Advances in Fuzzy Clustering and its Applications

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John Wiley & Sons, Ltd
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Well, here I am writing a foreword for this book. Here is the (free dictionary, Farlex) definition:

‘foreword - a short introductory essay preceding the text of a book.’

An essay about fuzzy clustering? For inspiration, I looked at the forewords in my first two books. When I wrote my first book about fuzzy clustering (Bezdek, 1981), I asked Lotfi Zadeh to write a foreword for it. By then, Lotfi and I were friends, so he did it, and I was happy. But why? Was it to prove to you that I could get him to do it? Was it because he would say things that had never been said about fuzzy models? Was it a promotional gimmick that the publisher thought would get more buyers interested? Was it . . . hmmm, I still didn’t know, so I read more carefully.

Lotfi speculated on a variety of possibilities for fuzzy clustering in that foreword. The most interesting sentence (Bezdek, 1981, p. 5) was perhaps:

“Although the results of experimental studies reported in this book indicate that fuzzy clustering techniques often have significant advantages over more conventional methods, universal acceptance of the theory of fuzzy sets as a natural basis for pattern recognition and cluster analysis is not likely to materialize in the very near future.”

In short, his foreword was careful, and it was cautionary – Lotfi speculated that fuzzy clustering might not assume a central place in clustering, but this seems overshadowed by his more general worry about the role of fuzzy models in computation.

My second book (Bezdek and Pal, 1992) was much more similar to this volume than my first, because the 1981 effort was a one-author text, while the 1992 book was a collection of 51 papers (the “chapters”) that Pal and I put together (we were editors, just like de Oliveira and Pedrycz) that seemed to provide a state-of-the-art “survey” of what was happening with fuzzy models in various pattern recognition domains in 1992. Perhaps the principal difference between these two books is that fuzzy clustering was only one of the five topics of our 1992 book, whereas the current volume is only about fuzzy clustering. The other noticeable difference was that the papers we collected had already been published elsewhere, whereas the chapters in this book have not.

I am looking at the foreword to our 1992 book right now, again written by Lotfi. Well, a lot of positive things happened for fuzzy sets in the 11 years that separated these two forewords (read, Japan builds fuzzy controllers), and Lotfi’s 1992 foreword was both more historical and more confident than the 1981 offering. Here is the first sentence of that 1992 forward:

“To view the contents of this volume in a proper perspective it is of historical interest to note that the initial development of the theory of fuzzy sets was motivated in large measure by problems in pattern recognition and cluster analysis.”
Did you notice that Lotfi used exactly the same term “pattern recognition and cluster analysis” in both forewords? In contradistinction, I believe that most people today view clustering as one of many topics encompassed by the much broader field of pattern recognition (classifier design, feature selection, image processing, and so on). My guess is that Lotfi probably used the term pattern recognition almost as a synonym for classification. This is a small point, but in the context of this volume, an interesting one, because to this day, Lotfi contends that the word cluster is ill defined, and hence cluster analysis is not really a topic at all. Nonetheless, you have in your hands a new book about fuzzy cluster analysis.

What should I point out to you in 2006 about this topic? Well, the main point is that fuzzy clustering is now a pretty mature field. I just “googled” the index term “fuzzy cluster analysis,” and the search returned this statistic at 1 p.m. on September 6, 2006:

“Results 1–10 of about 1 640 000 for fuzzy cluster analysis (0.34 seconds).”

Never mind duplication, mixed indexing, and all the other false positives represented by this statistic. The fact is fuzzy clustering is a pretty big field now. There are still some diehard statisticians out there who deny its existence, much less its value to real applications, but by and large this is no longer a controversial undertaking, nor is its real value to practitioners questionable. Moreover, I can pick any chapter in this book and get returns from Google that amaze me. Example: Chapter 4 has the somewhat exotic title “Fuzzy Clustering with Minkowski Distance Functions.” What would you guess for this topic – 12 papers? Here is the return:

“Results 1–10 of about 20 000 for Fuzzy Clustering with Minkowski distance functions (0.37 seconds).”

