.

In spite of the richness of conventional mathematical methods, they are very often thought to be dry and cold. One reason lies in their inability to describe the beauty of white mountains, blue lakes, the rising sun, the full moon, or the richness of the fragrance of a spring flower. No doubt, one can estimate the volume of snow or the heights of the mountains, or the frequencies of vibrating musical strings, but the conventional mathematical methods cannot be used to narrate logically the feelings and the emotions associated with perception.

The study of such formless uncertainties provides us with a scientific challenge. Scientists have started now to think of giving a morphology to this amorphous uncertainty. In the past, mathematicians have distained this challenge and have increasingly chosen to flee from natural mentation by devising theories unrelated to human perception, feelings and emotions.

It was in 1965 when Lotfi A. Zadeh published his first celebrated paper on *Fuzzy Sets* and it is now almost two decades ago since he first introduced me to this new type of information and uncertainty. He showed me the path which leads to somewhat beautiful gardens full of immortal and ever increasing fragrance. Though I was taught the notions of cognition and perception at school, I was very ignorant about the uncertainty and its pervasiveness around these notions. Indeed this uncertainty has been distained by scientists and mathematicians.

No one had seen the beauty of these *Fuzzy Sets* before Professor Lotfi Zadeh, and it was he who showed promise of consolidating this beauty into an organized field with rich theories and promising applications.

Professor Zadeh coined the word *Fuzzy Sets*. *Fuzzy Sets* deal with sets of objects or phenomena which are vague and do not have sharp boundaries. The calculus of *Fuzzy Sets* is a very promising tool for dealing with the *U-Type Two* uncertainty (just as probability theory deals with the *U-Type One* uncertainty). Indeed, the applications of these fuzzy sets, which once were thought to be dull and dry, can be found in many scientific and scholarly works. It is true that Boole introduced the beautiful notion of binary sets which are so pervasive in our digital world, however, this beauty is naked and without any adornment. Boolean logic is unable to model the human cognition and thinking process. This is the very reason that no one today is indifferent to the *logic of Fuzzy Sets*. In fact, many view their first encounter with the fuzzy logic as a totally new and exciting experience in their scientific life.

From the purely mathematical view point, the evolution of the theory is very exciting but complex. Many scientific theories start by borrowing notions from the already developed areas of mathematics but, in this case, Professor Zadeh introduced the basic notion of 'vagueness' having no sharp morphology and which is so common in human thought processes.

Indeed, Professor Zadeh laid the foundation of fuzzy mathematics on a very robust rock. It now serves the needs of many existing scientific disciplines, but equally important is that many new disciplines, such as the study of neural networks, have started arising around this mathematics. Thus, this mathematics has united several noble (both old and new) narrow streams of scientific disciplines into one while, at the same time, instilling life into several other streams that have been dormant.

Since 1968, when the notion of fuzzy mathematics was first introduced to me, I have done many studies on this topic. These studies have brought many intellectual and scientific revelations to me. Presently, I am engaged in several scientific studies using fuzzy logic. For example, the research in my laboratory is heavily committed to the *U-Type Two* uncertainty through such studies as neural networks and neural computing, signal and image processing, cognitive information processing, cognitive vision fields, perception, etc., with applications to intelligent robotic systems and medical imaging. The newly developing technology based upon

optoelectronics and molecular electronics computing will make it possible to process the *U-Type Two* uncertainty and cognitive information associated with signals and images the way our brains do.

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''The senses, the mind and the intelligence are the breeding grounds of desire and lust; they veil the real knowledge of the living entity and bewilder the embodied soul''.

''The active senses are superior to the passive matter; mind is higher than the senses; intelligence is still superior than the mind, but the soul is the most superior''. ''Bhagavad-Gita''