Knowledge discovery of consensus and conflict interval-based temporal patterns: A novel group decision approach

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\begin{abstract}
Temporal pattern mining problems, developed from sequential pattern mining problems, have recently been discussed frequently regarding the gathering of temporal sequences and aggregating them in order to gain insight into consensus decision-making. Existing temporal pattern mining problems reveal only point-based relations; however, in reality, several interval-based circumstances exist, which enable precisely describing temporal relationships. Practical applications include the order and duration of investors purchasing stocks and portfolio management. This study proposes a novel model and its associated algorithm for identifying consensus and conflict patterns from user-provided subjective interval-based temporal sequences. We conducted an experiment on stock investments in the semiconductor industry by drawing on collected authentic datasets and user ratings to demonstrate the model’s effectiveness. The experimental results reveal six consensus patterns and one pair of conflict patterns from the participants’ subjective investment intuitions, which is consistent with common sense concerning the semiconductor stock market.
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1. Introduction

Several problems in the decision sciences, such as in group decision-making [1], may not be addressed directly using mathematical models or structured approaches. For example, decisions on resource allocation or performance appraisals for an enterprise cannot lead to a consensus in meetings in a company [2]. When the members of a group are requested to offer opinions for a collective solution, the diverse range of opinions is often conflicting. Achieving a consensus in group decision-making often involves reaching a compromise. The process of group decision-making may not be ideal, but it is a necessary and appropriate process in reality. Because of the importance of group decision-making, researchers have focused considerably on the problem of reaching a consensus in groups with different participant opinions [3–7].

Two major steps are involved in a group’s attempt to reach a consensus among the various opinions in the decision-making process [8]. First, different opinions should be fairly and openly expressed. Reliance on information technology currently enables decision makers to satisfy this requirement. Decision makers can gather opinions through the Internet or other means of communication in the business environment. Every group member can receive information fairly and openly. Moreover, every member can provide an opinion without any obstruction. Second, when collecting a myriad of opinions, the decision maker must aggregate them in order to obtain a consensus. The second step is more difficult than the first because the process of generating a consensus among various opinions always involves conflict. Therefore, how to identify conflict and reach a consensus is a fundamental problem in group decision-making. Our research objective is to provide a group-decision support system which can identify conflict and consensus opinions.

This study investigates the consensus and conflict relationships among interval-based temporal sequences. Basically, there are two kinds of temporal sequences: point-based and interval-based temporal sequences. In the following, we first introduce point-based and then interval-based temporal sequences. A point-based temporal sequence is a list of temporal items, connected by their time relationships, where the less-than (\textless) and equality (=) signs are temporal comparison operators (Fig. 1). For example, one point-based temporal sequence, \((a \textless b = c)\), indicates the following: (1) \(a\) occurs before \(b\) and \(c\); and (2) \(b\) and \(c\) occur simultaneously. The above temporal items are called point-based temporal items, because this traditional expression reveals only two point-based relationships (i.e., the co-occurrence and order of items). In actu-
ality, a number of interval-based circumstances exist that can be described more precisely as the temporal relationships between items’ starting and ending points. For example, if $a$ and $b$ occur together (i.e., $a = b$), then it is useful to know whether their starting points are equal (Fig. 1). In addition, if $b$ occurs after $a$ (i.e., $a < b$), knowing whether $b$ occurs slightly before $a$ or whether $b$ meets $a$ completely is valuable. In this study, an interval-based item, $a$, can be written as $(a^+, a^-)$, whereas the superscript “+” denotes a starting point and “−” denotes an ending point. A list consisting of many interval-based items is called an interval-based temporal sequence, for example, $(a^+ < b^- < c^- < a^-)$ (Fig. 1). Moreover, if an interval-based temporal sequence is given or recommended on the basis of a person’s subjective thoughts, then it is also called his/her interval-based “temporal preferences.”

