OEOP: A Novel Algorithm for Periodic Pattern Mining

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Abstract

Research on periodic pattern mining has gained a great attention in the past decade. Periodic pattern mining discovers valid periodic patterns in a time-related dataset. This study proposed an efficient 2-D linked structure and the OEOP (One Event One Pattern) algorithm to discover all kinds of valid segments in each single event sequence. Then, this study combines these valid segments found by OEOP into 1-patterns with multiple events, and multiple patterns with multiple events periodic patterns. The experimental results show that the proposed algorithm has good performance and scalability.

Keywords: Periodic pattern, asynchronous sequence, data mining, pattern mining, sequential pattern.

1. Introduction

Periodic patterns commonly appear in all kinds of time-series databases. For instance, trajectories of objects, weather, tides, stock market prices, DNA sequences, etc. The discovery of patterns with periodicity is of great importance and has rapidly developed in recent years. The periodic pattern mining models include full-cycle periodic pattern mining [1], segment-wise periodic pattern mining [2], partial periodic pattern mining [3], frequent partial periodic pattern mining [3], and asynchronous periodic pattern mining [4, 5, 6, 7, 8].

This study proposed an efficient linked list structure and the OEOP (One Event One Pattern) algorithm to discover all kinds of valid segments in each single event sequence. Afterwards, by calculating the offsets of the valid 1-pattern segments, the proposed MEOP (Multiple Events One Pattern) algorithm and MEMP (Multiple Events Multiple Patterns) algorithm merged them into multiple-event patterns.

2. Notations and Definitions

Let \( E = \{e_1, e_2, \ldots, e_n\} \) be a set of all events. An eventset \( X \) is a nonempty subset of \( E \). An eventset with \( k \) events is called a \( k \)-eventset. A sequence \( D \) is an ordered list of eventsets. For example, \( E = \{a, b, c, d\} \), \( X = \{a, b, c\} \) is a 3-eventset, \( D = (\{a, b, c\}, \{b, c\}, \{a, c, d\}, \{b, a, c, d\}, \{a, c, d\}, \{a, c\}, \{d, a, b, c, d\}) \) is a sequence.

Definition 1. A pattern with period \( l \) is a nonempty sequence \( P = (p_1, p_2, \ldots, p_l) \), where \( p_i \) is an eventset and \( p_i \) is either an eventset or \(*\), for \( 2 \leq i \leq l \). The symbol \(*\)
indicates a “don’t care” position. A pattern $P$ is called an $i$-pattern if exactly $i$ positions in $P$ contain eventsets.

**Definition 2.** For two patterns $P=(p_1, p_2, \ldots, p_l)$ and $P'=(p'_1, p'_2, \ldots, p'_l)$ with the same period $l$, $P$ is a specialization of $P$ (i.e., $P$ is a generalization of $P'$) if and only if $p_i \subseteq p'_i$ or $p_i = ^* $, for $1 \leq i \leq l$.

**Definition 3.** For pattern $P=(p_1, p_2, \ldots, p_l)$ with period $l$ and a sequence of eventsets $D=(d_1, d_2, \ldots, d_l)$, we say that $P$ matches $D$ or $D$ supports $P$ if and only if $p_i \subseteq d_i$ or $p_i = ^*$, for $1 \leq i \leq l$. $D$ is also called a match (or a match block) of $P$.

**Definition 4.** Given a pattern $P$ with period $l$, a original sequence $D$, and $k$ subsequences $D_1, D_2, \ldots, D_k$ of $D$, if $D_i (1 \leq i \leq k)$ matches $P$ and the distance of $D_i$ and $D_{i+1} (1 \leq i \leq k-1)$ equals 0, the sequence $D_1 D_2 \ldots D_k$ is called a $k$-segment (or a continuous matching block with the repetition $k$) of $P$.

**Problem Definition.** Given a sequence of eventsets $D$, a minimum repetition $\text{min}_\text{rep}$, a periodic pattern $P$ indicates that there exists a valid subsequence $S$ with respect to $P$ in $D$ and $S$ is a set of non-overlapping valid segments, where each valid segment has at least $\text{min}_\text{rep}$ contiguous matches of $P$. Periodic pattern mining (PPM) discovers all periodic patterns in $D$.

