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Hill

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[54] **HIGH-PERFORMANCE PLAYER FOR DISTRIBUTED, TIME-BASED MEDIA**

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[51] **Int. Cl.**[6] **H04N 7/10**; H04N 7/14

[52] **U.S. Cl.** **348/7**; 348/10; 348/13; 348/12; 455/5.1; 455/4.2

[58] **Field of Search** 348/7, 10, 13, 348/12, 6; 455/5.1, 4.2, 3.1, 6.2; 370/428, 522; H04N 7/10, 7/14

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[57] **ABSTRACT**

The present invention is directed to a system and method for enabling a user to view a moving picture with synchronized audio using a workstation connected to a digital network. The user may change both speed and direction, as well as jump between arbitrary points in the movie being played. According to the present invention, digitized movie data may be accessed from different sources (e.g., network servers, local disks). These sources vary in speed and response time as a result of their capabilities (e.g., limited I/O bandwidth) and transient events (e.g., resource contention). The present invention adapts to these varying conditions in order to maintain a stable output.

18 Claims, 7 Drawing Sheets

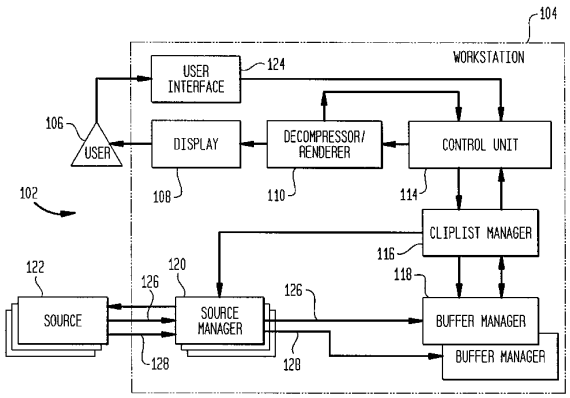

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FIG. 1

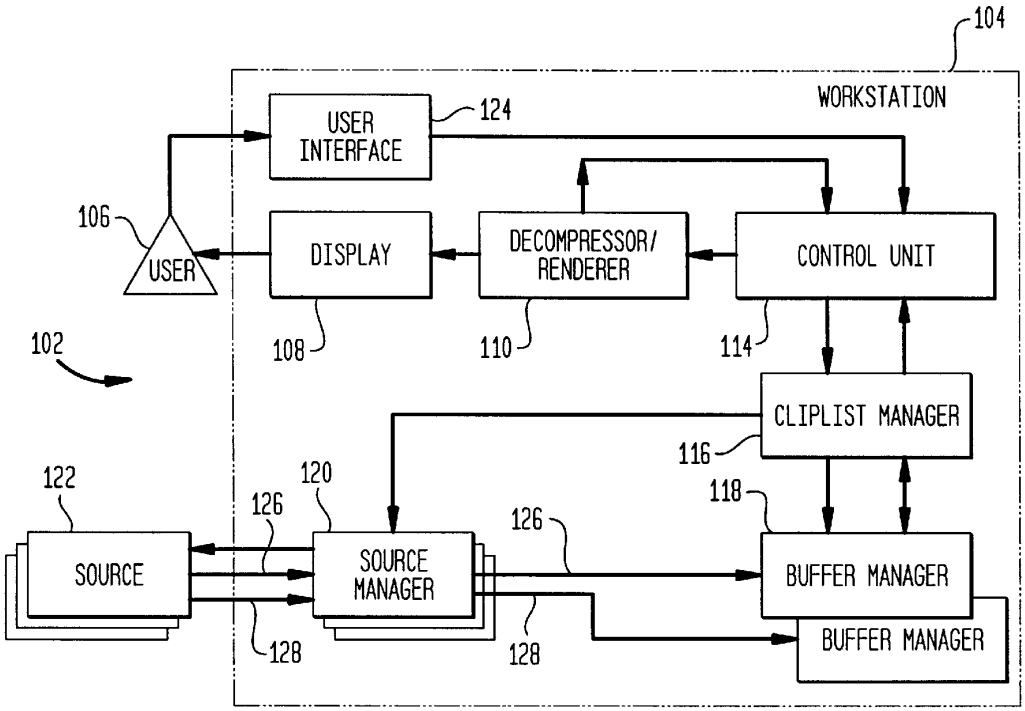
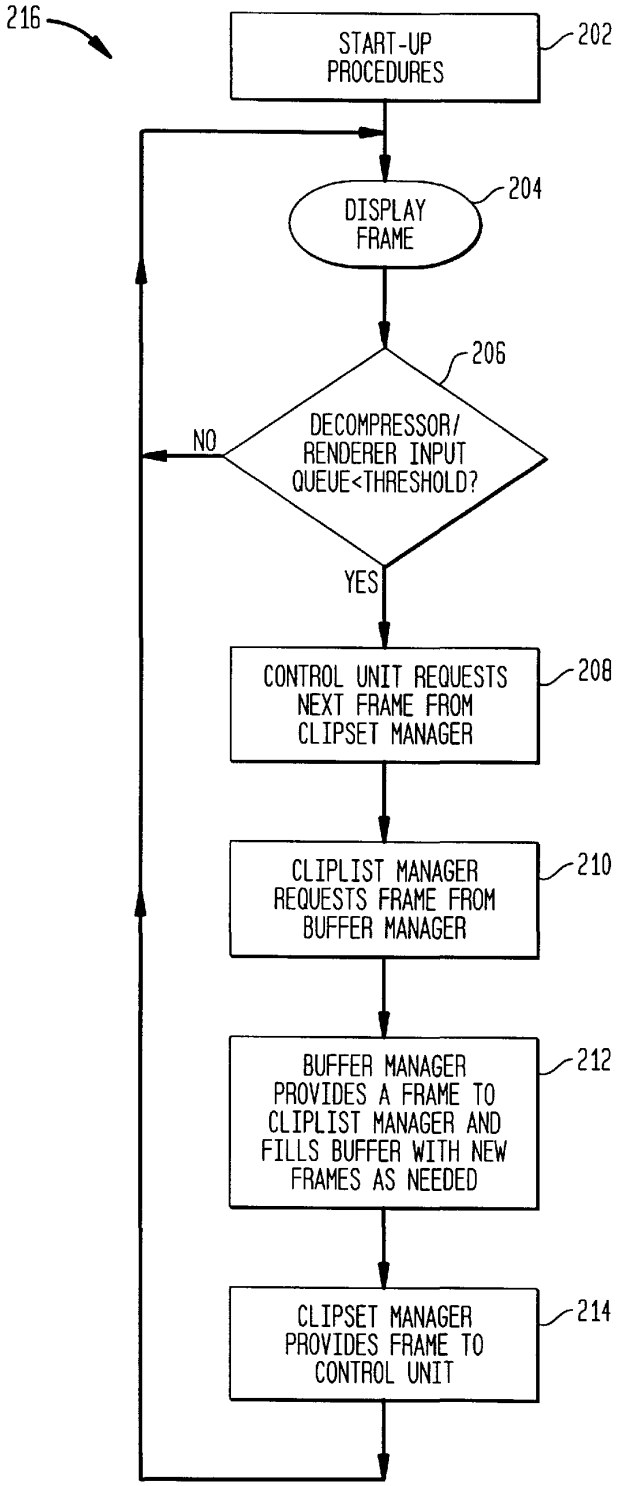

104
WORKSTATION
USER INTERFACE
124
106
USER
DISPLAY
DECOMPRESSOR/ RENDERER
CONTROL UNIT
102
108
110
114
CLIPLIST MANAGER
116
118
122
120
126
126
SOURCE
SOURCE MANAGER
BUFFER MANAGER
BUFFER MANAGER
128
128

FIG. 2


216
START-UP PROCEDURES
202
DISPLAY FRAME
204
DECOMPRESSOR/ RENDERER INPUT QUEUE<THRESHOLD?
206
NO
YES
CONTROL UNIT REQUESTS NEXT FRAME FROM CLIPSET MANAGER
208
CLIPLIST MANAGER REQUESTS FRAME FROM BUFFER MANAGER
210
BUFFER MANAGER PROVIDES A FRAME TO CLIPLIST MANAGER AND FILLS BUFFER WITH NEW FRAMES AS NEEDED
212
CLIPSET MANAGER PROVIDES FRAME TO CONTROL UNIT
214