There aren’t 20 000 papers out there about this topic, but there are probably a few hundred, and this is what makes the current book useful. Most of these chapters offer an encapsulated survey of (some of) the most important work on their advertised contents. This is valuable, because I don’t want to sift through 20 000 entries to find the good stuff about Minkowski-based fuzzy clustering – I want the experts to guide me to 20 or 30 papers that have it.

Summary. We no longer need worry whether the topics in this fuzzy clustering book are good stuff – they are. What we need that these chapters provide is a quick index to the good stuff. And for this, you should be grateful (and buy the book, for which de Oliveira and Pedrycz will be grateful!), because if you rely on “google,” you can spend the rest of your life sifting through the chaff to find the grain.

Jim Bezdek
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Clustering has become a widely accepted synonym of a broad array of activities of exploratory data analysis and model development in science, engineering, life sciences, business and economics, defense, and biological and medical disciplines. Areas such as data mining, image analysis, pattern recognition, modeling, and bio-informatics are just tangible examples of numerous pursuits that vigorously exploit the concepts and algorithms of clustering treated as essential tools for problem formulation and development of specific solutions or a vehicle facilitating interpretation mechanisms. The progress in the area happens at a high pace and these developments concern the fundamentals, algorithmic enhancements, computing schemes, and validation practices. The role of fuzzy clustering becomes quite prominent within the general framework of clustering. This is not surprising given the fact that clustering helps gain an interesting insight into data structure, facilitate efficient communication with users and data analysts, and form essential building blocks for further modeling pursuits. The conceptual underpinnings of fuzzy sets are particularly appealing, considering their abilities to quantify a level of membership of elements to detected clusters that are essential when dealing with the inherent phenomenon of partial belongingness to the group. This feature is of particular interest when dealing with various interpretation activities.

Even a very quick scan of the ongoing research reveals how dynamic the area of fuzzy clustering really is. For instance, a simple query on Science Direct “fuzzy clustering” returns slightly under 400 hits (those are the papers published since 2000). A similar search on ISI Web of Knowledge returns more than 500 hits. In IEEE Xplore one can find around 800 hits. More than half of these entries have been published after 2000. These figures offer us an impression about the rapid progress in the area and highlight a genuine wealth of the applications of the technology of fuzzy clustering.

This volume aims at providing a comprehensive, coherent, and in depth state-of-the-art account on fuzzy clustering. It offers an authoritative treatment of the subject matters presented by leading researchers in the area. While the volume is self-contained by covering some fundamentals and offering an exposure to some preliminary material on algorithms and practice of fuzzy clustering, it offers a balanced and broad coverage of the subject including theoretical fundamentals, methodological insights, algorithms, and case studies.

The content of the volume reflects the main objectives we intend to accomplish. The organization of the overall material helps the reader to proceed with some introductory material, move forward with more advanced topics, become familiar with recent algorithms, and finally gain a detailed knowledge of various application-driven facets.

The contributions have been organized into five general categories: Fundamentals, Visualization, Algorithms and Computational Aspects, Real-time and Dynamic Clustering, and Applications and Case Studies. They are fairly reflective of the key pursuits in the area.

Within the section dealing with the fundamentals, we are concerned with the principles of clustering as those are seen from the perspective of fuzzy sets. We elaborate on the role of fuzzy sets in data analysis, discuss the principles of data organization, and present fundamental algorithms and their augmentations. Different paradigms of unsupervised learning along with so-called knowledge-based clustering and data organization are also addressed in detail. This part is particularly aimed at the readers who would intend to gather some background material and have a quick yet carefully organized look at the essential of the methodology of fuzzy clustering.
In fuzzy clustering, visualization is an emerging subject. Due to its huge potential to address interpretation and validation issues visualization deserves to be treated as a separate topic.

