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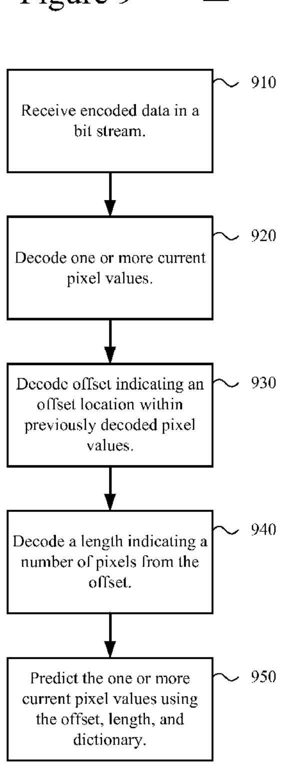
[Continued on next page]

(54) Title: DICTIONARY ENCODING AND DECODING OF SCREEN CONTENT

Figure 9


900
Receive encoded data in a bit stream.
910
Decode one or more current pixel values.
920
Decode offset indicating an offset location within previously decoded pixel values.
930
Decode a length indicating a number of pixels from the offset.
940
Predict the one or more current pixel values using the offset, length, and dictionary.
950

(57) Abstract: A method and device are provided for encoding and/or decoding video and/or image content using dictionary modes. For example, the method and device predict current pixel values from previous pixel values stored in a 1-D dictionary. The method and device predict current pixel values from previous pixel values using a pseudo 2-D dictionary mode. Yet the method and device predict current pixel values using a pseudo 2-D dictionary mode. Yet the method and device predict current pixel values from previous pixel values in a reference picture using an inter pseudo 2-D dictionary mode. Pixel values can be predicted from previous pixel values (e.g., stored in a dictionary) that are identified by an offset and a length. Yet the method and device encode pixel values using hash matching of pixel values.

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DICTIONARY ENCODING AND DECODING OF SCREEN CONTENT

BACKGROUND

[001] Engineers use compression (also called source coding or source encoding) to reduce the bit rate of digital video. Compression decreases the cost of storing and transmitting video information by converting the information into a lower bit rate form. Decompression (also called decoding) reconstructs a version of the original information from the compressed form. A "codec" is an encoder/decoder system.

[002] Over the last two decades, various video codec standards have been adopted, including the ITU-T H.261, H.262 (MPEG-2 or ISO/IEC 13818-2), H.263 and H.264 (MPEG-4 AVC or ISO/IEC 14496-10) standards, the MPEG-1 (ISO/IEC 11172-2) and MPEG-4 Visual (ISO/IEC 14496-2) standards, and the SMPTE 421M standard. More recently, the HEVC standard (ITU-T H.265 or ISO/IEC 23008-2) has been approved. Extensions to the HEVC standard (*e.g.*, for scalable video coding/decoding, for coding/decoding of video with higher fidelity in terms of sample bit depth or chroma sampling rate, or for multi-view coding/decoding) are currently under development. A video codec standard typically defines options for the syntax of an encoded video bitstream, detailing parameters in the bitstream when particular features are used in encoding and decoding. In many cases, a video codec standard also provides details about the decoding operations a decoder should perform to achieve conforming results in decoding. Aside from codec standards, various proprietary codec formats define other options for the syntax of an encoded video bitstream and corresponding decoding operations.

[003] Encoding and decoding of specific types of content, such as screen content, can present different challenges from coding normal video content. For example, screen content can include areas of similar content (e.g., large graphical areas with the same color or a smooth gradient) and areas of repeated content. Encoding and decoding such content using normal video coding techniques can produce results that are inefficient and that reduce quality (e.g., by producing compression artifacts).

SUMMARY

[004] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

[005] Techniques are described for improving efficiency of encoding and/or decoding of video and/or image data. In some innovations, a one-dimensional (1-D) dictionary mode is used to encode and/or decode pixel values using previous pixel values (e.g., previously reconstructed or previously decoded pixel values) stored in a 1-D dictionary. In the 1-D dictionary mode, current pixel values can be predicted (e.g., predicted exactly, without requiring any residual) using an offset that identifies a location within the 1-D dictionary and a length indicating a number of pixel values being predicted.

[006] In other innovations, a pseudo 2-D dictionary mode is used to encode and/or decode pixel values using previous pixel values (e.g., previously reconstructed or previously decoded pixel values). In the 2-D dictionary mode, current pixel values can be predicted (e.g., predicted exactly, without requiring any residual) using an X and Y offset and a length. An inter pseudo 2-D dictionary mode can also be used to encode and/or decode pixel values using pixel values in a reference picture (e.g., identified within the reference picture by an X and Y offset and a length from a corresponding pixel location in the reference corresponding to a current pixel location in a current picture being encoded or decoded).

[007] In other innovations, an encoder calculates hash values for previously encoded pixel values (e.g., for every 1, 2, 4, and 8 pixel values). Current pixel values being encoded are then matched against the previously encoded pixel values by creating a hash of the current pixel values and matching the hash values.

[008] The technologies described herein can be applied to coding of screen content. Screen content refers to video and/or image content that is computer-generated (e.g., text, graphics, and/or other artificial content that is computer-generated). An example of screen content is an image of a computer desktop graphical user interface comprising text, icons,

menus, windows, and/or other computer text and graphics. The technologies described herein can also be applied to content other than screen content.

[009] The foregoing and other objects, features, and advantages of the invention will become more apparent from the following detailed description, which proceeds with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[010] Figure 1 is a diagram of an example computing system in which some described embodiments can be implemented.

[011] Figures 2a and 2b are diagrams of example network environments in which some described embodiments can be implemented.

[012] Figure 3 is a diagram of an example encoder system in conjunction with which some described embodiments can be implemented.

[013] Figure 4 is a diagram of an example decoder system in conjunction with which some described embodiments can be implemented.

[014] Figures 5a and 5b are diagrams illustrating an example video encoder in conjunction with which some described embodiments can be implemented.

[015] Figure 6 is a diagram illustrating an example video decoder in conjunction with which some described embodiments can be implemented.

[016] Figure 7 is a diagram illustrating an example of encoding a block of pixel values using a 1-D dictionary mode.

[017] Figure 8 is a diagram illustrating an example of decoding a block of pixel values using a 1-D dictionary mode

[018] Figure 9 is a flowchart of an example method for decoding pixel values using a dictionary mode.

[019] Figure 10 is a flowchart of an example method for decoding pixel values using a 1-D dictionary mode.

[020] Figure 11 is a flowchart of an example method for encoding pixel values using a dictionary mode.

DETAILED DESCRIPTION

[021] The detailed description presents innovations in the use of dictionary modes during encoding and/or decoding. In particular, the detailed description presents innovations for encoding and/or decoding digital video and/or image content (e.g., video content such as screen content) using 1-D dictionary modes, pseudo 2-D dictionary modes, and/or inter pseudo 2-D dictionary modes. For example, various 1-D, pseudo 2-D, and inter pseudo 2-D dictionary modes can be applied to encode and/or decode pixel values in video content (e.g., in a video picture) based on previously encoded or decoded (e.g., reconstructed) pixel values (e.g., in the video picture) stored in dictionaries (e.g., 1-D dictionaries) or stored in other locations (e.g., stored in a reconstructed picture).

[022] Techniques are described for improving efficiency of encoding and/or decoding of video and/or image data. In some innovations, a dictionary mode is used to encode and/or decode pixel values using previous pixel values (e.g., previously reconstructed or previously decoded pixel values) stored in a dictionary or in another location. In dictionary mode, current pixel values can be predicted (e.g., predicted exactly, without requiring any residual) using an offset that identifies a location within previous pixel values (e.g., in a dictionary) and a length indicating a number of pixel values being predicted. Lossless prediction can be performed by predicting pixel values exactly from previous pixel values.

[023] Some of these innovations improve efficiency of encoding and/or decoding digital picture content (e.g., image content and/or video content). For example, a dictionary coding mode can be applied to reduce the bits needed to code digital picture content. In situations where screen content is being encoded and/or decoded, the various 1-D, pseudo 2-D, and inter pseudo 2-D dictionary coding modes can be applied to reduce the coding complexity and/or the number of bits needed to code the content. In other innovations

encoding of digital picture content can be improved by calculating hash values of various groupings of pixels (e.g., 1 pixel, 2 pixels, 4 pixels, 8 pixels, and so on) and matching hash values to identify matching pixel values to use for predicting current pixel values being encoded (e.g., for encoding using the various dictionary modes described herein).

[024] The technologies described herein can be applied to coding of screen content. Screen content refers to video and/or image content that is computer-generated (e.g., text, graphics, and/or other artificial content that is computer-generated). An example of screen content is an image of a computer desktop graphical user interface comprising text, icons, menus, windows, and/or other computer text and graphics. The technologies described herein can also be applied to content other than screen content (e.g., other types of digital video and/or image content).

[025] Although operations described herein are in places described as being performed by a video encoder or video decoder, in many cases the operations can be performed by another type of media processing tool (e.g., digital image or digital picture encoder, digital image or digital picture decoder).

[026] Some of the innovations described herein are illustrated with reference to syntax elements and operations specific to the HEVC standard. For example, reference is made to the draft version JCTVC-N1005 of the HEVC standard – "High Efficiency Video Coding (HEVC) Range Extensions Text Specification: Draft 4," JCTVC-N1005, July 2013. The innovations described herein can also be implemented for other standards or formats.

[027] More generally, various alternatives to the examples described herein are possible. For example, some of the methods described herein can be altered by changing the ordering of the method acts described, by splitting, repeating, or omitting certain method acts, etc. The various aspects of the disclosed technology can be used in combination or separately. Different embodiments use one or more of the described innovations. Some of the innovations described herein address one or more of the problems noted in the background. Typically, a given technique/tool does not solve all such problems.

I. Example Computing Systems

[028] Figure 1 illustrates a generalized example of a suitable computing system (100) in which several of the described innovations may be implemented. The computing system (100) is not intended to suggest any limitation as to scope of use or functionality, as the innovations may be implemented in diverse general-purpose or special-purpose computing systems.

[029] With reference to Figure 1, the computing system (100) includes one or more processing units (110, 115) and memory (120, 125). The processing units (110, 115) execute computer-executable instructions. A processing unit can be a general-purpose central processing unit ("CPU"), processor in an application-specific integrated circuit ("ASIC") or any other type of processor. In a multi-processing system, multiple processing units execute computer-executable instructions to increase processing power. For example, Figure 1 shows a central processing unit (110) as well as a graphics processing unit or co-processing unit (115). The tangible memory (120, 125) may be volatile memory (*e.g.*, registers, cache, RAM), non-volatile memory (*e.g.*, ROM, EEPROM, flash memory, etc.), or some combination of the two, accessible by the processing unit(s). The memory (120, 125) stores software (180) implementing one or more innovations for 1-D, pseudo 2-D, and/or inter pseudo 2-D dictionary mode coding, in the form of computer-executable instructions suitable for execution by the processing unit(s).

[030] A computing system may have additional features. For example, the computing system (100) includes storage (140), one or more input devices (150), one or more output devices (160), and one or more communication connections (170). An interconnection mechanism (not shown) such as a bus, controller, or network interconnects the components of the computing system (100). Typically, operating system software (not shown) provides an operating environment for other software executing in the computing system (100), and coordinates activities of the components of the computing system (100).

[031] The tangible storage (140) may be removable or non-removable, and includes magnetic disks, magnetic tapes or cassettes, CD-ROMs, DVDs, or any other medium which can be used to store information and which can be accessed within the computing system

(100). The storage (140) stores instructions for the software (180) implementing one or more innovations for 1-D, pseudo 2-D, and/or inter pseudo 2-D dictionary mode coding.

[032] The input device(s) (150) may be a touch input device such as a keyboard, mouse, pen, or trackball, a voice input device, a scanning device, or another device that provides input to the computing system (100). For video, the input device(s) (150) may be a camera, video card, TV tuner card, or similar device that accepts video input in analog or digital form, or a CD-ROM or CD-RW that reads video samples into the computing system (100). The output device(s) (160) may be a display, printer, speaker, CD-writer, or another device that provides output from the computing system (100).

[033] The communication connection(s) (170) enable communication over a communication medium to another computing entity. The communication medium conveys information such as computer-executable instructions, audio or video input or output, or other data in a modulated data signal. A modulated data signal is a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media can use an electrical, optical, RF, or other carrier.

[034] Any of the disclosed innovations can be implemented as computer-executable instructions or a computer program product stored on one or more computer-readable storage media and executed on a computing device (e.g., any available computing device, including smart phones or other mobile devices that include computing hardware). Computer-readable storage media are any available tangible media that can be accessed within a computing environment (e.g., one or more optical media discs such as DVD or CD, volatile memory components (such as DRAM or SRAM), or nonvolatile memory components (such as flash memory or hard drives)). By way of example and with reference to Fig. 1, computer-readable storage media include memory 1020 and 1025, and storage 1040. The term computer-readable storage media does not include signals and carrier waves. In addition, the term computer-readable storage media does not include communication connections (e.g., 170).

[035] The innovations can be described in the general context of computer-executable instructions, such as those included in program modules, being executed in a computing

system on a target real or virtual processor. Generally, program modules include routines, programs, libraries, objects, classes, components, data structures, etc. that perform particular tasks or implement particular abstract data types. The functionality of the program modules may be combined or split between program modules as desired in various embodiments. Computer-executable instructions for program modules may be executed within a local or distributed computing system.

[036] The terms “system” and “device” are used interchangeably herein. Unless the context clearly indicates otherwise, neither term implies any limitation on a type of computing system or computing device. In general, a computing system or computing device can be local or distributed, and can include any combination of special-purpose hardware and/or general-purpose hardware with software implementing the functionality described herein.

[037] The disclosed methods can also be implemented using specialized computing hardware configured to perform any of the disclosed methods. For example, the disclosed methods can be implemented by an integrated circuit (*e.g.*, an ASIC (such as an ASIC digital signal process unit (“DSP”), a graphics processing unit (“GPU”), or a programmable logic device (“PLD”), such as a field programmable gate array (“FPGA”)) specially designed or configured to implement any of the disclosed methods.