### 3. Proposed Data Structures and Algorithms

This section presents the mining process and introduces the proposed data structures for storing pattern information. First, the OEOP algorithm generates all valid 1-pattern segments for each event of the dataset. For different events, by computing the offsets of the valid 1-pattern segments, either the MEOP algorithm or the MEMP algorithm will merge them into multiple events patterns.

#### 3.1. Proposed Process for Periodic Pattern Mining

The proposed mining process for periodic patterns consists of the 6 steps. Figure 1 illustrates the steps of the proposed mining process for periodic pattern mining.

**Figure 1. Proposed Process for PPM**
3.2. The linked Data Structures

To accelerate the mining process and properly record the pattern information of the list of time instants, we introduce the following three structures, **START** node, **END** node, and **VALID** node.

**START node:** A structure consists of three fields. The first field, *stime*, saves the starting time instant of a 1-pattern; the second field, *next_s*, is a pointer that links to the next START node; the third field, *list_e*, is a pointer linking to an END node.

**END node:** A structure consists of four fields. The first field, *etime*, saves an ending time instant of a 1-pattern; the second field, *period*, records the period of the pattern; the third field, *rep_num*, stores the repetition of the pattern; the last field, *next_e*, is a pointer that links to the next END node.

**VALID node:** A 4-field structure to record a valid 1-pattern. The fields, *stime*, *etime*, *period*, and *rep_num*, indicate the starting time instant, the ending time instant, the period, and the repetition of the 1-pattern, respectively.

3.3. OEOP (One Event One Pattern Mining) Algorithm

Given a sequence of eventsets D, for each event e, we first generate the list of time instants of e, denoted as TL(e). The preliminary goal of OEOP is to discover all valid 1-patterns in TL(e). For each list of time instants TL(e) of event e, with the minimal repetition min_rep, and the maximal period Lmax, the OEOP algorithm utilizes the new linked list structures and generates all valid 1-pattern segments of event e. The details of OEOP are as follows:

**OEOP Algorithm**

**Input:** the list of time instants TL(e) for event e, min_rep, Lmax

**Output:** valid segments VS of event e

**Method:**

1. L = null;
//L : the list of Start node allocate a valid array VS
2. for each time instant t in TL(e) do
3. {
4. allocate a START node X;
5. X.stime = t;
6. X.next = null;
7. X.list_e = null;
8. L.insert(X); // insert X at the end of L
9. for each X_i node L do
10. {
11. for each Y_j node in X_i.list_e do
12. {
13. if ( t - Y_j.etime = Y_j.period )
14. Y_j.etime = t; Y_j.rep_num++ ;
15. if ( t - Y_j.etime > Y_j.period )
16. {
17. if ( Y_j.rep_num >= min_rep )
18. move VS(Y_j) ;
19. //insert Y_j at the end of VS array
20. free (Y_j); // delete Y_j
21. }
22. if ( t-X_i.stime <= Lmax )
23. {
24. allocate END node Y;
25. Y.etime = t;
26. Y.period = t - X_i.stime ;
}
4. Experimental Results

All experiments were performed on an Intel Pentium M processor (1.73GHz) PC with 1.50 GB main memory, running the Microsoft Windows XP operating system. The proposed algorithm was implemented in C language.

4.1 Datasets

GenBank Sequences

By using the Entrez interface from the National Center for Biotechnology Information database (http://www.ncbi.nlm.nih.gov/sites/entrez), we randomly selected two protein genbank sequences with different data sizes.