The part entitled *Algorithms and Computational Aspects* focuses on the major lines of pursuits on the algorithmic and computational augmentations of fuzzy clustering. Here the major focus is on the demonstration of effectiveness of the paradigm of fuzzy clustering in high-dimensional problems, distributed problem solving, and uncertainty management.

The chapters arranged in the group entitled *Real-time and Dynamic Clustering* describe the state-of-the-art algorithms for dynamical developments of clusters, i.e., for clustering built for data gathered over time. Since new observations are available at each time instant, a dynamic update of clusters is required.

The *Applications and Case Studies* part is devoted to a series of applications in which fuzzy clustering plays a pivotal role. The primary intent is to discuss its role in the overall design process in various tasks of prediction, classification, control, and modeling. Here it becomes highly instructive to highlight at which phase of the design clustering is of relevance, what role it plays, and how the results – information granules – facilitate further detailed development of models or enhance interpretation aspects.

**PART I  FUNDAMENTALS**

The part on *Fundamentals* consists of four chapters covering the essentials of fuzzy clustering and presenting a rationality and a motivation, basic algorithms and their various realizations, and cluster validity assessment.

Chapter 1 starts with an introduction to basic clustering algorithms including hard, probabilistic, and possibilistic ones. Then more advanced methods are presented, including the Gustafson–Kessel algorithm and kernel-based fuzzy clustering. Variants on a number of algorithm components as well as on problem formulations are also considered.

Chapter 2 surveys the most relevant methods of relational fuzzy clustering, i.e., fuzzy clustering for relational data. A distinction between object and relational data is presented and the consequences of this distinction on clustering algorithms are thoroughly analyzed. A most useful taxonomy for relational clustering algorithms together with some guidelines for selecting clustering schemes for a given application can also be found in this chapter.

In Chapter 3 the authors offer a contribution that deals with another fundamental issue in clustering: distance functions. The focus is on fuzzy clustering problems and algorithms using the Minkowski distance – definitely an interesting and useful idea.

In Chapter 4 the authors discuss the combination of multiple partitioning obtained from independent clustering runs into a consensus partition – a topic that is gaining interest and importance. A relevant review of commonly used approaches, new consensus strategies (including one based on information-theoretic K-means), as well as a thorough experimental evaluation of these strategies are presented.

**PART II  VISUALIZATION**

Visualization is an important tool in data analysis and interpretation. Visualization offers the user the possibility of quickly inspecting a huge volume of data, and quickly selecting data space regions of interest for further analysis. Generally speaking, this is accomplished by producing a low-dimensional graphical representation of the clusters. The part of the book on *Visualization* consists of two major contributions.

Chapter 5 reviews relevant approaches to validity and visualization of clustering results. It also presents novel tools that allow the visualization of multi-dimensional data points in terms of bi-dimensional plots which facilitates the assessment of clusters’ goodness. The chapter ends with an appendix with a comprehensive description of cluster validity indexes.

Chapter 6 aims at helping the user to visually explore clusters. The approach consists of the construction of local, one-dimensional neighborhood models, the so-called neighborgrams. An algorithm is
included that generates a subset of neighborgrams from which the user can manage potential cluster candidates during the clustering process. This can be viewed as a form of integrating user domain knowledge into the clustering process.

PART III  ALGORITHMS AND COMPUTATIONAL ASPECTS

This part provides the major lines of work on algorithmic and computational augmentations of fuzzy clustering with the intention of demonstrating its effectiveness in high-dimensional problems, distributed problem solving and uncertainty handling. Different paradigms of unsupervised learning along with so-called knowledge-based clustering and data organization are also addressed.

Chapter describes and evaluates a clustering algorithm based on the Yager’s participatory learning rule. This learning rule pays special attention to current knowledge as it dominates the way in which new data are used for learning. In participatory clustering the number of clusters is not given a priori as it depends on the cluster structure that is dynamically built by the algorithm.