[038] For the sake of presentation, the detailed description uses terms like “determine” and “use” to describe computer operations in a computing system. These terms are high-level abstractions for operations performed by a computer, and should not be confused with acts performed by a human being. The actual computer operations corresponding to these terms vary depending on implementation.

II. Example Network Environments

[039] Figures 2a and 2b show example network environments (201, 202) that include video encoders (220) and video decoders (270). The encoders (220) and decoders (270) are

connected over a network (250) using an appropriate communication protocol. The network (250) can include the Internet or another computer network.

[040] In the network environment (201) shown in Figure 2a, each real-time communication ("RTC") tool (210) includes both an encoder (220) and a decoder (270) for bidirectional communication. A given encoder (220) can produce output compliant with a variation or extension of the HEVC standard, SMPTE 421M standard, ISO-IEC 14496-10 standard (also known as H.264 or AVC), another standard, or a proprietary format, with a corresponding decoder (270) accepting encoded data from the encoder (220). The bidirectional communication can be part of a video conference, video telephone call, or other two-party communication scenario. Although the network environment (201) in Figure 2a includes two real-time communication tools (210), the network environment (201) can instead include three or more real-time communication tools (210) that participate in multi-party communication.

[041] A real-time communication tool (210) manages encoding by an encoder (220). Figure 3 shows an example encoder system (300) that can be included in the real-time communication tool (210). Alternatively, the real-time communication tool (210) uses another encoder system. A real-time communication tool (210) also manages decoding by a decoder (270). Figure 4 shows an example decoder system (400), which can be included in the real-time communication tool (210). Alternatively, the real-time communication tool (210) uses another decoder system.

[042] In the network environment (202) shown in Figure 2b, an encoding tool (212) includes an encoder (220) that encodes video for delivery to multiple playback tools (214), which include decoders (270). The unidirectional communication can be provided for a video surveillance system, web camera monitoring system, remote desktop conferencing presentation or other scenario in which video is encoded and sent from one location to one or more other locations. Although the network environment (202) in Figure 2b includes two playback tools (214), the network environment (202) can include more or fewer playback tools (214). In general, a playback tool (214) communicates with the encoding tool (212) to determine a stream of video for the playback tool (214) to receive. The playback tool (214)

receives the stream, buffers the received encoded data for an appropriate period, and begins decoding and playback.

[043] Figure 3 shows an example encoder system (300) that can be included in the encoding tool (212). Alternatively, the encoding tool (212) uses another encoder system. The encoding tool (212) can also include server-side controller logic for managing connections with one or more playback tools (214). Figure 4 shows an example decoder system (400), which can be included in the playback tool (214). Alternatively, the playback tool (214) uses another decoder system. A playback tool (214) can also include client-side controller logic for managing connections with the encoding tool (212).

III. Example Encoder Systems

[044] Figure 3 is a block diagram of an example encoder system (300) in conjunction with which some described embodiments may be implemented. The encoder system (300) can be a general-purpose encoding tool capable of operating in any of multiple encoding modes such as a low-latency encoding mode for real-time communication, transcoding mode, and regular encoding mode for media playback from a file or stream, or it can be a special-purpose encoding tool adapted for one such encoding mode. The encoder system (300) can be implemented as an operating system module, as part of an application library or as a standalone application. Overall, the encoder system (300) receives a sequence of source video frames (311) from a video source (310) and produces encoded data as output to a channel (390). The encoded data output to the channel can include content encoded using 1-D, pseudo 2-D, and/or inter pseudo 2-D dictionary modes.

[045] The video source (310) can be a camera, tuner card, storage media, or other digital video source. The video source (310) produces a sequence of video frames at a frame rate of, for example, 30 frames per second. As used herein, the term “frame” generally refers to source, coded or reconstructed image data. For progressive video, a frame is a progressive video frame. For interlaced video, in example embodiments, an interlaced video frame is de-interlaced prior to encoding. Alternatively, two complementary interlaced video fields are encoded as an interlaced video frame or separate fields. Aside from indicating a

progressive video frame, the term "frame" or "picture" can indicate a single non-paired video field, a complementary pair of video fields, a video object plane that represents a video object at a given time, or a region of interest in a larger image. The video object plane or region can be part of a larger image that includes multiple objects or regions of a scene.

[046] An arriving source frame (311) is stored in a source frame temporary memory storage area (320) that includes multiple frame buffer storage areas (321, 322, ... , 32*n*). A frame buffer (321, 322, etc.) holds one source frame in the source frame storage area (320). After one or more of the source frames (311) have been stored in frame buffers (321, 322, etc.), a frame selector (330) periodically selects an individual source frame from the source frame storage area (320). The order in which frames are selected by the frame selector (330) for input to the encoder (340) may differ from the order in which the frames are produced by the video source (310), *e.g.*, a frame may be ahead in order, to facilitate temporally backward prediction. Before the encoder (340), the encoder system (300) can include a pre-processor (not shown) that performs pre-processing (*e.g.*, filtering) of the selected frame (331) before encoding. The pre-processing can also include color space conversion into primary and secondary components for encoding. Typically, before encoding, video has been converted to a color space such as YUV, in which sample values of a luma (Y) component represent brightness or intensity values, and sample values of chroma (U, V) components represent color-difference values. The chroma sample values may be sub-sampled to a lower chroma sampling rate (*e.g.*, for YUV 4:2:0 format), or the chroma sample values may have the same resolution as the luma sample values (*e.g.*, for YUV 4:4:4 format). Or, the video can be encoded in another format (*e.g.*, RGB 4:4:4 format).

[047] The encoder (340) encodes the selected frame (331) to produce a coded frame (341) and also produces memory management control operation ("MMCO") signals (342) or reference picture set ("RPS") information. If the current frame is not the first frame that has been encoded, when performing its encoding process, the encoder (340) may use one or more previously encoded/decoded frames (369) that have been stored in a decoded frame temporary memory storage area (360). Such stored decoded frames (369) are used as reference frames for inter-frame prediction of the content of the current source frame (331). Generally, the encoder (340) includes multiple encoding modules that perform encoding tasks

such as partitioning into tiles, intra prediction estimation and prediction, motion estimation and compensation, frequency transforms, quantization and entropy coding. The exact operations performed by the encoder (340) can vary depending on compression format. The format of the output encoded data can be a variation or extension of HEVC format, Windows Media Video format, VC-1 format, MPEG-x format (*e.g.*, MPEG-1, MPEG-2, or MPEG-4), H.26x format (*e.g.*, H.261, H.262, H.263, H.264), or another format.

[048] The encoder (340) can partition a frame into multiple tiles of the same size or different sizes. For example, the encoder (340) splits the frame along tile rows and tile columns that, with frame boundaries, define horizontal and vertical boundaries of tiles within the frame, where each tile is a rectangular region. Tiles are often used to improve options for parallel processing. A frame can also be organized as one or more slices, where a slice can be an entire frame or region of the frame. A slice can be decoded independently of other slices in a frame, which improves error resilience. The content of a slice or tile is further partitioned into blocks or other sets of samples for purposes of encoding and decoding.

[049] For syntax according to the HEVC standard, the encoder splits the content of a frame (or slice or tile) into coding tree units. A coding tree unit ("CTU") includes luma sample values organized as a luma coding tree block ("CTB") and corresponding chroma sample values organized as two chroma CTBs. The size of a CTU (and its CTBs) is selected by the encoder, and can be, for example, 64x64, 32x32 or 16x16 sample values. A CTU includes one or more coding units. A coding unit ("CU") has a luma coding block ("CB") and two corresponding chroma CBs. For example, a CTU with a 64x64 luma CTB and two 64x64 chroma CTBs (YUV 4:4:4 format) can be split into four CUs, with each CU including a 32x32 luma CB and two 32x32 chroma CBs, and with each CU possibly being split further into smaller CUs. Or, as another example, a CTU with a 64x64 luma CTB and two 32x32 chroma CTBs (YUV 4:2:0 format) can be split into four CUs, with each CU including a 32x32 luma CB and two 16x16 chroma CBs, and with each CU possibly being split further into smaller CUs. The smallest allowable size of CU (*e.g.*, 8x8, 16x16) can be signaled in the bitstream.

[050] Generally, a CU has a prediction mode such as inter or intra. A CU includes one or more prediction units for purposes of signaling of prediction information (such as

prediction mode details, etc.) and/or prediction processing. A prediction unit ("PU") has a luma prediction block ("PB") and two chroma PBs. For an intra-predicted CU, the PU has the same size as the CU, unless the CU has the smallest size (*e.g.*, 8x8). In that case, the CU can be split into four smaller PUs (*e.g.*, each 4x4 if the smallest CU size is 8x8) or the PU can have the smallest CU size, as indicated by a syntax element for the CU. A CU also has one or more transform units for purposes of residual coding/decoding, where a transform unit ("TU") has a transform block ("TB") and two chroma TBs. A PU in an intra-predicted CU may contain a single TU (equal in size to the PU) or multiple TUs. As used herein, the term "block" can indicate a CU, CB, PB, TB or other set of sample values, depending on context. The encoder decides how to partition video into CTUs, CUs, PUs, TUs, etc.

[051] Returning to Figure 3, the encoder represents an intra-coded block of a source frame (331) in terms of prediction from other, previously reconstructed sample values in the frame (331). For intra spatial prediction for a block, the intra-picture estimator estimates extrapolation of the neighboring reconstructed sample values into the block. The intra-prediction estimator outputs prediction information (such as prediction mode (direction) for intra spatial prediction), which is entropy coded. An intra-prediction predictor applies the prediction information to determine intra prediction values.

[052] For the various dictionary coding modes described herein, the encoder can calculate hash values of previously reconstructed sample values (e.g., groupings of 1 pixel, 2 pixels, 4 pixels, 8 pixels, and so on) and compare those has values for a hash value of a current pixel value being encoded. Matches of length one or more can be identified in the previously reconstructed sample values based on the hash comparison and the current pixel value (or values) can be encoded using the various 1-D and pseudo 2-D dictionary modes described herein (or the inter pseudo 2-D dictionary mode with reference to a reference picture).

[053] The encoder (340) represents an inter-coded, predicted block of a source frame (331) in terms of prediction from reference frames. A motion estimator estimates motion of the block with respect to one or more reference frames (369). When multiple reference frames are used, the multiple reference frames can be from different temporal directions or the same temporal direction. A motion-compensated prediction reference region is a region

of samples in the reference frame(s) that are used to generate motion-compensated prediction values for a block of samples of a current frame. The motion estimator outputs motion information such as motion vector information, which is entropy coded. A motion compensator applies motion vectors to reference frames (369) to determine motion-compensated prediction values.

[054] The entropy coder of the encoder (340) compresses quantized transform coefficient values as well as certain side information (*e.g.*, motion vector information, QP values, mode decisions, parameter choices). In particular, the entropy coder can compress data for elements of an index map using a coefficient coding syntax structure. Typical entropy coding techniques include Exp-Golomb coding, arithmetic coding, differential coding, Huffman coding, run length coding, variable-length-to-variable-length ("V2V") coding, variable-length-to-fixed-length ("V2F") coding, LZ coding, dictionary coding, probability interval partitioning entropy coding ("PIPE"), and combinations of the above. The entropy coder can use different coding techniques for different kinds of information, and can choose from among multiple code tables within a particular coding technique.

[055] The coded frames (341) and MMCO/RPS information (342) are processed by a decoding process emulator (350). The decoding process emulator (350) implements some of the functionality of a decoder, for example, decoding tasks to reconstruct reference frames. The decoding process emulator (350) uses the MMCO/RPS information (342) to determine whether a given coded frame (341) needs to be reconstructed and stored for use as a reference frame in inter-frame prediction of subsequent frames to be encoded. If the MMCO/RPS information (342) indicates that a coded frame (341) needs to be stored, the decoding process emulator (350) models the decoding process that would be conducted by a decoder that receives the coded frame (341) and produces a corresponding decoded frame (351). In doing so, when the encoder (340) has used decoded frame(s) (369) that have been stored in the decoded frame storage area (360), the decoding process emulator (350) also uses the decoded frame(s) (369) from the storage area (360) as part of the decoding process.

[056] The decoded frame temporary memory storage area (360) includes multiple frame buffer storage areas (361, 362, ..., 36*n*). The decoding process emulator (350) uses the MMCO/RPS information (342) to manage the contents of the storage area (360) in order to

identify any frame buffers (361, 362, etc.) with frames that are no longer needed by the encoder (340) for use as reference frames. After modeling the decoding process, the decoding process emulator (350) stores a newly decoded frame (351) in a frame buffer (361, 362, etc.) that has been identified in this manner.

[057] The coded frames (341) and MMCO/RPS information (342) are buffered in a temporary coded data area (370). The coded data that is aggregated in the coded data area (370) contains, as part of the syntax of an elementary coded video bitstream, encoded data for one or more pictures. The coded data that is aggregated in the coded data area (370) can also include media metadata relating to the coded video data (*e.g.*, as one or more parameters in one or more supplemental enhancement information ("SEI") messages or video usability information ("VUI") messages).

[058] The aggregated data (371) from the temporary coded data area (370) are processed by a channel encoder (380). The channel encoder (380) can packetize the aggregated data for transmission as a media stream (*e.g.*, according to a media stream multiplexing format such as ISO/IEC 13818-1), in which case the channel encoder (380) can add syntax elements as part of the syntax of the media transmission stream. Or, the channel encoder (380) can organize the aggregated data for storage as a file (*e.g.*, according to a media container format such as ISO/IEC 14496-12), in which case the channel encoder (380) can add syntax elements as part of the syntax of the media storage file. Or, more generally, the channel encoder (380) can implement one or more media system multiplexing protocols or transport protocols, in which case the channel encoder (380) can add syntax elements as part of the syntax of the protocol(s). The channel encoder (380) provides output to a channel (390), which represents storage, a communications connection, or another channel for the output.

IV. Example Decoder Systems

[059] Figure 4 is a block diagram of an example decoder system (400) in conjunction with which some described embodiments may be implemented. The decoder system (400) can be a general-purpose decoding tool capable of operating in any of multiple decoding

modes such as a low-latency decoding mode for real-time communication and regular decoding mode for media playback from a file or stream, or it can be a special-purpose decoding tool adapted for one such decoding mode. The decoder system (400) can be implemented as an operating system module, as part of an application library or as a standalone application. Overall, the decoder system (400) receives coded data from a channel (410) and produces reconstructed frames as output for an output destination (490). The coded data can include content encoded using 1-D, pseudo 2-D, and/or inter pseudo 2-D dictionary modes.

