5-2019

Concluding remarks

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Chapter 8
Concluding Remarks

Abstract This chapter summarizes the major contributions in this book and discusses their possible positions and requirements in some future scenarios. Section 8.1 follows the book structure to revisit the key contributions of this book in both theories and applications. The developed algorithms, such as the VA-ARTs for hyperparameter adaptation and the GHF-ART for multimedia representation and fusion, and the four applications, such as clustering and retrieving socially enriched multimedia data, are concentrated using one paragraph and three paragraphs, respectively. In Sect. 8.2, the roles of the proposed ART-embodied algorithms in social media clustering tasks are highlighted, and their possible evolutions using the state-of-the-art representation learning techniques to fit the increasingly rich social media data and demands are discussed.

8.1 Summary of Book

This book discusses the research on social media data clustering and presents a class of solutions based on the adaptive resonance theory (ART) to major social media mining applications. It has two parts, where Part I includes the background knowledge on clustering for social media analytics and the theories and algorithms of ART and its extensions for handling social media clustering challenges. Specifically,

- **Chapter** 1 discusses the importance and the role of clustering in social media analytics, the main characteristics of social media data, and the major challenges and requirements of social media data clustering.
- This background discussion is followed by a literature review, as described in **Chap.** 2, which offers a bird's eye view of existing clustering algorithms and the associated techniques that can address the social media clustering challenges, and it details major social media mining tasks where clustering holds a potential.
- With sufficient background knowledge, **Chap.** 3 provides a theoretical analysis on the adaptive resonance theory (ART), detailing the proof of the meaning of its similarity measure and learning functions and offering the geometric interpretation of its clustering behaviors. Subsequently, a class of ART variants is illustrated

L. Meng et al., *Adaptive Resonance Theory in Social Media Data Clustering*, Advanced Information and Knowledge Processing,
https://doi.org/10.1007/978-3-030-02985-2_8

which solves one or more challenges in the respective social media clustering tasks, including

1. **Vigilance Adaptation ARTs (VA-ARTs)** which has three variants with different methods for adaptively tuning the vigilance parameter ρ during clustering, making ART more robust to the initialization of manual parameter settings.
2. **User preference incorporation** which uses a two-channel Fuzzy ART, one for the input features of data objects and another one for the user preferences. It incorporates user preferences in the form of groups of similar data objects with user-provided semantic labels, which serve as predefined clusters to partition the feature space before clustering.
3. **Probabilistic ART** for clustering short text which employs the data representation and learning functions that are different from Fuzzy ART to model the cluster weights as the probability of word occurrences.
4. **Generalized Heterogeneous Fusion ART (GHF-ART)** for clustering multimodal data which is a multi-channel ART, allowing different feature channels to have different representation and learning functions to fit the characteristics of heterogeneous data and using a *robustness measure* to adaptively weight the similarities computed by each of the feature channels.
5. **Online Multimodal Co-indexing ART (OMC-ART)** for indexing and searching multimodal data streams which employs an online normalization method to perform online clustering of upcoming data streams and builds a two-layer indexing base for the quickly searching and targeting for relevant data objects.

- Part II, i.e. Chaps. 4–7, investigates the application of ART variants (in Chap. 3) for four social media mining tasks, including
  - **Personalized web image organization** which focuses on discovering the semantic groups of web images by clustering their surrounding text and incorporating user preferences to guide the generation of user-desired cluster structures.

    This is achieved by a two-step semi-supervised hierarchical clustering algorithm, called the Personalized Hierarchical Theme-ased Clustering (PHTC). In the first step, a fusion of Probabilistic ART with user preference incorporation (See Sects. 3.4 and 3.5) is used to obtain data clusters, of which the cluster weights are modeled to be the probabilistic distribution of tag occurrences; while in the second one, an agglomerative algorithm is proposed to create a multi-branch tree structure for a compact and semantically meaningful organization of web images.

    Experiments are conducted on two real-world datasets are conducted to analyze the performance of PHTC and show that it requires a much lower time cost and usually generates the data hierarchy with a higher quality and more systematical structure than existing hierarchical clustering algorithms.
  - **Socially-enriched multimedia data co-clustering** where the composite data object containing multimodal information, such as images, articles, and user descriptions is clustered

GHF-ART (See Sect. 3.6) is used as a natural solution to this problem, which handles the heterogeneous data using multiple independent feature channels. This allows the data to have different representation and learning mechanisms, and it uses a *robustness measure* to adaptively weight the similarities obtained from each feature channel for an effective fusion of heterogeneous features

Three social media datasets, including two web image datasets with surrounding text and one netnews dataset with semantic annotations, are used to evaluate the performance of GHF-ART in terms of sensitivity to algorithm parameters, effectiveness of *robustness measure*, clustering performance comparison, robustness to noise and time cost. The experimental results show that GHF-ART is much faster and can generate clusters of a higher quality than the compared algorithms in different parameter and dataset settings.

– **Community discovery in heterogeneous social networks** where clustering algorithms were applied to discover the groups of social users that share some common interests or behaviors in social networks, called a community. The shared characteristics of the users are expected to be identified through their heterogeneous associations, such as friends, (re-)posts, likes, and comments.