Chapter 8 offers a comprehensive and in-depth study on fuzzy clustering of fuzzy data.

The authors of Chapter 9 also address the problem of clustering fuzzy data. In this case, clustering is based on the amount of mutual inclusion between fuzzy sets, especially between data and cluster prototypes.

Extraction of semantically valid rules from data is an active interdisciplinary research topic with foundations in computer and cognitive sciences, psychology, and philosophy. Chapter 10 addresses this topic from the clustering perspective. The chapter describes a clustering framework for extracting interpretable rules for medical diagnostics.

Chapter 11 focuses on the combination of regression models with fuzzy clustering. The chapter describes and evaluates several regression models for updating the partition matrix in clustering algorithms. The evaluation includes an analysis of residuals and reveals the interesting characteristics of this class of algorithm.

Hierarchical fuzzy clustering is discussed in Chapter 12. The chapter presents a clustering-based systematic approach to fuzzy modeling that takes into account the following three issues: (1) the number of clusters required a priori in fuzzy clustering; (2) initialization of fuzzy clustering methods, and (3) the trade off between accuracy and interpretability.

Chapter 13 deals with the process of inferring dissimilarity relations from data. For this, two methods are analyzed with respect to factors such as generalization and computational complexity. The approach is particularly interesting for applications where the nature of dissimilarity is conceptual rather than metric.

Chapter 14 describes how clustering and feature selection can be unified to improve the discovery of more relevant data structures. An extension of the proposed algorithm for dealing with an unknown number of clusters is also presented. Interesting applications on image segmentation and text categorization are included.

PART IV  REAL-TIME AND DYNAMIC CLUSTERING

Real-time and dynamic clustering deals with clustering with time-varying or noisy data and finds its applications in areas as distinct as video or stock market analysis. Three chapters focus on this timely topic.

Chapter 15 provides a review of dynamic clustering emphasizing its relationship with the area of data mining. Data mining is a matter of paramount relevance today and this chapter shows how dynamic clustering can be brought into the picture. The chapter also describes two novel approaches to dynamic clustering.

Chapter 16 describes the development of an efficient online version of the fuzzy C-means clustering for data streams, i.e., data of potentially unbound size whose continuous evolution is not under the control of the analyzer.
Chapter 17 presents two approaches to real-time clustering and generation of rules from data. The first approach concerns a density-driven approach with its origin stemming from the techniques of mountain and subtractive clustering while the second one looks at the distance based with foundations in the \( k \)-nearest neighbors and self-organizing maps.

**PART V APPLICATIONS AND CASE STUDIES**

The last part of the book includes three chapters describing various applications and interesting case studies in which fuzzy clustering plays an instrumental role. The function of fuzzy clustering is discussed in the overall design process in a variety of tasks such as prediction, classification, and modeling.

Chapter 18 presents a novel clustering algorithm that incorporates spatial information by defining multiple feature partitions and shows its application to the analysis of magnetic resonance images.

Chapter 19 exploits both the \( K \)-means and the fuzzy \( C \)-means clustering algorithms as the means to identify correlations between words in texts, using the hyperspace analogue to language (HAL) model.

Another bio-medical application is provided in Chapter 20 where fuzzy clustering techniques are used in the identification of cancerous cells.

**FINAL REMARKS**

All in all, fuzzy clustering forms a highly enabling technology of data analysis. The area is relatively mature and exhibits a rapid expansion in many different directions including a variety of new concepts, methodologies, algorithms, and innovative and highly advanced applications.

We do hope that the contributions compiled in this volume will bring the reader a fully updated and highly comprehensive view of the recent developments in the fundamentals, algorithms, and applications of fuzzy clustering.

Our gratitude goes to all authors for sharing their expertise and recent research outcomes and reviewers whose constructive criticism was of immense help in producing a high quality volume. Finally, our sincere thanks go to the dedicated and knowledgeable staff at John Wiley & Sons, Ltd, who were highly instrumental in all phases of the project.