Tutorial on
Type-2 and Non Stationary Type-1 Fuzzy Logic Systems

Under the framework of the 10th International Conference on Intelligent Systems Design and Applications, ISDA '10
November 29 – December 1, 2010, Cairo, Egypt
Conference web page: http://cig.iet.unipi.it/isda2010

Tutorial Presenter

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Abstract

Standard (type-1) fuzzy logic has been extraordinarily successful in both academic terms and in terms of its impact in industry and commerce. However, type-1 fuzzy sets have specific limitations when it comes to representing uncertainty in the fuzzy sets themselves and in representing the variability which is always present in human reasoning. To address these limitations, type-2 fuzzy logic systems and non-stationary fuzzy logic systems have been introduced, and these are currently areas of significant research interest. This tutorial will introduce standard fuzzy sets, illustrate some of their limitations and will then detail how these limitations can be overcome using both type-2 and non-stationary fuzzy systems. Practical methods will be outlined, reinforced with worked examples using software implementations. By the end of the tutorial, even those with no previous experience of fuzzy logic should be enabled to apply these methods in their own application areas and/or begin research in this fascinating and exciting area.

Introduction

Fuzzy logic has been extraordinarily successful since its original inception by Lotfi Zadeh in 1965. It is now common place to find fuzzy methods employed in a wide range of consumer electronic devices (such as fuzzy logic auto-focus cameras, fuzzy logic washing machines, fuzzy control of lifts, etc.) and standard fuzzy methods have been available in common software packages such as the MATLAB Fuzzy Logic Toolbox for many years. These advances have all featured the conventional, standard form of fuzzy logic known as type-1 fuzzy logic.

Zadeh himself recognised the limitations of type-1 fuzzy logic as early as 1975 and introduced a higher level in which fuzzy sets were themselves expressed as fuzzy sets (rather than as real numbers), thus creating essentially a third-dimension. Zadeh termed these sets *type-2 fuzzy sets* and went on to briefly outline how they might be utilised in practice. Unfortunately, though, the algorithmic complexities of type-2 fuzzy logic were beyond the capabilities of the computers available at the time, and type-2 fuzzy logic went largely ignored.

More recently, first Mendel and then other researchers such as John and Hagras, inspired a renewed interest in type-2 fuzzy sets. This came about initially by restricting type-2 fuzzy sets to a special category known as *interval* type-2 fuzzy sets in which the third-dimension was restricted to values of either zero or one. Mendel's advocacy of interval type-2 fuzzy logic systems, particularly through his book "*Uncertain Rule-Based Fuzzy Logic Systems*", stimulated research in the area and, in conjunction with advances in computational power, soon practical interval type-2 systems were realisable in reasonable time on the average desktop computer. This culminated in two seminal papers: the technical "*Interval Type-2 Fuzzy Logic Systems Made Simple*" (Mendel, John and Liu; 2006), and the application paper "*A Hierarchical Type-2 Fuzzy Logic Control Architecture for Autonomous Mobile Robots*" (Hagras; 2004).

More recently, the successes of interval type-2 fuzzy logic prompted researchers, led predominantly by the efforts of Hagras and John, to look again at Zadeh's original *general* type-2 fuzzy sets and systems. While type-2 fuzzy sets themselves are relatively straight-forward, see for example "*Type-2 Fuzzy Sets Made Simple*" (Mendel and John; 2002), specialist techniques are required to adequately represent, perform inference and interpret the output(s) of general type-2 fuzzy logic systems and this is now an extremely fertile area of current research.

While type-2 fuzzy sets capture the notion of *uncertainty* in the definitions of fuzzy sets, they do not capture the notion of *variability* in reasoning. It is well-known and well-accepted that all humans reasoning, including in 'experts', is characterised by both *inter-expert variability* (differences in opinion between different experts) and *intra-expert variability* (differences in the opinion of a single expert assessed over short periods of time). While such variability is particularly recognised in medical diagnosis, it has been largely ignored in the context of automated decision support systems and especially (and perhaps more surprisingly) in fuzzy logic systems.