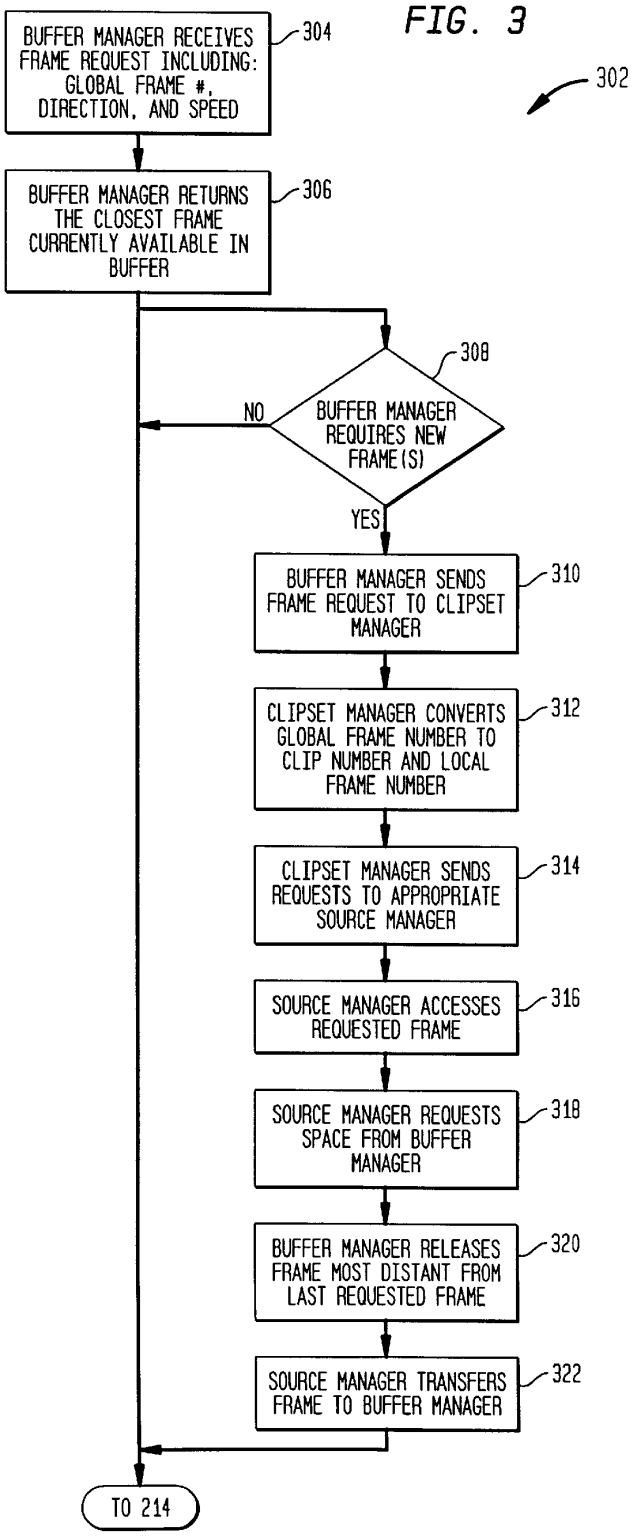


FIG. 3
302
BUFFER MANAGER RECEIVES FRAME REQUEST INCLUDING: GLOBAL FRAME #, DIRECTION, AND SPEED
304
BUFFER MANAGER RETURNS THE CLOSEST FRAME CURRENTLY AVAILABLE IN BUFFER
306
BUFFER MANAGER REQUIRES NEW FRAME(S)
308
NO
YES
BUFFER MANAGER SENDS FRAME REQUEST TO CLIPSET MANAGER
310
CLIPSET MANAGER CONVERTS GLOBAL FRAME NUMBER TO CLIP NUMBER AND LOCAL FRAME NUMBER
312
CLIPSET MANAGER SENDS REQUESTS TO APPROPRIATE SOURCE MANAGER
314
SOURCE MANAGER ACCESSES REQUESTED FRAME
316
SOURCE MANAGER REQUESTS SPACE FROM BUFFER MANAGER
318
BUFFER MANAGER RELEASES FRAME MOST DISTANT FROM LAST REQUESTED FRAME
320
SOURCE MANAGER TRANSFERS FRAME TO BUFFER MANAGER
322
TO 214

FIG. 4A

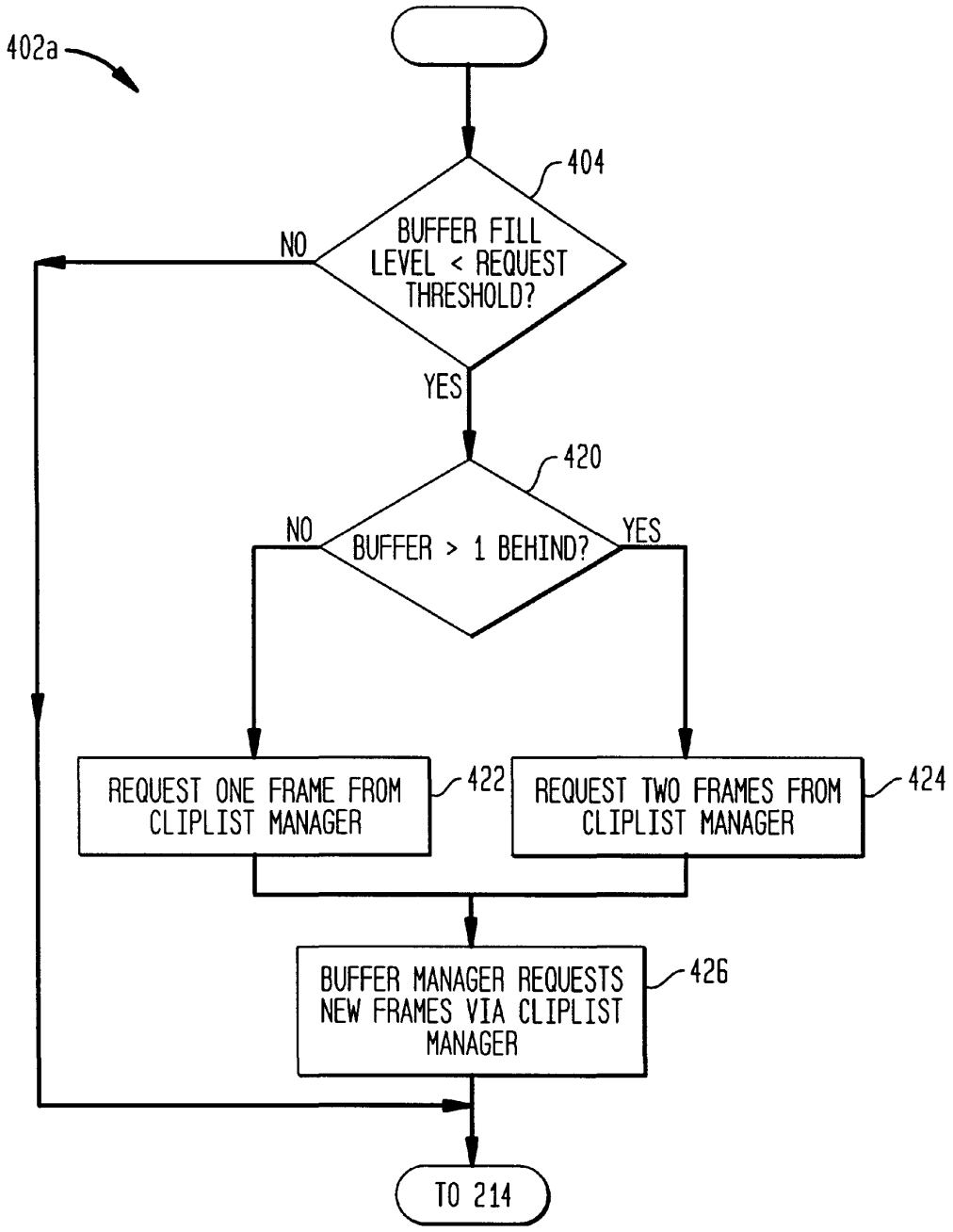

402a
404
BUFFER FILL LEVEL < REQUEST THRESHOLD?
NO
YES
420
BUFFER > 1 BEHIND?
NO
YES
REQUEST ONE FRAME FROM CLIPLIST MANAGER
422
REQUEST TWO FRAMES FROM CLIPLIST MANAGER
424
BUFFER MANAGER REQUESTS NEW FRAMES VIA CLIPLIST MANAGER
426
TO 214