[060] The decoder system (400) includes a channel (410), which can represent storage, a communications connection, or another channel for coded data as input. The channel (410) produces coded data that has been channel coded. A channel decoder (420) can process the coded data. For example, the channel decoder (420) de-packetizes data that has been aggregated for transmission as a media stream (*e.g.*, according to a media stream multiplexing format such as ISO/IEC 13818-1), in which case the channel decoder (420) can parse syntax elements added as part of the syntax of the media transmission stream. Or, the channel decoder (420) separates coded video data that has been aggregated for storage as a file (*e.g.*, according to a media container format such as ISO/IEC 14496-12), in which case the channel decoder (420) can parse syntax elements added as part of the syntax of the media storage file. Or, more generally, the channel decoder (420) can implement one or more media system demultiplexing protocols or transport protocols, in which case the channel decoder (420) can parse syntax elements added as part of the syntax of the protocol(s).

[061] The coded data (421) that is output from the channel decoder (420) is stored in a temporary coded data area (430) until a sufficient quantity of such data has been received. The coded data (421) includes coded frames (431) and MMCO/RPS information (432). The coded data (421) in the coded data area (430) contain, as part of the syntax of an elementary coded video bitstream, coded data for one or more pictures. The coded data (421) in the coded data area (430) can also include media metadata relating to the encoded video data (*e.g.*, as one or more parameters in one or more SEI messages or VUI messages).

[062] In general, the coded data area (430) temporarily stores coded data (421) until such coded data (421) is used by the decoder (450). At that point, coded data for a coded

frame (431) and MMCO/RPS information (432) are transferred from the coded data area (430) to the decoder (450). As decoding continues, new coded data is added to the coded data area (430) and the oldest coded data remaining in the coded data area (430) is transferred to the decoder (450).

[063] The decoder (450) periodically decodes a coded frame (431) to produce a corresponding decoded frame (451). As appropriate, when performing its decoding process, the decoder (450) may use one or more previously decoded frames (469) as reference frames for inter-frame prediction. The decoder (450) reads such previously decoded frames (469) from a decoded frame temporary memory storage area (460). Generally, the decoder (450) includes multiple decoding modules that perform decoding tasks such as entropy decoding, inverse quantization, inverse frequency transforms, intra prediction, motion compensation and merging of tiles. The exact operations performed by the decoder (450) can vary depending on compression format.

[064] For example, the decoder (450) receives encoded data for a compressed frame or sequence of frames and produces output including decoded frame (451). In the decoder (450), a buffer receives encoded data for a compressed frame and, at an appropriate time, makes the received encoded data available to an entropy decoder. The entropy decoder entropy decodes entropy-coded quantized data as well as entropy-coded side information, typically applying the inverse of entropy encoding performed in the encoder. A motion compensator applies motion information to one or more reference frames to form motion-compensated prediction values for any inter-coded blocks of the frame being reconstructed. An intra prediction module can spatially predict sample values of a current block from neighboring, previously reconstructed sample values.

[065] For the various dictionary coding modes described herein, the decoder can decode current pixel values in a matching mode and/or a direct mode. In matching mode, the decoder decodes current pixel values that are predicted from previously decoded pixel values (e.g., previously reconstructed pixel values) which may be stored in a 1-D dictionary or in another location (e.g., a reconstructed picture). For example, the decoder can receive one or more codes indicating an offset (e.g., within a dictionary) and a length (indicating a number

of pixel values to be predicted from the offset). In direct mode, the decoder can decode pixel values directly without prediction.

[066] In non-dictionary modes, the decoder (450) also reconstructs prediction residuals. An inverse quantizer inverse quantizes entropy-decoded data. For example, the decoder (450) sets values for QP for a picture, tile, slice and/or other portion of video based on syntax elements in the bitstream, and inverse quantizes transform coefficients accordingly. An inverse frequency transformer converts the quantized, frequency domain data into spatial domain information. For an inter-predicted block, the decoder (450) combines reconstructed prediction residuals with motion-compensated predictions. The decoder (450) can similarly combine prediction residuals with predictions from intra prediction. A motion compensation loop in the video decoder (450) includes an adaptive de-blocking filter to smooth discontinuities across block boundary rows and/or columns in the decoded frame (451).

[067] The decoded frame temporary memory storage area (460) includes multiple frame buffer storage areas (461, 462, ..., 46*n*). The decoded frame storage area (460) is an example of a decoded picture buffer. The decoder (450) uses the MMCO/RPS information (432) to identify a frame buffer (461, 462, etc.) in which it can store a decoded frame (451). The decoder (450) stores the decoded frame (451) in that frame buffer.

[068] An output sequencer (480) uses the MMCO/RPS information (432) to identify when the next frame to be produced in output order is available in the decoded frame storage area (460). When the next frame (481) to be produced in output order is available in the decoded frame storage area (460), it is read by the output sequencer (480) and output to the output destination (490) (*e.g.*, display). In general, the order in which frames are output from the decoded frame storage area (460) by the output sequencer (480) may differ from the order in which the frames are decoded by the decoder (450).

V. Example Video Encoders

[069] Figures 5a and 5b are a block diagram of a generalized video encoder (500) in conjunction with which some described embodiments may be implemented. The encoder

(500) receives a sequence of video pictures including a current picture as an input video signal (505) and produces encoded data in a coded video bitstream (595) as output.

[070] The encoder (500) is block-based and uses a block format that depends on implementation. Blocks may be further sub-divided at different stages, *e.g.*, at the prediction, frequency transform and/or entropy encoding stages. For example, a picture can be divided into 64x64 blocks, 32x32 blocks or 16x16 blocks, which can in turn be divided into smaller blocks of sample values for coding and decoding. In implementations of encoding for the HEVC standard, the encoder partitions a picture into CTUs (CTBs), CUs (CBs), PUs (PBs) and TU (TBs).

[071] The encoder (500) compresses pictures using intra-picture coding and/or inter-picture coding. Many of the components of the encoder (500) are used for both intra-picture coding and inter-picture coding. The exact operations performed by those components can vary depending on the type of information being compressed.

[072] A tiling module (510) optionally partitions a picture into multiple tiles of the same size or different sizes. For example, the tiling module (510) splits the picture along tile rows and tile columns that, with picture boundaries, define horizontal and vertical boundaries of tiles within the picture, where each tile is a rectangular region. The tiling module (510) can then group the tiles into one or more tile sets, where a tile set is a group of one or more of the tiles.

[073] The general encoding control (520) receives pictures for the input video signal (505) as well as feedback (not shown) from various modules of the encoder (500). Overall, the general encoding control (520) provides control signals (not shown) to other modules (such as the tiling module (510), transformer/scaler/quantizer (530), scaler/inverse transformer (535), intra-picture estimator (540), motion estimator (550) and intra/inter switch) to set and change coding parameters during encoding. In particular, the general encoding control (520) can decide whether and how to use dictionary modes during encoding. The general encoding control (520) can also evaluate intermediate results during encoding, for example, performing rate-distortion analysis. The general encoding control (520) produces general control data (522) that indicates decisions made during encoding, so that a

corresponding decoder can make consistent decisions. The general control data (522) is provided to the header formatter/entropy coder (590).

[074] If the current picture is predicted using inter-picture prediction, a motion estimator (550) estimates motion of blocks of sample values of the current picture of the input video signal (505) with respect to one or more reference pictures. The decoded picture buffer (570) buffers one or more reconstructed previously coded pictures for use as reference pictures. When multiple reference pictures are used, the multiple reference pictures can be from different temporal directions or the same temporal direction. The motion estimator (550) produces as side information motion data (552) such as motion vector data and reference picture selection data. The motion data (552) is provided to the header formatter/entropy coder (590) as well as the motion compensator (555).

[075] The motion compensator (555) applies motion vectors to the reconstructed reference picture(s) from the decoded picture buffer (570). The motion compensator (555) produces motion-compensated predictions for the current picture.

[076] In a separate path within the encoder (500), an intra-picture estimator (540) determines how to perform intra-picture prediction for blocks of sample values of a current picture of the input video signal (505). The current picture can be entirely or partially coded using intra-picture coding. Using values of a reconstruction (538) of the current picture, for intra spatial prediction, the intra-picture estimator (540) determines how to spatially predict sample values of a current block of the current picture from neighboring, previously reconstructed sample values of the current picture.

[077] For the various dictionary coding modes described herein, the encoder (500) can calculate hash values of previously reconstructed sample values (e.g., groupings of 1 pixel, 2 pixels, 4 pixels, 8 pixels, and so on) and compare those has values for a hash value of a current pixel value being encoded. Matches of length one or more can be identified in the previously reconstructed sample values based on the hash comparison and the current pixel value (or values) can be encoded using the various 1-D and pseudo 2-D dictionary modes described herein (or the inter pseudo 2-D dictionary mode with reference to a reference picture).

[078] The intra-prediction estimator (540) produces as side information intra prediction data (542), such as information indicating whether intra prediction uses spatial prediction or one of the various dictionary modes (*e.g.*, a flag value per intra block or per intra block of certain prediction mode directions), prediction mode direction (for intra spatial prediction). The intra prediction data (542) is provided to the header formatter/entropy coder (590) as well as the intra-picture predictor (545). According to the intra prediction data (542), the intra-picture predictor (545) spatially predicts sample values of a current block of the current picture from neighboring, previously reconstructed sample values of the current picture.

[079] In non-dictionary modes, the intra/inter switch selects values of a motion-compensated prediction or intra-picture prediction for use as the prediction (558) for a given block. In non-dictionary modes, the difference (if any) between a block of the prediction (558) and corresponding part of the original current picture of the input video signal (505) provides values of the residual (518). During reconstruction of the current picture, reconstructed residual values are combined with the prediction (558) to produce a reconstruction (538) of the original content from the video signal (505). In lossy compression, however, some information is still lost from the video signal (505).

[080] In the transformer/scaler/quantizer (530), for non-dictionary modes, a frequency transformer converts spatial domain video information into frequency domain (*i.e.*, spectral, transform) data. For block-based video coding, the frequency transformer applies a discrete cosine transform ("DCT"), an integer approximation thereof, or another type of forward block transform to blocks of prediction residual data (or sample value data if the prediction (558) is null), producing blocks of frequency transform coefficients. The encoder (500) may also be able to indicate that such transform step is skipped. The scaler/quantizer scales and quantizes the transform coefficients. For example, the quantizer applies non-uniform, scalar quantization to the frequency domain data with a step size that varies on a frame-by-frame basis, tile-by-tile basis, slice-by-slice basis, block-by-block basis or other basis. The quantized transform coefficient data (532) is provided to the header formatter/entropy coder (590).

[081] In the scaler/inverse transformer (535), for non-dictionary modes, a scaler/inverse quantizer performs inverse scaling and inverse quantization on the quantized transform

coefficients. An inverse frequency transformer performs an inverse frequency transform, producing blocks of reconstructed prediction residuals or sample values. The encoder (500) combines reconstructed residuals with values of the prediction (558) (*e.g.*, motion-compensated prediction values, intra-picture prediction values) to form the reconstruction (538).

[082] For intra-picture prediction, the values of the reconstruction (538) can be fed back to the intra-picture estimator (540) and intra-picture predictor (545). Also, the values of the reconstruction (538) can be used for motion-compensated prediction of subsequent pictures. The values of the reconstruction (538) can be further filtered. A filtering control (560) determines how to perform deblock filtering and sample adaptive offset ("SAO") filtering on values of the reconstruction (538), for a given picture of the video signal (505). The filtering control (560) produces filter control data (562), which is provided to the header formatter/entropy coder (590) and merger/filter(s) (565).

[083] In the merger/filter(s) (565), the encoder (500) merges content from different tiles into a reconstructed version of the picture. The encoder (500) selectively performs deblock filtering and SAO filtering according to the filter control data (562), so as to adaptively smooth discontinuities across boundaries in the frames. Tile boundaries can be selectively filtered or not filtered at all, depending on settings of the encoder (500), and the encoder (500) may provide syntax within the coded bitstream to indicate whether or not such filtering was applied. The decoded picture buffer (570) buffers the reconstructed current picture for use in subsequent motion-compensated prediction.

[084] The header formatter/entropy coder (590) formats and/or entropy codes the general control data (522), quantized transform coefficient data (532), intra prediction data (542) and packed index values, motion data (552) and filter control data (562). For example, the header formatter/entropy coder (590) uses context-adaptive binary arithmetic coding ("CABAC") for entropy coding of various syntax elements of a coefficient coding syntax structure.

[085] The header formatter/entropy coder (590) provides the encoded data in the coded video bitstream (595). The format of the coded video bitstream (595) can be a variation or

extension of HEVC format, Windows Media Video format, VC-1 format, MPEG-x format (*e.g.*, MPEG-1, MPEG-2, or MPEG-4), H.26x format (*e.g.*, H.261, H.262, H.263, H.264), or another format.

[086] Depending on implementation and the type of compression desired, modules of the encoder can be added, omitted, split into multiple modules, combined with other modules, and/or replaced with like modules. In alternative embodiments, encoders with different modules and/or other configurations of modules perform one or more of the described techniques. Specific embodiments of encoders typically use a variation or supplemented version of the encoder (500). The relationships shown between modules within the encoder (500) indicate general flows of information in the encoder; other relationships are not shown for the sake of simplicity.

VI. Example Video Decoders

[087] Figure 6 is a block diagram of a generalized decoder (600) in conjunction with which several described embodiments may be implemented. The decoder (600) receives encoded data in a coded video bitstream (605) and produces output including pictures for reconstructed video (695). The format of the coded video bitstream (605) can be a variation or extension of HEVC format, Windows Media Video format, VC-1 format, MPEG-x format (*e.g.*, MPEG-1, MPEG-2, or MPEG-4), H.26x format (*e.g.*, H.261, H.262, H.263, H.264), or another format.

[088] The decoder (600) is block-based and uses a block format that depends on implementation. Blocks may be further sub-divided at different stages. For example, a picture can be divided into 64x64 blocks, 32x32 blocks or 16x16 blocks, which can in turn be divided into smaller blocks of sample values. In implementations of decoding for the HEVC standard, a picture is partitioned into CTUs (CTBs), CUs (CBs), PUs (PBs) and TU (TBs).

