West Indian Journal of Engineering Vol. 23, No. 2, (January 2001) Theme Paper (Kong) 17 - 20

Overview of Fuzzy Thinking

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The following is a broad overview of the state of the art of fuzzy logic and neural network technologies gleamed from exposure by the author to leading researchers in the area on both sides of the Atlantic. Excerpts of the author's own research are also included. This area is of tremendous importance to the region and it is imperative that we embrace this technology without delay.

1. The New Computing

Fuzzy logic, soft computing and neural networks are a few of the terms used to describe a method of computing that the region (the Caribbean region) as a whole would be well advised to put into application. It may come as a surprise that applications based on these technologies are in fact a lot simpler to develop than those using older technologies. A fuzzy logic controller for example is just a bunch of fuzzy rules describing a method of control. The knowledge encoded in these rules may be obtained from a trained operator who may be familiar with the process under control or directly from the process itself. They are useful not because they are complex but because they are simple. Cheap sensors and microprocessors may be used as opposed to those that would be required using conventional methods with no loss of performance. Neuro-fuzzy systems are also model free estimators that function as universal function approximators. They can therefore be used to model a wide variety of non-linear dynamical systems in any discipline. Because of its potential for modelling and controlling inexactly known systems Bart Kosko one of the leading proponents of fuzzy logic has even advocated its use in making decisions at governmental levels [1,2].

2. Intelligent Models

This type of computing becomes a bit more complex when the human expert is taken out of the loop and knowledge about the process to be modelled or controlled whether man-made or natural must be obtained from the process itself. Invariably neural networks are the main workhorses for obtaining this knowledge. Although the use of this technology had many false starts, it is clear that it is not a fad and in fact a natural progression in the history of modelling in the engineering discipline. Its main function can be said to be model free regression although this functionality comes in a number of different guises in a variety of different types of networks. Model free regression is a natural progression from model based linear regression and more recently model based non-linear regression, both of which rely on the basic model structure from human experts for which the parameters are determined experimentally. No model is assumed using model free regression and in more complex cases it is simply impossible for the human mind to conceive of the model involved. This is obvious in the case of systems with more than a few state variables, in fact, hundreds or even thousands of variables can be considered using model free regression with an underlying model practically unimaginable.

However, apart from the network concept, everything else about neural networks looks almost exactly like classical Newtonian optimisation methods used in both linear and non-linear regression. Learning rules typically are vector gradient methods, steepest descent, conjugate gradient, etc., but applied to (or backpropagated through) a network, which can be appropriately sized to meet the application as opposed to a predetermined fixed model. Neural networks are in fact a mixture of the old and the new.

3. Controlling Chaos

These are indeed powerful tools but perhaps the more important shift that they easily facilitate is that away from the emphasis on linear systems to non-linear systems. The second millennium that has been called many things can easily be described as the millennium of linear systems. The invention of linear algebra has shaped much of our processes and ways of thinking. Thus, almost every industrial process is based on getting the process to behave linearly so that it can be controlled. Similarly, a lot of our thought processes are linear. Towards the end of the second millennium, the linear bubble began to burst in a dramatic way with the discovery of the severe limitations of linear models, in fact it literally led to Chaos, a term which is now used technically to describe the most interesting behaviour of non-linear

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systems [3]. Not only was it discovered that linear models were limited, but that they were not even fundamental. Thus, fractal geometry [4] emerged as the non-linear geometry that can best describe the universe that we live in, complete with dramatic pictures of intricate complexity.

Neural networks are the most appropriate tools for discovering this complexity with its scaleable architecture. Undoubtedly, non-linearity would be the emphasis of the new millennium. By nature it would be difficult to predict its impact on the way we live. The linearity restrictions put an effective cap on the way things were done. This cap applied to the rate of industrial production. Industrial plants were forced to operate within narrow limits to maintain the linear approximations essential for control of the plant.

Additionally, many new processes would emerge for which symbolic mathematics simply fails. That is, these processes cannot be modelled or controlled using techniques based on symbolic mathematics. This is a direct and unavoidable consequence of increasing complexity beyond what currently applies.

4. Failure of Symbolic Mathematics

There are also future applications that on the surface appear to be less significant, but are also of tremendous importance. Lofti Zadeh talks about a revolution in computing back to where it started, i.e., with words [5,6]. Computing first started with words, but because of the ambiguities involved with this sort of computing there was a gradual movement towards the increasing use of symbolic computing. He indicated that this is evident by the increasing numbers of equations in technical papers. Symbolic computing was less ambiguous and more precise than the use of words. But as was pointed out by Zadeh, there are limitations to the use of symbols as the complexity of computation increases. That is, for computing to become more complex there is no choice but to use fuzzy logic. Fuzzy logic can effectively be used to describe what can be called 'precisiated' natural language, i.e., fuzzy logic computations are effectively computing with words or perceptions. The term 'precisiated' taken to mean that although words remain ambiguous, the nature of the fuzziness can be more precise. As the complexity of our systems grows symbolic mathematics would fail and would be replaced by 'perceptronic' mathematics the details of which are currently being considered.