FIG. 4B

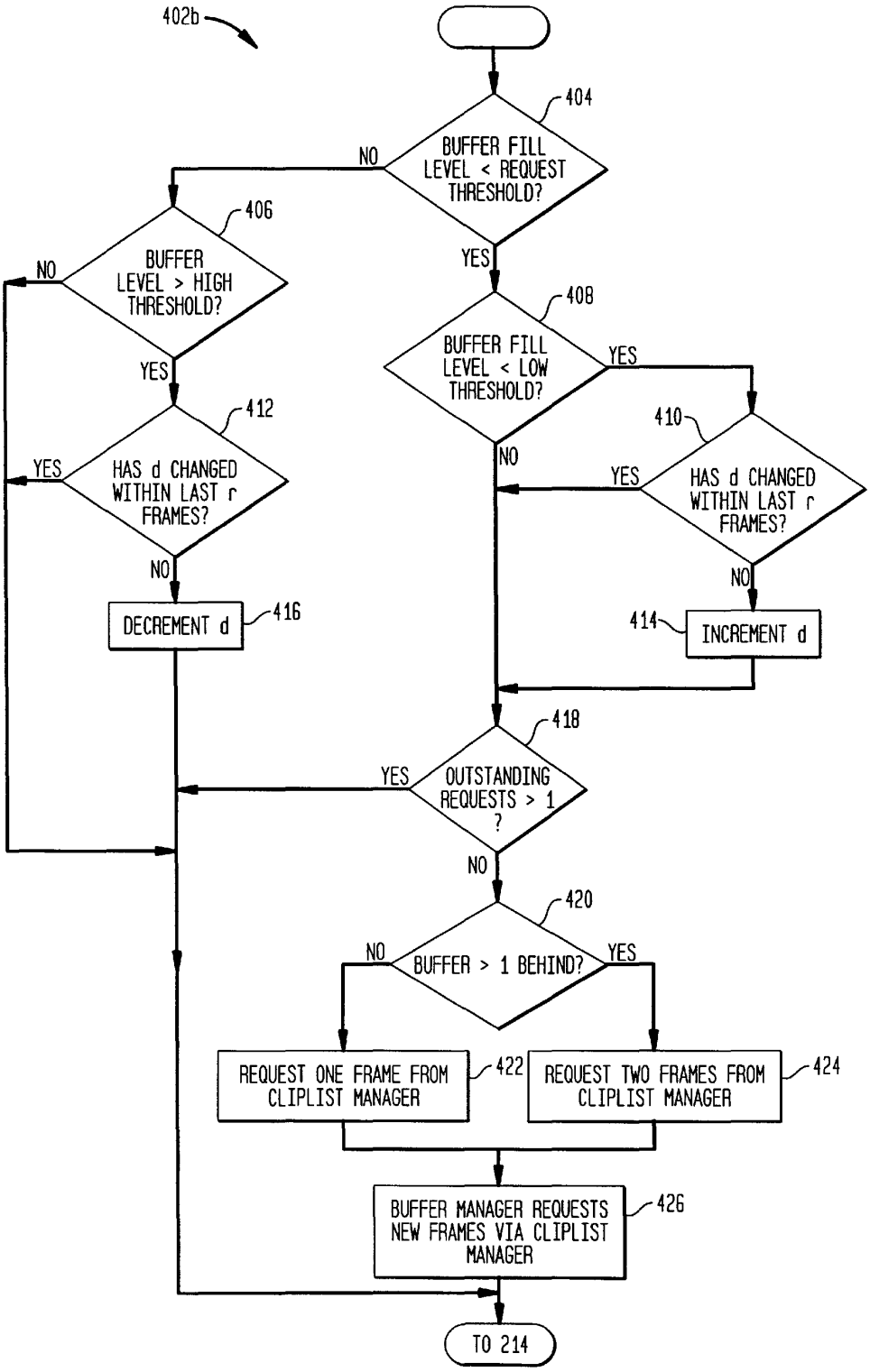

402b
404
BUFFER FILL LEVEL < REQUEST THRESHOLD?
NO
YES
406
BUFFER LEVEL > HIGH THRESHOLD?
NO
YES
408
BUFFER FILL LEVEL < LOW THRESHOLD?
YES
NO
412
HAS d CHANGED WITHIN LAST r FRAMES?
YES
NO
410
HAS d CHANGED WITHIN LAST r FRAMES?
YES
NO
DECREMENT d
416
INCREMENT d
414
418
OUTSTANDING REQUESTS > 1 ?
YES
NO
420
BUFFER > 1 BEHIND?
NO
YES
REQUEST ONE FRAME FROM CLIPLIST MANAGER
422
REQUEST TWO FRAMES FROM CLIPLIST MANAGER
424
BUFFER MANAGER REQUESTS NEW FRAMES VIA CLIPLIST MANAGER
426
TO 214

