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# Sequence optimization for media objects with due date constraints in multimedia presentations from digital libraries

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ABSTRACT

This study investigates sequence optimization of media objects in a multimedia presentation that is dynamically composed from digital libraries. Each media object can be associated with a due date. The aim is to schedule the media objects in a delay-prone network environment such that the overall presentation lag and the due date penalties of the media objects of presentations can be minimized. We formulate the sequencing problem with buffer constraints in the media player into a flowshop scheduling problem and present a reduction strategy with a branch and bound algorithm to derive optimal sequences. The algorithm can be applied in applications with up to a dozen objects to be scheduled. In addition, we propose a modified NEH-based heuristic algorithm which can provide approximate solutions with an average error rate of less than 4%. The computation-efficient heuristic, when deployed in applications with heavily loaded servers, can obtain near-optimal sequences for problems with more than a dozen objects. The proposed algorithms are embedded into a prototype system for providing digital library services.



## 1. Introduction

In a multimedia digital library system, a query to the database typically retrieves a number of relevant media objects. In general, while most existing systems provide interfaces for users to view the objects by repetitively "clicking, downloading, and playing" the objects one by one, there is a desire of users for a "TV-like" presentation style where the objects are continuously played. A presentation of this kind sequentially combines and continuously presents the media objects such that the user does not have to repetitively click to retrieve and play the media objects. Applications preferring a TV-like presentation would arise from any system that can combine multiple separate media objects into a continuous presentation. Examples include assembling a TV-like documentary based on queries to a multimedia database, continuously showing media items in an online multimedia album, etc. A continuously played TV-like presentation particularly suits hand-held portable devices such as pocket PCs, organizers, and cell phones. The input interfaces of these portable devices usually are more difficult to operate than a mouse. In particular, traditional repetitive "click-and-play" operations are less effective when users are in motion. In practice, to suit more users with different navigation preferences, the design of the navigation interface should provide both click-and-play and TV-like presentations.

In a typical online multimedia presentation application, the media objects are retrieved from a server through the Internet. The total latency of a presentation is thus an important factor in the overall quality of the

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service. To cope with the congestion and delay problems, a commonly used strategy is to "prefetch" the media objects before their presentation due time. In an on-the-fly assembled presentation delivered from digital libraries, there is no pre-defined order for presenting the media objects. Hence, the ordering of the objects is determined dynamically on-the-fly. In a typical multimedia presentation, the modalities of the media objects might include text, images, audio, video, vector graphics, etc. Each media type has its unique data compression capabilities. For the same amount of data transmitted, the expected presentation durations for different media types differ drastically. To reduce the total presentation lag, the delivery and presentation order of the media objects should be properly planned.

Media streaming technology is an example application of prefetch technology that aims to reduce the presentation lag. A streaming-based media player prefetches and buffers small chunks of a media object so that the data can be processed before it is rendered. As soon as the buffer is full, the media object starts to play. While the media object is playing, more data is being downloaded. Typically, for a multimedia presentation delivered through a network environment with a reasonable bandwidth, the only playback idle time is the initial download duration for the first chunk, which in general is rather short. Therefore, a practical approach is to present the streamed objects before other non-streamed objects to keep the overall presentation latency low. The main theme of this study is to explore and exploit optimization techniques for ordering the non-streamed media objects of a prefetch-enabled presentation through a slow network such that the presentation lag is minimized.

In general, the end-to-end delay of a presentation depends on: access delay in the server side, communication delay due to network transmission, packetization, buffering, depacketization, and rendering overhead at the player site. In an environment where the bandwidth of the communication channel is rather restricted, the communication delay dominates the end-to-end delay. In this study, we assume that the download time of an object is deterministic. This assumption is reasonable for applications where the end-to-end transmission delay is mainly attributed to a last-mile bottleneck or a server-assigned bandwidth quota limit. In these cases, the end-to-end transmission usually does not exhibit significant bandwidth variations. As compared to commonly-adopted approaches that use random sequences, simulation experiments to be presented in Section 7 nevertheless show that optimized sequences based on the deterministic download transmission time significantly reduce the presentation lags in real life network environments with stochastic variations in the transmission rate.

In Lin et al. [22,23], we provided the essential background and an overview of the prefetch-enabled media object scheduling problems [4] with different real-life constraints. A number of different problem settings have been thoroughly discussed. We identified several problem settings that had never before been explored. In this study, we propose a solution for a specific one of these un-solved problems. Specifically, this study considers the media object scheduling problems with a player-side "buffer constraint" and "due-date" constraints on the media objects. The player-side buffer constraint is common in applications where the multimedia objects are to be presented in small-scale devices, such as pocket PCs and organizers, with restricted memory capacity. The due-date constraints arise from commercial online services in which the media servers are implemented to automatically insert various intermittent media objects for advertisements while the users are viewing a presentation that dynamically combines media objects retrieved from the servers. These advertisement media objects are presented between two neighboring objects in the presentation. Often, an advertisement object is required to be completed within a predetermined time slot in the final presentation, mostly depending on the agreements between service providers and funding supporters. The problems addressed in this paper will be mathematically formulated and computationally solved. Numerical simulations will be described to assess the performance of the proposed algorithms under real-life wireless network conditions.

## 2. Notations and problem statements

To better illustrate the operations scenarios of the problem setting under study, Fig. 1 shows a Gantt chart illustrating the download and playback of a sequence of media objects. The objective is to find an optimal sequence of media objects with the minimum sum of total presentation time and due date penalties, which are calculated from the overdue times of the media objects. This object sequencing problem could be formulated as a two-machine flowshop scheduling problem subject to a player-side buffer constraint and presentation due date constraints. The correspondence is shown in Table 1.

This study assumes that a media object can be downloaded only if the free space of the buffer is sufficient to accommodate the object. Once the playback of an object is finished, the buffer space occupied by this object is immediately released. In the literature, there are several papers investigating flowshop scheduling with an upper limit on the number of objects that can be allocated in the intermediate storage buffer. For the case without a buffer constraint (denoted as $\infty$-*buffer* in Papadimitriou and Kanellakis [29]), an optimal solution can be obtained by Johnson's algorithm [16]. For the case in which no job is allowed to be kept in the intermediate storage buffer

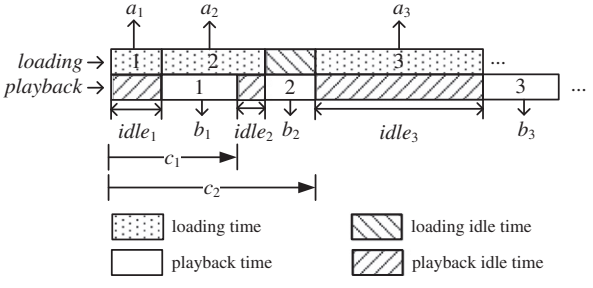


**Fig. 1.** Illustration of the notations used in problem formulation.