Preface

In 1975, Zadeh proposed Type-2 Fuzzy Sets (T2 FS) as an extension to the previously introduced ordinary fuzzy sets (now called type-1 fuzzy sets). Type-2 fuzzy sets have the ability to capture the uncertainty about membership functions of fuzzy sets through fuzzification of the membership function of type-1 fuzzy sets. Instead of using a single crisp number from the unit interval $[0, 1]$ as the membership value, as is done in a type-1 fuzzy set, in a T2 FS one or more crisp numbers are used as membership values, and with different strengths. More precisely, a membership grade in a T2 FS is a type-1 fuzzy set; this introduces a new third dimension into a fuzzy set which provides more degrees of freedom for handling uncertainties. Unfortunately, practitioners are still cautious to put general T2 FSs to real use due to their computational complexity. Consequently, there has been extensive research toward simplification of the concepts of and operations for T2 FSs, so that Interval Type-2 Fuzzy Sets (IT2 FSs) are often the preferred method of choice.

As a special variation of a general T2 FS, an IT2 FS uses a subinterval of $[0, 1]$ as its membership value. This is in contrast to the membership grades in T2 FSs that are type-1 fuzzy sets. Simplicity of the concept of IT2 FSs in comparison with general T2 FSs, together with the affordable complexity of their operations, has made IT2 FSs a widely used framework for implementation of fuzzy systems.

There has been a recent steady increase of attention and interest in T2 FS theory from the research community. As of 1999 (when intensive research into T2 FSs began), less than 40 publications had anything to do with T2 FSs or logic. As of 2012, there are thousands of articles that have something to do with T2 FSs or logic. Quite a change in less than 15 years.

On one hand, there have been various studies on T2 FS theories with the objectives of providing a uniform set of definitions and terms, a simple introduction of concepts, justification of their existence, and development of efficient algorithms for performing basic operations. On the other hand, there are endeavors related to the applications of T2 FSs. This book is intended to explore recent developments in the theoretical foundations and novel applications of general and
IT2 FSs and systems. Leading researchers in the field of T2 FSs have participated in the preparation of this book through contribution of their most important and recent achievements in theory and applications of T2 FSs. The chapters cover novel theoretical aspects of T2 FSs, methods for generating their membership functions, and promising applications. This book is organized in three parts.

Part I is dedicated to the theoretical foundations of T2 FSs and is composed of eight chapters. In chapter “Interval Type-2 Fuzzy Logic Systems and Perceptual Computers: Their Similarities and Differences”, Mendel, compares Interval type-2 fuzzy logic systems and Perceptual Computers and highlights their similarities and differences. By focusing on inputs and membership functions, fuzzifiers versus encoders, rules versus Computing with Words (CWW) engines, inference versus output of CWW engine, output processing versus decoder, and outputs versus recommendation plus data, this chapter shows that the differences outnumber the similarities. In chapter “A Survey of Continuous Karnik–Mendel Algorithms and Their Generalizations”, Liu summarizes the extensions of the continuous Karnik–Mendel Algorithms in type-2 fuzzy logic. It provides a general framework for the analysis and design of the Karnik–Mendel algorithms with numerical analysis. In chapter “Two Differences Between Interval Type-2 and Type-1 Fuzzy Logic Controllers: Adaptiveness and Novelty”, Wu explores the differences between interval type-2 and type-1 fuzzy logic controllers. This chapter shows that adaptiveness and novelty are two fundamental differences between interval type-2 and type-1 fuzzy logic controllers. In chapter “Interval Type-2 Fuzzy Markov Chains” Figueroa-García presents a framework to use IT2 FSs in Markov chains analysis. This is useful for handling multiple experts’ opinions and perceptions, multiple definitions of type-1 fuzzy Markov chains, and uncertain type-1 fuzzy sets. In chapter “zSlices Based General Type-2 Fuzzy Sets and Systems”, Wagner and Hagras provide a concise introduction to zSlices based general T2 FSs and their associated set-theoretic operations. In chapter “Geometric Type-2 Fuzzy Sets”, Coupland and John give a review and technical overview of the geometric representation of a T2 FS and explore logical operators used to manipulate this representation. In chapter “Type-2 Fuzzy Sets and Bichains”, Harding, Walker and Walker study the variety generated by the truth value algebra of T2 FSs. They identify weakly projective bichains for the variety generated by the truth value algebra of T2 FSs with only its two semilattice operations in its type. In chapter “Type-2 Fuzzy Sets and Conceptual Spaces”, Aisbett and Rickard extend the conceptual space theory to incorporate T2 FS structures. They study the usefulness of directional overlap (subsethood) as a metric-free notion of similarity. Moreover, they relate the theory of conceptual spaces to conventional multivariate classification and CWW and illustrate its application to land use assessment tasks.