[089] The decoder (600) decompresses pictures using intra-picture decoding and/or inter-picture decoding. Many of the components of the decoder (600) are used for both intra-

picture decoding and inter-picture decoding. The exact operations performed by those components can vary depending on the type of information being decompressed.

[090] A buffer receives encoded data in the coded video bitstream (605) and makes the received encoded data available to the parser/entropy decoder (610). The parser/entropy decoder (610) entropy decodes entropy-coded data, typically applying the inverse of entropy coding performed in the encoder (500) (*e.g.*, context-adaptive binary arithmetic decoding). For example, the parser/entropy decoder (610) uses context-adaptive binary arithmetic decoding for entropy decoding of various syntax elements of a coefficient coding syntax structure. As a result of parsing and entropy decoding, the parser/entropy decoder (610) produces general control data (622), quantized transform coefficient data (632), intra prediction data (642) and packed index values, motion data (652) and filter control data (662).

[091] The general decoding control (620) receives the general control data (622) and provides control signals (not shown) to other modules (such as the scaler/inverse transformer (635), intra-picture predictor (645), motion compensator (655) and intra/inter switch) to set and change decoding parameters during decoding.

[092] If the current picture is predicted using inter-picture prediction, a motion compensator (655) receives the motion data (652), such as motion vector data and reference picture selection data. The motion compensator (655) applies motion vectors to the reconstructed reference picture(s) from the decoded picture buffer (670). The motion compensator (655) produces motion-compensated predictions for inter-coded blocks of the current picture. The decoded picture buffer (670) stores one or more previously reconstructed pictures for use as reference pictures.

[093] In a separate path within the decoder (600), the intra-prediction predictor (645) receives the intra prediction data (642), such as information indicating whether intra prediction uses spatial prediction or one of the dictionary modes (*e.g.*, a flag value per intra block or per intra block of certain prediction mode directions), prediction mode direction (for intra spatial prediction). For intra spatial prediction, using values of a reconstruction (638) of the current picture, according to prediction mode data, the intra-picture predictor (645)

spatially predicts sample values of a current block of the current picture from neighboring, previously reconstructed sample values of the current picture.

[094] For the various dictionary coding modes described herein, the decoder can decode current pixel values in a matching mode and/or a direct mode. In matching mode, the decoder decodes current pixel values that are predicted from previously decoded pixel values (e.g., previously reconstructed pixel values) which may be stored in a 1-D dictionary or in another location (e.g., a reconstructed picture). For example, the decoder can receive one or more codes indicating an offset (e.g., within a dictionary) and a length (indicating a number of pixel values to be predicted from the offset). In direct mode, the decoder can decode pixel values directly without prediction

[095] In non-dictionary modes, the intra/inter switch selects values of a motion-compensated prediction or intra-picture prediction for use as the prediction (658) for a given block. For example, when HEVC syntax is followed, the intra/inter switch can be controlled based on a syntax element encoded for a CU of a picture that can contain intra-predicted CUs and inter-predicted CUs. The decoder (600) combines the prediction (658) with reconstructed residual values to produce the reconstruction (638) of the content from the video signal.

[096] To reconstruct the residual, for non-dictionary modes, the scaler/inverse transformer (635) receives and processes the quantized transform coefficient data (632). In the scaler/inverse transformer (635), a scaler/inverse quantizer performs inverse scaling and inverse quantization on the quantized transform coefficients. An inverse frequency transformer performs an inverse frequency transform, producing blocks of reconstructed prediction residuals or sample values. For example, the inverse frequency transformer applies an inverse block transform to frequency transform coefficients, producing sample value data or prediction residual data. The inverse frequency transform can be an inverse DCT, an integer approximation thereof, or another type of inverse frequency transform.

[097] For intra-picture prediction, the values of the reconstruction (638) can be fed back to the intra-picture predictor (645). For inter-picture prediction, the values of the reconstruction (638) can be further filtered. In the merger/filter(s) (665), the decoder (600)

merges content from different tiles into a reconstructed version of the picture. The decoder (600) selectively performs deblock filtering and SAO filtering according to the filter control data (662) and rules for filter adaptation, so as to adaptively smooth discontinuities across boundaries in the frames. Tile boundaries can be selectively filtered or not filtered at all, depending on settings of the decoder (600) or a syntax indication within the encoded bitstream data. The decoded picture buffer (670) buffers the reconstructed current picture for use in subsequent motion-compensated prediction.

[098] The decoder (600) can also include a post-processing deblock filter. The post-processing deblock filter optionally smoothes discontinuities in reconstructed pictures. Other filtering (such as de-ring filtering) can also be applied as part of the post-processing filtering.

[099] Depending on implementation and the type of decompression desired, modules of the decoder can be added, omitted, split into multiple modules, combined with other modules, and/or replaced with like modules. In alternative embodiments, decoders with different modules and/or other configurations of modules perform one or more of the described techniques. Specific embodiments of decoders typically use a variation or supplemented version of the decoder (600). The relationships shown between modules within the decoder (600) indicate general flows of information in the decoder; other relationships are not shown for the sake of simplicity.

VII. Innovations for 1-D Dictionary Mode

[0100] This section presents various innovations for one-dimensional (1-D) dictionary mode. Some innovations relate to signaling pixel values using an offset and a length, while others relate to signaling pixel values directly. Still others relate to vertical scanning and horizontal scanning.

[0101] In particular, using the 1-D dictionary mode when encoding pixel values can improve performance and reduce needed bits when encoding video content, particularly screen content (e.g., when performing screen capture). Screen content typically includes repeated structures (*e.g.*, graphics, text characters), which provide areas with the same pixel values that can be encoded with prediction to improve performance.

A. 1-D Dictionary Mode – Introduction

[0102] In 1-D dictionary mode, sample values (e.g., pixel values) are predicted by reference (using offset and length) to previously sample values stored in a 1-D dictionary (e.g., previously reconstructed sample values). For example, a video encode or image encoder can encode current sample values with reference to a 1-D dictionary storing previous sample values (e.g., reconstructed or original sample values) that are used to predict and encode the current sample values. A video decoder or image decoder can decode current sample values with reference to a 1-D dictionary storing previously decoded (e.g., reconstructed) sample values that are used to predict and decode the current sample values.

[0103] In the 1-D dictionary mode, one or more current pixel values can be predicted from one or more previous pixel values (e.g., in scan order). The prediction can be performed by matching the current pixel values with the previous pixel values so that current pixel values can be predicted exactly (e.g., without requiring any residual). The term “matching mode” describes encoding and/or decoding using matching pixel values in a dictionary (or from another source, such as a reconstructed picture). In situations where there are no matching pixel values (e.g., at the beginning of a frame or where there are no matches found in the dictionary of previous pixel values), then one or more current pixel values can be coded directly. The term “direct mode” describes encoding and/or decoding pixel values directly.

[0104] In some implementations, pixel values are encoded and decoded as combined pixels (a combination of Y, U, and V values for the pixel, or a combination of R, G, and B values for the pixel, are encoded/decoded together). In other implementations, pixel values are encoded and decoded as separate components (e.g., separate 1-D dictionaries can be maintained for each of Y, U, and V components or R, G, and B components). Pixel values can be encoded and decoded in various YUV data formats (e.g., YUV 4:4:4, YUV 4:2:2, YUV 4:2:0, etc.) or in various RGB data formats (e.g., RGB, GBR, BGR, etc.).

[0105] Encoding and/or decoding of pixel values using the 1-D dictionary mode can be applied to video or image content that is divided into distinct areas, such as blocks. Generally, any size block can be used. In some implementations, video content (e.g., a video picture or frame) is divided into coding units with sizes of 64x64, 32x32, 16x16, or 8x8 sample values.

[0106] In some implementations, dictionary coding can be combined with other types of coding. For example, pixel values can be coded using one of the dictionary modes described herein (e.g., 1-D dictionary mode). The coded pixel values can then be coded using another coding technique (e.g., context-based arithmetic coding or another coding technique).

B. Signaling Offset and Length

[0107] In the 1-D dictionary mode, when there are matching pixel values, the offset and length values are signaled to indicate the position in the 1-D dictionary where the matching pixel values are located to predict the current pixel values. For example, one or more current pixel values can be predicted from one or more previous pixel values stored in the 1-D dictionary that are identified within the 1-D dictionary by offset (the position back in the 1-D dictionary from the current pixel value) and length (the number of pixel values that are predicted from the offset). As should be understood, an offset of 5 means five pixels back in the 1-D dictionary from the current pixel value (e.g., in some implementations a negative sign is added to the offset, which would be an offset of -5 in this example).

[0108] In the 1-D dictionary mode, in some implementations pixel values in a current block can be predicted from pixel values in a previous block (e.g., depending on the maximum size of the dictionary). For example, in a picture coded using 64x64 blocks, pixel values from the fourth block in the picture can be predicted (e.g., using offset and length) from pixel values from the first block in the picture that are stored in a 1-D dictionary.

[0109] The offset can be encoded and signaled (e.g., in a bit stream) in a format that divides the possible offset values into a number of ranges, and encodes the offset values by range. In this way, an offset can be encoded as a two-part code with the first part identifying the offset range and the second part indicating the offset value within the range.

[0110] In a specific implementation, the offset values are coded using the following ranges. In addition, in this implementation zero-based numbering is applied so that offset values are decreased by 1 before the offset values are encoded and increased by 1 after the offset values are decoded. The ranges (with their offset range codes), corresponding offset values, and number of bits are indicated by the following table (Table 1).

Range	Offset values	Number of bits to represent offset value
Range 1 (code: 1)	[0, 3]	2 bits
Range 2 (code: 01)	[4, 19]	4 bits
Range 3 (code: 001)	[20, 275]	8 bits
Range 4 (code: 0001)	[276, 65,811]	16 bits
Range 5 (code: 0000)	[more than 65,811]	N bits

Table 1 – Example Ranges for Offset Values

[0111] Using the implementation depicted in Table 1 above, offsets can be encoded, signaled, and decoded. As an example, an offset value of 415 (representing an original offset value of 416, which is decreased by 1 for encoding) would be encoded in Range 4. Because Range 4 starts with an offset value of 276, the value to be coded would be 415 – 276 = 139. The encoded offset would be generated by combining the offset range code of “0001” (representing Range 4) followed by the 16-bit value of “0000000010001011” (the 16-bit binary value for the decimal number 139). Putting the two parts of the code together (the offset range code and the offset value code) results in the following combined code for the encoded offset: “00010000000010001011”. As another example, an offset value of 45 (representing an original offset value of 46, which is decreased by 1 for encoding) would be encoded in Range 3. Because Range 3 starts with an offset value of 20, the value to be coded would be 45 – 20 = 25. The encoded offset would be generated by combining the offset range code of “001” (representing Range 3) followed by the 8-bit value of “00011001” (the 8-bit binary value for the decimal number 25). Putting the two parts of the code together (the offset range code and the offset value code) results in the following combined code for the encoded offset: “00100011001”.

[0112] As depicted in Table 1 above, Range 5 represents offset values of more than 65,811 using N bits where N represents the number of bits needed to represent the maximum offset value. In some implementations, the maximum offset value is determined from the current dictionary size. For example, if the current dictionary size is 300,000, then N can be set to 18 (i.e., 18 bits are needed to represent the maximum offset value of 300,000), and therefore an offset value between 65,811 and 300,000 would use 18 bits to encode the offset value. It should be understood that the offset value for Range 5 begins at 65,812, so to represent 300,000 only 18 bits are needed to represent the amount over 65,811 (i.e., only 18 bits are needed to represent 300,000 – 65,812 = 234,188). In other implementations, the maximum offset value is pre-determined and does not depend on the current dictionary size. For example, if the pre-determined maximum offset value is 800,000, then N can be set to 20.

[0113] In other implementations, the offset values can be coded using a different number of ranges and/or ranges covering different groupings of offset values.

[0114] In a specific implementation, the length values are coded by range, similar to the offset values. In addition, in this implementation zero-based numbering is applied so that length values are decreased by 1 before the length values are encoded and increased by 1 after the length values are decoded. The ranges (with their length range codes), corresponding length values, and number of bits are indicated by the following table (Table 2).

Range	Length values	Number of bits to represent length value
Range 1 (code: 1)	[0, 3]	2 bits
Range 2 (code: 01)	[4, 19]	4 bits
Range 3 (code: 001)	[20, 275]	8 bits
Range 4 (code: 000)	[more than 275]	N bits

Table 2 – Example Ranges for Length Values

[0115] Using the implementation depicted in Table 2 above, lengths can be encoded, signaled, and decoded. As an example, a length value of 2 (representing an original length value of 3, which is decreased by 1 for encoding) would be encoded in Range 1. The encoded length would be generated by combining the length range code of “1” (representing Range 1) followed by the 2-bit value of “10” (the 2-bit binary value for the decimal number 2). Putting the two parts of the code together (the length range code and the length value code) results in the following combined code for the encoded length: “101”. As another example, a length value of 56 (representing an original length value of 57, which is decreased by 1 for encoding) would be encoded in Range 3. Because Range 3 starts with an offset value of 20, the value to be coded would be 56 – 20 = 36. The encoded length would be generated by combining the length range code of “001” (representing Range 3) followed by the 8-bit value of “00100100” (the 8-bit binary value for the decimal number 36). Putting the two parts of the code together (the length range code and the length value code) results in the following combined code for the encoded length: “00100100100”.

[0116] As depicted in Table 2 above, Range 4 represents length values of more than 275 using N bits where N represents the number of bits needed to represent the maximum length value. In some implementations, the maximum length value is the number of pixels left in the current block being encoded or decoded. For example, if the current pixel value being encoded or decoded is the 3,000th pixel value in a current 64x64 block (a block having 4,096 pixel values), then the maximum length value is 1,096 (4,096 – 3,000), which can be represented by 10 bits (N = 10). It should be understood that the offset value for Range 4 begins at 276, so to represent 1,096 only 10 bits are needed to represent the amount over 275 (i.e., only 10 bits are needed to represent 1,096 – 276 = 820). In other implementations, the maximum length value is pre-determined and does not depend on the current dictionary size. For example, if the pre-determined maximum length value is 4,096, then N can be set to 12.