FIG. 5A

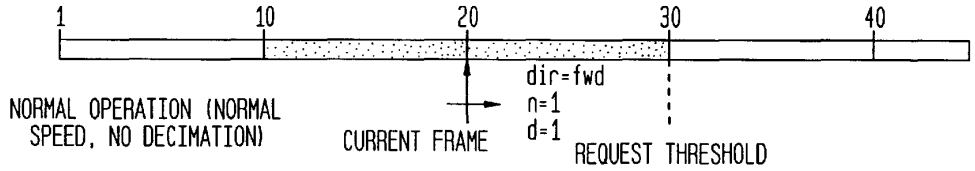


FIG. 5B

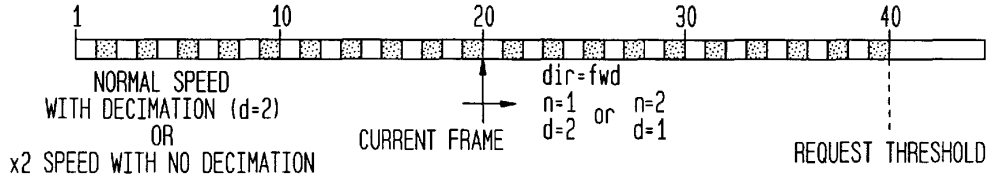


FIG. 5C

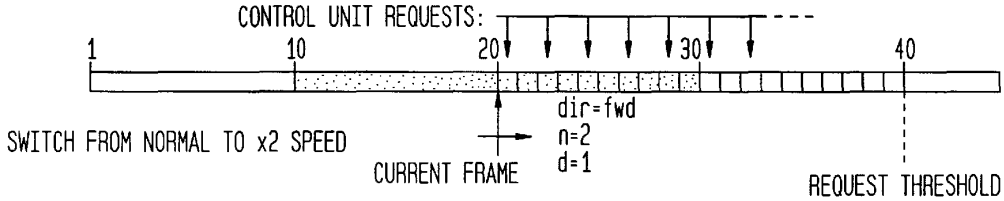


FIG. 5D

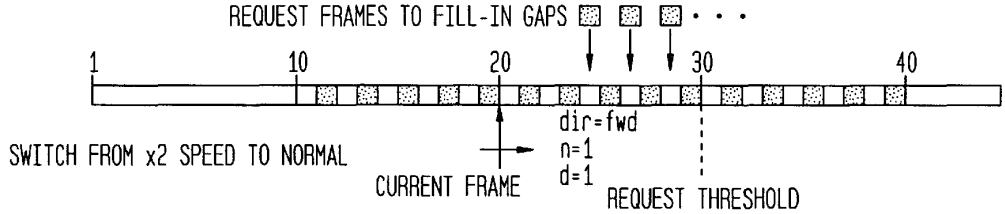


FIG. 6A

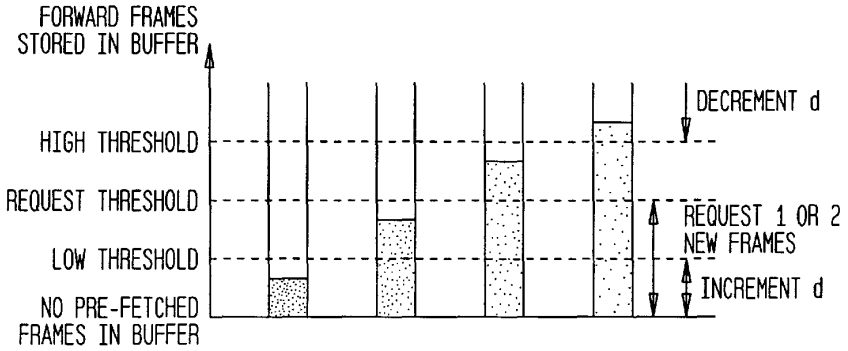


FIG. 6B

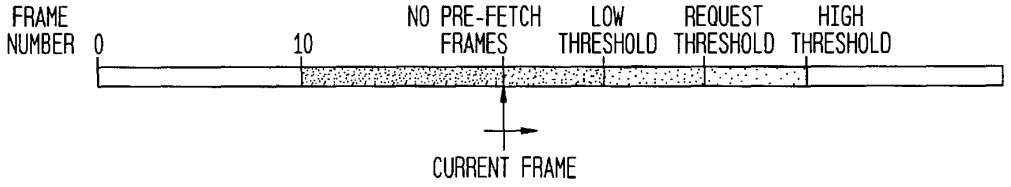
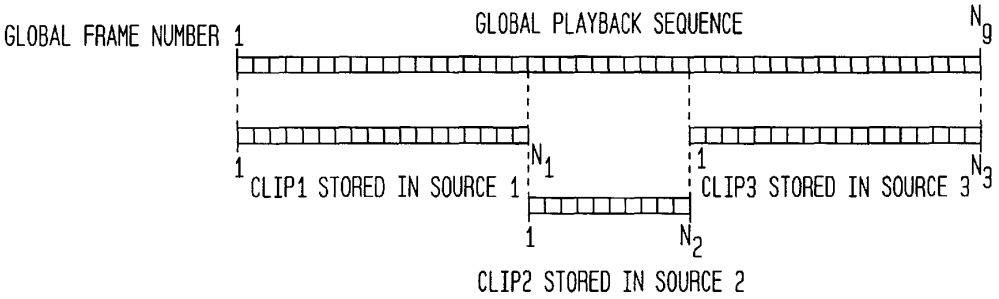


FIG. 7



HIGH-PERFORMANCE PLAYER FOR DISTRIBUTED, TIME-BASED MEDIA

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to audio/video playback devices, and more particularly to playing movie data held in various storage devices with varying bandwidth capabilities, where the movie player adapts to these varying conditions.

2. Related Art

Today, a wide variety of applications demand that a workstation display a moving image with accompanying sound. Often these workstations must access the audio and video data from multiple sources, some local and some accessed via a network connection. This data must be supplied to the display unit at a constant rate in order to achieve a steady picture. Problems arise when the data is not provided to the workstation at the required rate.

This problem is particularly acute when the data source must be accessed via a network. Delays in accessing data over standard networks tend to be longer and have a wider variance than accessing data from a local source (e.g., local RAM, local disk drive). Conventionally, one must insure that the network provides the data at a constant rate in order to achieve an acceptable output.

This solution, known as a "server push" solution, requires a powerful and complex server. The client, however, may be very simple. The client sends a request specifying what to play, and how fast to play it. The server responds by sending the requested information at the requested rate. Again, the rate at which the information flows from the server to the client must be very close to constant as the client has limited memory to buffer the information.

This approach presents several problems. Any interruption in the flow of data will cause an immediate degradation in output quality. Thus, there is no allowance for network contention or errors. Further, there is no feedback from the client to the server to advise the server of problems with the transmission. The client only sends messages to the server when the user issues a playback command, such as "stop," or "fast forward."

The primary advantage associated with the server push solution is the minimal cost of client hardware and software. However, this advantage is more than offset by the cost of a sophisticated server which must provide a guaranteed bandwidth and actively monitor the status of the client. This complexity has a deleterious effect on server reliability: increased sophistication results in decreased reliability.

A need exists for a system which offers high-performance, user-controlled playback over a general purpose computer network. Users often want to integrate this capability into an existing network which performs numerous other tasks as well. However, existing networks often are unreliable and unsophisticated, precluding the use of a server-push solution. Another solution which accommodates the use of an existing network would have obvious cost advantages over the server-push which requires a new, sophisticated network dedicated almost exclusively to audio/video playback.

Also, users have often invested heavily in relatively sophisticated client hardware, such as conventional personal computers or high-performance workstations. Again, this does not fit the server-push solution.

Numerous applications exist for the appropriate solution. Multi-media software, commonly used today in a variety of

environments, integrates moving pictures and sound. Dedicated machines are also being developed for playing games over a network. These games also involve sophisticated graphics and sound.

Finally, modern animation is often developed in a shared network environment where multiple animators access a common database. It is often the case where data needs to be accessed from different sources. Ideally, the scene currently being edited by the animator will be stored locally for easy access. In order to develop the scene in context, it is very useful to be able to play the scenes immediately before and after. These surrounding scenes, called "hook-ups", often are stored as part of a large library accessed via the network.

These hook-ups may be copied to the local machine before being played. However, this takes time and does not insure that the animator has been provided with the latest copy as editing of all scenes may be ongoing.

Thus, what is requires is an improved system and method for utilizing existing computer networks and client hardware to provide user-controlled, high performance audio/video playback.

SUMMARY OF THE INVENTION

Briefly stated, the present invention is directed to a system and method for user-controlled playback of synchronized audio and video information where the data is accessed via sources of varying bandwidth capabilities.

The system provides a buffer management system whereby the strategy for accessing data adapts as source capabilities change. The system attempts to prefetch data that is likely to be required in the near future. This buffering allows the system to provide constant picture quality in case the flow of data slows.

The present invention monitors the fill level of the buffer and if it has difficulty maintaining an acceptable level of data, the system begins to selectively make fewer requests. This allows the buffer to catch-up while easing the burden placed on the sources to provide data. As the buffer fills, the request strategy returns to normal.

The present invention also retains a certain amount of data just displayed. Having this data on hand allows the system to respond immediately to user requests for a change in direction of play.

Further features and advantages of the invention, as well as the structure and operation of various embodiments of the invention, are described in detail below with reference to the accompanying drawings. In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. The drawing in which an element first appears is indicated by the leftmost digit(s) in the corresponding reference number.

BRIEF DESCRIPTION OF THE FIGURES

The present invention will be described with reference to the accompanying drawings, wherein:

FIG. **1** is a block diagram of a digital network environment according to a preferred embodiment of the present invention;

FIG. **2** is a flowchart representing the general operation of the preferred embodiment;

FIG. **3** is a flowchart representing the preferred input/output operation of the buffer manager;

FIG. **4A** is a flowchart representing the basic operation of the preferred buffer management strategy;

FIG. 4B is a flowchart representing the operation of the preferred buffer management strategy including additional structures to account for abnormal operating conditions;

FIG. 5 represents the buffer management strategy given a variety of operating conditions;

FIG. 6 summarizes the various thresholds applied to the buffer fill level according to the preferred buffer management strategy; and

FIG. 7 represents the organization and representation of movie data within the preferred embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Overview of the Invention

The present invention is directed to a system and method for enabling a user to view a moving picture with synchronized audio using a workstation connected to a digital network. The user may change both speed and direction, as well as jump between arbitrary points in the movie being played. According to the present invention, digitized movie data may be accessed from different sources (e.g., network servers, local disks). These sources vary in speed and response time as a result of their capabilities (e.g., limited I/O bandwidth) and transient events (e.g., resource contention). The present invention adapts to these varying conditions in order to maintain a stable output.

FIG. **1** is a block diagram of a digital network environment **102** within which the invention is used. A user **106** utilizes the workstation **104** to play movie data. The workstation **104** may be a conventional personal computer, a high performance workstation, or dedicated hardware specially suited for audio/video playback. The user **106** views the movie data on display **108** while issuing control information (e.g., "go forward," "go backward," "play faster") via a standard user interface **124** (e.g., keyboard, mouse, joystick).