In order to address this, the notion of non-stationary fuzzy sets were introduced in the paper "*Non-Stationary Fuzzy Sets*" (Garibaldi, 2008). Non-stationary fuzzy sets are essentially type-1 fuzzy sets which move slightly (are perturbed) over time, so that minor differences in the output of a fuzzy system utilising such sets are observed when inference is repeated. In this manner, non-stationary systems may be used to mimic the effect of an expert producing slightly different advice when faced with the same data, and so may be used to produce a range of outputs rather than a single 'answer'. Consensus methods may then be used to form the best overall answer.

Outline of the Tutorial Topics

The half-day (4 hours) tutorial will cover the following topics:

- An introduction to standard (type-1) fuzzy sets and systems, and fuzzy rule-based inference
- Limitations of type-1 fuzzy methods
- Type-2 fuzzy sets and systems (interval and general type-2)
- Non-stationary fuzzy sets and systems
- Type-2 and non-stationary software
- Current research topics in type-2 and non-stationary fuzzy systems

Intended Audience

The tutorial is intended for a wide range of researchers, including those entirely new to fuzzy systems and those already familiar with standard (type-1) fuzzy methods. It is intended to introduce the techniques of type-2 and non-stationary fuzzy systems on a practical level, so that attendees will be able to apply them in their particular area(s) of interest. There are no prerequisites, other than a general interest in learning about this rapidly emerging and exciting research area.

Biography of the Presenter

Dr Garibaldi is an Associate Professor and Reader in the *Intelligent Modelling and Analysis (IMA) Research Group* (http://www.ima.ac.uk) within the School of Computer Science, University of Nottingham, UK. The group currently has five permanent academics, two support staff, eight research fellows and over 30 PhD students (including Marie Curie Fellows). Members of the IMA group are involved in a wide range of multi- and interdisciplinary research initiatives, including many externally funded projects. The IMA group undertakes research into intelligent modelling and data analysis techniques to enable deeper and clearer understanding of complex physical and physiological problems. A particular strength of the group lies in the biomedical and security fields where extremely large data volumes have to be analysed in (near) real-time to very high levels of accuracy. Typical techniques used by the IMA group include AI based Data Mining, Artificial Immune Systems, Computational Modelling, Discrete and Agent-Based Simulation, Fuzzy Methodologies, Image Analysis and Multi-Sensor Data Fusion. The main research objectives of the IMA group are to:

- Investigate novel and adventurous real-world problems across multi-disciplinary boundaries
- Focus on modelling, representation and transformation techniques to enable better decisions
- Support the integration of emerging methodologies with more traditional approaches

Dr Garibaldi's main research interest is in the development of artificial intelligence techniques for biomedical decision support and in the modelling of human decision making, primarily in the context of medical applications. His work to date has particularly concentrated on utilising fuzzy methods to model the imprecision and uncertainty inherent in medical knowledge representation and decision making. This has been applied in areas such as the assessment of immediate neonatal outcome, the detection of pre-cancerous changes in cells through analysis of FTIR spectra, and the assessment of complex multi-modal datasets in, for example, breast cancer prognosis and early detection of Alzheimer's disease.

In his work on modelling human reasoning, he has focussed for many years on the importance of recognising the inherent variability in human decision making, both in the variation observable between experts in any given context and in the variation that any one particular expert exhibits over time. A central hypothesis of his work is that it is absolutely essential to model variation in decision making in order for decision support systems to be widely accepted in the real world. This interest has led to the study of type-2 fuzzy logic systems as mechanisms for adequately representing and dealing with *uncertainty* in human reasoning, and led to Dr Garibaldi's introduction of the concept of non-stationary fuzzy logic systems for representing *variability*.

A specific interest is in the transfer of medical intelligent systems into clinical use and this has led to the study of methods of evaluating intelligent systems and mechanisms for their implementation. Dr Garibaldi also has an interest in generic machine learning techniques such as clustering and classification, optimisation techniques such as simulated annealing and genetic algorithms, particularly when applied to the optimisation of decision making models, and in the study of adaptive and time-varying behaviour. He has published well over 100 papers in journals, as book chapters and at international conferences on the subjects of fuzzy reasoning (including both type-2 and non-stationary fuzzy systems), data clustering and classification, biomedical informatics, and other general aspects of machine learning and optimisation.

Contact Information

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