Stock Price Series

Second, we selected the 2008 Taiwan Stock Exchange Capitalization Weighted Stock Index (TAIEX) by Taiwan Stock Exchange Co., Ltd. (TSEC) and Dow Jones Industrial Average Index ($INDU) by Dow Jones & Company. Due to TSEC regulations, the daily change of TAIEX is limited to between -7% and 7%. Therefore, we transformed both TAIEX and $INDU numerical index series to the symbolic series using the following formula:

\[
\text{Change rate}(i\text{-th day}) = \frac{\text{(i-th day’s index} - \text{(i-1)-th day’s index})}{\text{(i-1)-th day’s index}}
\]

\[
\text{Event}(i\text{-th day}) = A, \text{if Change rate}(i\text{-th day})\geq 3\%
\]

\[
\text{Event}(i\text{-th day}) = B, \text{if } 3\% > \text{Change rate}(i\text{-th day})\geq 1\%
\]

\[
\text{Event}(i\text{-th day}) = C, \text{if } 1\% > \text{Change rate}(i\text{-th day})\geq -1\%
\]

\[
\text{Event}(i\text{-th day}) = D, \text{if } -1\% > \text{Change rate}(i\text{-th day})\geq -3\%
\]

\[
\text{Event}(i\text{-th day}) = E, \text{if } -3\% > \text{Change rate}(i\text{-th day})
\]

The basic information of each sequence investigated in the experiments is given in Table 1.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Length</th>
<th>Event (count)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AJ131352</td>
<td>1104</td>
<td>a:331, t:363, g:217, c:191</td>
</tr>
<tr>
<td>X60729</td>
<td>1615</td>
<td>a:474, t:467, g:367, c:307</td>
</tr>
<tr>
<td>2008 TAIEX</td>
<td>248</td>
<td>A:16, B:44, C:111, D: 51, E:26</td>
</tr>
<tr>
<td>2008 $INDU</td>
<td>252</td>
<td>A:18, B:41, C:119, D:20, E:20</td>
</tr>
</tbody>
</table>

4.2. Numbers of valid segments and sub-sequences

By applying the OEOP algorithm on the X60729 GenBank sequence, the 2008 TAIEX sequence and the 2008 $INDU sequence, we obtained valid 1-patterns. Then, by utilizing MEMP and APP algorithms, we generated valid sub-sequences. Table 2 (a)-(c) list the numbers of valid segments for the X60729 GenBank sequence, the 2008 TAIEX sequence and the 2008 $INDU sequence with \( \text{min_rep}=3, \text{period}=3 \).
Table 2. Numbers of valid segments of X60729 GenBank, 2008 TAIEX, 2008 INDU

<table>
<thead>
<tr>
<th>X60729</th>
<th>number of valid segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a, * , *)</td>
<td>65</td>
</tr>
<tr>
<td>(t, * , *)</td>
<td>62</td>
</tr>
<tr>
<td>(c, * , *)</td>
<td>36</td>
</tr>
<tr>
<td>(a, g , *)</td>
<td>18</td>
</tr>
<tr>
<td>(a, g , g)</td>
<td>6</td>
</tr>
<tr>
<td>(t, g , *)</td>
<td>4</td>
</tr>
<tr>
<td>(a, t , *)</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2008 TAIEX</th>
<th>number of valid segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B, * , *)</td>
<td>2</td>
</tr>
<tr>
<td>( C, * , *)</td>
<td>71</td>
</tr>
<tr>
<td>( D, * , *)</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2008 INDU</th>
<th>number of valid segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>( B, * , *)</td>
<td>2</td>
</tr>
<tr>
<td>( C, * , *)</td>
<td>71</td>
</tr>
<tr>
<td>( D, * , *)</td>
<td>7</td>
</tr>
</tbody>
</table>

(a) (b) (c)

4.3. OEOP Results

Figure 2 shows the relationship between length of sequence and running time. Apparently, running time significantly relates to the lengths of sequences. In Figure 3, as expected, the increase in the size of min_rep is observed with decreasing running time, for both X60729 GenBank and 2008 TAIEX sequences.

Figure 2. Length of Sequence vs Running Time
![Figure 2](image)

Figure 3. min_rep vs Number of Valid Segments
![Figure 3](image)

5. Conclusions

This study proposed an efficient linked list structure and OEOP algorithm to discover all kinds of valid segments in each single event sequence. The proposed MEOP and MEMP algorithms merge 1-patterns into multi-event 1-patterns or multi-event multi-patterns. Implementing these algorithms on real datasets, the experimental results show that these algorithms have good performance and scalability.

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References


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