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Ganesan et al.

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(54) **VARIABLE BIT RATE ENCODING**

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(52) **U.S. Cl.** **375/240.02**; 375/240.03

(58) **Field of Classification Search** 375/240, 375/240.01, 240.02, 240.03, 240.12, 240.16; 382/236; 386/329
See application file for complete search history.

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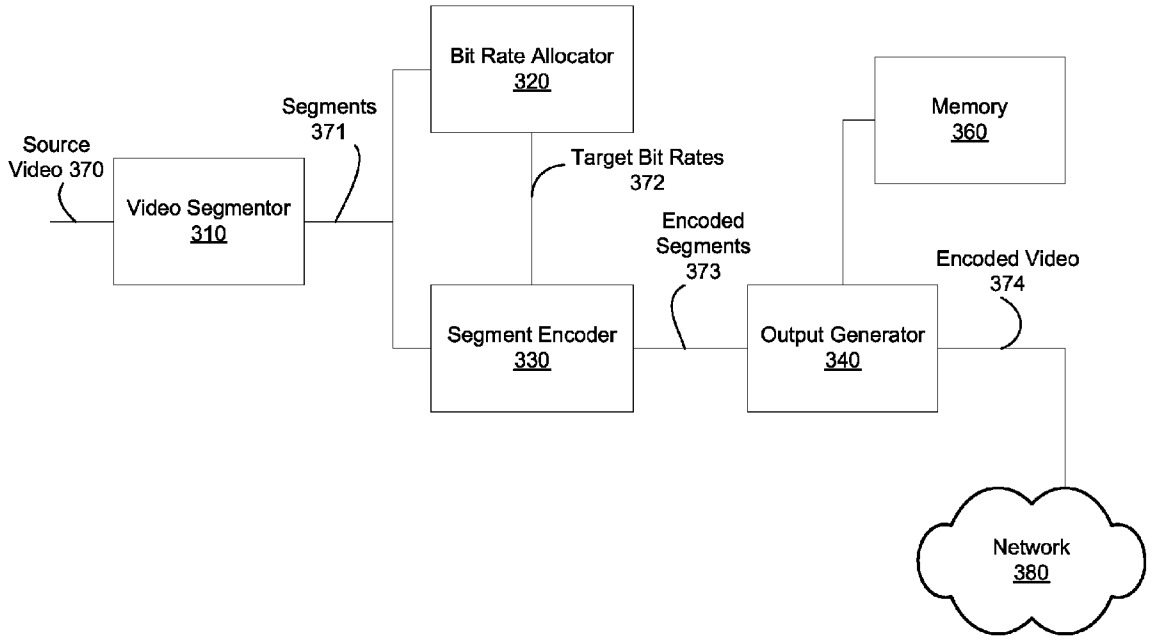
* cited by examiner

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(74) *Attorney, Agent, or Firm* — Mahamedi Paradice Kreisman LLP

(57) **ABSTRACT**

A system, machine-readable medium and method for processing video comprising a video segmentor configured to receive a source video and to split the source video into segments; a bit rate allocator configured to receive the segments and generate target bit rates corresponding to the segments; a first encoder coupled to receive the plurality of segments and the target bit rates and configured to encode each of the segments using one of the target bit rates to generate encoded segments; and an output generator configured to receive the encoded segments and generate an encoded video.

