Explains for the first time how "computing with words" can aid in making subjective judgments

Lotfi Zadeh, the father of fuzzy logic, coined the phrase "computing with words" (CWW) to describe a methodology in which the objects of computation are words and propositions drawn from a natural language. *Perceptual Computing* explains how to implement CWW to aid in the important area of making subjective judgments, using a methodology that leads to an interactive device—a "Perceptual Computer"—that propagates random and linguistic uncertainties into the subjective judgment in a way that can be modeled and observed by the judgment maker.

This book focuses on the three components of a *Perceptual Computer*—encoder, CWW engines, and decoder—and then provides detailed applications for each. It uses interval type-2 fuzzy sets (IT2 FSs) and fuzzy logic as the mathematical vehicle for perceptual computing, because such fuzzy sets can model first-order linguistic uncertainties whereas the usual kind of fuzzy sets cannot. Drawing upon the work on subjective judgments that Jerry Mendel and his students completed over the past decade, *Perceptual Computing* shows readers how to:

- Map word-data with its inherent uncertainties into an IT2 FS that captures these uncertainties
- Use uncertainty measures to quantify linguistic uncertainties
- Compare IT2 FSs by using similarity and rank
- Compute the subsethood of one IT2 FS in another such set
- Aggregate disparate data, ranging from numbers to uniformly weighted intervals to nonuniformly weighted intervals to words
- Aggregate multiple-fired IF-THEN rules so that the integrity of word IT2 FS models is preserved

Free MATLAB-based software is also available online so readers can apply the methodology of perceptual computing immediately, and even try to improve upon it. *Perceptual Computing* is an important go-to for researchers and students in the fields of artificial intelligence and fuzzy logic, as well as for operations researchers, decision makers, psychologists, computer scientists, and computational intelligence experts.

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Contents

Preface

Life is full of subjective judgments: those we make that affect others and those that others make that affect us. Such judgments are personal opinions that have been influenced by one's personal views, experience, or background, and can also be interpreted as personal assessments of the levels of variables of interest. They are made using a mixture of qualitative and quantitative information. Emotions, feelings, perceptions, and words are examples of qualitative information that share a common attribute: they cannot be directly measured; for example, eye contact, touching, fear, beauty, cloudiness, technical content, importance, aggressiveness, and wisdom. Data (one- or multidimensional) and possibly numerical summarizations of them (e.g., statistics) are examples of quantitative information that share a common attribute: they can be directly measured or computed from direct measurements; for example, daily temperature and its mean value and standard deviation over a fixed number of days; volume of water in a lake estimated on a weekly basis, as well as the mean value and standard deviation of the estimates over a window of years; stock price or stock-index value on a minute-to-minute basis; and medical data, such as blood pressure, electrocardiograms, electroencephalograms, X-rays, and MRIs.

Regardless of the kind of information—qualitative or quantitative—there is uncertainty about it, and more often than not the amount of uncertainty can range from small to large. Qualitative uncertainty is different from quantitative uncertainty; for example, words mean different things to different people and, therefore, there are linguistic uncertainties associated with them. On the other hand, measurements may be unpredictable—random—because either the quantity being measured is random or it is corrupted by unpredictable measurement uncertainties such as noise (measuring devices are not perfect), or it is simultaneously random and corrupted by measurement noise.

Yet, in the face of uncertain qualitative and quantitative information one is able to make subjective judgments. Unfortunately, the uncertainties about the information propagate so that the subjective judgments are uncertain, and many times this happens in ways that cannot be fathomed, because these judgments are a result of things going on in our brains that are not quantifiable.

It would be wonderful to have an interactive device that could aid people in making subjective judgments, a device that would propagate random and linguistic uncertainties into the subjective judgment, but in a way that could be modeled and observed by the judgment maker. This book is about a methodology, perceptual computing, that leads to such a device: a perceptual computer (Per-C, for short). The Per-C is not a single device for all problems, but is instead a device that must be designed for each specific problem by using the methodology of perceptual computing.