As with clustering socially-enriched multimodal data, this problem should be addressed by taking advantage of GHF-ART's low computational cost, not needing to know the number of clusters a priori, and its ability to effectively fuse multimodal data. By adopting a set of specific feature representation and learning functions, GHF-ART can handle various heterogeneous types of social links, including relational links, textual links in articles and textual links in short text

The performance of GHF-ART was analyzed on two social network datasets in terms of parameter selection, clustering performance comparison, effectiveness of the weighting function and time cost. The experimental results show that the performance of GHF-ART is only sensitive to the vigilance parameter, which controls the intra-cluster similarity . Additionally, a suitable value of the vigilance parameter could be selected by tuning the vigilance parameter until a small number of small clusters are generated. The effectiveness of GHF-ART on clustering heterogeneous social network data is also demonstrated by comparing the performance of GHF-ART with existing algorithms, evaluating its capability of discovering the key features of clusters and analyzing the correlations across heterogeneous links in case studies.

– **Online multimodal co-indexing and retrieval of social media data** where clustering algorithms are used to investigate the online indexing and retrieval of multimodal social media data streams, with the application for building a search engine enabling multimodal queries.

OMC-ART (See Sect. 3.7) is used in this case, which performs online clustering of multimodal data and generates a two-layer hierarchy as the indexing structure. The first layer contains clusters with their generalized feature distributions and salient features, while the second one includes data objects from the respective clusters. In this way, a data object is represented by the salient features of both cluster weights and their own features. A fast ranking algorithm is

incorporated to sort similar clusters and then rank the data objects therein. This ranking approach enables the groups of data objects that are similar to the user query to be selected for ranking before the dissimilar ones, so the ranking may stop without searching through the whole database if the ranking list remains unchanged after presenting a fixed number of data objects.

Experiments were conducted on two multimodal web image collections and an e-commerce product dataset. OMC-ART was found to have a lower response time and better performance in both precision and recall. Moreover, this book further showcases how to develop a prototype website for searching e-commerce products, in terms of the web interface design, the implementation details of the client and server end and the effects on using multimodal queries for search.

8.2 Prospective Discussion

Adaptive Resonance Theory in Social Media Data Clustering stands on a fundamental breakthrough in the cognitive and neural theory, i.e. adaptive resonance theory (ART), which simulates how a brain processes information to perform memory, learning, recognition, and prediction. It offers initiatives on

1. A systematic illustration of the characteristics of social media data.
2. The roles and challenges of clustering in social media analytics.
3. The mathematical demonstration of ART's learning mechanisms in clustering.
4. The ART extensions that handle the complexity and characteristics of social media data in real-world social media mining tasks.

Both cutting-edge research and real-world practices on machine learning and social media analytics are included in this book, answering

- How to process big and continuous multimedia data streams created on the social Web?
- How to analyze social networks with the users' heterogeneous data?
- How to understand users interests by learning from their online posts and behaviors?
- How to build a personalized search engine allowing multimodal queries by automatically indexing and searching multimodal information in an online manner?

Through both the theoretical proof in Chap. 3 and the practical applications in Chaps. 4–7, this book has shown the strong theoretical basis of ART in clustering and demonstrated the superior properties of the ART-based clustering algorithms, i.e. low computational cost, no need for predefined clusters and its flexibility in handling various learning tasks for social media data. Providing both a systematic literature review and a step-by-step guide in real-world case studies, this book is expected to

- shed light on the advances and development of using the clustering approaches based on ART for resolving up-to-date problems in social media analytics.

- broaden the audience's insights on clustering as a fundamental technique for unsupervised knowledge discovery and data mining that converts social media data to actionable intelligence.
- equip the audience with state-of-the-art machine learning techniques for tackling challenges in clustering big social media data.

Along with the evolution of the forms and tools in the social networking platforms for user communication, new challenges and issues in social media analytics are increasing. For example, the availability of location information leads to research on online-offline recommendations of e-commerce products to the users who either browse similar products online or visit the shops; the increasing popularity of short video sharing websites leads to research of user profiling/understanding from short videos; the idea that a single user usually uses multiple social networking apps leads to research on user account unification and multi-view user analysis using multiple social networks; and the booming of images and movies leads to searching for images/frames with specific semantics. It can be foreseen that much richer attributes of social media data will occur, leading to new requirements in social media analytics and new challenges in social media data clustering.

New technologies for natural language processing, computer vision, and machine learning have been developed for understanding multimedia data, such as the word2vector technique for text representation [3, 6], the long-term short-term memory (LSTM) for sentence analysis [1, 4] and the convolutional neural networks for image understanding [2, 5].

Such circumstances will create a need for developing novel clustering algorithms to analyze the "upgraded" social media data, and this book's authors hope that the fundamentals introduced here will serve as the basis for boosting the development of ART-based clustering algorithms with cutting-edge techniques to contribute to the new age of social media analytics, in terms of new architectures for learning from the emerging data, new theories for data-independent robust learning, and new applications where clustering holds a potential.

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