25 Claims, 9 Drawing Sheets



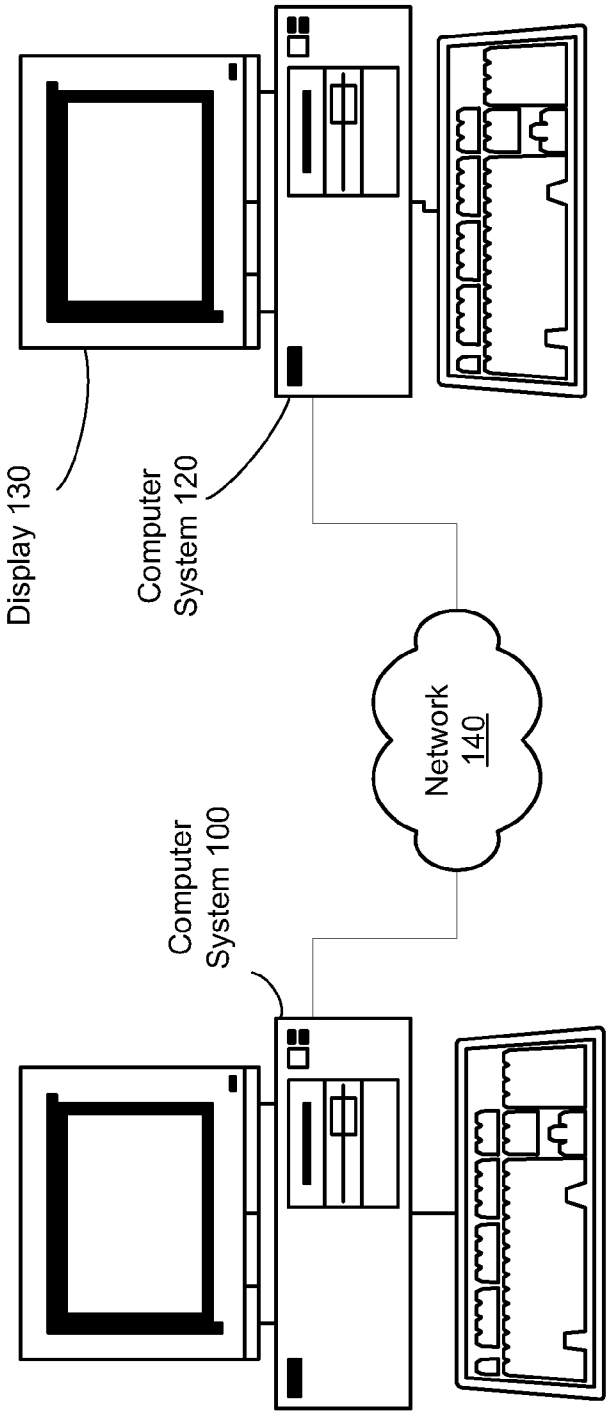

Display 130
Computer System 120
Network 140
Computer System 100

FIG. 1

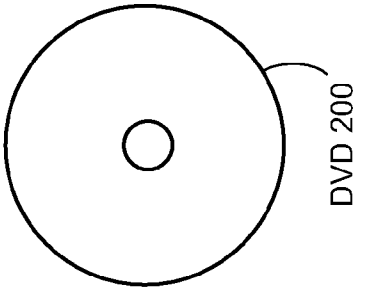

DVD 200

FIG. 2

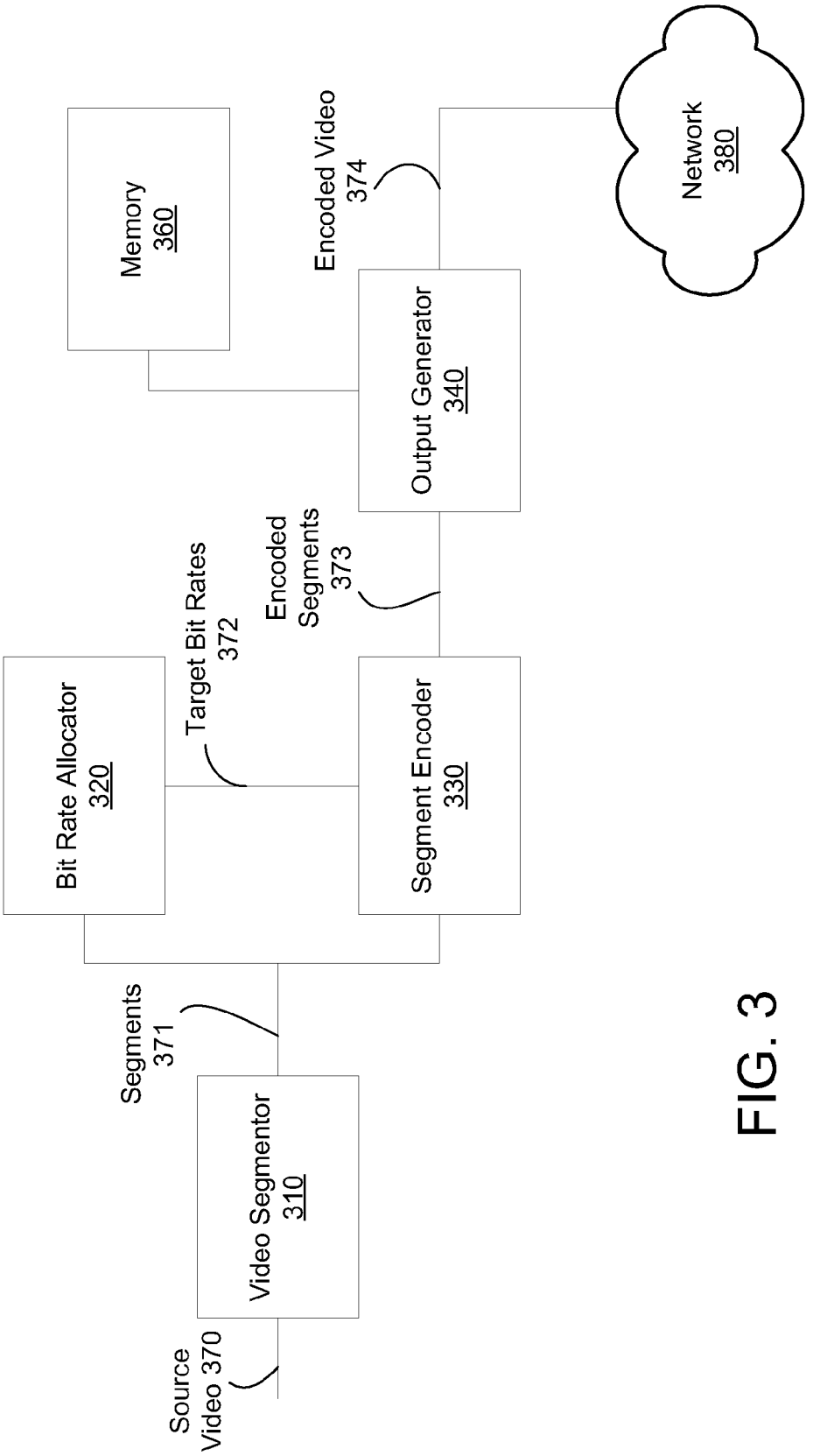

Source Video 370
Video Segmentor 310
Segments 371
Bit Rate Allocator 320
Target Bit Rates 372
Segment Encoder 330
Encoded Segments 373
Output Generator 340
Memory 360
Encoded Video 374
Network 380

FIG. 3

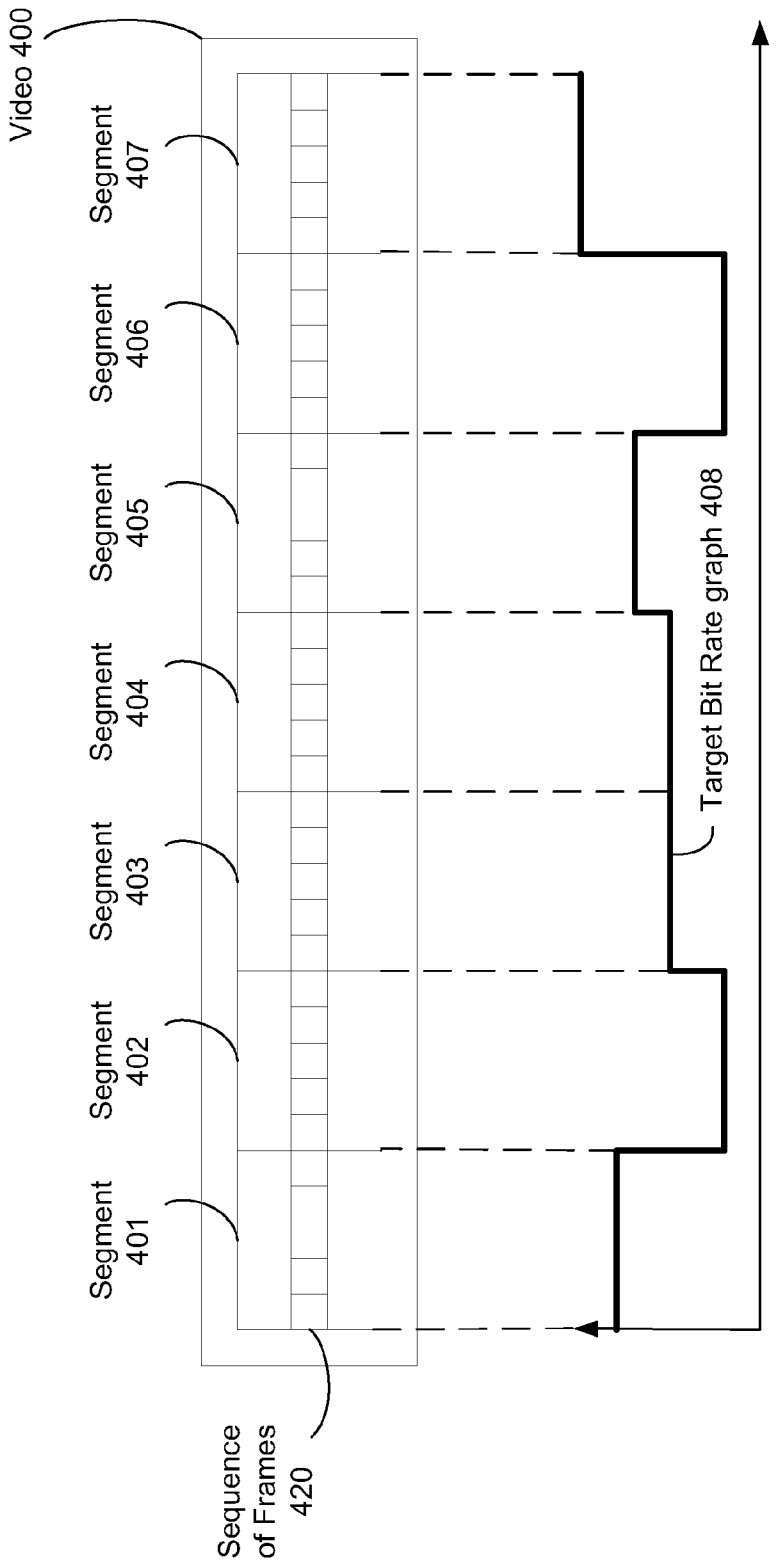

Video 400
Segment 407
Segment 406
Segment 405
Segment 404
Segment 403
Segment 402
Segment 401
Target Bit Rate graph 408
Sequence of Frames 420

FIG. 4

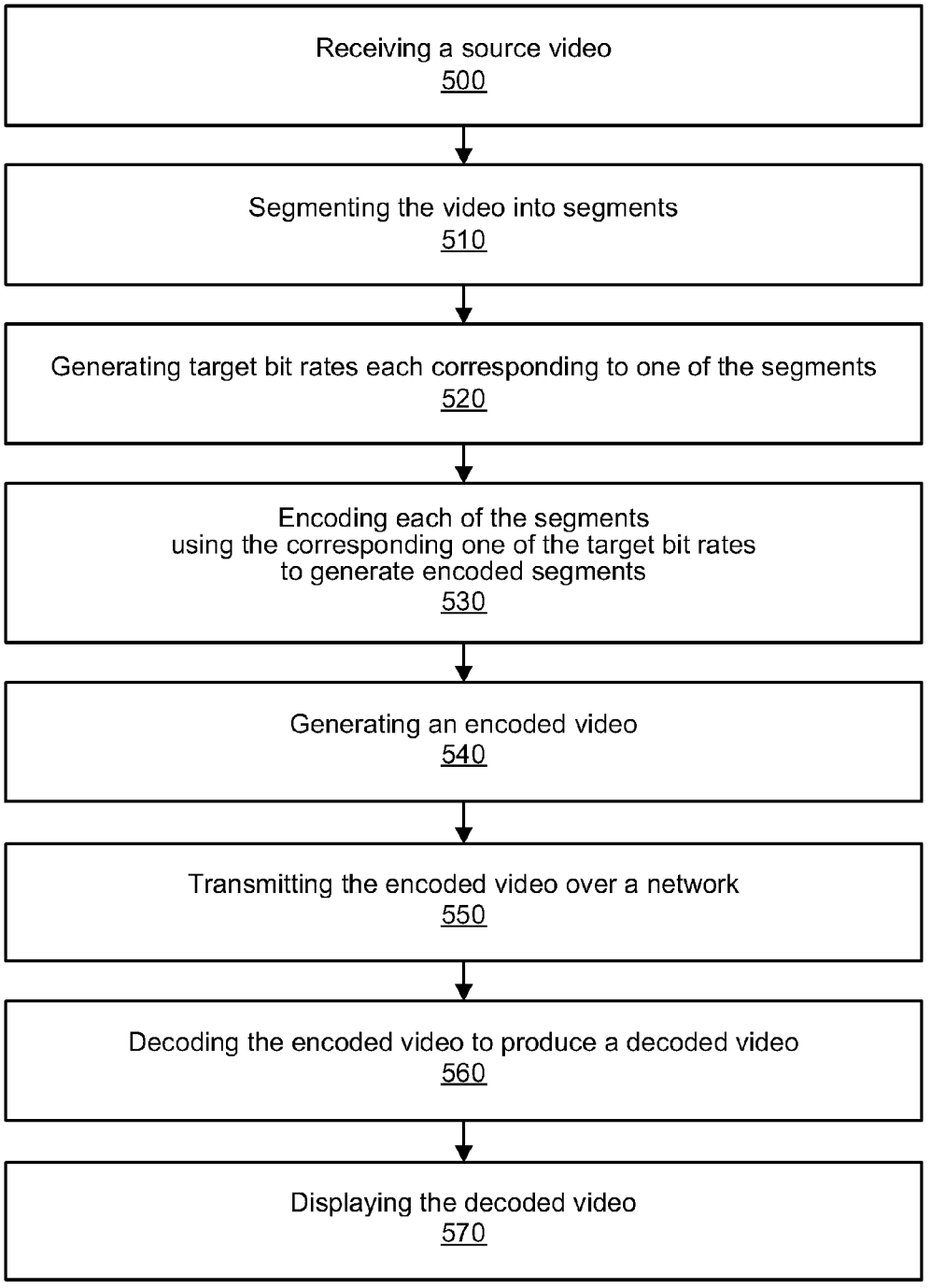

Receiving a source video
500
Segmenting the video into segments
510
Generating target bit rates each corresponding to one of the segments
520
Encoding each of the segments
using the corresponding one of the target bit rates
to generate encoded segments
530
Generating an encoded video
540
Transmitting the encoded video over a network
550
Decoding the encoded video to produce a decoded video
560
Displaying the decoded video
570