5. Research Directives

The main hurdles as pointed out by Bart Kosko at Computational Intelligence in Modelling, Control and Automation (CIMCA '2001, Las Vegas, Nevada) in the use of fuzzy logic and the areas that should be the focus of active research is the need for a better understanding of how these function for high dimensional systems and why certain shapes make better fuzzy set membership functions than others. Most fuzzy logic systems are low dimensional, i.e., systems with small numbers of inputs requiring only a few rules. In many cases, triangular membership functions are used although some of the latest research by Kosko points to the Sinc function being the most efficient shape for membership functions. The dimensionality problem is extremely challenging since solving this problem is the only way that systems would be able to grow in complexity. Also, as non-linear systems are being increasingly explored, new and interesting properties are being discovered, one of which is that of stochastic resonance, a peculiar property of non-linear dynamical systems which show that adding small amounts of noise to a signal actually improves it. Neuro-fuzzy systems also exhibiting stochastic resonance include systems of perception in human beings. Thus, noise is beginning to be added to CD music and DVD films to improve the quality. This is intuitively ridiculous and goes against the grain of a century of knowledge in electrical engineering, yet it works.

6. High Dimensionality

The nature of high dimensional dynamical systems was studied as part of the PhD research of the author and discussed in more detail in the thesis 'Intelligent Optimal Non-Linear Control'. Interest in this area was first spurred on by Kanerva's work [7]. What any controller sees after the receipt of data from transmitters and after all signal processing is a time varying real number vector. A longer vector would be required the more complex the system (i.e., more state variables, more inputs, etc.). It is on the basis of this vector that the knowledge of the process is determined and for which a control strategy devised. Control strategies can be thought of as fuzzy rules determining actions for various inputs. It is important to understand the nature of high dimensional input space for the design of fuzzy controllers (especially for more complex systems). To start with phenomenon that can effectively be described as quantum begin to emerge. A fuzzy set in high dimensional space is the equivalent of a hypersphere or bubble in this space. The strange behaviour starts when bubbles begin to pop into existence only if they are of a certain size and pop out of existence if reduced below a certain size. If two bubbles in hyperspace get too close to each other, they suddenly merge. That is the more precise we can be about specific properties, the less we can be about the others. In technical terms, this high dimensional space is normally distributed with mean of $n/3$ and variance of $n/18$ for space of dimension n. The fraction of space enclosed by a bubble of radius r can be determined from normal distribution tables as plotted in **Figure 1**:

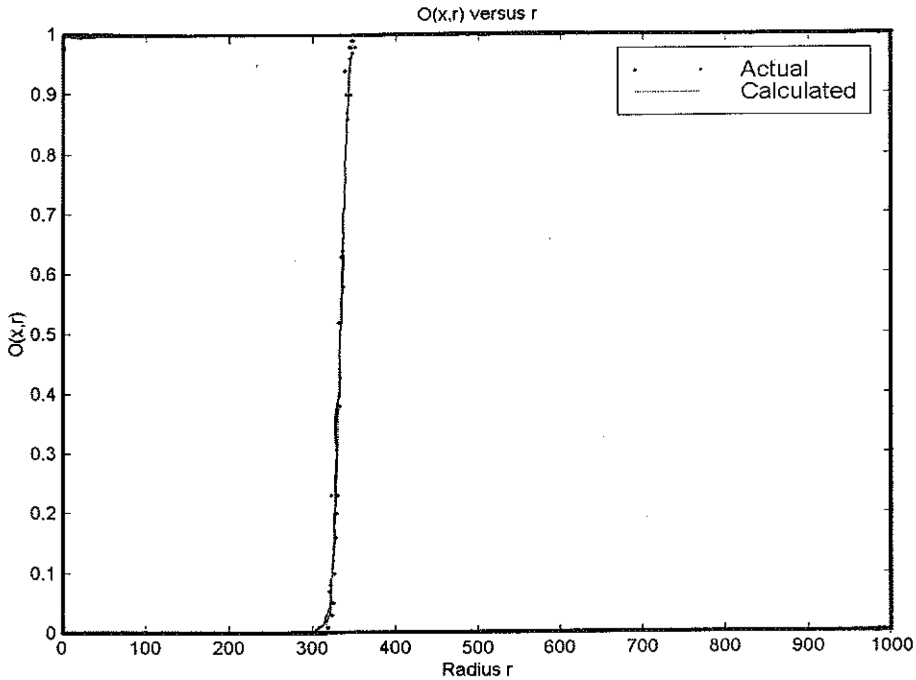

FIGURE 1: *Sizes of Bubbles in Hyperspace of Varying Radii (n=1000)*

$$|O(x,r)| \approx \Phi\left\{(r - n/3)/\sqrt{n/18}\right\}$$

Notice how bubbles pop into existence close to the radius $n/3$. The size of the intersection of bubbles as their separation changes in hyperspace can be determined from the function (shown in **Figure 2**) for bubbles of varying radii):