[0117] In other implementations, the length values can be coded using a different number of ranges and/or ranges covering different groupings of length values.

[0118] In some implementations, a maximum offset and/or a maximum length is known. When the maximum offset and/or maximum length is known, coding efficiency can be improved. For example, when coding the value of the matching offset, the maximum offset can be set to the current dictionary size (e.g., if the current dictionary size is 10 pixels, the offset cannot be greater than 10). When encoding the value of the matching length, the maximum length can be set to the number of pixels left in the current block (e.g., the current coding unit (CU)). For example, if the current pixel value being encoded or decoded is the 15th pixel in an 8x8 block, then the maximum length can be set to 49. When the maximum value is known (for the offset and/or length), it can be signaled more efficiently. For example, the number of bits needed to encode the maximum value can be determined by calculating ceiling($\log_2$(maximum)), which can be used to define the “N” bits in Table 1 and Table 2 above.

[0119] In some implementations, the minimum offset and length are 1, which can be coded as 0 when converted to zero-based numbering.

[0120] The 1-D dictionary mode can be applied to encode and/or decode pixel values within a block. For example, the 1-D dictionary mode (as well as the other dictionary modes described herein) can be applied to encode and/or decode pixel values within blocks of a video frame (e.g., blocks of various sizes, such as 4x4 blocks, 8x8 blocks, 16x16 blocks, 32x32 blocks, and 64x64 blocks).

[0121] In some implementations, the offset and length can overlap the current pixel value being encoded/decoded. As an example, consider pixel values [P-2, P-1, P0, P1, P2, P3] where P-2 and P-1 are the last two pixel values in the 1-D dictionary, P0 is the current pixel value being encoded/decoded, and P1 through P3 are the next pixel values to be encoded/decoded. In this situation, an offset of 1 and a length of 3 (un-encoded offset and length values) is a valid condition in which P0 is predicted from P-1, P1 is predicted from P0, and P2 is predicted from P1. As should be understood, an offset of 1 (un-encoded value, which would be 0 when encoded) means one position back from the current pixel value into the 1-D dictionary (e.g., in some implementations a negative sign is added to the offset, which would be an offset of -1 in this example).

C. Horizontal and Vertical Scanning

[0122] The 1-D dictionary mode supports horizontal and vertical scanning, which can be used to convert between the 1-D dictionary and the two dimensional representation of video or image content (e.g., blocks of two dimensional video or image content). For example, pixel values within a block of video content can be scanned horizontally when encoding and decoding. With horizontal scanning, pixel values are added to the 1-D dictionary in horizontal scanning order (e.g., from left to right in a row of pixels). Pixel values within a block of video content can also be scanned vertically when encoding and decoding. With vertical scanning, pixel values are added to the 1-D dictionary in vertical scanning order (e.g., from top to bottom in a column of pixels).

[0123] In some implementations, both horizontal and vertical scanning are supported. In order to support both horizontal and vertical scanning, two 1-D dictionaries can be maintained, one 1-D dictionary (a horizontal scanning 1-D dictionary) that stores pixel values in the horizontal scanning order and another 1-D dictionary (a vertical scanning 1-D dictionary) that stores pixel values in the vertical scanning order. When a pixel value needs to be added, it can be added to both the horizontal scanning 1-D dictionary and to the vertical scanning 1-D dictionary. The ordering of the pixel values will be different in both dictionaries as the order depends on which scanning order is used.

[0124] In some implementations, adding to the 1-D dictionaries is performed at different times. For example, when encoding or decoding a block in horizontal scanning mode, pixel values can be added to a horizontal scanning 1-D dictionary when they are encoded or decoded. When the current block has been encoded or decoded, the pixel values can then be added to the vertical scanning 1-D dictionary.

[0125] In an implementation that supports both horizontal and vertical scanning, the scanning order can be changed (e.g., on a block-by-block basis or on some other basis). For example, if one block of a picture uses horizontal scanning, pixel values for that block will be added to the horizontal scanning 1-D dictionary (in horizontal scanning order), and the pixel values for the block will also be added to the vertical scanning 1-D dictionary (in vertical scanning order). If another block of the picture uses vertical scanning, pixel values for that block will be added to the vertical scanning 1-D dictionary (in vertical scanning order), and the pixel values for the block will also be added to the horizontal scanning 1-D dictionary (in horizontal scanning order).

D. Reducing Dictionary Size

[0126] The size of the 1-D dictionary can be limited (e.g., to balance the cost of maintaining the dictionary against the benefit of predicting pixel values). Reducing the size of the dictionary (e.g., pruning the dictionary) can be performed at various times. For example, the size of the dictionary can be checked when adding a pixel value to the dictionary. If the dictionary is larger than a maximum size (e.g., a pre-determined maximum size, such as 500K), the dictionary can be reduced in size (e.g., by removing the oldest entries in the dictionary).

[0127] In some implementations, a pre-defined maximum dictionary size is defined. If the dictionary is greater than the pre-defined maximum dictionary size, then a portion of the dictionary is removed (e.g., the oldest portion of the dictionary). In a specific implementation, if the dictionary is greater than the threshold size, then one-third of the dictionary is removed. For example, in some implementation, the basic dictionary size is defined as 1<<18. If the current dictionary size is equal to or greater than 1.5 times basic dictionary size, the oldest 0.5 times basic dictionary size elements are removed from the dictionary.

[0128] In some implementations, the dictionary is only checked periodically (and pruned if needed). For example, the dictionary can be checked after encoding and/or decoding a block, a CU, or a CTU. In a specific implementation, the size of the dictionary is checked after encoding or decoding a CTU, and reduced in size by one-third if above the maximum size. In such implementation, it should be guaranteed that the maximum number of elements that may be added to the dictionary between two checks should be no greater than the dictionary buffer size minus the removing threshold. For example, the basic dictionary size is defined as 1<<18, and the removing threshold is defined as 1.5 times basic dictionary size, which should be 1<<18 + 1<<17. If the dictionary size is checked after encoding or decoding a CTU (suppose the CTU size is 4096), the minimum buffer used for the dictionary should be 1<<18 + 1<<17 + 4096.

E. Reconstruction in Scanning Order

[0129] After decoding the pixel values, the pixel values are reconstructed to re-create the video content in two dimensions. Reconstructing the pixel values in scanning order can be performed at various points during the decoding process. For example, after the pixel values for a specific area of video content (e.g., a block, a CU, or a CTU) have been decoded, they can be reconstructed in scanning order.

[0130] In some implementations, the reconstruction is performed after the pixel values have been decoded for a CU as follows. If horizontal scanning is used for a CU, the following equation (Equation 1) is used to reconstruct the pixel values for the CU with width "w" and height "h" in scanning order (rec[i][j] is the reconstructed pixel at row "i" and column "j"; pixel[] are the decoded pixels):

$$rec[i][j] = pixel[\ i * w + j\ ] \qquad \text{(Equation 1)}$$

If vertical scanning is used for a CU, the following equation (Equation 2) is used to reconstruct the pixel values for the CU with width "w" and height "h" in scanning order:

$$rec[i][j] = pixel[\ j * h + i\ ] \qquad \text{(Equation 2)}$$

F. Direct Mode

[0131] When using the 1-D dictionary mode, there may be situations where a matching pixel value is not found. For example, during encoding the encoder can look back in the dictionary to determine if there is a pixel value (or a sequence of multiple pixel values) that match the current pixel value being encoded (or that match multiple pixel values currently being encoded). If a match is found, the current pixel value(s) can be encoded in matching mode using the offset and length coding described above in this section. However, if a matching pixel value is not found in the dictionary, then the current pixel value can be encoded using a direct mode. In the direct mode, the current pixel value can be coded directly (e.g., the Y, U, and V components of the pixel value, or R, G, and B components of the pixel value, can be encoded directly without reference to any other pixel value in the dictionary).

[0132] In some implementations, an escape code or flag is used to indicate when direct mode is used for a pixel value. For example, an encoder can place the escape code or flag in the bitstream with the directly encoded pixel value so that the decoder knows that the pixel value is encoded using direct mode. In this way, the decoder can distinguish between pixel values encoded in direct mode and pixel values encoded using matching mode. In addition, coding in the 1-D dictionary mode can support switching between matching mode and direct mode as needed (e.g., on a pixel-by-pixel basis).

G. Example Encoding/Decoding

[0133] Figs. 7 is a diagram illustrating a simplified example 700 of how pixel values can be encoded using the 1-D dictionary mode. As depicted in the example 700, three rows (the first, second, and last row) of an 8x8 block of example pixel values 710 is depicted. The block of example pixel values 710 are depicted using 3-byte YUV or RGB values. The pixel values in the block are labeled for reference purposes beginning with pixel zero (P_0) in horizontal scanning order.

[0134] As illustrated in the example 700, the pixel values are encoded using the 1-D dictionary mode 720. The first pixel value P_0 is added as the first entry in the 1-D dictionary (e.g., the first pixel value may be the first pixel in the first block of a video frame). Because there are no previous pixel values in the 1-D dictionary, the first pixel value P_0 is encoded in direct mode and added to the encoded bit stream. The second pixel value P_1 is also added to the 1-D dictionary in direct mode because it does not match any previous pixel values in the dictionary. The third pixel value P_2 is also added to the 1-D dictionary in direct mode. The state of the 1-D dictionary and the encoded bit stream are depicted at 730. The encoded bit stream is depicted in a simplified format that indicates the first three pixels are encoded using the direct mode (e.g., the direct mode may be indicated by an escape code in the encoded bit stream).

[0135] When the fourth pixel value P_3 is encoded, a match is found in the 1-D dictionary. Specifically, P_0 matches P_3 and therefore P_3 can be encoded in the matching mode using an offset value and a length value with reference to P_0 in the 1-D dictionary. After the matching pixel P_0 is identified in the 1-D dictionary, the length of matching pixel values can be determined. In this example, two pixel values match (i.e., P_3 and P_4 match P_0 and P_1). In order to encode the offset and length, this example 700 uses the ranges described above in this section (Table 1 and Table 2). First, the offset and length values are reduced by one (to convert to zero-based numbering) and encoded using the ranges. Specifically, the offset value of 2 (3 – 1) is encoded according to the first row of Table 1 as “110” (the first “1” indicating

Range 1, and the "10" indicating an offset value of 2). The length value of 1 (2 – 1) is encoded according to the first row of Table 2 as "101" (the first "1" indicating Range 1, and the "01" indicating a length value of 1). Appending the length and offset results in a code of "110101". The state of the 1-D dictionary and the encoded bit stream are depicted at 740. The encoded bit stream is depicted in a simplified format that indicates the first three pixels are encoded using the direct mode and the fourth and fifth pixel values are encoded in matching mode and are predicted from the first and second pixel values.

[0136] Figs. 8 is a diagram illustrating a simplified example 800 of how pixel values can be decoded using the 1-D dictionary mode. As depicted in the example 800, the encoded bit stream generated from encoding the block in Fig. 7 is decoded using the 1-D dictionary mode 810. The first three pixel values are decoded in the direct mode and added to the dictionary, as depicted at 820.

[0137] The fourth and fifth pixel values are decoded using the matching mode. In this example, the encoded bitstream representation for the fourth and fifth pixel values is "110101," which is decoded using the offset and length ranges defined by Table 1 and Table 2 above in this section. Specifically, the offset is decoded as 2 and the length is decoded as 1. Using the offset and length, the pixel values that are used for the prediction are identified. In this example, the offset of 2 (three pixels back after adding 1 to compensate for the zero-based numbering) identifies the first pixel value in the dictionary. The length indicates that two pixel values are predicted (after adding 1 to the length to compensate for the zero-based numbering). Therefore, the fourth and fifth pixel values are predicted from the first and second pixel values and added to the dictionary, as depicted at 830.

[0138] Once the 8x8 block has been decoded, it is reconstructed in horizontal scanning order. The reconstructed 8x8 block is depicted at 840.

VIII. Innovations for Pseudo 2-D Dictionary Mode

[0139] This section presents various innovations for the pseudo 2-D dictionary mode. The pseudo 2-D dictionary mode is similar to the 1-D dictionary mode described in Section

VII above and therefore the operation of the pseudo 2-D dictionary mode is the same as the 1-D dictionary mode except for the differences described in this section.

[0140] While the 1-D dictionary mode maintains a 1-D dictionary of previous pixel values, the pseudo 2-D dictionary mode does not maintain a separate dictionary. Instead, with the pseudo 2-D dictionary mode, all of the previously pixel values can be used for prediction (e.g., all of the previously reconstructed pixel values from the beginning of the picture or frame). For example, a video or image encoder or decoder can ordinarily maintain all reconstructed pixel values (e.g., for the current picture or frame) during encoding and decoding (e.g., for use during prediction).

[0141] Because the pseudo 2-D dictionary mode predicts current pixel values from pixel values in a two dimensional picture (e.g., previously reconstructed pixel values), the pseudo 2-D dictionary mode uses a two offset values, an X offset value (offsetX) and a Y offset value (offsetY). The offsetX and offsetY values can be signaled independently using the techniques described above in the 1-D dictionary section (e.g., using the ranges described in Table 1). For example, if a pixel value at 100, 100 (X/Y from the top-left of the current picture) is being predicted from a pixel value at 10, 20, then the offsetX can be set to 90 (indicating 90 pixels left in the reconstructed pixel values for the picture, which can also be indicated by -90) and the offsetY can be set to 80 (indicating 80 pixels up in the reconstructed pixel values for the picture, which can also be indicated by -80).

[0142] In the pseudo 2-D dictionary mode, the structure of the block is taken into consideration when performing prediction. For example, consider a current 8x8 block that is coded using horizontal scanning. If a pixel value of the current block is predicted from a previous 8x8 block, and the length of the prediction is 9 (i.e., longer than one row of an 8x8 block), then the pixel values used for prediction in the previous 8x8 block will wrap around two rows of the block (or from the last row of one block to the first row of the next).