FIG. 5

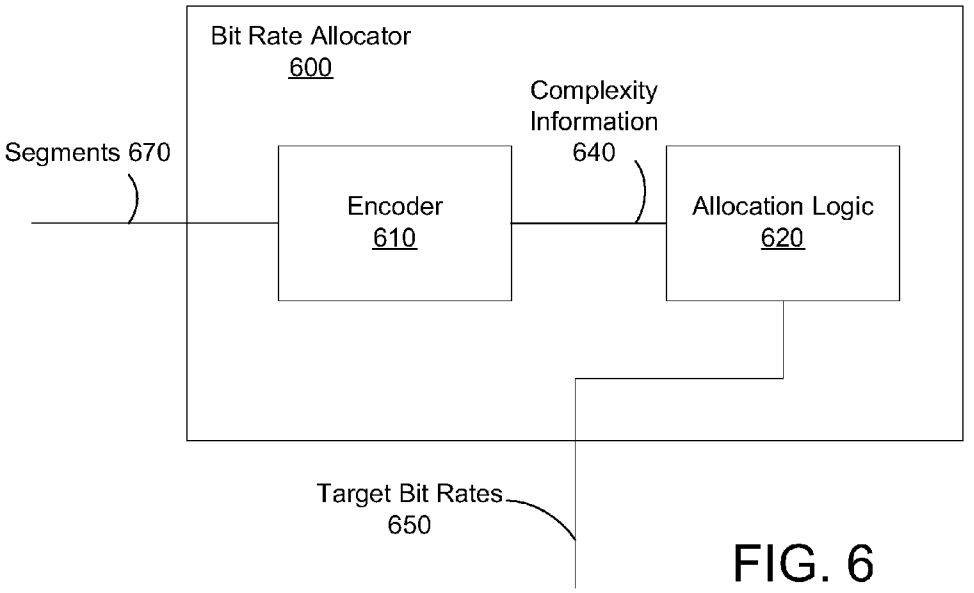

Bit Rate Allocator
600
Complexity
Information
640
Segments 670
Encoder
610
Allocation Logic
620
Target Bit Rates
650

FIG. 6

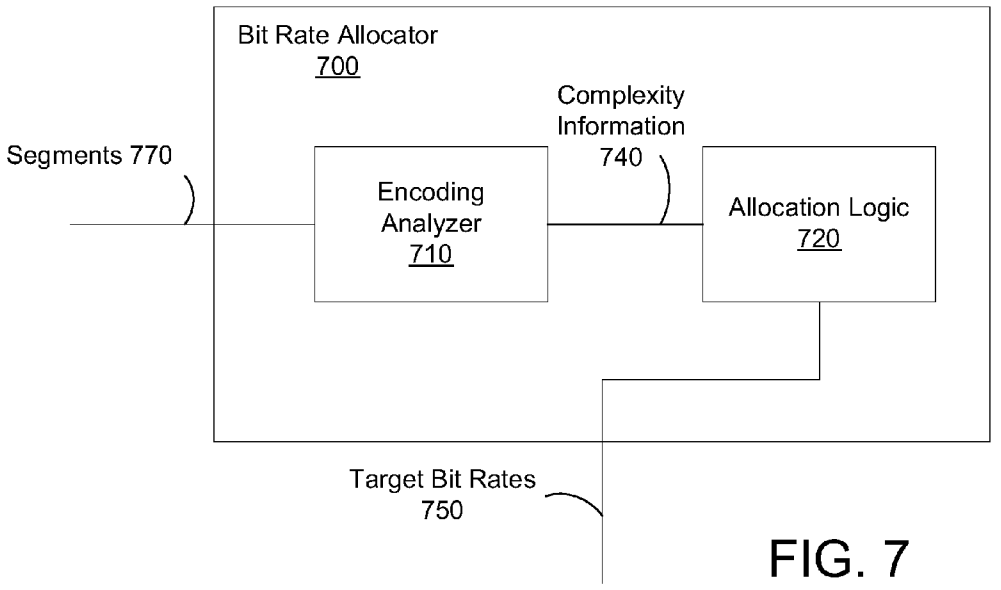

Bit Rate Allocator
700
Complexity
Information
740
Segments 770
Encoding
Analyzer
710
Allocation Logic
720
Target Bit Rates
750

FIG. 7

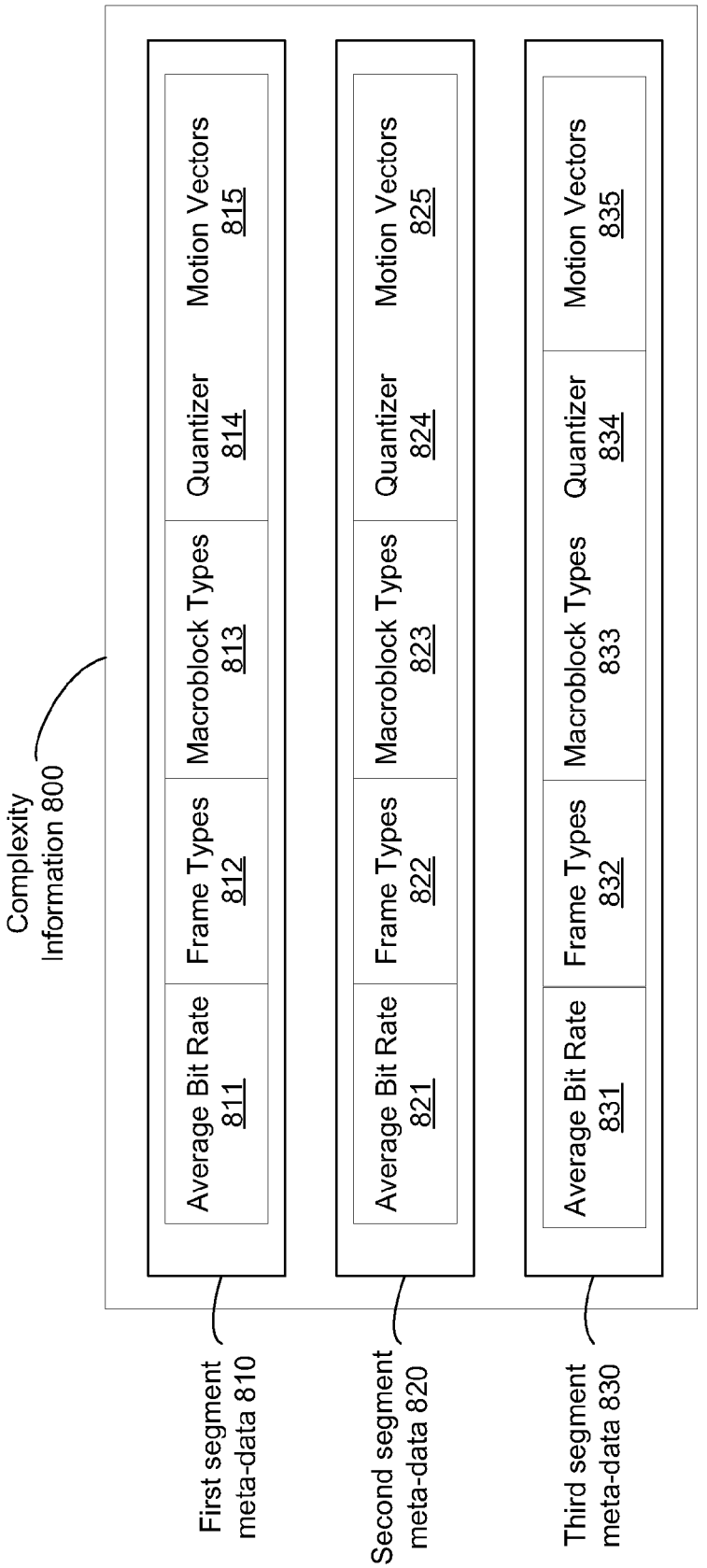

Complexity Information 800
Average Bit Rate 811
Frame Types 812
Macroblock Types 813
Quantizer 814
Motion Vectors 815
First segment meta-data 810
Average Bit Rate 821
Frame Types 822
Macroblock Types 823
Quantizer 824
Motion Vectors 825
Second segment meta-data 820
Average Bit Rate 831
Frame Types 832
Macroblock Types 833
Quantizer 834
Motion Vectors 835
Third segment meta-data 830