Movie data is composed of synchronized audio and video information. This information is broken into fundamental units called frames. For each video frame there is an associated audio frame. A video frame contains the video information to display a single image. An audio frame contains the audio information associated with that image. For ease of notation, the term 'frame' will be used throughout to refer to either audio or video frames, as they are generally treated the same.

A clip is a sequence of frames. The movie data of interest to a user will be composed of one or more clips.

Clips may be stored in different locations within the digital network environment **102**. For purposes of discussion, assume that the movie data of interest to the user contains N_c clips, each stored in a separate source **122**. The clips may or may not be stored according to a conventional compression format. Each source **122** may be any type of digital memory, and may be accessed either locally or via a network server. Note that a source may be a site on the Internet.

The workstation **104** contains a control unit **114** responsible for the overall control of the system. The control unit **114** receives control information from the user **106** via the user interface **124**. Examples of control information include commands to stop, reverse play, speed-up play, slow-down play, or skip to an arbitrary frame. The control unit **114** also receives control information from the decompressor/renderer **110**. This control path will be discussed below.

The display **108** provides a video image for the user **106**, while a conventional speaker (not shown) provides the audio. The decompressor/renderer **110** is responsible for decompressing the video and audio and presenting them to the display **108** in correct synchronization. The control unit **114** is responsible for feeding frames to the decompressor/renderer **110** in the proper sequence. Note that decompression is only required if the movie data is stored in a compressed format (e.g., JPEG for video information).

The buffer manager **118** provides frames upon request to the control unit **114** via the cliplist manager **116**. In order to provide frames quickly, the buffer manager **118** stores a limited number of frames in local digital memory, such as random access memory (RAM) or a local disk drive. The goal is to always have available the next frame required by the control unit **114** when that frame is requested. The buffer manager **118** accomplishes this goal by fetching frames likely to be required before they are requested. This will be referred to as prefetching future frames.

The buffer manager **118** also retains a certain number of the frames most recently sent to the control unit **114**. This allows the buffer manager **118** to respond immediately if the direction of play is reversed. These frames will be referred to as history frames.

The buffer manager **118** transfers frames to the control unit **114** via the cliplist manager **116**. It is the responsibility of the cliplist manager **116** to keep track of where within the digital network environment **102** each clip is stored. Thus, in order to replenish it's store of frames, the buffer manager **118** must request them via the cliplist manager **116**.

The cliplist manager **116** requests frames from a particular source **122** via the appropriate source manager **120**. The source manager **120** provides the necessary interface (i.e., hardware or software) for communicating with a source **122**. The digital network environment **102** includes an arbitrary number of sources (N_c) from which frames may be accessed. The workstation **104** provides one source manager **120** for each source **122**.

Movie data flows between the source **122**, the source manager **120**, and the buffer manager **118** along discrete paths, or tracks, with one track for each type of information. Two tracks will be described with respect to the preferred embodiment: audio and video. However, these are discussed by way of example only. Other types of data might also be useful. For example, in the context of professional video editing, user commentary would be a useful supplement to append to particular portions of the movie data.

Audio data flows along the audio track **126**, as shown in FIG. **1**. Similarly, video data flows along the video track **128**. Note that a separate buffer manager **118** is provided for each track. The buffer managers generally operate independently of each other, with two exceptions. First, they must provide audio and video frames to the control unit **114** synchronously so that image and audio are correctly aligned. Second, the concept of priority tracks, discussed in detail below, forces them to operate in a somewhat interdependent manner. However, unless otherwise specifically noted, the buffer managers all operate in an identical fashion, and all will be referred to as buffer manager **118**.

General Operation

FIG. **2** is a flowchart **216** representing the general operation of the present invention. The following discussion will also make references to the system depicted in FIG. **1**. In step **202**, the control unit **114** initiates start-up procedures when the user first requests playback of movie data. These procedures basically involve filing the buffer manager **118** with the appropriate frames, passing the first frame to the control unit **114**, and issuing other preparatory commands. A detailed description is provided below.

In step **204**, the control unit **114** causes the first frame to be displayed to the user by passing the data to the

decompressor/renderer **110**. The operation of the decompressor/renderer **110** is well known in the art, and as such will not be discussed in detail herein.

In step **206**, the control unit **114** monitors the input queues of the decompressor/renderer **110**. When the queue fill level drops below a certain threshold, the control unit **114** requests the next frame from the cliplist manager **116**, as shown in step **208**.

In step **210**, the cliplist manager **116** requests this frame from the buffer manager **118**. The buffer manager **118** provides a frame to the cliplist manager **116**, as shown in step **212**. The buffer manager **118** then refills its buffers with new frames as they are needed. This refill operation is critical to the present invention, and is described in detail below with respect to FIG. **3** and FIG. **4**.

In step **214**, the cliplist manager **116** gives the frame to the control unit **114**, which, in turn, gives it to the decompressor/renderer **110**. The operation continues by displaying the next frame, step **204**. Frames are displayed without interruption until the input queue in the decompressor/renderer **110** again falls below a threshold.

Buffer **1/0**

FIG. **3** is a flowchart **302** providing the detailed operation of step **212** as shown in FIG. **2**. In general, buffer manager **118** responds to requests for frames from cliplist manager **116** then determines whether new frames need to be loaded. If new frames are required, it uses the cliplist manager **116** to retrieve these frames from the appropriate source **122**. The source **122** accesses the requested frame then requests space from the buffer manager **118** before transferring it.

In step **304**, the buffer manager **118** receives a frame request from cliplist manager **116**. The request includes a global frame number (described below), the direction of play (i.e., forward or reverse), and the speed of play.

In step **306**, the buffer manager **118** returns the closest frame currently available in the buffer. Normally the exact frame is available. However, under certain circumstances this will not be the case (e.g., the buffer manager **118** was unable to retrieve a particular frame in time due to resource contention). Displaying the closest frame rather than the exact frame will cause some degradation in performance. This degradation, though, is preferable to suspending operation and displaying a blank screen.

At this point, the flowchart **302** indicates two paths. One path shows control passing back to step **214**, the other to step **308**. According to the preferred embodiment, these two paths are performed concurrently.

In step **308**, the buffer manager **118** determines whether additional future frames must be prefetched in order to have them on hand when they are later requested by the control unit **114**. This determination is described in detail below with respect to FIG. **4**. In a preferred embodiment, the buffer manager **118** either makes no request, requests one frame, or requests two frames. If the buffer manager **118** requests no frames, normal operation continues through step **214** without any further action by the buffer manager until the control unit **114** makes another request.

If the buffer manager **118** requests either one or two new frames, operation continues to step **310**. Note that frames may be referenced in one of two different ways. The control unit **114** and the buffer manager **118** reference frames according to a global frame number, as shown in FIG. **7**. Here, three clips are shown (N_c=3), each of a different length (N_1, N_2, N_3) and stored in a different source. The three clips together form the global playback sequence.

Frames may either be referenced according to their position within the global playback sequence (i.e., global frame number), or according to their position within the clip from which they originate (i.e., local frame number). The control unit **114** and the buffer manager **118** reference frames according to the former. Thus, requests from the control unit **114** may be answered by the buffer manager **118** without having to translate the frame number.

In step **310**, the buffer manager **118** sends requests for new frames to the cliplist manager **116**. The cliplist manager **116** maintains the mapping between global and local frame numbers. Thus, in step **312**, the cliplist manager **116** converts the global frame number to a clip number and local frame number.

In step **314**, the cliplist manager **116** requests the frames from the appropriate source manager **120**. The source manager **120** in step **316** retrieves the requested frame data from the source **122**.

In step **318**, the source manager **120** requests space in memory for the new frame(s) from the buffer manager **118**. The buffer manager **118** must then release a frame it is currently storing to provide space for the incoming frame, as shown in step **320**.

Many possible strategies might be used to determine which frame is released. According to a preferred embodiment, the buffer manager **118** releases the frame that is most distant from the frame that the buffer manager **118** has most recently requested. In general, the goal is to retain frames that are likely to be used soon and to release those unlikely to be needed. This simple approach works well in practice and is easily implemented.

In step **322**, the source manager **120** transfers the requested frame to the buffer manager **322**. Operation continues in step **214** with no further action by the buffer manager **118** until the control unit **114** requests another frame.