[0143] In some implementations, the following equation (Equation 3) is used to reconstruct a current pixel in a picture in the pseudo 2-D dictionary mode. In this equation, the dimensions of the current block are width (w) x height (h), the current pixel is the pixel at position “c” (counting from zero) in the current block, (x0, y0) is the start position of the top left of the current block, the offset is (oX, oY), the scanning order is horizontal, the matching length is one, and pictureRec[] is the reconstruction of the current picture.

$$\text{pixel}[c] = \text{pictureRec}[y0 - oY + c / w]\,[x0 - oX + c \,\%\, w] \qquad \text{(Equation 3)}$$

[0144] The remaining aspects of the pseudo 2-D dictionary mode are discussed above with regard to the 1-D dictionary mode (e.g., signaling of length, maximum number of bits to code length and offset, support for both horizontal and vertical scanning modes, processing pixel value components together (e.g., Y, U, and V or R, G, and B), etc.).

IX. Innovations for Inter Pseudo 2-D Dictionary Mode

[0145] This section presents various innovations for the inter pseudo 2-D dictionary mode. The inter pseudo 2-D dictionary mode is similar to the pseudo 2-D dictionary mode described in Section VIII above and therefore the operation of the inter pseudo 2-D dictionary mode is the same as the pseudo 2-D dictionary mode except for the differences described in this section.

[0146] While the pseudo 2-D dictionary model uses the reconstructed pixel values in the current picture for prediction, the inter pseudo 2-D dictionary mode uses the pixels values in a reference picture (or multiple reference pictures) for prediction. In some implementations, the reference picture used for prediction in the inter pseudo 2-D dictionary mode is signaled (e.g., by signaling a reference picture list and a reference picture index into the list). Alternatively, a default reference picture can be used for prediction (e.g., to avoid the signaling overhead for the specific reference picture from multiple available reference pictures). In some implementations, the default reference picture is the first picture in reference picture list 0.

X. Example Methods for Decoding Pixel Values using a Dictionary Mode

[0147] Methods can be provided for decoding pixel values using the 1-D dictionary mode, pseudo 2-D dictionary mode, and/or inter pseudo 2-D dictionary mode.

[0148] Fig. 9 is a flowchart of an example method 900 for decoding pixel values using a dictionary mode. At 910, encoded data is received in a bit stream. For example, the encoded data can be encoded video data and/or encoded image data.

[0149] At 920, one or more current pixel values are decoded using a dictionary mode. For example, dictionary mode can be a 1-D dictionary mode, a pseudo 2-D dictionary mode, or an inter pseudo 2-D dictionary mode. The one or more current pixel values can be decoded for a block of video content. Decoding the one or more current pixel values comprise performing operations 930 through 950.

[0150] At 930, an offset is decoded indicating an offset location within previously decoded pixel values. For example, decoding the offset can comprise decoding an offset range code and an offset value code to obtain an offset value that identifies the offset location within a 1-D dictionary of previously decoded (e.g., previously reconstructed) pixel values in a current picture. Decoding the offset can also comprise decoding a two dimensional offset with X and Y offset values for identifying a previous pixel value using the pseudo 2-D dictionary mode or the inter pseudo 2-D dictionary mode. Furthermore, when using the inter pseudo 2-D dictionary mode, reference picture information can be decoded (e.g., separately from the offset).

[0151] At 940, a length is decoded indicating a number of pixels being predicted from the offset that was decoded at 930. For example, decoding the length can comprise decoding a length range code and a length value code.

[0152] At 950, the one or more current pixel values are predicted from one or more previous pixel values at the offset. The one or more current pixel values can be predicted exactly using the same pixel values (e.g., YUV or RGB component values) as the one or more previous pixel values without any residual or other modification. The number of pixel values being predicted is indicated by the length.

[0153] The one or more current pixel values, after being predicted, can be used for reconstructing a two-dimensional video picture or image (e.g., using a horizontal or vertical scanning order for a current block).

[0154] Fig. 10 is a flowchart of an example method 1000 for decoding pixel values using a 1-D dictionary mode. At 1010, encoded data is received in a bit stream. For example, the encoded data can be encoded video data and/or encoded image data.

[0155] At 1020, a number of current pixel values are decoded using the 1-D dictionary mode. The 1-D dictionary mode stores previously decoded pixel values (e.g., previously reconstructed pixel values in a current picture) in a 1-D dictionary. Decoding the number of current pixel values comprise performing operations 1030 through 1070.

[0156] At 1030, an offset range code is decoded. The offset range code indicates a number of bits for an offset value code. For example, possible offset values can be divided into a number of ranges (e.g., as depicted in Table 1 above), with the offset range code indicating the range and the number of bits used for the offset value code.

[0157] At 1040, the offset value code is decoded (using the number of bits indicated at 1030) to produce an offset value. The offset value identifies a location within the 1-D dictionary of previously decoded pixel values. If both a horizontal scanning 1-D dictionary and a vertical scanning 1-D dictionary are used, the offset value may identify the location within the dictionary corresponding to the scanning order of the current pixels (e.g., the scanning order of the current block).

[0158] At 1050, a length range code is decoded. The length range code indicates a number of bits for a length value code. For example, possible length values can be divided into a number of ranges (e.g., as depicted in Table 2 above), with the length range code indicating the range and the number of bits used for the length value code.

[0159] At 1060, the length value code is decoded (using the number of bits indicated at 1050) to produce the length value. The length value specifies the number of pixels being predicted.

[0160] At 1070, the current pixel values are predicted from pixel values in at least one dictionary using the offset value and the length value. The current pixel values can be predicted from corresponding pixel values in a 1-D dictionary storing previous pixel values in a scan order corresponding to the current pixel values (e.g., horizontal or vertical scanning order). The location in the 1-D dictionary is identified by the offset value with the number of current pixel vales being predicted indicated by the length value. The current pixel values can be predicted exactly using the same pixel values (e.g., YUV or RGB component values) as the previous pixel values in the dictionary without any residual or other modification.

[0161] The current pixel values, after being predicted, can be used for reconstructing a two-dimensional video picture or image (e.g., using a horizontal or vertical scanning order for a current block).

XI. Innovations for Encoding in the 1-D and Pseudo 2-D Dictionary Modes

[0162] This section presents various innovations for encoding that can be applied to the 1-D, pseudo 2-D, and/or inter pseudo 2-D dictionary modes. Some innovations relate to finding matching pixel values within the dictionary and/or previously reconstructed pixel values, while others related to the cost of signaling in matching mode and early termination.

A. Hash Based Matching in 1-D Dictionary Mode

[0163] In some implementations, a video or image encoder uses a hash-based search technique to identify matching pixel values. In a specific implementation of the hash-based search technique, hash values are calculated and stored for every 1 pixel (e.g., every combined pixel that treats the components of the pixel, such as Y, U, and V components, or R, G, and B components, together), every 2 pixels, every 4 pixels, and every 8 pixels. For example, hash values can be created when a pixel value is added to a dictionary (e.g., added to a 1-D dictionary) for each combination of 1, 2, 4, and 8 pixels of which the current pixel is a part. As an example, a first pixel value can be encoded and added to a 1-D dictionary. A hash value for the first pixel value can be determined and added (e.g., to a hash table). A second pixel value can be encoded and added to the 1-D dictionary. A hash value for the second pixel value can be determined and added. In addition, a hash value for the 2-pixel combination (the first pixel value and the second pixel value) can be calculated and added, and so on as additional pixel values are added to the 1-D dictionary.

[0164] Matching is then performed to see if a pixel value (or pixel values) in the hash matches the current pixel value (or current pixel values) being encoded. First, a check is made to match every 1 pixel value using the hashed pixel values (e.g., by creating a hash of 1 current pixel value and comparing it to hashes of previous 1 pixel values in a dictionary). If a 1 pixel match is found, an encoder can check how many pixels can match from the current pixel to determine the length (the number of pixels that match from the current pixel). If a matching length of 2 is found (e.g., if a current pixel value matches a pixel value in the dictionary at a specific offset with length 2), then matching can proceed with 2 pixels and above (e.g., pixel values at other offsets in the dictionary with a length of 2, or more, may match the current pixel) without the need to check hashes of 1 pixel anymore for the current pixel. Similarly, if a matching length of 4 is found, then hash checking begins with 4 pixels and above, and similarly with 8 pixels. In some implementations, hash search is implemented with 1, 2, 4, and 8 pixels. In other implementations, hash search can use greater or fewer pixels.

[0165] As an example, consider a dictionary that ends with the following eight pixel values (with the value and location indicated, e.g., p-3 is the pixel three pixels back in the dictionary with a pixel value of 3):

[… 4(p-8), 3(p-7), 4(p-6), 7(p-5), 1(p-4), 3(p-3), 4(p-2), 5(p-1)]

The current pixels are going to be encoded by the encoder:

3(p0), 4(p1), 7(p2), 1(p3), 6(p4), 2(p5)

Encoding begins in the hash encoding mode by checking the hash value for 1 pixel p0. The hash value for p0 matches the 1 pixel hash value of p-3 (and both p0 and p-3 have a pixel value of 3). The hash matching only determines the start position of the checking. From the start position, the encoder also needs to check the actual number of matching pixel values. Therefore, the encoder checks for the length of matching pixel values. In this example, the encoder checks whether p0 == p-3 (both p0 and p-3 have a pixel value of 3, so yes), then checks whether p1 == p-2 (both have a pixel value of 4, so yes), then checks whether p2 == p-1 (the pixel values do not match, 7 != 5, so the encoder stops and determines that the matching length is 2). Next, the encoder starts to check from hash values for two pixels (because a match with a length of 2 has already been found, the encoder does not check for hash matches of 1 pixel anymore). The hash value for p0p1 matches the 2 pixel has value of p-7p-6. Then, the encoder checks for the length of matching pixel values. In this example, the encoder checks whether p0p1 == p-7p-6 (both have pixel values of 3, 4, so yes), then checks whether p2 == p-5 (both have a pixel value of 7, so yes), then checks whether p3 == p-4 (both have a pixel value of 1, so yes), then checks whether p4 == p-3 (the pixel values do not match, 6 != 3, so the encoder stops and determines that the matching length is 4). The encoder can then proceed to check hash matches of 4 pixels to see if a longer matching length can be found (and eventually with hash matches of 8 pixels). When the encoder is done checking, the current pixel values will be encoded with the largest matching length found.

[0166] Even if a pixel value (or multiple pixel values) in a dictionary (e.g., a 1-D dictionary) have the same hash value as a current pixel value, matching is still performed to see if the pixel values in the dictionary can be used for prediction. For example, the hash value for a pixel in a 1-D dictionary may be the same as the hash value for a current pixel. The pixel value in the 1-D dictionary still needs to be compared to determine if the pixel value of the current pixel is the same (i.e., different pixel values can have the same hash value).

[0167] In some implementations, even if a match is found for one or more current pixels, the cost of encoding the one or more current pixels (e.g., in terms of number of bits) in matching mode using an offset and length can be greater than the cost of encoding the one or more current pixels directly (e.g., in terms of number of bits). In this situation, the one or more current pixels can be coded directly (e.g., the encoder can switch from matching mode to direct mode for the one or more current pixels, which can be identified in the bit stream by an escape code or flag). The encoder can switch between matching mode and direct mode when needed (e.g., on a pixel by pixel basis, on a block by block basis, or on some other basis).

[0168] In some implementations, early termination is performed by the encoder. For example, if enough pixel values have been processed (e.g., N pixel values), and the average matching length (for direct mode, the matching length can be considered as 1) is smaller than a threshold (e.g., a threshold value of T), dictionary mode estimation can be terminated early (e.g., on a block by block basis). For example, dictionary mode can be terminated and the picture can be re-encoded using other encoding modes, or dictionary mode can be terminated for the remainder of the picture or a portion of the picture (e.g., the current block). Early termination can be performed when the average matching length is small enough that dictionary mode would be less efficient than other encoding modes (e.g., less efficient than normal intra mode, normal inter mode, etc.). For example, the average matching length threshold T can be 2 or 3 in some implementations.

B. Hash Based Matching in Pseudo 2-D Dictionary Mode

[0169] Hash based matching during encoding can be performed in the pseudo 2-D dictionary mode (and in the inter pseudo 2-D dictionary mode) similar to the hash based matching described above for the 1-D dictionary mode.

[0170] Similar to the 1-D dictionary mode, hash values are created for previous pixel values in groupings of 1, 2, 4, and 8 pixel values. However, when matching, the pseudo 2-D dictionary mode (and inter pseudo 2-D dictionary mode) starts checking with 8 pixel hash values (instead of starting with 1 pixel hash matches). If a match of length 8 is found, then the maximum length should be no less than 8 and there is no need to check hash values for 4 pixels or less. However, if a match of length 8 is not found, then checking starts for matches of 4 pixels, and so on down to 1 pixel. If an 8 pixels match is not found by hash matching, and the current matching length is 7 (e.g., hash matching for 4 pixels is found and from that start position, an encoder found actually there are 7 matching pixels), an encoder can terminate here as there is no match for 8 pixels.

C. Example Methods for Encoding Pixel Values using a Dictionary Mode

[0171] Methods can be provided for encoding pixel values using the 1-D dictionary mode, pseudo 2-D dictionary mode, and/or inter pseudo 2-D dictionary mode. Encoding can comprise computing hash values of previous pixel values (e.g., reconstructed pixel values) and comparing the hash values to hash values of current pixel values to be encoded. Matches can be identified by offset and length (e.g., in a 1-D dictionary or a previously encoded values in a picture) and encoded. Encoding can be performed in direct mode if no match is found.

[0172] Fig. 11 is a flowchart of an example method 1100 for encoding pixel values using a dictionary mode. At 1110, one or more current pixel values are encoded in a dictionary mode (e.g., 1-D dictionary mode, pseudo 2-D dictionary mode, or inter pseudo 2-D dictionary mode). Encoding the current pixel values comprises performing operations according to 1120 through 1150.

[0173] At 1120, hash values are calculated for previously encoded pixel values (e.g., reconstructed pixel values). For example, hash values can be calculated for combinations of 1 pixel, 2 pixels, 4 pixels, and 8 pixels.

[0174] At 1130, a hash value is calculated for the one or more current pixel values to be encoded.

[0175] At 1140, the hash value for the one or more current pixel values is compared to the hash values of the previously encoded pixel values to determine if a match is found. Once a match is found (e.g., for 1 pixel value), then the length of pixels that match can be determined.