FIG. 8

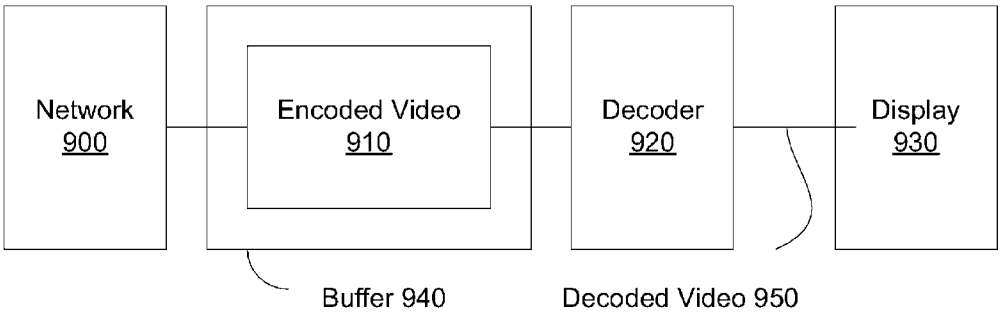

Network
900
Encoded Video
910
Decoder
920
Display
930
Buffer 940
Decoded Video 950

FIG. 9

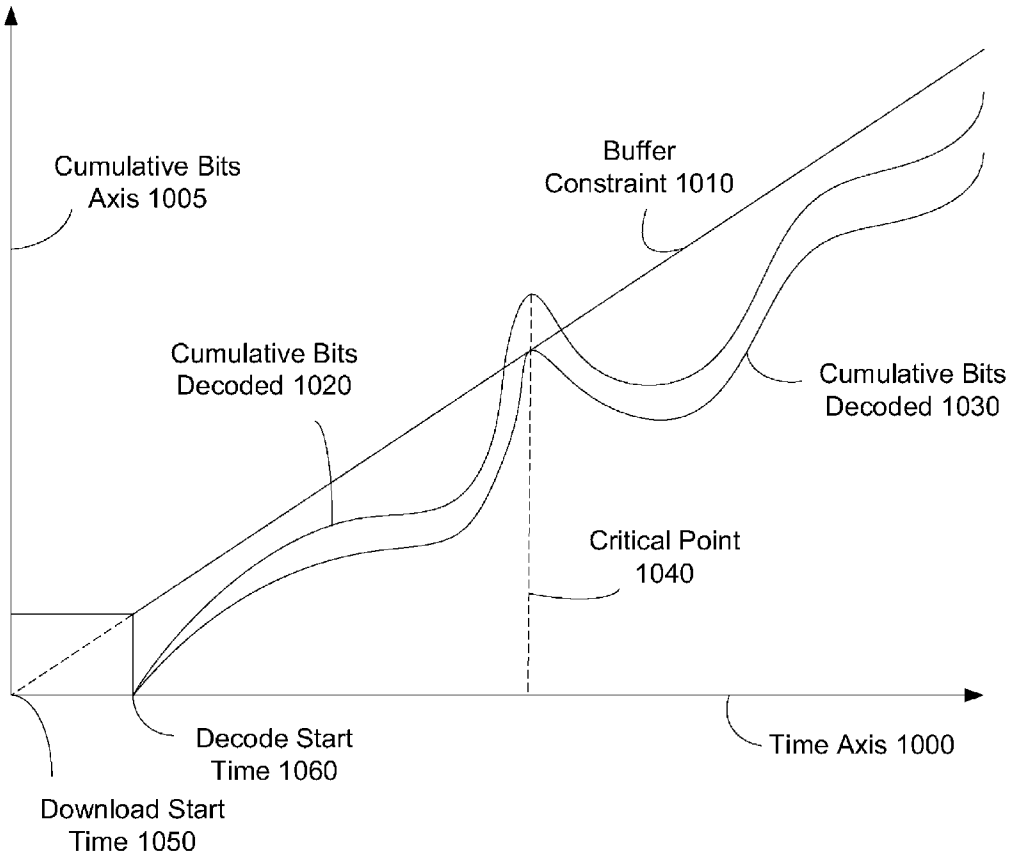

Cumulative Bits
Axis 1005
Buffer
Constraint 1010
Cumulative Bits
Decoded 1020
Cumulative Bits
Decoded 1030
Critical Point
1040
Decode Start
Time 1060
Time Axis 1000
Download Start
Time 1050

FIG. 10

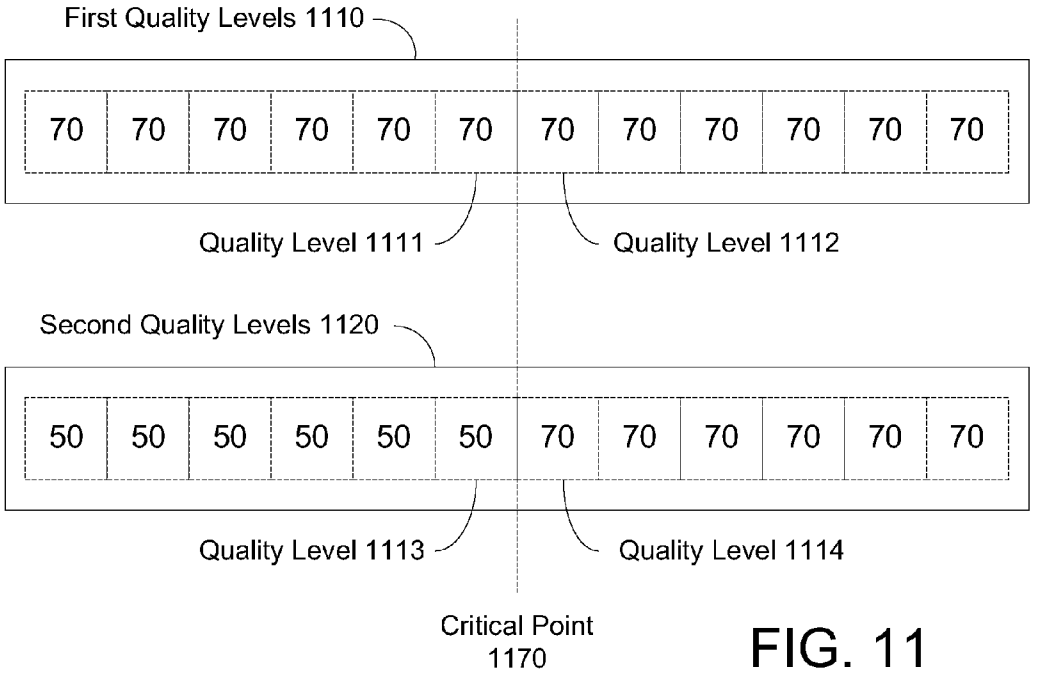

First Quality Levels 1110
70 70 70 70 70 70 70 70 70 70 70 70
Quality Level 1111
Quality Level 1112
Second Quality Levels 1120
50 50 50 50 50 50 70 70 70 70 70 70
Quality Level 1113
Quality Level 1114
Critical Point 1170