Buffer Management

FIG. **4** is a flowchart **402** representing the buffer management strategy of the present invention, and is a detailed representation of step **308** as shown in FIG. **3**. The following discussion will also involve FIG. **5** and FIG. **6**, which depict the buffer management strategy under a variety of operating conditions.

The buffer management strategy is first described under normal operating conditions, as depicted in FIG. **4**A The strategy is then described under a variety of abnormal conditions: high speed play, starting play, stopping play, reduced source bandwidth, increasing play speed, decreasing play speed, changing direction, and jumps in location. FIG. **4**B includes additional operational details relating to how these conditions are handled.

Normal Operation

First consider the case where the user is playing the movie at a normal play speed in the forward direction (i.e., normal operation). The goal of the buffer manager **118** is to retain some frames that have recently been shown to the user (i.e., history frames), and to get frames that will soon be shown to the user if the current speed and direction are maintained (i.e., future frames).

Referring to FIG. **4**A, the buffer manager **118** determines whether the buffer fill level has dropped below the request threshold, as shown in step **404**. The buffer fill level refers to the number of future frames currently being stored in the buffer manager **118**, not frames that have been requested but not yet received. The request threshold represents the optimum number of future frames stored in the buffer at any given time, and should be determined based on the characteristics of a particular system (e.g., I/O bandwidth, source latency).

The buffer manager **118** retains a number of history frames equal to the request threshold as well; the reasons for this will become apparent when reverse-play is discussed.

The buffer manager **118** will not request additional frames when the fill level exceeds the request threshold. Additional frames might be requested if the fill level drops below the threshold depending upon other factors. For the purposes of discussing normal operation, assume that these factors do not come into play and at least one additional frame will be requested when the fill level does not exceed the request threshold.

In step **420**, the buffer manager **118** determines by how many frames the request threshold exceeds the fill level. The buffer manager **118** will request one new frame from the cliplist manager **116** if the request threshold exceeds the fill level by one frame (i.e., one frame behind). If the buffer manager **118** is more than one frame behind, it will request two new frames. However, in a preferred embodiment no more than two new frames will be requested for each request received from the cliplist manager **116** in order to avoid overloading the sources. Hence, if the play rate is 24 frames per second, the sources will not be asked to supply more than 48 frames per second. However, the present invention is not limited to requesting only two frames at a time, as would be apparent to one skilled in the art.

In step **422**, the buffer manager **118** requests one new frame. Under normal operating conditions, the global frame number of the new frame is calculated by adding one to the last request made by the buffer manager **118**. In step **424**, the buffer manager requests the next two frames following the last request. The buffer manager **118** requests these frames via the cliplist manager **116** in step **426**. Operation continues with step **214**.

FIG. **5**(*a*) provides an example of the normal operation of the buffer manager **118** (i.e., forward play at normal speed). In this example, the control unit **114** has recently asked for frame 20. As was mentioned previously, the control unit **114** provides the direction and the speed of play in addition to a global frame number with every frame request.

When the control unit **114** requests global frame 20 (via the cliplist manager **116**), the buffer manager **118** replies by providing global frame 20 to control unit **114** via cliplist manager **116** and checks the fill level against the request threshold (for this example, request threshold=10). The buffer manager **118** does this by checking to see if it has frames 21 through 31. Normally, the most distant frame has not been requested. Assuming this is the case, the buffer manager **118** will then request global frame 31. This request is sent to the cliplist manager, which maps the global frame number to a clip number and local frame number and forwards the request to the appropriate source.

As mentioned above, the source manager **120** contacts the buffer manager **118** to reserve space for the new frame once it has been retrieved. In the preferred embodiment, the buffer manager **118** releases the frame that is most distant from the frame that the buffer manager has most recently requested. Here, global frame number **10** is released.

The following sections will discuss buffer management strategy under abnormal conditions (i.e., conditions other than forward play, normal speed).

High Speed Play

The sources **122** and the decompressor/renderer **110** often have difficulty displaying every frame at speeds faster than normal playback. The current invention solves this problem by showing every nth frame, where n is the absolute value of the rate of play, rounded up. So, to play at two times normal speed, every second frame is shown at the same rate (frames/second) as before. FIG. **5**(*b*) depicts this situation.

In steps **422** and **424** of FIG. **4**A, the buffer manager now adds n to the last frame requested when determining which frames to request. Note that the control unit **114** and the buffer manager **118** may get out of phase. The control unit may request frames 34, 36, 38, 40, . . . , while the buffer manager may be requesting 35, 37, 39, 41, ... In this case, the buffer manager **118** returns the closest frame it has. This will result in no loss of quality for the user, nor will it impair the user's ability to perform any task otherwise available.

Now when computing the buffer fill level, every nth frame is counted rather than every frame. The buffer manager **118** must look further into the future to meet the request threshold. As shown in FIG. **5**(*b*), the request threshold moves twice as far into the future at double speed. This alteration does not require that the buffer manager **118** operate faster or store more information; it only requires that the frames be fetched in a different order.

Note that the strategy for releasing frames from the buffer manager **118** that was discussed above continues to work with this modified strategy for requesting frames.

Inadequate Source Bandwidth

The preceding discussion assumed that the sources **122** will always be able to provide frames at the normal play rate. The buffer management strategy described thus far will operate properly with some jitter in source performance, so long as the sources **122** perform at the desired rate averaged over several frames (less than half the number of frames stored by the buffer manager **118**). However, not all sources will be able to meet this requirement. Some problems may be transitory (e.g., temporary resource contention), others will be continuous (e.g., low-speed networks).

The current invention solves this problem by modifying the buffer management strategy in several ways. These modifications are reflected in flowchart **402***b* of FIG. **4**B.

First, the buffer manager **118** monitors the number of requests for frames that are outstanding with the sources **122**. Having a large number of outstanding requests will not likely increase performance. It will, however, increase latency when the user changes direction or jumps to another clip. This is because all of the old, outstanding requests must be processed before any new requests. Thus, keeping the queue of outstanding requests short reduces latency.

Thus, the buffer manager **118** limits itself to two outstanding requests, as shown in step **418** of FIG. **4**B. This works well for configurations that have been tested. With high-latency, high-bandwidth networks, the number may have to be increased. Decreasing the number might make sense for networks with very low latency and very low bandwidth.

In step **418** of FIG. **4**B, the buffer manager **118** determines the number of outstanding requests before it requests new frames. No new requests are made if the number of outstanding requests is greater than two. Note that under these circumstances the buffer manager **118** will tend to fall behind, since it only requests new frames when the control unit **114** requests frames.

The current invention solves this problem by monitoring the buffer fill level and decimating requests from the buffer manager **118** when the fill level drops below a low threshold.

In step **408**, the buffer manager **118** determines whether the buffer fill level has dropped below the low threshold. A decimation factor d is maintained for each track. Each track begins with a decimation value of one (i.e., no decimation). The buffer manager **118** increments by one the decimation factor for a given track when the buffer fill level associated with that track drops below the low threshold, as shown in step **414**.

In the absence of decimation, the buffer manager **118** determines which frame to request by adding n (i.e., the

speed of play) to the global frame number of the last frame requested. With decimation, the buffer manager **118** determines the next request by adding n×d to the last global frame number requested, where d is the track's decimation factor. FIG. **5**(*b*) illustrates an example of this operation.

Note that this operation is functionally equivalent to high speed play (n=2) with no decimation, with one difference. Even though the buffer manager **118** begins decimating it's requests in order to catch up, the control unit **114** continues to request each frame. As described in step **306** (FIG. **3**), the buffer manager **118** returns the closest available frame. Thus, the control unit **114** displays each frame d times during periods of decimation while the buffer manager **118** catches up. By comparison, this does not occur during high speed play. Here, every nth frame is displayed once, resulting in video and sound that appears n× faster because the same number of frames are being displayed per second.

In step **406**, the buffer manager **118** determines whether the buffer fill level exceeds a high threshold. This situation might occur after a period of decimation and result in some oscillation. The buffer manager **118** decrements the decimation factor d for a given track when this occurs, as shown in step **416**. Thus, in the case of transitory problems, the decimation factor will be reduced when the problem is solved.