[0176] At 1150, when a match is found, the one or more current pixel values are encoded using an offset and length. For example, the offset and length can indicate a location in a 1-D dictionary where the current pixel values are predicted or a location within a previously reconstructed picture (e.g., using X and Y offset values for a pseudo 2-D dictionary mode or an inter pseudo 2-D dictionary mode).

We claim:

1. In a computing device with a video decoder or image decoder, a method comprising:

receiving encoded data for a picture in a bit stream; and

decoding one or more current pixel values from the encoded data, comprising:

decoding an offset from the encoded data indicating an offset location within previously decoded pixel values;

decoding a length from the encoded data; and

predicting the one or more current pixel values from one or more corresponding pixel values in the previously decoded pixel values at the offset location, wherein a number of pixels being predicted is indicated by the length.

2. The method of claim 1 wherein the one or more current pixel values and the one or more corresponding pixel values are combined YUV pixel values.

3. The method of claim 1 wherein the offset indicates an offset location is within a one-dimensional dictionary of previously decoded pixel values, and wherein the one or more current pixel values are decoded according to a 1-D dictionary mode.

4. The method of claim 3 wherein decoding the offset comprises:

decoding an offset range code indicating a range of offset values and a number of bits to decode for an offset value; and

based on the offset range code, decoding the offset value from the indicated number of bits for the offset value;

wherein the offset location within the one-dimensional dictionary is identified by the offset value.

5. The method of claim 3 further comprising:

adding the decoded one or more current pixel values to the one-dimensional dictionary.

6. The method of claim 3 wherein the one-dimensional dictionary is a horizontal scanning one-dimensional dictionary, the method further comprising:

adding the decoded one or more current pixel values to the horizontal scanning one-dimensional dictionary in horizontal scanning order; and

adding the decoded one or more current pixel values to a vertical scanning one-dimensional dictionary in vertical scanning order.

7. The method of claim 3 further comprising:

determining a size of the one-dimensional dictionary; and

when the size of the one-dimensional dictionary is greater than a pre-determined maximum, reducing the size of the one-dimensional dictionary.

8. The method of claim 1 wherein decoding the length comprises:

decoding an length range code indicating a range of length values and a number of bits to decode for a length value; and

based on the length range code, decoding the length value from the indicated number of bits for the length value;

wherein the number of pixels being predicted is identified by the length value.

9. The method of claim 1 wherein the one or more current pixel values are decoded in a matching mode that predicts the one or more current pixel values from the one or more corresponding pixel values in the previously decoded pixel values, the method further comprising:

decoding one or more other current pixel values from the encoded data, comprising:

decoding the one or more other current pixel values using a direct mode in which the one or more other current pixel values are encoded directly without prediction.

10. The method of claim 1 further comprising:

reconstructing at least a portion of the picture in one of a horizontal scanning order and a vertical scanning order using, at least in part, the decoded one or more current pixel values.

11. The method of claim 1 wherein the offset indicates an X/Y offset location within a current picture of previously decoded pixel values, and wherein the one or more current pixel values are decoded according to a pseudo 2-D dictionary mode.

12. The method of claim 11 wherein decoding the offset comprises:

decoding an X offset value from a first offset range code indicating a range of offset values and a number of bits to decode for the X offset value; and

decoding a Y offset value from a second offset range code indicating a range of offset values and a number of bits to decode for the Y offset value;

wherein the X/Y offset location within the previously decoded pixel values is identified by the X offset value and the Y offset value.

13. In a computing device with a video decoder or image decoder, a method comprising:

receiving encoded data for a picture in a bit stream; and

decoding a number of current pixel values from the encoded data using a 1-D dictionary mode, comprising:

decoding an offset range code, wherein the offset range code indicates a number of bits for an offset value code;

decoding the offset value code from the indicated number of bits to produce an offset value, wherein the offset value identifies a location in at least one dictionary of previously decoded pixel values;

decoding a length range code, wherein the length range code indicates a number of bits for a length value code;

decoding the length value code from the indicated number of bits to produce a length value; and

predicting the current pixel values from corresponding pixel values at the location, in the at least one dictionary, identified by the offset value with the number of current pixel vales being predicted indicated by the length value.

14. The method of claim 13 wherein the at least one dictionary comprises:

a horizontal scanning one-dimensional dictionary; and

a vertical scanning one-dimensional dictionary.

15. The method of claim 14 further comprising:

adding the decoded number of current pixel values to the horizontal scanning one-dimensional dictionary in horizontal scanning order; and

adding the decoded number of current pixel values to the vertical scanning one-dimensional dictionary in vertical scanning order.

16. The method of claim 13 further comprising:

reconstructing at least a portion of the picture in one of a horizontal scanning order and a vertical scanning order using, at least in part, the decoded number of current pixel values.

17. In a computing device with a video encoder or image encoder, a method comprising:

encoding data for a picture, including using a dictionary mode for encoding one or more current pixel values, the encoding comprising:

calculating hash values for previously encoded pixel values;

calculating a hash value for the one or more current pixel values to be encoded;

determining if the hash value for the one or more current pixel values matches a hash value for the previously encoded pixel values;

when a match is found, encoding the one or more current pixel values using an offset and length that predicts the one or more current pixel values from the matching previously encoded pixel values.

18. The method of claim 17 wherein the previously encoded pixel values are stored in a one-dimensional dictionary.

19. The method of claim 17 wherein the one or more current pixel values and the previously encoded pixel values are one of combined YUV pixel values, combined RGB pixel values, and combined GBR pixel values.

20. The method of claim 17 wherein calculating the hash values for the previously encoded pixel values comprises:

calculating hash values for each 1 pixel value of the previously encoded pixel values;

calculating hash values for each 2 pixel values of the previously encoded pixel values;

calculating hash values for each 4 pixel values of the previously encoded pixel values; and

calculating hash values for each 8 pixel value of the previously encoded pixel values.

21. The method of claim 17 further comprising:

switching to a direct encoding mode that encodes pixel values directly if a cost of encoding the pixel values with prediction from the previously encoded pixel values is greater than a cost of encoding the pixel values in direct mode.

22. The method of claim 17 further comprising:

calculating an average match length;

when the average match length is below a threshold value, switching to an encoding mode other than the dictionary mode for a current block.

23. A computing device, comprising a processing unit and memory, adapted to perform the method of any of claims 1-22.

24. One or more computer-readable media storage media storing computer-executable instructions for causing a computing device programmed thereby to perform the method of any of claims 1-22.

Figure 1

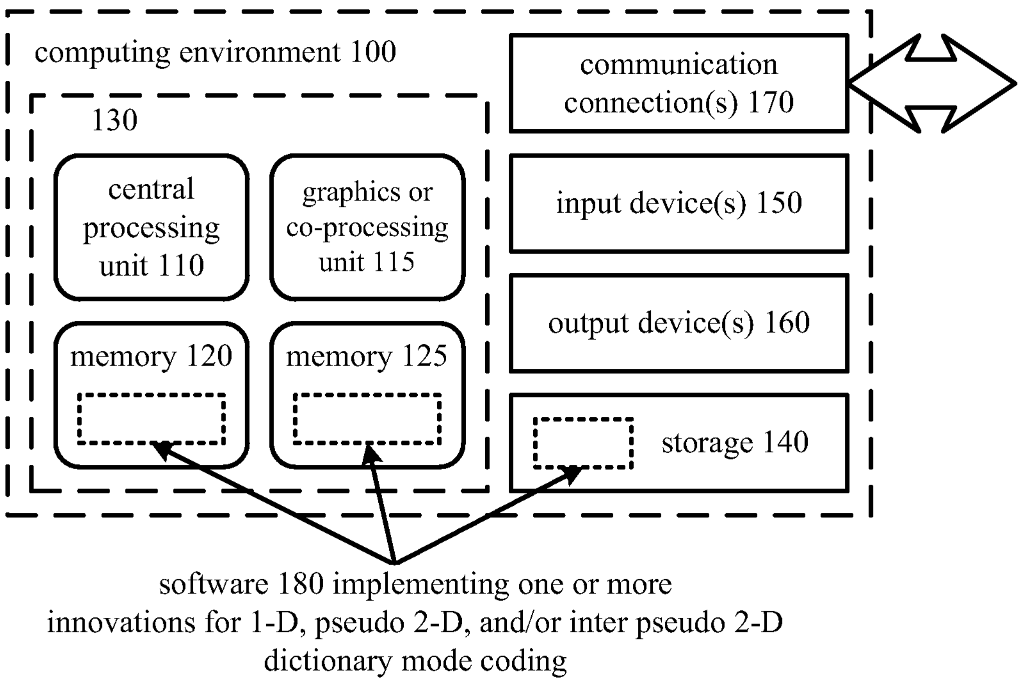

computing environment 100
130
central processing unit 110
graphics or co-processing unit 115
memory 120
memory 125
communication connection(s) 170
input device(s) 150
output device(s) 160
storage 140
software 180 implementing one or more innovations for 1-D, pseudo 2-D, and/or inter pseudo 2-D dictionary mode coding

Figure 2a

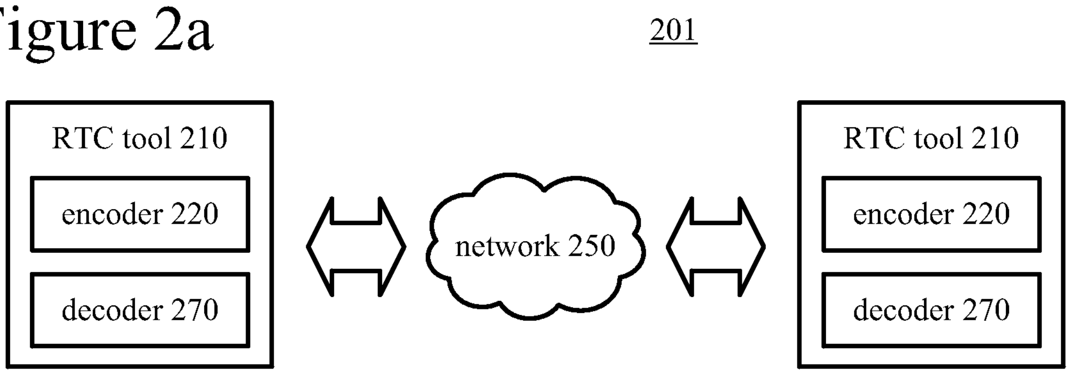


Figure 2b

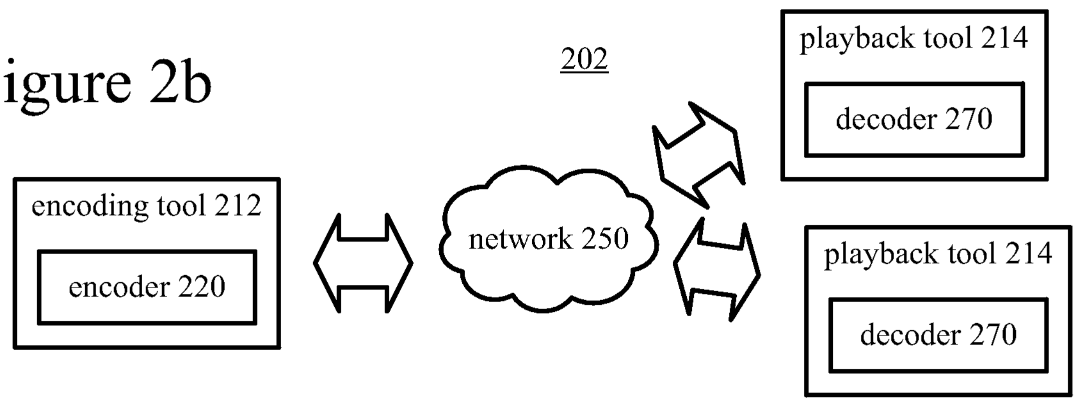


Figure 3

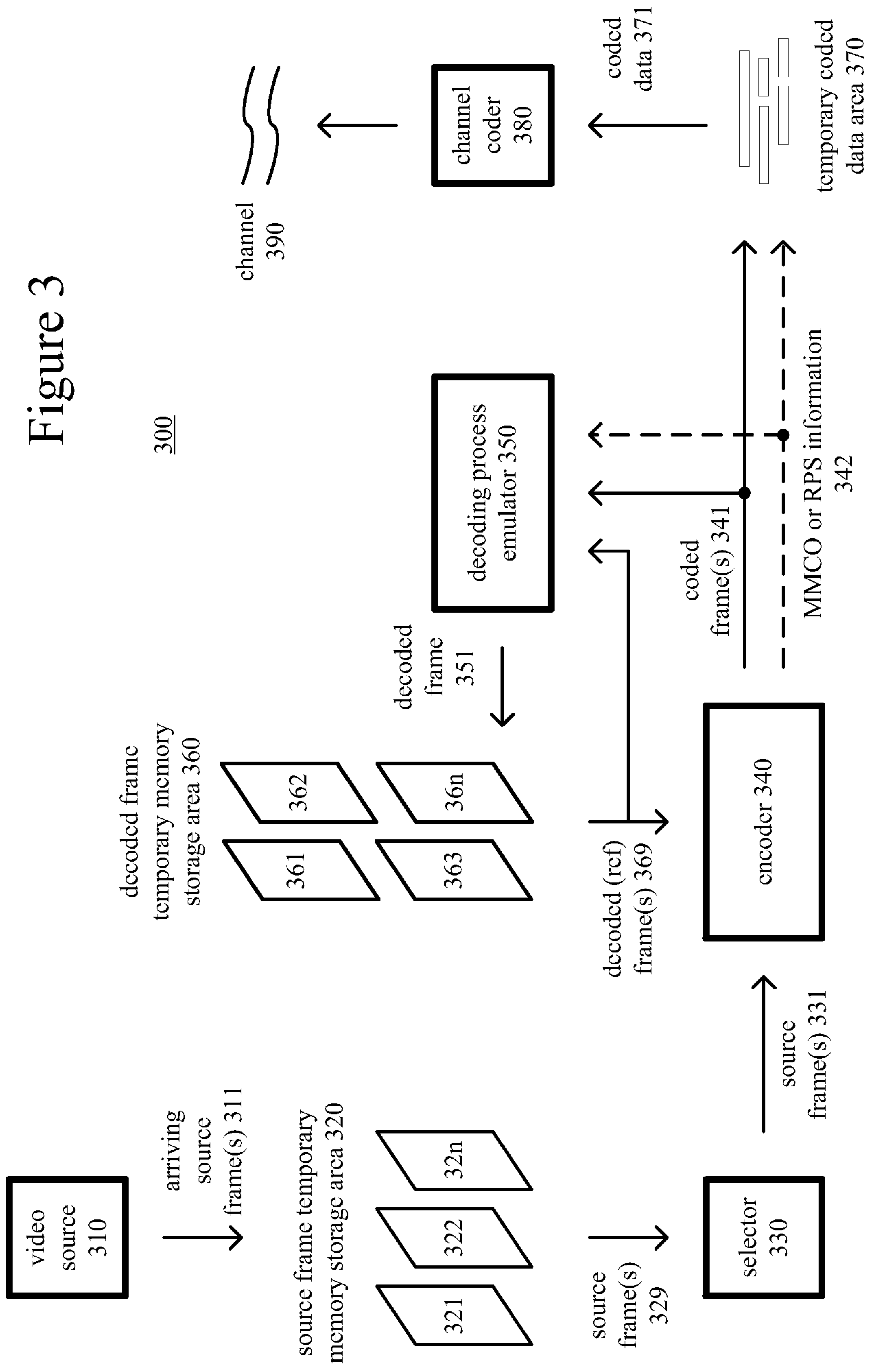

300
video source 310
arriving source frame(s) 311
source frame temporary memory storage area 320
321
322
32n
source frame(s) 329
selector 330
source frame(s) 331
encoder 340
decoded (ref) frame(s) 369
decoded frame temporary memory storage area 360
361
362
363
36n
decoded frame 351
decoding process emulator 350
coded frame(s) 341
MMCO or RPS information 342
temporary coded data area 370
coded data 371
channel coder 380
channel 390