FIG. 11

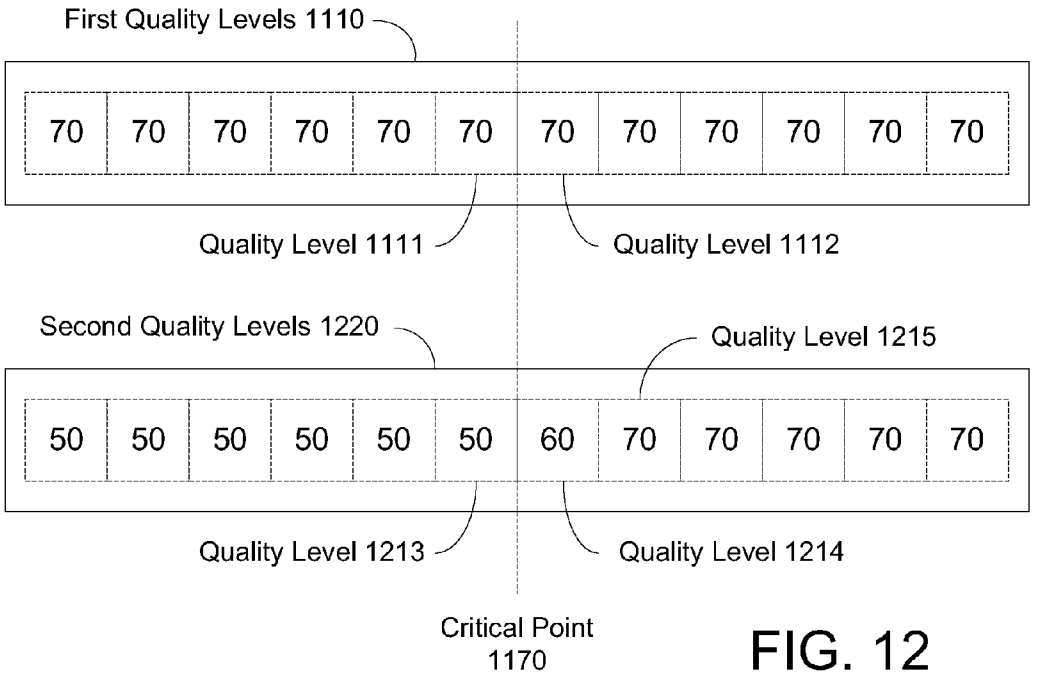

First Quality Levels 1110
70 70 70 70 70 70 70 70 70 70 70 70
Quality Level 1111
Quality Level 1112
Second Quality Levels 1220
Quality Level 1215
50 50 50 50 50 50 60 70 70 70 70 70
Quality Level 1213
Quality Level 1214
Critical Point 1170

FIG. 12

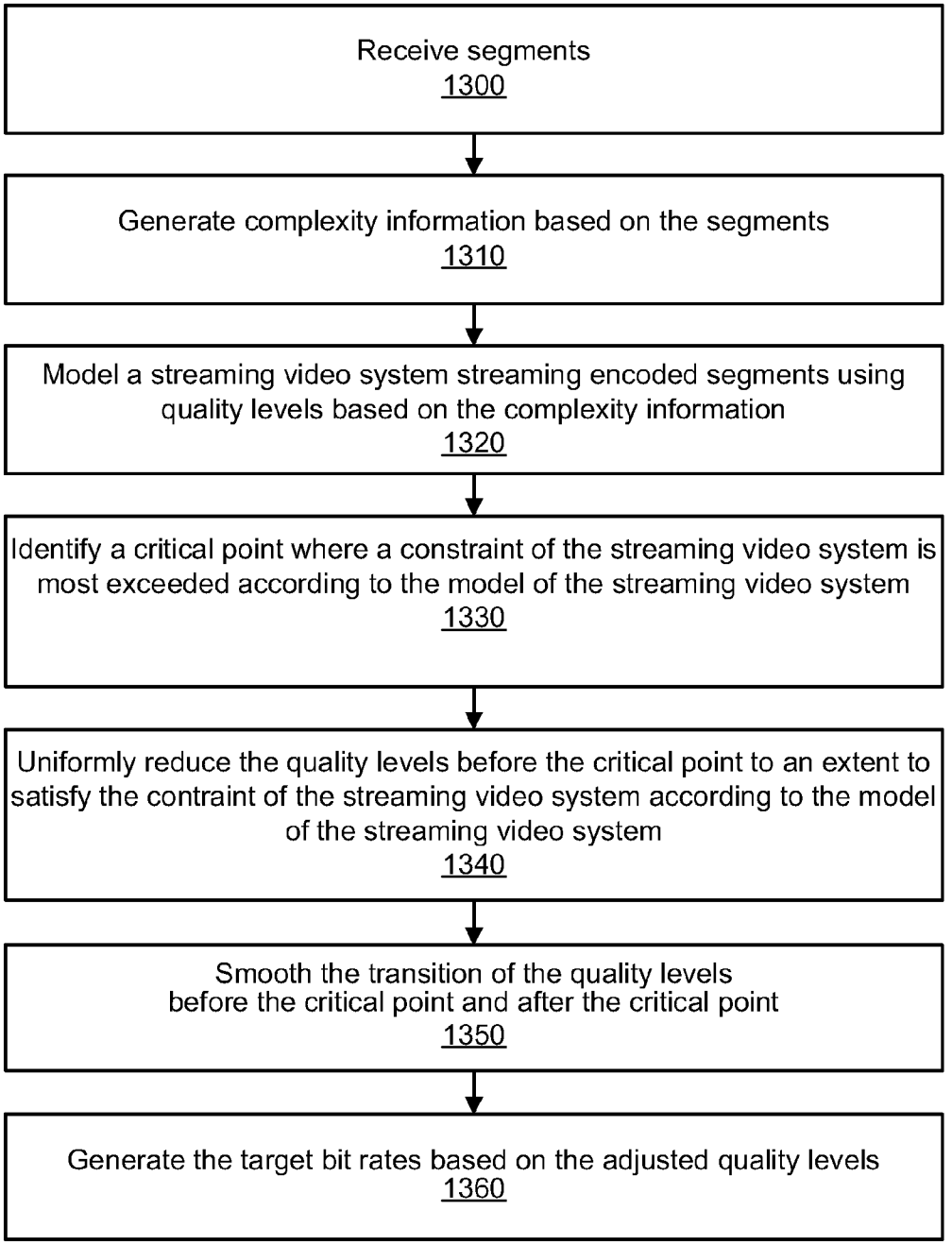

Receive segments
1300
Generate complexity information based on the segments
1310
Model a streaming video system streaming encoded segments using quality levels based on the complexity information
1320
Identify a critical point where a constraint of the streaming video system is most exceeded according to the model of the streaming video system
1330
Uniformly reduce the quality levels before the critical point to an extent to satisfy the contraint of the streaming video system according to the model of the streaming video system
1340
Smooth the transition of the quality levels before the critical point and after the critical point
1350
Generate the target bit rates based on the adjusted quality levels
1360

FIG. 13

VARIABLE BIT RATE ENCODING

BACKGROUND

1. Field of the Invention

This invention relates generally to the field of video systems. More particularly, the invention relates to a system, apparatus and method for streaming videos.

2. Description of the Related Art

Video on Demand (VOD) systems allow users to request and view videos over a network. The video is compressed in order to transmit the video over a network with limited bandwidth.

Constant bit rate (CBR) compression allocates a constant number of bits to each frame or small number of frames of the video. By using a bit rate that is less than the download rate of the network, CBR video can be streamed over that network. However, CBR compression compromises video quality because some frames of video may have more image complexity than others and some frame-to-frame image changes may be more significant than others.

Variable bit rate (VBR) compression generally achieves better image quality than CBR compression for a given bit rate by assigning less bits to the simpler frames and more bits to the more complex frames. However, during periods of complex video sequences, the bandwidth required may exceed the download rate of the network. Thus, VBR compressed video generally cannot be streamed without a large buffer to cushion against periods of bandwidth deficits. Larger buffers require longer delays to fill before viewing can begin.

Constant average bit rate (CABR) compression is a compromise between CBR compression and VBR compression. CABR compression uses a buffer that grows by the target bit rate each frame. The bits in the buffer decrease by the bits used for each frame. No more bits can be used than those in the buffer and any unused bits are made available to subsequent frames. Thus, CABR compression allows for some cross frame allocation of bits to improve video quality while the buffer constrains the average bit rate over a limited number of frames. CABR video can be streamed.

What is needed is a video compression scheme that allows for more flexibility in bit allocation to improve video quality while allowing for the compressed video to be streamed.

SUMMARY

A system, machine-readable medium and method for processing video is described. According to some embodiments, the system includes a video segmentor configured to receive a source video and to split the source video into segments; a bit rate allocator configured to receive the segments and generate target bit rates corresponding to the segments; an encoder coupled to receive the segments and target bit rates and configured to encode each of the segments using one of the target bit rates to generate encoded segments; and an output generator configured to receive the encoded segments and generate an encoded video.

In some embodiments, the bit rate allocator includes a complexity estimator and an allocation logic. The complexity estimator is configured to generate complexity information for each of the segments. The bit rate allocator is configured to receive the complexity information and generate the target bit rates.

In some embodiments, the segments each have a set of first quality levels based on the complexity information. The allocation logic is configured to adjust the first quality levels to a set of second quality levels to an extent that a model of a streaming video system predicts that the streaming video system can stream a sequence of the encoded segments using the second quality levels. The target bit rates are generated based on the second quality levels.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

FIG. **1** illustrates a streaming video system according to one embodiment of the invention.

FIG. **2** is a representation of an embodiment of a machine-readable medium of the present invention.

FIG. **3** is a block diagram of one embodiment of streaming video system of the present invention.

FIG. **4** is a diagram of the relationship between target bit rates and segments according to one embodiment of the invention.

FIG. **5** is a flow chart that illustrates an embodiment of a method of streaming video.

FIG. **6** is a block diagram of a bit rate allocator using an encoder according to one embodiment of the invention.