This basic approach to decimation does not work well. It tends to oscillate badly. To dampen the oscillations, the decimation factor is changed at most once every r requests for frames from the control unit, as illustrated by steps **410** and **412**. The value of r is a tunable parameter. Increasing r reduces the oscillations but can result in the decimation factor not increasing fast enough in response to sudden network problems. Careful tuning of r and the number of future frames stored by the buffer manager **118** can minimize the problem.

FIG. **6** graphically summarizes the various thresholds applied to the buffer fill level. FIG. **6**(*a*) shows that d is incremented by one when the fill level is less than the low threshold, and decremented by one when the fill level increases above the high threshold. Also, the buffer manager **118** requests two new frames when the fill level is two frames less than the request threshold, one frame when the fill level is one frame less than the request threshold, and no frames requested otherwise.

The buffer management strategy also treats audio and video information differently. In general, a movie consists of an audio track and a video track. The audio information is typically much smaller than the video information. Also, users are far more aware of losing audio information than video information. Thus, the buffer manager **118** decimates the video track more aggressively than the audio track.

The current invention implements this strategy by designating certain tracks as priority tracks. Audio tracks are marked as priority tracks by default. Video tracks are not normally marked as priority tracks.

When the buffer manager **118** associated with a priority track determines that it must increment or decrement the decimation factor, it increments or decrements a global decimation factor gas well. Priority tracks are never actually decimated; the decimation factor associated with a priority track is used to monitor how much that track has contributed to global decimation. Rather than decimating a priority track, all the other tracks are decimated instead in an attempt to reduce resource contention. This should allow the priority tracks to catch up.

Now, in steps **422** and **424** for non-priority tracks, the next frame requested is found by adding n×(d+g) to the number of the last frame requested. Again, priority tracks are never decimated. The next frame is therefore found by adding n to the last frame requested, as before.

Finally, the buffer manager **118** normally uses the global frame number last requested as the starting point for determining which frame to request next. In extreme cases this frame can be further in the past than the most recent frame that the control unit **114** has requested. When this happens, the number of the frame most recently requested by the control unit **114** is used as the starting point instead.

Increasing Play Rate

FIG. **5**(*c*) illustrates the situation where the user changes speed from normal (n=1) to twice normal (n=2). The buffer manager **118** had been requesting every frame, according to normal operating conditions. With the speed increase, the control unit **114** now expects the buffer manager **118** to provide every other frame. Thus, the change in speed effectively reduces the buffer fill level by half, as the control unit **114** is no longer interested in every other frame stored in the buffer.

This may cause the buffer manager **118** to decimate until the buffer fill level stabilizes at the new play speed. This decimation may be noticeable to the user, though it may be minimized by tuning the size of the buffer and the high and low thresholds.

Decreasing Play Rate

FIG. **5**(*d*) illustrates the situation where the user changes speed from twice normal (n=2) to normal (n=1). Both the buffer manager **118** and the control unit **114** had been requesting every other frame. With the speed decrease, the control unit **114** now expects the buffer manager **118** to provide every frame.

In this situation, the buffer manager **118** must try to fill in the missing frames (i.e., infill). It can concentrate on this as there is no need to fetch frames that are further in the future; the buffer manager **118** already has closely spaced frames twice as far in the future as it needs.

The problem is to decide where to start trying to infill. If the buffer manager **118** begins by requesting the first missing frame, this may not allow the source **122** enough time to retrieve the frame before the control unit **114** requests it. Preferably, the buffer manager **118** will skip a few frames into the future to begin to infill. The exact number to skip should be tuned according to a particular configuration, and depends primarily on system latency.

The buffer manager **118** will continue to provide the closest available frame to the control manager **114** during the brief period before infilling begins. As a result, available frames will be displayed multiple times wherever new frames could not be infilled before being requested by control unit **114**. Though the user will experience some momentary degradation in picture and sound quality, this is preferable to halting operation while the buffer manager **118** infills completely.

Changing Direction

As described above, the buffer manager **118** retains the n_h frames most recently sent to the control unit **114** (i.e., history frames), where n_h equals the request threshold. Thus, the buffer manager **118** retains as many history frames as the optimum number of future frames. This situation is illustrated by FIG. **5**(*a*) and FIG. **6**(*b*).

Retaining history frames allows the current invention to change direction of play instantly without any degradation in audio or picture quality. The buffer manager **118** simply begins returning past frames when requested by the control unit **114**. The operation proceeds exactly as described above.

Note that some degradation of performance will likely result if the number of outstanding requests for new frames

is not limited. As discussed above, the buffer manager **118** preferably limits itself to one outstanding request. Allowing more causes latency problems when the direction of play is reversed. Upon reversing direction, the buffer manager **118** will immediately begin requesting new frames according to the new direction. However, these requests must wait until all the pending requests made while playing in the opposite direction are satisfied first.

This problem might be solved by providing the buffer manager **118** with the capability to abort these outstanding requests. According to the preferred embodiment, the costs in additional system complexity associated with such capability outweigh the benefits associated with reduced latency. Thus, limiting the number of outstanding requests to one is the preferable solution.

Starting

The buffer manager **118** has no frames stored when the user **106** begins using the workstation **104**. Play cannot begin until the buffer manager **118** receives the appropriate frames. At start-up, the control unit **114** advises the cliplist manager **116** of the first frame selected by the user **106**; this might be the first frame in the global playback sequence or some arbitrary point therein. The cliplist manager **116** passes this information on to the buffer manager **118**, which requests a group of frames on either side of this starting frame. This initial request may vary in size; preferably the buffer manager **118** will request as many frames as can be stored.

The delay perceived by the user **106** should be minimal. Assuming that the sources **122** are capable of delivering data at approximately the same rate that frames are display, the delay will equal the amount of play time stored in the buffer. This is an acceptable start-up delay, particularly if other tasks may be accomplished concurrently, such as other initialization procedures.

Stopping

Play may halt for a variety of reasons. The user may stop playback by issuing the appropriate command via the user interface **124**, or the control unit **114** may reach the first or last frame in the global playback sequence. As in the starting case, the cliplist manager **116** advises the buffer manager **118** of the situation. The buffer manager **118** preferably takes advantage of this opportunity to ensure that the optimum number of future and history frames are currently being stored. If frames are missing, the buffer manager **118** will immediately make the appropriate requests.

When the user **106** issues a stop command, the decompressor/renderer **110** notifies the control unit **114** of the frame currently being displayed. Due to decompression and rendering latency, this is not likely to be the frame that the control unit **114** has most recently handled. By providing this information from the decompressor/renderer **110** to the control unit **114**, the user can be given more rapid response to stop requests.

Jumps in Location

The user interface **124** allows the user **106** to issue commands such as "go to frame 42." It is unlikely that the buffer manager **118** will have frame 42 when this command is issued. Thus, jumps in location are treated like the start up case, where the first frame to be shown is the target frame of the "go to" command.

Supporting Multiple Clips

In typical usage, the current invention accesses a global playback sequence consisting of several clips. The cliplist manager **116** specifies where each clip can be found (e.g., file name on the local disk, server identification number and file name), which frame in the clip is the first to play, and which frame in the clip is the last to play. The compilation of this data is known as the cliplist. A typical cliplist might look like:

server1/sequence1/scene2/latest.movie 50 138
local myscene3.movie 0 123
server1/sequence1/scene4/latest.movie 0 50

This example cliplist has three clips. The first clip is local frames 50 through 138 from the file "/sequence1/scene2/latest.movie". Similarly, the second clip is local frames 0 through 123 in "myscene3.movie", and the third clip is local frames 0 through 50 in "/sequence1/scene4/latest.movie". The second clip is stored locally on the user's workstation. The first and third are located on server1.

The cliplist manager **116** determines the overall length in frames of the global playback sequence (e.g., 138−50+1+124+51=264), and builds a table which maps global frame numbers to clip numbers and local frame numbers. The cliplist manager **116** also creates three source managers **120** of the appropriate types. The source managers **120** may be implemented as hardware or software, as would be well known to someone skilled in the art.

An example operation might proceed as follows. The control unit **114** requests global frame number 95 from the cliplist manager **116**, which forwards the request to the buffer manager **118**. The buffer manager **118** returns this frame (or the closest available frame) and determines whether any new frames need to be requested.