Chapters in Part II, discuss different methodologies for generating membership functions of interval and general T2 FSs. In chapter “Modeling Complex Concepts with Type-2 Fuzzy Sets: The Case of User Satisfaction of Online
Services”, Moharrer, Tahayori and Sadeghian propose a two-phase methodology for generating membership functions of general T2 FSs that model complex concepts. As a case study, they extensively discuss modeling of human perceptions of the linguistic terms that are used in evaluating online satisfaction. The chapter is of importance from at least two points of view. First, a decompositional method for implicit calculation of type-1 fuzzy set models of an individual’s perception of a complex concept is discussed. Second, a fuzzy approach to the representation of uncertainty in measurement is adopted for constructing the membership functions of general T2 FSs. In chapter “Construction of Interval Type-2 Fuzzy Sets From Fuzzy Sets: Methods and applications”, Pagola et al. present three different methods to construct IT2 FS from type-1 fuzzy sets so that the footprint of uncertainties of the IT2 FSs adapt to the model’s uncertainty. In chapter “Interval Type-2 Fuzzy Membership Function Generation Methods for Representing Sample Data”, Rhee and Choi discuss three methods based on heuristics, histograms, and Interval Type-2 Fuzzy C-Means clustering for automatic generation of interval type-2 fuzzy membership functions from sample data.

Finally, chapters in Part III introduce novel application of T2 FSs. In chapter “Type-2 Fuzzy Logic in Image Analysis and Pattern Recognition”, Melin and Castillo show experimental results for several edge detectors that are used to preprocess the same image sets. By way of experiments, they find the better edge detector that can be used to improve the training data of a neural network for an image recognition system. In chapter “Reliable Tool Life Estimation with Multiple Acoustic Emission Signal Feature Selection and Integration Based on Type-2 Fuzzy Logic”, Ren, Baron, Balazinski, and Jemielniak present a type-2 fuzzy tool life estimation system. In their proposed system, type-2 fuzzy analysis is used as a powerful tool to model acoustic emission signal features, and also as a very good estimator for the related ambiguities and uncertainties. In chapter “A Review of Cluster Validation with an Example of Type-2 Fuzzy Application in R”, Ozkan and Türksen explain how interval valued type 2 fuzziness can be used to develop a new cluster validation procedure. Their approach identifies the number of clusters based on the stability of cluster centers with respect to the level of fuzziness. In chapter “Type-2 Fuzzy Set and Fuzzy Ontology for Diet Application”, Lee, Wang, and Hsu provide a T2 FS and fuzzy ontology for a diet application. They use a type-2 fuzzy markup language to describe the related knowledge base and rule base.

This book outlines notable achievements in the realm of T2 FS to date. The editors hope the materials covered in this book, provided by the leading scholars in the field, motivate and accelerate future progress. Of course, there are still many theoretical and applied issues that need to be addressed before the full potential of Type-2 Fuzzy Systems is realized. The editors encourage the readers to participate in research opportunities that are associated with T2 FSs, e.g., to investigate and demonstrate the applicability, effectiveness, and potential advantages of T2 FSs over type-1 fuzzy sets in a wide range of complex real world problems.
The editors would also like to express their sincere thanks to the distinguished authors for their contributions. The editors would also like to acknowledge the invaluable, continuous assistance, and advice from the Springer editorial team, Brett Kurzman, Elizabeth Dougherty, and Rebecca Hytowitz.
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