FIG. **7** is a block diagram of a bit rate allocator using an encoding analyzer according to an embodiment of the invention.

FIG. **8** is a block diagram that illustrates one embodiment of complexity information.

FIG. **9** is a block diagram that illustrates one embodiment of a streaming video system.

FIG. **10** is a graph that illustrates an embodiment of a model of a streaming video system.

FIG. **11** is a block diagram that illustrates a quality adjustment with an abrupt transition according to one embodiment of the present invention.

FIG. **12** is a block diagram that illustrates a quality adjustment with a smoothed transition according to an embodiment of the present invention.

FIG. **13** is a flow chart that illustrates a method of allocating target bit rates according to one embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Described below is a system, machine-readable medium and method for streaming video. Throughout the description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art that the present invention may be practiced without some of these specific details. In other instances, well-known devices and methods are not included in the description or shown in the figures to avoid obscuring the underlying principles of the present invention.

Embodiments of the invention may be implemented in a video on demand (VOD) system as illustrated generally in FIG. **1**. The VOD system includes a computer system **100** coupled through a network **140** to a computer system **120** including a display **130**.

In one embodiment, the computer system **100** is configured to receive a video over the network **140** or from a DVD, for example, and encode the video according to a method of the present invention. The encoded video can then be streamed

over the network **140** and received by the computer system **120** to be presented on the display **130**.

In some embodiments, the streaming video system of the present invention uses special-purpose hardware to generate the encoded video. In some embodiments, a centralized server streams the encoded video over the network to systems configured to receive and present the video. These systems can include special purpose hardware to decode the video received from the network and televisions and other display systems to display the decoded video. In other embodiments, the streaming video system is configured to transmit and receive video in a peer-to-peer network configuration.

FIG. **2** illustrates one embodiment of a machine-readable medium of the present invention. A DVD **200** is a digital versatile disc also known as a digital video disc. The DVD **200** can be used to store software to execute an embodiment of a method of the present invention. Machine-readable mediums also include dynamic random access memory (DRAM), flash memory, and a hard disk drive, for example.

FIG. **3** illustrates a block diagram of one embodiment of a video streaming system of the present invention.

A video segmenter **310** is configured to receive a source video **370** and split the source video **370** into segments **371**. In one embodiment, the video is uniformly split among the segments such that each segment has the same number of frames. In other embodiments, the video is split unevenly. The present invention is not limited to any particular video format. For example, the format of the video **370** may be Digital Video (DV) Encoder Type 1, DV Encoder Type 2, MPEG-1 (Moving Picture Experts Group format 1), MPEG-2, MPEG-4, or Real Video.

A bit rate allocator **320** receives the segments **371** and generates target bit rates **372** each corresponding to one of the segments **371**. In one embodiment, the bit rate allocator **320** is configured to allocate target bit rates to each segment to manage quality so that the streaming video system can stream the video using those target bit rates under nominal conditions of the streaming video system.

A segment encoder **330** receives the segments **371** and the target bit rates **372**. The segment encoder **330** encodes each of the segments **371** using the corresponding one of the target bit rates **372** to generate encoded segments **373**. In one embodiment, each of the segments **371** is a single frame of the source video **370**. The segment encoder **330** encodes the frame in each segment using the corresponding one of the target bit rates **372**. Alternatively, each of the segments **371** is a sequence of frames of the source video **370**. The segment encoder **330** encodes the sequence of frames in each segment using the corresponding one of the target bit rates **372**. In one embodiment, the segment encoder **330** uses variable bit rate (VBR) encoding. In other embodiments, the segment encoder **330** can use other encoding methods such as constant bit rate (CBR) encoding.

An output generator **340** is configured to receive the encoded segments **373** and generate an encoded video **374**. In one embodiment, the output generator **340** stores the encoded video **374** in a memory **360** and subsequently streams the encoded video **374** on a network **380**. The memory **360** can be a DVD, DRAM, hard disk memory or flash memory, for example. In some embodiments, the encoded video **374** is transmitted to a server which streams the video **374** on the network **380**. Alternatively, the output generator **340** streams the encoded video **374** directly onto the network **380**.

FIG. **4** shows a diagram of one embodiment of a relationship between the target bit rates and the segments.

In the illustrated embodiment, a video **400** having a sequence of frames **420** is split into a segment **401**, a segment **402**, a segment **403**, a segment **404**, a segment **405**, a segment **406**, and a segment **407**. Each of the segments consists of five frames of the sequence of frames **420**.

A target bit rate graph **408** shows the variation in the target bit rates as a function of segment. In the illustrated embodiment, the segment **407** is allocated a higher target bit rate than the segment **402**. By controlling the allocation of the target bit rates among the segments, more bits can be allocated to segments with more complex video and less bits can be allocated to segments with less complex video so that overall video quality can be improved for a given overall average bit rate.

The size of each segment is chosen to be small enough to provide fine-grained control over the bit-rate allocation in the encoded video. In one embodiment, each segment is a single frame of video, enabling control of the bits allocated to each frame of video. In other embodiments, each segment is a sequence of many frames of video spanning seconds of video playback time.

FIG. **5** illustrates one embodiment of a method of streaming video according to the present invention.

In step **500**, a source video is received. The source video can be in a format using VBR encoding, CBR encoding, or constant average bit rate (CABR) encoding. Other encoding methods may be used.

In step **510**, the source video is split into segments. In one embodiment each segment is a single frame of the source video. In other embodiments, each segment is a sequence of frames of the source video.

In step **520**, target bit rates corresponding to each of the segments is generated.

In some embodiments, the source video is encoded in a VBR format and the target bit rates are the average bit rate used in each segment of the source video. In other embodiments, the target bit rates are based on the average bit rate used in each segment of the source video, but adjusted to be within the constraints of the streaming video system.

In another embodiment, an encoding process is applied to each segment of the source video and the target bit rates are the average bit rates assigned to each segment of the source video by the encoding process. In some embodiments, the target bit rates are based on the average bit rate assigned to each segment of the source video by the encoding process, but adjusted to be within the constraints of the streaming video system.

In step **530**, each of the segments is encoded using a corresponding one of the target bit rates to generate the encoded segments. In one embodiment, each segment is encoded using VBR encoding. In other embodiments, each segment is encoded using other encoding methods.

In step **540**, an encoded video is generated. In one embodiment, the encoded segments are generated in sequence to produce an encoded video. In another embodiment, the encoded segments are generated in parallel and sequenced to generate an encoded video.

In step **550**, the encoded video is streamed. In one embodiment, the encoded video is directly streamed onto a network. In another embodiment the encoded video is stored in a memory and the memory is subsequently accessed to stream the encoded video. In yet another embodiment the encoded video is transferred to a server which streams the video upon request.

In step **560**, the encoded video is decoded to generate a decoded video. The decoded video is in a format suitable for being transmitted to a display system.

In step **570**, the decoded video is displayed. The decoded video may be displayed on a computer monitor, television and other display devices for displaying video.

FIG. **6** illustrates one embodiment of a bit rate allocator of the present invention. An encoder **610** is configured to receive the segments **670**, encode the segments **670** and generate complexity information **640**. In one embodiment, the complexity information **640** includes the average bit rate allocated to each of the segments **670**. In another embodiment, the complexity information **640** includes additional meta-data such as frame types, macroblock types, quantizer, and motion vectors used when encoding the segments **640**.

In some embodiments, the encoder **610** uses the same encoding algorithm as the segment encoder **330** shown in FIG. **3**. In one embodiment, the segment encoder **330** is configured to be in a mode to generate encoded video that can be decoded into a presentation quality video and the encoder **610** is configured to operate rapidly to provide an indication of the relative complexity of each of the segments **670** rather than produce high quality video. In some embodiments, the encoder **610** is configured to operate in a super-fast, constant quality, one pass mode. In other embodiments, when the available time for encoding is not a constraint, the encoder **610** is configured to use more time to produce better quality video compression.

The allocation logic **620** is configured to receive the complexity information **640** and generate target bit rates **650** corresponding to each of the segments **670**.

In one embodiment, the allocation logic **620** uses the target bit rates in the complexity information **640** as the target bit rates **670**. In another embodiment, the allocation logic **620** is configured to adjust the target bit rates in the complexity information **640** to maintain streaming capability. The complexity information **640** can include meta-data used to derive accurate estimates of the video quality that may be achieved for each segment at various target bit rates. Using a model of the streaming video system, the allocation logic **620** predicts whether the streaming video system has the capacity to stream the segments **670** encoded with the target bit rates **650**.

The model of the streaming video system is based on the characteristics of streaming video system. Some characteristics, such as network bandwidth, may be fixed by the system configuration. A streaming video system with higher network bandwidths can sustain higher average bit rates. Other streaming video system characteristics, such as buffer size, may be varied within the constraints of a given system configuration. A streaming video system that employs a longer initial delay to build a larger buffer can tolerate longer periods in which the bit rate exceeds the network bandwidth but requires a longer delay between the time the video begins downloading and the time the video presentation begins.