Assuming normal playback speed and a request threshold of **10**, the buffer manager **118** will check to see if global frames 96 through 106 are currently being stored, or whether they have been requested. The most likely case is that all but frame 106 will be requested or already stored. In this case, the cliplist manager **116** maps global frame 106 to clip **2**, local frame 17, then requests this frame from the second source manager **120**. Note that clip **1** occupies frames 1 through 89 of the global playback sequence, clip **2** occupies 90 through 213. Thus, global frame number 106 corresponds to local frame 17 (106−89) in clip **2**.

When that frame is received, the source manager **120** will arrange with the buffer manager **118** to have it inserted into the buffer as global frame 106.

If all of the global frames 96 through 106 have been requested or are stored in the buffer, no new frames will be requested. If more than one frame is needed, at most two will be requested.

While the preferred embodiment of the present invention has been described above, it should be understood that it has been presented by way of example only, and not limitation. Thus, the breadth and scope of the present invention should not be limited by the above-described exemplary embodiment, but should be defined only in accordance with the following claims and their equivalents.

Write Operations

The description of the present invention has thus far centered only on operations whereby movie data is read from memory and displayed. However, the foregoing discussion applies equally well to other embodiments where the movie data may be modified as it is displayed. The user interface **124** might provide editing controls for the user **106** to make alterations in the movie data. These alterations would be recorded by the control unit **114**, with the modified frame being sent back to the buffer manager **118** to replace the old frame. These, and other like embodiments would be readily apparent to someone skilled in the relevant art.

What is claimed is:

1. A system for playing digital movie data under the control of a user, wherein the movie data comprises a sequence of frames, said system comprising:

display means for displaying the movie data to said user;

control means, coupled to said display means, for providing the movie data to said display means under control of said user;

user interface means, coupled to said control means, for interacting with said user to provide said control of said user;

at least one source means that stores a portion of the movie data; and

buffer management means, coupled to said control means and to said source means, for storing a subset of the movie data and providing the movie data as needed to said control means, said buffer management means comprising:

local digital memory that stores a plurality of frames including future frames and history frames,

prefetch means for requesting future frames from said source means, wherein said prefetch means requests every dth future frame when said source means cannot provide future frames at the rate at which they are requested, and wherein d is greater than one; and

means for releasing a select frame from said local digital memory when a frame requested by said prefetch means becomes available.

2. The system of claim **1**, wherein said select frame is the frame in said subset most distant from the frame last requested by said prefetch means.

3. The system of claim **1**, wherein said user interface means comprises:

speed control means for causing said control means to provide every nth one of said frames to said display means; and

direction control means for controlling the order in which said frames are provided to said display means.

4. The system of claim **1**, further comprising:

cliplist management means, coupled to said control means and further coupled between said buffer management means and said source means, for tracking where said frames are stored within said source means and for routing requests from said prefetch means to said source means.

5. The system of claim **1**, wherein at least one of said source means comprises a digital memory accessed via a digital network.

6. The system of claim **5**, wherein said source means comprises a local disk drive.

7. The system of claim **1**, wherein said buffer management means provides a frame from said local digital memory nearest to the frame requested by said control means.

8. The system of claim **1**, wherein said prefetch means compares the buffer fill level to a request threshold and requests a select number of frames based on this comparison.

9. The system of claim **8**, wherein said prefetch means requests no frames if the buffer fill level is greater than said request threshold, one frame if the buffer fill level is equal to or one frame less than the request threshold, and two frames if the buffer fill level is two frames or more less than the request threshold.

10. The system of claim **1**, wherein said prefetch means makes fewer requests if the number of outstanding requests with said source means is greater than a threshold.

11. The system of claim **1**, wherein said buffer management means further comprises:

infill means for infilling gaps in said subset.

12. A workstation for playing digital movie data under the control of a user, wherein the movie data comprises a plurality of tracks, the plurality of tracks including at least an audio track and a video track, wherein each of the tracks comprises a sequence of synchronized frames, and wherein at least one remote source means stores a portion of the movie data, the workstation comprising:

display means for displaying the movie data to said user;

control means, coupled to said display means, for providing the movie data to said display means under control of said user;

user interface means, coupled to said control means, for interacting with said user to provide said control of said user;

a plurality of buffer management means, one for each of said tracks, coupled to said control means and to the remote source means, for storing a subset of the movie data and providing the movie data as needed to said control means, said buffer management means comprising:

local digital memory that stores a plurality of frames including future frames and history frames,

prefetch means for requesting future frames from the remote source means, and

means for releasing a select frame from said storage means when a frame requested by said prefetch means becomes available; and

cliplist management means, coupled to said control means and further coupled between said buffer management means and the remote source means, for tracking where said frames are stored within the remote source means and for routing requests for future frames from said prefetch means to the remote source means.

13. The workstation of claim **12**, wherein said prefetch means comprises:

retrieval means for selectively requesting future frames;

decimation means for causing said retrieval means to request every dth future frame when the remote source means cannot provide movie data at the rate requested; and

outstanding request means for causing said retrieval means to make fewer requests on the basis of the number of outstanding requests with the remote source means.

14. The workstation of claim **13**, wherein said decimation means comprises:

designation means for designating certain of said tracks as priority tracks;

decimation counter means for incrementing a decimation counter d when the buffer fill-level drops below a low threshold and decrementing said decimation counter d when the buffer fill-level exceeds a high threshold;

global decimation counter means for incrementing a global decimation counter g each time a decimation counter d is incremented for one of said priority tracks, and decrementing said global decimation counter g each time a decimation counter d is decremented for one of said priority tracks; and

means for causing said retrieval means to request every future frame for priority tracks, and every (d+g)th future frame for tracks not designated as priority tracks.

15. A method for playing digital movie data under the control of a user, wherein the movie data comprises a sequence of frames, and wherein at least one source stores a portion of the movie data, comprising the steps of:

(a) storing a plurality of frames including future frames and history frames in local storage, wherein said future

frames and said history frames are a subset of the movie data, and wherein a buffer fill level indicates the degree to which said future frames and said history frames fill the local storage;

(b) tracking the location of the frames comprising the movie data within the one or more sources;

(c) requesting future frames from the one or more sources, wherein said step of requesting includes the steps of:

(I) requesting a first number of future frames based on a comparison of said buffer fill level to a request threshold, and

(ii) requesting every dth future frame when said source means cannot provide future frames at the rate at which they are requested, and wherein d is greater than one; and

(d) displaying said locally stored frames under the control of the user.

16. The method of claim **15**, wherein said first number is zero if said buffer fill level is greater than said request threshold, wherein said first number is one if said buffer fill level is equal to or one frame less than said request threshold, and wherein said first number is two if said buffer fill level is two frames or more less than said request threshold.

17. A system for playing digital movie data under the control of a user, wherein the movie data comprises a sequence of frames, said system comprising:

display means for displaying the movie data to said user;

control means, coupled to said display means, for providing the movie data to said display means under control of said user;

user interface means, coupled to said control means, for interacting with said user to provide control to said user;

at least one source means that stores a portion of the movie data; and

buffer management means, coupled to said control means and to said source means, for storing a subset of the movie data and providing the movie data as needed to said control means, said buffer management means comprising:

local digital memory that stores a plurality of frames including future frames and history frames, wherein a buffer fill level indicates the degree to which said future frames and said history frames fill said local digital memory;

prefetch means for requesting every dth future frame from said source means, wherein said prefetch means increments d when said buffer fill-level drops below a low threshold and decrements d when said buffer fill-level exceeds a high threshold; and

means for releasing a select frame from said local digital memory when a frame requested by said prefetch means becomes available.

18. A method for playing digital movie data under the control of a user, wherein the movie data comprises a sequence of frames, and wherein at least one source stores a portion of the movie data, comprising the steps of:

(a) storing a plurality of frames including future frames and history frames in local storage, wherein said future frames and said history frames are a subset of the movie data, and wherein a buffer fill level indicates the degree to which said future frames and said history frames fill the local storage;

(b) tracking the location of the frames comprising the movie data within the one or more sources;

(c) requesting future frames from the one or more sources, wherein said step of requesting includes the steps of:

(I) requesting a first number of future frames based on a comparison of said buffer fill level to a request threshold, and

(ii) requesting every dth future frame, wherein d is incremented when said buffer fill-level drops below a low threshold, and wherein d is decremented when said buffer fill-level exceeds a high threshold; and

(d) displaying said locally stored frames under the control of the user.

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