Collecting many subjective temporal sequences from a group of people, and then gaining information from them, is helpful for decision makers. For example, with three point-based temporal sequences, $(a < b = c)$, $(a < b < c)$ and $(c < a < b)$, the consensus resulting from the three temporal sequences is $(a < b)$, because all three sequences are consistent with it; however, conflicts exist among the temporal relationships of $(a, c)$ and $(b, c)$. Identifying these consensus and conflicts from people’s subjective temporal sequences is useful; two examples are as follows.

1. When investors manage stocks in the stock market, they can adopt four strategies based on their experience: purchasing or selling certain stocks together; purchasing or selling stocks in a sequence; purchasing certain stocks but selling others together; and purchasing certain stocks but selling others in a sequence. However, if time-relevant information regarding the four approaches is uncertain, then investors cannot obtain their starting and ending points because the above four verbal statements remain ambiguous. Sharing more precise time-related information with investors has therefore become beneficial in stock investments these days. For example, the platform Seeking Alpha (seekingalpha.com) is a website that discusses investments. On this platform, people not only share their investment-related knowledge, but also discuss their subjective investment strategies. We consider this to be a kind of crowd wisdom in the Internet era. Moreover, another kind of data gathering method is the Delphi expert assessment method. We are able to ask fund managers to provide professional opinions. The consensus interval-based temporal patterns will be developed based on their subjective thoughts.

2. In the second application, employees are requested to develop a workflow from different perspectives. Sometimes, employees who understand their jobs better can provide a company with relevant knowledge to improve operational processes. Subsequently, the proposed model is used to discover consensus interval-based temporal patterns, which can be provided as a reference to managers. The managers are thereby able to gain better insight from the workflow recommendations suggested by employees.

Therefore, based on the above-mentioned examples, the notion of subjective interval-based temporal sequences, a general expression of essential human behavior, can be applied in many fields: (1) detailed information related to interval-based temporal relationships can provide decision makers with important insights; and (2) collecting numerous subjective interval-based temporal sequences and identifying consensus and conflict patterns based on these is relevant to the group decision-making problem.

To the best of our knowledge, no researcher has proposed consensus and conflict interval-based temporal pattern mining as a group decision support system. However, according to the mentioned arguments, this new problem can provide a novel approach to considering data mining and decision-making. The main contributions of this study are as follows:

1. We propose a novel model for identifying consensus and conflict interval-based temporal patterns based on users’ subjective data. We employ Allen’s thirteen temporal interval-based relationships [9] (i.e., during, containing, starting, started by, finishing, finished by, equal to, meeting, met by, before, after, overlapping, and overlapped by) for users to express their subjective temporal preferences for items.

2. This study introduces a novel concept of conflict among interval-based temporal sequences (discussed in Section 3).

3. For solving the problem, we propose a novel algorithm, consensus interval-based temporal pattern mining (CITPM), which is a modification of the algorithms proposed in [10,11] for detecting and identifying consensus and conflict patterns.

The experimental steps in this study are as follows: (1) We first developed a Web-based recommendation system for collecting subjective preferences on interval-based temporal items from online users. (2) Then the subjective interval-based temporal sequence dataset was used for consensus and conflict pattern mining. The applications of this recommendation system can provide stock portfolio recommendations, because numerous people have recently begun to search for information on stocks of interest directly on the Internet on sites such as Seeking Alpha (seekingalpha.com). By installing an appropriate recommendation mechanism on an online stock information site, users can search for desired items quickly.

The remainder of this paper is organized as follows: Section 2 provides an overview of critical works related to the temporal pattern mining problems. Section 3 introduces a formal definition of our novel model which identifies consensus and conflict interval-based temporal patterns. Section 4 presents the proposed algorithm. In Section 5, we describe the experiments for which we used collected real-world datasets and user ratings to evaluate the effectiveness of the proposed algorithm. Section 6 offers a conclusion and recommendations for future research.

2. Literature review and fundamentals of research problem

Before discussing our problem, providing the research background is necessary. We first review studies related to the sequential pattern mining (SPM) problem in Section 2.1, and temporal pattern mining problem in Section 2.2.
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