FIG. **7** illustrates another embodiment of a bit rate allocator of the present invention. In this embodiment, the segments **770** are encoded. An example of an encoded format is MPEG-2. Each of the segments **770** has an average bit rate that depends on the allocation of bits to the frames in that segment.

An encoding analyzer **710** is configured to receive the segments **770** and analyze the encoding of the segments **770** to determine the complexity information **640**. In one embodiment, the complexity information **740** includes the average bit rate allocated to each of the segments **770**. In another embodiment, the complexity information includes additional meta-data such as frame types, macroblock types, quantizer and the motion vectors used in each segment.

An allocation logic **720** is configured to receive the complexity information **740** and generate target bit rates **750**. The allocation logic **720** can be configured in embodiments similar to those described with reference to the allocation logic **620**.

FIG. **8** illustrates one embodiment of the complexity information of the present invention.

The complexity information **800** comprises a first segment meta-data **810**, a second segment meta-data **820** and a third segment meta-data **830**. The first segment meta-data **810** includes an average bit rate **811**, frame types **812**, macroblock types **813**, quantizer **814** and motion vectors **815**. The average bit rate **811** is the average bit rate allocated to the first segment. The frame types **812** are the data that indicate the use of frame types, such as intracoded frames, predictive coded frames and bi-directionally coded frames, within the first segment. The macroblock types **813** indicate the use of macroblock types used within the first segment. The quantizers **814** are the quantizers used in the first segment. The motion vectors **815** are the motion vectors used in the first segment.

A second segment meta-data **820** includes an average bit rate **821**, frame types **822**, macroblock types **823**, quantizer **824** and motion vectors **825**. The third segment meta-data **830** includes an average bit rate **831**, frame types **832**, macroblock types **833**, quantizer **834** and motion vectors **835**. The elements of the second segment meta-data **820** and the third segment meta-data **830** are analogous to the first segment meta-data **810** except they apply to the second and third segments, respectively.

Three segments are shown for illustration. In other embodiments, the complexity information includes meta-data for more segments. According to some embodiments, the complexity information **800** is used to derive accurate estimates of the video quality that may be achieved for each segment at various target bit rates. The complexity data **800** is not limited to the meta-data types illustrated here.

FIG. **9** is a block diagram illustrating one embodiment of a streaming video system. A buffer **940** receives a video streaming over a network **900**. In one embodiment, the network **900** includes a server that streams the video over the network **900**. An encoded video **910** is the portion of the streaming video that is stored in the buffer at any given time.

A decoder **920** receives the encoded video **910** from the buffer **940**. The decoder **920** decodes the encoded video **910** to generate a decoded video **950**. The display **930** displays the decoded video **950**. In order for the decoder **920** to provide the display **930** with a continuous stream of decoded video **950**, the decoder **920** must receive the encoded video **910** in a timely manner.

FIG. **10** is a graph illustrating one embodiment of a model of the streaming video system described with reference to FIG. **9**.

The graph has a time axis **1000** and a cumulative bits axis **1005**. At a download start time **1050**, the buffer **940** begins to receive bits of a video from the network **900**. The encoded video **910** is the portion of the video that is stored in the buffer at any given time. At a decode start time **1060**, the decoder **920** begins to access the buffer **940** to receive bits of the encoded video **910**. The delay between the download start time **1060** and the decode start time **1050** allows the buffer **940** to download the encoded video **910** ahead of the decoder. The longer the delay, the more margin the system has to tolerate video bit rates that are higher than the download rate. But a longer delay also increases the wait before the video requester begins to see the video.

A buffer constraint **1010** indicates the cumulative bits that have been received into the buffer **940** at any point in time. The slope of the buffer constraint **1010** is the download rate of the network **900**. Cumulative bits decoded **1020** illustrates the

cumulative bits used by the decoder **920** to decode a video encoded at given quality levels according to the model of the streaming video system. In one embodiment, the quality levels for each segment of the video are indicated by the complexity information generated by a target bit rate allocator.

The slope of the cumulative bits decoded **1020** at a given point in time is the rate of bits used by the decoder at that point in time to maintain a continuous stream of the decoded video **950**. At some times, the decoding rate is greater than the download rate. Under such conditions, the buffer **940** can sustain the operation of the decoder **920** for a limited period of time. During this period, the buffer **940** is being emptied by the decoder **920** at a faster rate than it is being filled by the network **900**. The buffer **940** will eventually become empty if the bit rate usage continues to exceed the download rate. When the buffer is empty, the decoder **920** stalls if it requires a higher bit rate than the download rate. In such cases the decoder **920** cannot maintain the continuous stream of the decoded video **950**. The presentation of the decoded video **950** on the display **930** stalls. Video stalling compromises the experience of viewing the video.

When the cumulative bits decoded **1020** exceeds the buffer constraint **1010**, the buffer **940** is empty. A streaming video system would stall if it required bits that were not available in the buffer **940**. In the model, the cumulative bits decoded **1020** continue to accumulate as if the decoder could continue to run. At a critical point **1040**, the cumulative bits decoded **1020** most exceeds the buffer constraint **1010**.

In order to avoid exceeding the constraint, the bit consumption usage prior to the critical point **1040** can be reduced by the extent that the cumulative bits decoded **1020** exceeds the buffer constraint **1010** at the critical point **1040**. Cumulative bits decoded **1030** illustrates the cumulative bits used by the decoder **920** to decode a video encoded at adjusted quality levels according to the model of the streaming video system. In one embodiment, the quality levels are adjusted to reduce the bit rate consumption prior to the critical point **1040** to an extent that the model predicts that the streaming video system can stream the video at the adjusted quality levels. The cumulative bits decoded **1030** does not exceed the buffer constraint **1010**.

By reducing quality levels uniformly throughout the period from the decode start time **1060** to the critical point **1040**, the bit rate consumption is reduced while distributing the degradation in quality evenly and over the longest relevant period. By distributing the quality reduction over the longest relevant period, the required cumulative bit reduction can be achieved while the quality reduction required at any given point in time is reduced. Alternatively, quality reduction may be distributed unevenly.

In one embodiment, the model predicts that the streaming video system can stream the video based on the nominal specifications of the streaming video system. If streaming video system does not perform to the modeled specifications, the streaming video may in fact stall in the streaming video system. In some embodiments, some margin for system performance degradation is incorporated into the model to reduce the likelihood that the streaming video may stall in the streaming video system.

In some embodiments, cumulative bits **1020** does not exceed the buffer constraint **1010**. No quality level adjustment is necessary to allow for the video to be streamable on the streaming video system. However, there may be some margin for quality levels to be increased. In this case, the critical point is the point in which there is the least margin in the buffer constraint. Quality levels can be increased throughout the video (before and after the critical point) to take advantage of the margin in the constraint. In other embodiments, the model may include more than one constraint and quality levels may be adjusted to satisfy all of these constraints and take advantage of any margin in these constraints.

FIG. **11** is a diagram that illustrates a quality adjustment using an abrupt transition according to one embodiment of the present invention.

First quality levels **1110** include quality levels corresponding to each segment in a sequence of segments of the video. Each quality level includes a numeric indication of the quality level. In one embodiment, the quality level may be indicated by the average bit rate allocated to the segment.

A critical point **1170** is the point where a model of the streaming video system indicates that the cumulative bits decoded most exceeds a constraint of the streaming video system. In some embodiments, the critical point **1170** corresponds to the boundary between segments. In other embodiments, the critical point **1170** corresponds to the boundary between frames, which may be within a multi-frame segment.

In the illustrated example, the first quality levels **1110** are 70 for all the segments. This quality level is determined by complexity information generated by the bit rate allocator. In some embodiments, the first quality levels vary by segment.

Second quality levels **1120** include quality levels corresponding to each segment in a sequence of segments of the video as adjusted by the allocation logic. For example, a quality level **1111** in the first quality levels **1110** is reduced to a quality level **1113** in the second quality levels **1120** before the critical point **1170**.

Since the quality levels after the critical point **1170** do not have an effect on the cumulative bits used at the critical point **1170**, the quality levels are not reduced after the critical point **1170**. For example, a quality level **1112** in the first quality levels **1110** is remains the same in a quality level **1114** in the second quality levels **1120** after the critical point **1170**.

In the illustrated embodiment, the transition between the quality levels before the critical point **1170** and after the critical point **1170** is an abrupt transition. The quality level **1113** corresponding to the last segment before the critical point **1170** is 50. The quality level **1114** corresponding to the first segment after the critical point **1170** is 70. The abrupt transition may result in a noticeable discontinuity in the quality of the video. This discontinuity may compromise the experience of viewing the video.

