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A new hierarchical ranking aggregation method

Jiankun Ding[a], Deqiang Han[a,*], Jean Dezert[b], Yi Yang[c]

[a] *MOE KLINNS Lab, Institute of Integrated Automation, School of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an 710049, China*
[b] *The French Aerospace Lab, ONERA, Chemin de la Hunière, Palaiseau F-91761, France*
[c] *SKLSVMS, School of Aerospace, Xi'an Jiaotong University, Xi'an 710049, China*

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ABSTRACT

The purpose of ranking aggregation (or fusion) is to combine multiple rankings to a consensus one. In the ranking aggregation, some of the items' preference orders are easy to distinguish, however, some others' are not. To specifically compare the ambiguous items, i.e., the items whose aggregated preference orders are difficult to distinguish, is helpful for ranking aggregation. In this paper, a new hierarchical ranking aggregation method is proposed. The items whose preference orders are easy to distinguish are first divided into different ranking levels (i.e., the ordered items subsets), and the ambiguous items are put into the same ranking level. The items in high ranking levels are ranked higher than the items in low ranking levels in the aggregated ranking. Then the items in the same ranking level are further compared and divided into multiple ranking sub-levels. The aggregated ranking is generated hierarchically by dividing the same ranking levels' (or sub-levels') items into sub-levels until each sub-level only includes one item. Furthermore, we discuss the way of using the insertion sort method for merging the adjacent levels' rankings to improve the quality of the aggregated ranking. The experiments and simulations show that our new hierarchical methods perform well in ranking aggregation.

1. Introduction

Multiple attribute decision making (MADM) [14,26] comprehensively uses different aspects of information for items provided by multiple attributes for decision making. MADM approaches are expected to obtain better results than those using only single attribute. Ranking aggregation (or ranking fusion) is an important branch in MADM, where each attribute (or information source) provides a ranking of items, i.e., a preference order list of items. Ranking aggregation approaches aggregate these rankings to a consensus one. Ranking aggregation has been increasingly used in a wide range of successful applications such as the information retrieval [11,29], bio-informatics [18], estimator ranking [28] and management [6,21].

The goal of ranking aggregation is to find a ranking that can best represent all the input rankings. In the traditional MADM framework, the ranking with the smallest average distance to all the available rankings to aggregate is usually treated as the optimal one [2,11,12]. Finding this optimal aggregated ranking can be formulated as an optimization problem, which is usually NP-hard [11]. Many heuristic ranking aggregation methods are proposed, which find solutions with the average distance to all the available rankings as small as possible, rather than find the optimal one directly. According to the imple-

* Corresponding author.
E-mail addresses: d4574b@163.com (J. Ding), deqhan@xjtu.edu.cn (D. Han), jean.dezert@onera.fr (J. Dezert), jiafeiyy@mail.xjtu.edu.cn (Y. Yang).

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mentations, heuristic ranking aggregation methods can be mainly divided into the *batch mode* [4,16,23,28] (or global mode) methods and the *instant-runoff mode* [5] (or Luce mode [17,27]) methods.

Batch mode methods generate the ranking positions of all the items in a batch. Borda count [2,4] is a representative batch mode method, which works based on the items' positions in input rankings directly. Another kind of batch mode methods work based on the pairwise comparisons [8] of items. For example, Copeland method [16,19,20] ranks the items according to the difference of the items' win times and lose times in the pairwise comparisons. Negahban et al. [23] introduced a kind of iterative ranking from pairwise comparisons, and later Yin et al. [28] proposed the ranking eigenvector (REV) method. Although these two methods analyze the ranking aggregation problem from different perspectives, they both use the eigenvector of the pairwise comparison matrix for ranking aggregation. Yin et al. [28] also introduced a self-weighted score addition (SWSA) method based on the pairwise comparison matrix. There are some other batch mode ranking aggregation methods. For example, Mark et al.[22] uses the insertion sort or the merge sort for generating the aggregated ranking. Dwork et al. [12] explains that the insertion sort in fact works based on a given aggregated ranking and generates a better one. Some methods apply stochastic optimization algorithms such as the genetic algorithm [25] and cross-entropy Monte Carlo algorithm [24,25] for searching the optimal aggregated ranking.