$$|O(x,\eta n/3) \cap O(y,\eta n/3| \approx$$

$$1 - \Phi\left\{(d + 2(1-\eta)n/3 - n/3)\sqrt{n/18}\right\},$$

$$d = |x - y|$$

Notice that at a specific separation dependent on radius bubbles merge. These statistics reveal that from the point of view of a specific point in space the rest of the space lies at or near the mean distance $n/3$ (clustered band). Furthermore, the space from the point of view of any of the points in the clustered band also appears as described above. This sounds counterintuitive because we are trying to represent a high dimensional space, using three-dimensional concepts.

This phenomenon becomes more pronounced as n increases, that is, the clustered band shrinks to an infinitesimally thin line and the curves for bubble sizes and bubble intersections become discontinuous. That is, the space effectively groups itself into categories. Whereas low dimensional systems can take on a continuous nature, high dimensional systems do not.

7. Consciousness

Meanwhile on the other side of the Atlantic, Aleksander *et al* are seriously considering the question of machine consciousness [8]. Computers computing with words or symbols are one thing but at what point can we say that they are becoming conscious. Much progress is being made in this area using a type of neural network which is a sort of networked digital state machine called the Neural Response Modellor (NRM) which models visual pathways in the human brain. Thus, precise mechanisms of visual awareness are being worked out and how it fits into the overall scheme of things as far as consciousness is concerned. Recent discussions with colleagues across the Atlantic in this area focus on whether or not in the search for consciousness we are looking in the right direction. The most advanced imaging techniques which use combinations of PET, MRI and EEG scans only indicate where neural activity is taking place. Perhaps the information needed is not what neural activity is taking place but the effect of this neural activity, and there are many theories, from synaptic plasticity to nucleic acid based methods of storing memories [9].

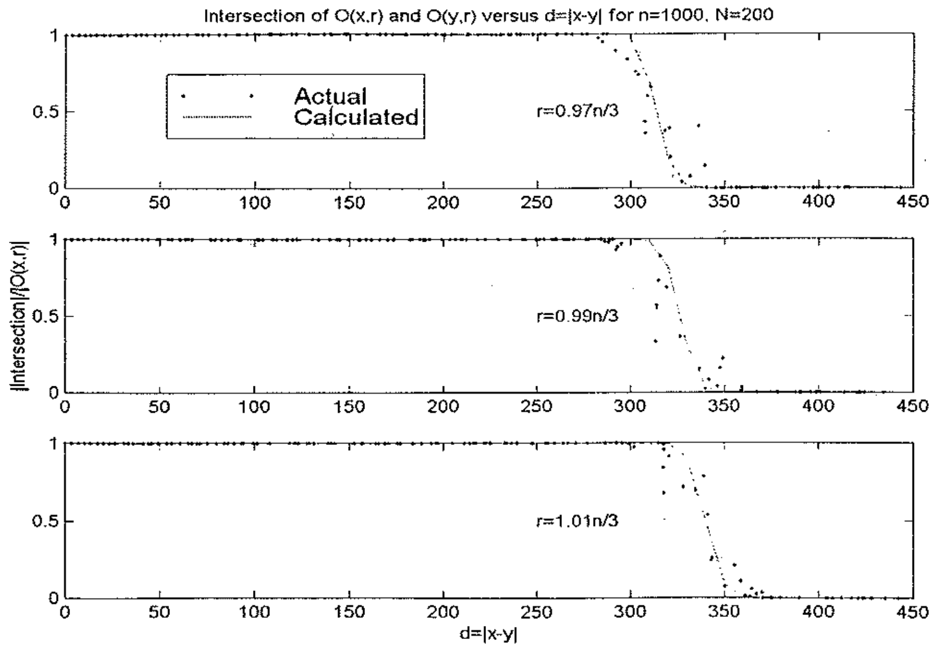

FIGURE 2: *Bubbles of Different Radii Merging*

8. Soft Computing

Soft computing is the term that is generally used for the incorporation of the various types of intelligent technologies in problem-solving. The best applications would be what are called Co-active Neuro-Fuzzy Inference Systems [10]. These are fuzzy inference systems with the encoded knowledge of human operators that can also learn independently. Neural networks are used for its adaptive learning capabilities whereas the basic inference engine is fuzzy logic-based. Fuzzy logic is also the basis for fuzzy interpretability using natural language and eventually computing with words at which point computers and human beings can be said to be performing the same types of computation even if their domains of operation may differ radically.

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