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Online mining maximal frequent structures in continuous landmark melody streams

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Abstract

In this paper, we address the problem of online mining maximal frequent structures (*Type I & II melody structures*) in unbounded, continuous landmark melody streams. An efficient algorithm, called MMS_{LMS} (Maximal Melody Structures of Landmark Melody Streams), is developed for online incremental mining of maximal frequent melody substructures in *one scan* of the continuous melody streams. In MMS_{LMS}, a space-efficient scheme, called CMB (Chord-set Memory Border), is proposed to constrain the upper-bound of space requirement of maximal frequent melody structures in such a streaming environment. Theoretical analysis and experimental study show that our algorithm is efficient and scalable for mining the set of all maximal melody structures in a landmark melody stream.

Keywords: Machine learning; Data mining; Landmark melody stream; Maximal melody structure; Online algorithm

1. Introduction

Recently, database and knowledge discovery communities have focused on a new data model, where data arrives in the form of continuous, rapid, huge, unbounded *streams*. It is often referred to as data streams or streaming data. Many applications generate large amount of data streams in real time, such as sensor data generated from sensor networks, transaction flows in retail chains, Web record and click streams in Web applications, performance measurement in network monitoring and traffic management, call records in telecommunications, etc. In such a data

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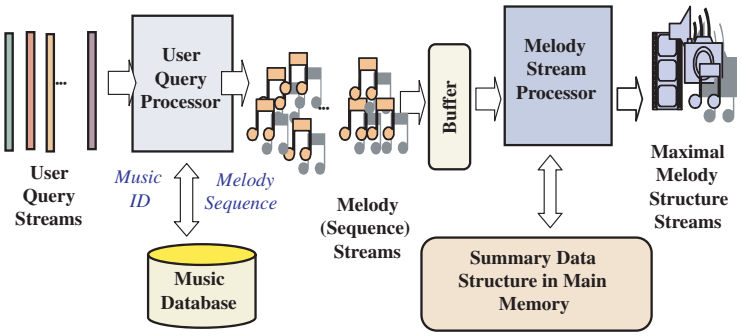

Fig. 1. Computation model for music melody streams.

stream model, knowledge discovery has two major characteristics (Babcock et al., 2002). First, the volume of a continuous stream over its lifetime could be huge and fast changing. Second, the continuous queries (not just one-shot queries) require timely answers, and the response time is short. Hence, it is not possible to store all the data in main memory or even in secondary storage. This motivates the design of in-memory *summary data structure* with small memory footprints that can support both one-time and continuous queries. In other words, data stream mining algorithms have to sacrifice the exactness of its analysis result by allowing some counting error.

Although several techniques have been developed recently for discovering and analyzing the content of *static music* data (Bakhmutora et al., 1997; Hsu et al., 2001; Shan and Kuo, 2003; Yoshitaka and Ichikawa, 1999; Zhu et al., 2001), new techniques are needed to analyze and discover the content of *streaming* music data. Thus, this paper studies a new problem of how to discover the maximal melody structures in a continuous unbounded melody stream. The problem comes from the context of online music-downloading services (such as *Kuro* at www.music.com.tw), where the streams in question are streams of queries, i.e., music-downloading requests, sent to the server, and we are interested in finding the maximal melody structures requested by most customers during some period of time. With the computation model of music melody streams presented in Fig. 1, the melody stream processor and the summary data structure are two major components in the music melody streaming environment. The user query processor receives user queries in the form of ⟨*Timestamp*, *Customer-ID*, *Music-ID*⟩, and then transforms the queries into music data (i.e., *melody sequences*) in the form of ⟨*Timestamp*, *Customer-ID*, *Music-ID*, *Melody-Sequence*⟩ by retrieving the music database. Note that a buffer can be optionally set for temporary storage of recent music melodies from the music melody streams.

In this paper, we present a novel algorithm MMS_{LMS} (Maximal Melody Structures of Landmark Melody Streams) for mining the set of all maximal melody structures in a landmark melody stream. Moreover, the music melody data and patterns are represented as sets of chord-sets (*Type I Melody structures*) or strings of chord-sets (*Type II Melody structures*). While providing a general framework of music stream mining, algorithm MMS_{LMS} has two major features, namely *one scan of music melody streams for online frequency collection*, and *prefix-tree-based compact pattern representation*. With these two important features, MMS_{LMS} is provided with the capability to work continuously in the unbounded streams for an arbitrary long time with bounded resources, and to quickly answer users' queries at any time.

2. Preliminaries

2.1. Music terminologies

In this section, we describe several features of music data used in this paper. For the basic