The instant-runoff mode methods decompose the aggregation of n items' rankings into n sequential rounds. In each round, only one item is ranked, and it will not participate in the unranked items' ranking in the follow rounds. Instant-runoff voting (IRV) [5] is a representative instant-runoff mode method. It only ranks the best item (or the worst item) in each round, which is selected according to the first place votes. In 2010, Qin et al. [27] proposed a probabilistic model, where coset-permutation distance is used for ranking aggregation. The coset-permutation distance based stagewise (CPS) works better than IRV, however, it has large computational cost for selecting the best item in each round. In 2015, we [9] proposed an instant-runoff ranking fusion method (IRRF) using the results of traditional batch mode ranking aggregation methods and a top-2 comparison based instant-runoff ranking fusion method (T2-IRRF), which is an improved IRRF by introducing more local comparison information into the selection of the best item in each round.

Traditional ranking aggregation methods all have their pros and cons, and there is no widely accepted one. In practice, some of the items' preference orders are easy to distinguish, and some other items' are not. Reflected in the ranking aggregation problem, some items have the same preference orders in input rankings; however, some other items have conflict orders in input rankings. A specific comparison between the ambiguous items, i.e., the items whose preference orders are difficult to distinguish, is beneficial to improving the performance of ranking aggregation. It is more proper to rank the items in multiple hierarchies, rather than in a single hierarchy. In this paper, a novel hierarchical ranking aggregation (HRA) method is proposed. HRA first divides the items into different ranking levels, i.e., multiple ordered items subsets, according to their comparisons with all the other items based on all the input rankings (i.e., the rankings to aggregate). Then, the items in the same ranking level are further divided into multiple sub-levels according to the pairwise comparisons between themselves until each ranking level (or sub-level) only has one item. The ranking aggregation is implemented hierarchically, where the ambiguous items, i.e., the items in the same ranking level, are specifically ranked according to the pairwise comparisons between themselves. HRA merges different levels' rankings according to the following criterion, i.e., the items in high ranking levels are ranked higher than all the items in low ranking levels. Moreover, we use the insertion sort [12,22] for merging the adjacent levels' rankings, where the low level's items are inserted into the high level's ranking one by one (the top item of the low level's ranking first). By using the insertion sort the performance of ranking aggregation is further improved. The research work in this paper is an extension of our preliminary work presented in [10], where the basic idea of the hierarchical ranking aggregation is briefly introduced. In this paper, we refine the way in the preliminary HRA proposed in [10] of dealing with the cases where all items are ambiguous, and better performance is obtained. We also further discuss the way of merging adjacent level's rankings. More theoretical analyses on HRA are provided. More examples and simulations are also provided for the comparisons between our proposed methods and the traditional ones. These are all added values (contributions) of this paper. Simulation results show that the new ranking aggregation methods can effectively improve the performance of ranking aggregation, which is desired for decision making.

The rest of this paper is organized as follows: Section 2 introduces the basics of ranking aggregation in MADM. Then, a novel ranking aggregation method is proposed in Section 3. In Section 4, we analyze the performance of the novel hierarchical ranking aggregation method we proposed. In Section 5, we evaluate the performances of our proposed methods using Monte Carlo simulations. The conclusion is drawn in Section 6.

2. Ranking aggregation in multiple attribute decision making

2.1. Conceptions and formulations in ranking aggregation

Given a set of items $X = \{x_1, x_2, \dots, x_n\}$, a ranking is an order list of these items according to a certain criterion. The ranking in general can be categorized into three types [1,2,13,29]: the total ranking, the partial ranking, and the top-k ranking. In the total ranking, all the items are ranked, i.e., all the items are assigned ranking positions. In the partial ranking and the top-k ranking, only a part of items are ranked. The top-k ranking is a special case of the partial ranking, where only the top-k items are assigned ranking positions. Here, we only focus on the total ranking problem. Given multiple available rankings originated from different information sources (or attributes), the ranking aggregation (or fusion) generates a consensus