In 1996, Lotfi Zadeh, the father of fuzzy logic, published a paper with the very provocative title "Fuzzy Logic = Computing With Words." Recalling the song, "Is That All There Is?," his article's title might lead one to incorrectly believe that, since fuzzy logic is a very well-developed body of mathematics (with lots of real-world application), it is straightforward to implement his paradigm of computing with words. The senior author and his students have been working on one class of applications for computing with words for more than 10 years, namely, subjective judgments. The result is the perceptual computer, which, as just mentioned, is not a single device for all subjective judgment applications, but is instead very much application dependent. This book explains how to design such a device within the framework of perceptual computing.

We agree with Zadeh, so fuzzy logic is used in this book as the mathematical vehicle for perceptual computing, but not the ordinary fuzzy logic. Instead, interval type-2 fuzzy sets (IT2 FSs) and fuzzy logic are used because such fuzzy sets can model first-order linguistic uncertainties (remember, words mean different things to different people), whereas the usual kind of fuzzy sets (called type-1 fuzzy sets) cannot.

Type-1 fuzzy sets and fuzzy logic have been around now for more than 40 years. Interestingly enough, type-2 fuzzy sets first appeared in 1975 in a paper by Zadeh; however, they have only been actively studied and applied for about the last 10 years. The most widely studied kind of a type-2 fuzzy set is an IT2 FS. Both type-1 and IT2 FSs have found great applicability in function approximation kinds of problems in which the output of a fuzzy system is a number, for example, time-series forecasting, control, and so on. Because the outputs of a perceptual computer are words and possibly numbers, it was not possible for us to just use what had already been developed for IT2 FSs and systems for its designs. Many gaps had to be filled in, and it has taken 10 years to do this. This does not mean that the penultimate perceptual computer has been achieved. It does mean that enough gaps have been filled in so that it is now possible to implement one kind of computing with words class of applications.

Some of the gaps that have been filled in are:

- A method was needed to map word data with its inherent uncertainties into an IT2 FS that captures these uncertainties. The *interval approach* that is described in Chapter 3 is such a method.
- Uncertainty measures were needed to quantify linguistic uncertainties. Some uncertainty measures are described in Chapter 2.

- How to compare IT2 FSs by using similarity was needed. This is described in Chapter 4.
- How to rank IT2 FSs had to be solved. A simple ranking method is also described in Chapter 4.
- How to compute the subsethood of one IT2 FS in another such set had to be determined. This is described in Chapter 4.
- How to aggregate disparate data, ranging from numbers to uniformly weighted intervals to nonuniformly weighted intervals to words, had to be determined. Novel weighted averages are a method for doing this. They include the interval weighted average, fuzzy weighted average and the linguistic weighted average, and are described in Chapter 5.
- How to aggregate multiple-fired if–then rules so that the integrity of word IT2 FS models is preserved had to be determined. Perceptual reasoning, which is described in Chapter 6, does this.

We hope that this book will inspire its readers to not only try its methodology, but to improve upon it.

So that people will start using perceptual computing as soon as possible, we have made free software available online for implementing everything that is in this book. It is MATLAB-based (MATLAB® is a registered trademark of The Mathworks, Inc.) and was developed by the second author, Feilong Liu, and Jhiin Joo, and can be obtained at http://sipi.usc.edu/~mendel/software in folders called "Perceptual Computing Programs (PCP)" and "IJA Demo." In the PCP folder, the reader will find separate folders for Chapters 2–10. Each of these folders is self-contained, so if a program is used in more than one chapter it is included in the folder for each chapter. The IJA Demo is an interactive demonstration for Chapter 7.

We want to take this opportunity to thank the following individuals who either directly contributed to the perceptual computer or indirectly influenced its development: Lotfi A. Zadeh for type-1 and type-2 fuzzy sets and logic and for the inspiration that "fuzzy logic = computing with words," the importance of whose contributions to our work is so large that we have dedicated the book to him; Feilong Liu for codeveloping the interval approach (Chapter 3); Nilesh Karnik for codeveloping the KM algorithms; Bob John for codeveloping the wavy slice representation theorem; Jhiin Joo for developing the interactive software for the investment judgment advisor (Chapter 7); Terry Rickard for getting us interested in subsethood; and Nikhil R. Pal for interacting with us on the journal publication judgment advisor.

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