FIG. **12** is a diagram that illustrates a quality adjustment using a smoothed transition according to one embodiment of the present invention. In this case, the elements are identical to those illustrated in FIG. **11** except that quality level **1214** is 60. The transition from 50 at quality level **1213** to 70 at quality level **1215** happens over one more segment as compared to the abrupt transition illustrated in FIG. **11**. In other embodiments, the transition may happen over more segments to generate a smoother transition.

FIG. **13** is a flow chart that illustrates a method of allocating target bit rates according to one embodiment of the present invention.

In step **1300**, segments are received. In some embodiments, the received segments are in an encoded format, such as MPEG-2.

In step **1310**, complexity information is generated based on the segments. In one embodiment, the complexity information is generated by analyzing the encoding of the segments as received. In another embodiment, the complexity information is generated by encoding the segments using an encoding process. In one embodiment, the complexity information

includes meta-data including the average bit rate, frame types, macroblock types, quantizer, and motion vectors used in each segment.

In step **1320**, a streaming video system is modeled streaming the encoded video using quality levels based on the complexity information. In one embodiment, the model includes a buffer constraint indicating the cumulative bits downloaded into a buffer at any point in time. Other constraints may be used.

In step **1330**, a critical point is identified were a constraint of the streaming video system is most exceeded according to the model of the streaming video system. In one embodiment, the critical point is the point where the cumulative bits decoded most exceeds the buffer constraint.

In step **1340**, the quality levels are uniformly reduced before the critical point to an extent to satisfy the constraint of the streaming video system according to the model of the streaming video system. In other embodiments, the quality is reduced unevenly before the critical point.

In step **1350**, the transition between the quality levels before the critical point and the quality levels after the critical point is smoothed. In one embodiment, the transition between the quality levels before the critical point and the quality levels after the critical point changes linearly over the quality levels corresponding to two or more segments in the transition.

In step **1360**, the target bit rates for each segment are generated based on the adjusted quality levels. Thus, target bit rates are allocated to manage quality within the constraints of the streaming video system.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

What is claimed is:

1. A system for processing video comprising:

a video segmentor configured to receive a source video and to split the source video into a plurality of segments;

a bit rate allocator comprising a complexity estimator and an allocation logic, the bit rate allocator being configured to (i) receive the plurality of segments, (ii) generate complexity information for each of the plurality of segments, and (iii) generate a plurality of target bit rates corresponding to the plurality of segments by using the complexity information, wherein the plurality of segments has a plurality of first quality levels based on the complexity information;

wherein the allocation logic is configured to adjust the plurality of first quality levels to a plurality of second quality levels based, at least in part, on a model of a streaming video system predicting that the streaming video system can stream a sequence of a plurality of encoded segments using the plurality of second quality levels;

wherein adjusting the plurality of first quality levels to the plurality of second quality levels includes identifying a critical point in the sequence of the plurality of encoded segments to adjust the plurality of first quality levels up to the critical point, the critical point being where the model of the stream video system predicts that a constraint is most exceeded while streaming the sequence of the plurality of encoded segments using the plurality of first quality levels;

wherein the plurality of target bit rates are based, at least in part, on the plurality of second quality levels;

a first encoder configured to (i) receive the plurality of segments and the plurality of target bit rates, and (ii) encode each of the plurality of segments using one of the plurality of target bit rates to generate the plurality of encoded segments; and

an output generator configured to receive the plurality of encoded segments and generate an encoded video.

2. The system of claim **1**, wherein the source video comprises a sequence of frames, each of the plurality of segments being one frame in the sequence of frames.

3. The system of claim **1**, wherein the source video comprises a sequence of frames, each of the plurality of segments being a plurality of frames in the sequence of frames.

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

a network coupled to the output generator, the output generator streaming the encoded video on the network;

a decoder configured to receive the encoded video on the network and decode the encoded video to generate a decoded video; and

a display configured to display the decoded video.

5. The system of claim **1**, wherein the complexity estimator comprises a second encoder configured to encode the plurality of segments and generate the complexity information.

6. The system of claim **5**, wherein the second encoder is configured to encode the plurality of segments in an expedited mode.

7. The system of claim **6**, wherein the second encoder is configured to encode the plurality of segments using constant quality, one-pass encoding.

8. The system of claim **5**, wherein the first encoder and the second encoder are configured to encode the plurality of segments using the same encoding algorithm.

9. The system of claim **1**, wherein the source video has a variable bit rate encoding, the complexity estimator is configured to analyze the variable bit rate encoding and generate complexity information for each of the plurality of segments.

10. The system of claim **1**, wherein the complexity information comprises a plurality of average bit rates each corresponding to one of the plurality of segments.

11. The system of claim **1**, wherein the complexity information comprises a plurality of meta-data each corresponding to one of the plurality of segments.

12. The system of claim **11**, wherein each of the plurality of meta-data comprises frame types, macroblock types, quantizer and motion vectors corresponding to one of the plurality of segments.

13. The system of claim **1**, wherein the allocation logic uniformly reduces the plurality of first quality levels up to the critical point to generate the plurality of second quality levels.

14. The system of claim **1**, wherein the streaming video system comprises a buffer configured to receive the plurality of encoded segments from a network and provide the plurality of encoded segments to a decoder, the constraint being exceeded to an extent that the decoder requires portions of the plurality of encoded segments that are unavailable in the buffer.

15. The system of claim **1**, wherein the allocation logic is configured to generate a smooth transition between the plurality of second quality levels before the critical point and the plurality of second quality levels after the critical point.

16. A method for processing video, the method being performed by a processor and comprising:

receiving a source video;

splitting the source video into a plurality of segments;

generating complexity information for each of the plurality of segments, and generating a plurality of target bit rates corresponding to the plurality of segments by using the complexity information, wherein the plurality of segments has a plurality of first quality levels based on the complexity information;

adjusting the plurality of first quality levels to a plurality of second quality levels based, at least in part, on a model of a streaming video system predicting that the streaming video system can stream a sequence of the plurality of encoded segments using the plurality of second quality levels;

wherein adjusting the plurality of first quality levels to the plurality of second quality levels includes identifying a critical point in the sequence of the plurality of encoded segments to adjust the plurality of first quality levels up to the critical point, the critical point being where the model of the stream video system predicts that a constraint is most exceeded while streaming the sequence of the plurality of encoded segments using the plurality of first quality levels;

wherein the plurality of target bit rates are based, at least in part, on the plurality of second quality levels;

performing a first encoding process on each of the plurality of segments of the source video using one of the plurality of target bit rates to generate the plurality of encoded segments; and

generating an encoded video comprising the plurality of encoded segments.

17. The method of claim **16**, wherein the source video comprises a sequence of frames, each of the plurality of segments being one frame in the sequence of frames.

18. The method of claim **16**, wherein the source video comprises a sequence of frames, each of the plurality of segments being a plurality of frames in the sequence of frames.

19. The method of claim **16**, further comprising:

streaming the encoded video on a network;

decoding the encoded video to generate a decoded video; and

displaying the decoded video.

20. The method of claim **16**, wherein generating complexity information for each of the plurality of segments comprises performing a second encoding process on the plurality of segments.

21. A non-transitory computer readable storage medium that provides instructions for a processor, the instructions when executed by the processor cause the processor to perform a method for processing video comprising:

receiving a source video;

splitting the source video into a plurality of segments;

generating complexity information for each of the plurality of segments, and generating a plurality of target bit rates corresponding to the plurality of segments by using the complexity information, wherein the plurality of segments has a plurality of first quality levels based on the complexity information;

adjusting the plurality of first quality levels to a plurality of second quality levels based, at least in part, on a model of a streaming video system predicting that the streaming video system can stream a sequence of the plurality of encoded segments using the plurality of second quality levels;

wherein adjusting the plurality of first quality levels to the plurality of second quality levels includes identifying a critical point in the sequence of the plurality of encoded segments to adjust the plurality of first quality levels up to the critical point, the critical point being where the model of the stream video system predicts that a constraint is most exceeded while streaming the sequence of the plurality of encoded segments using the plurality of first quality levels;

wherein the plurality of target bit rates are based, at least in part, on the plurality of second quality levels;

performing a first encoding process on each of the plurality of segments of the source video using one of the plurality of target bit rates to generate the plurality of encoded segments; and

generating an encoded video comprising the plurality of encoded segments.

22. The non-transitory computer readable storage medium of claim **21**, wherein the source video comprises a sequence of frames, each of the plurality of segments being one frame in the sequence of frames.

23. The non-transitory computer readable storage medium of claim **21**, wherein the source video comprises a sequence of frames, each of the plurality of segments being a plurality of frames in the sequence of frames.

24. The non-transitory computer readable storage medium of claim **21**, further comprising:

streaming the encoded video on a network;

decoding the encoded video to generate a decoded video; and

displaying the decoded video.

25. The non-transitory computer readable storage medium of claim **21**, wherein generating complexity information for each of the plurality of segments comprises performing a second encoding process on the plurality of segments.

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