Figure 4

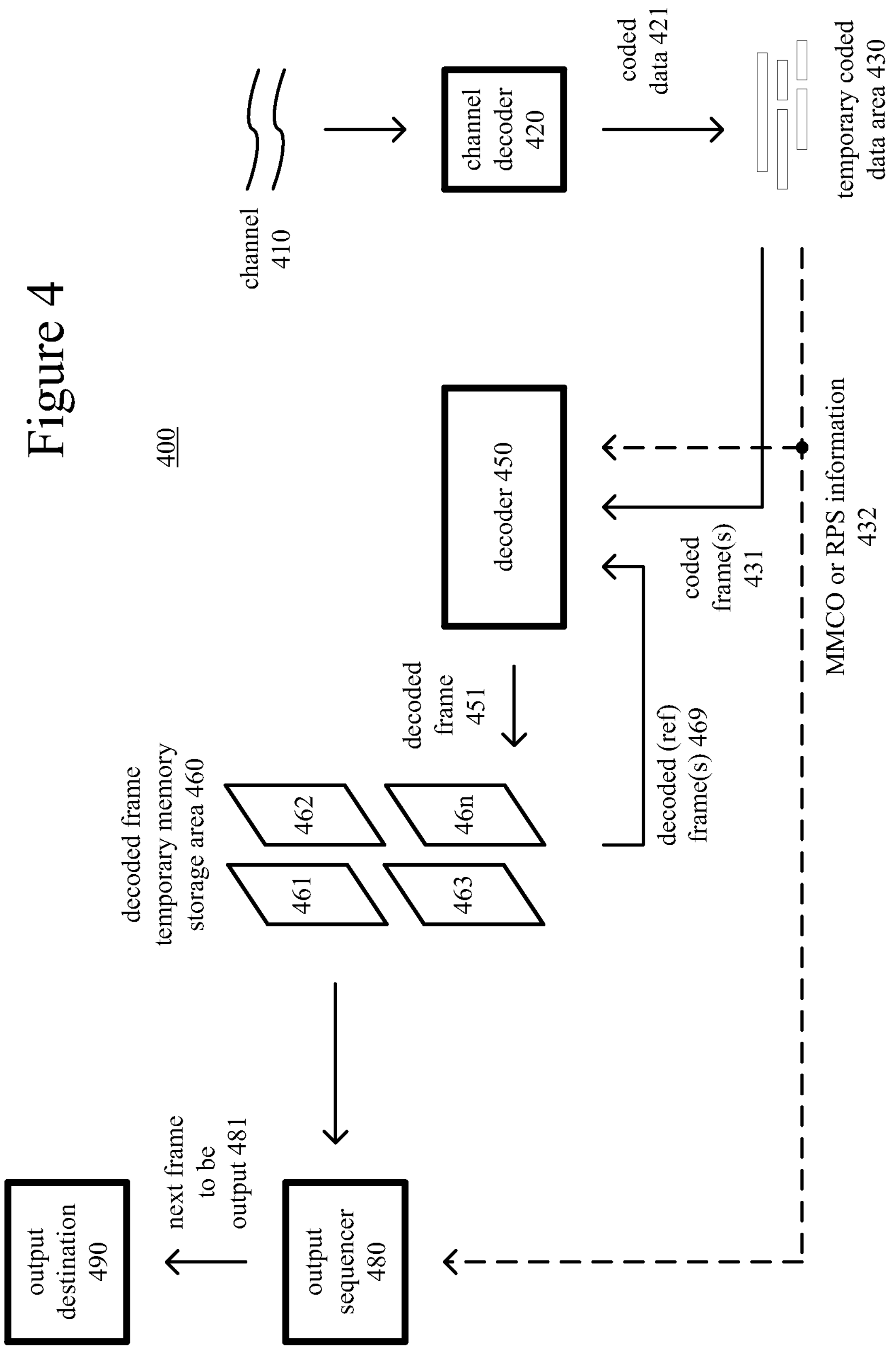
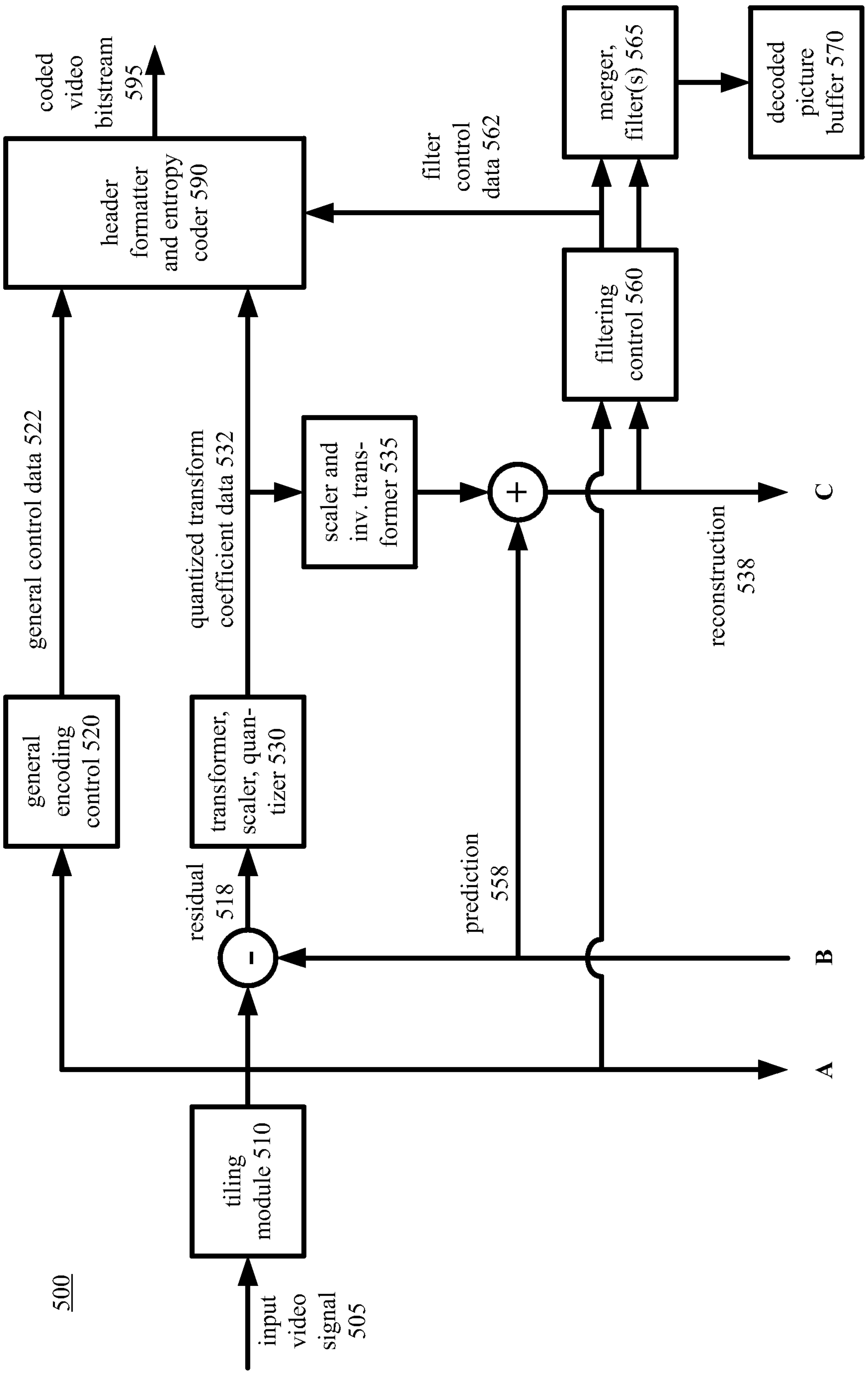

400
channel 410
channel decoder 420
coded data 421
temporary coded data area 430
coded frame(s) 431
MMCO or RPS information 432
decoder 450
decoded frame 451
decoded frame temporary memory storage area 460
461
462
463
46n
decoded (ref) frame(s) 469
output sequencer 480
next frame to be output 481
output destination 490

Figure 5a


500
input video signal 505
tiling module 510
general encoding control 520
general control data 522
transformer, scaler, quantizer 530
residual 518
quantized transform coefficient data 532
scaler and inv. transformer 535
prediction 558
reconstruction 538
filtering control 560
filter control data 562
merger, filter(s) 565
decoded picture buffer 570
header formatter and entropy coder 590
coded video bitstream 595
A
B
C

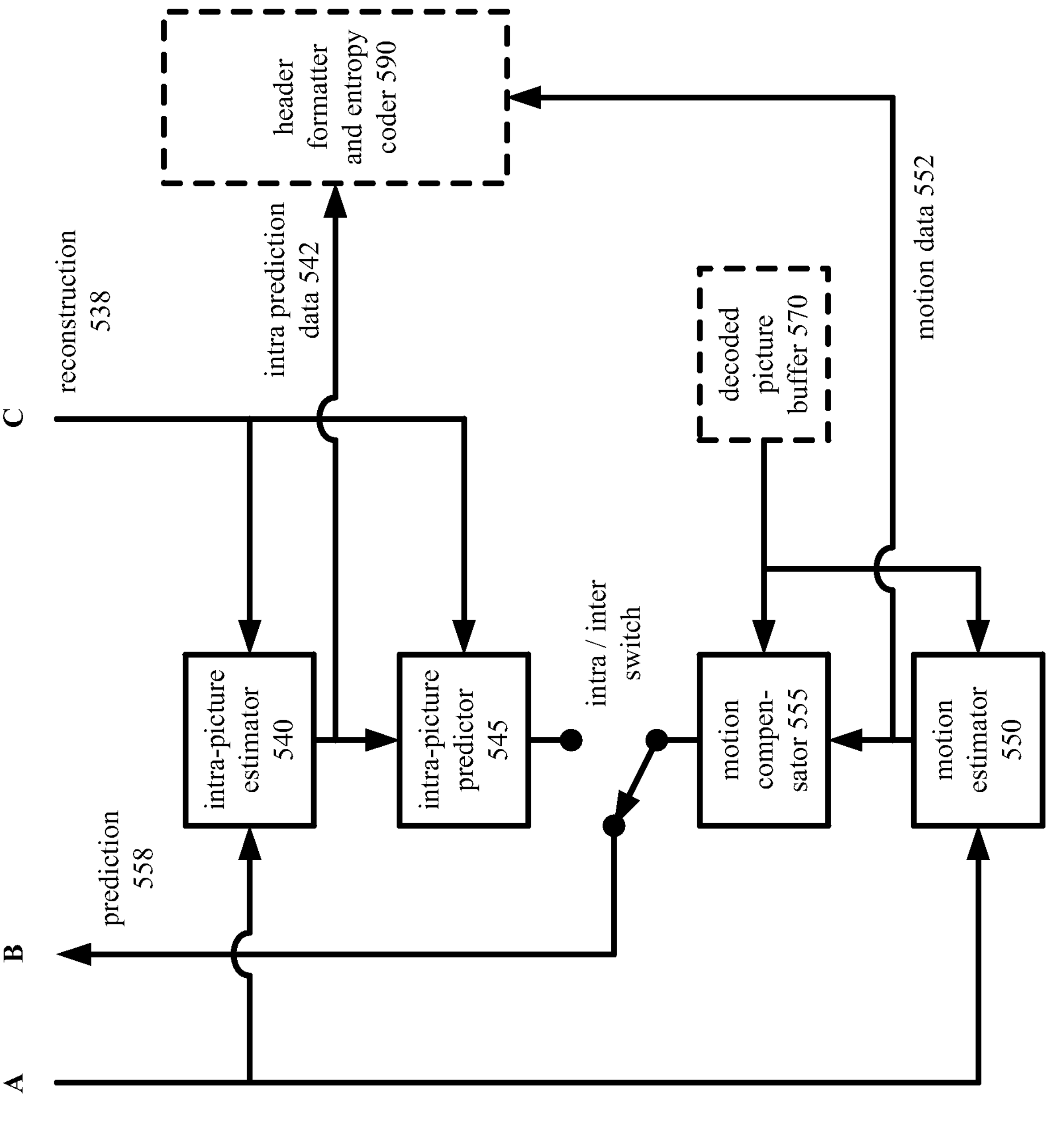

header formatter and entropy coder 590
reconstruction 538
intra prediction data 542
C
decoded picture buffer 570
motion data 552
intra-picture estimator 540
intra-picture predictor 545
intra / inter switch
motion compen-sator 555
motion estimator 550
prediction 558
B
A

Figure 5b

500

Figure 6

600

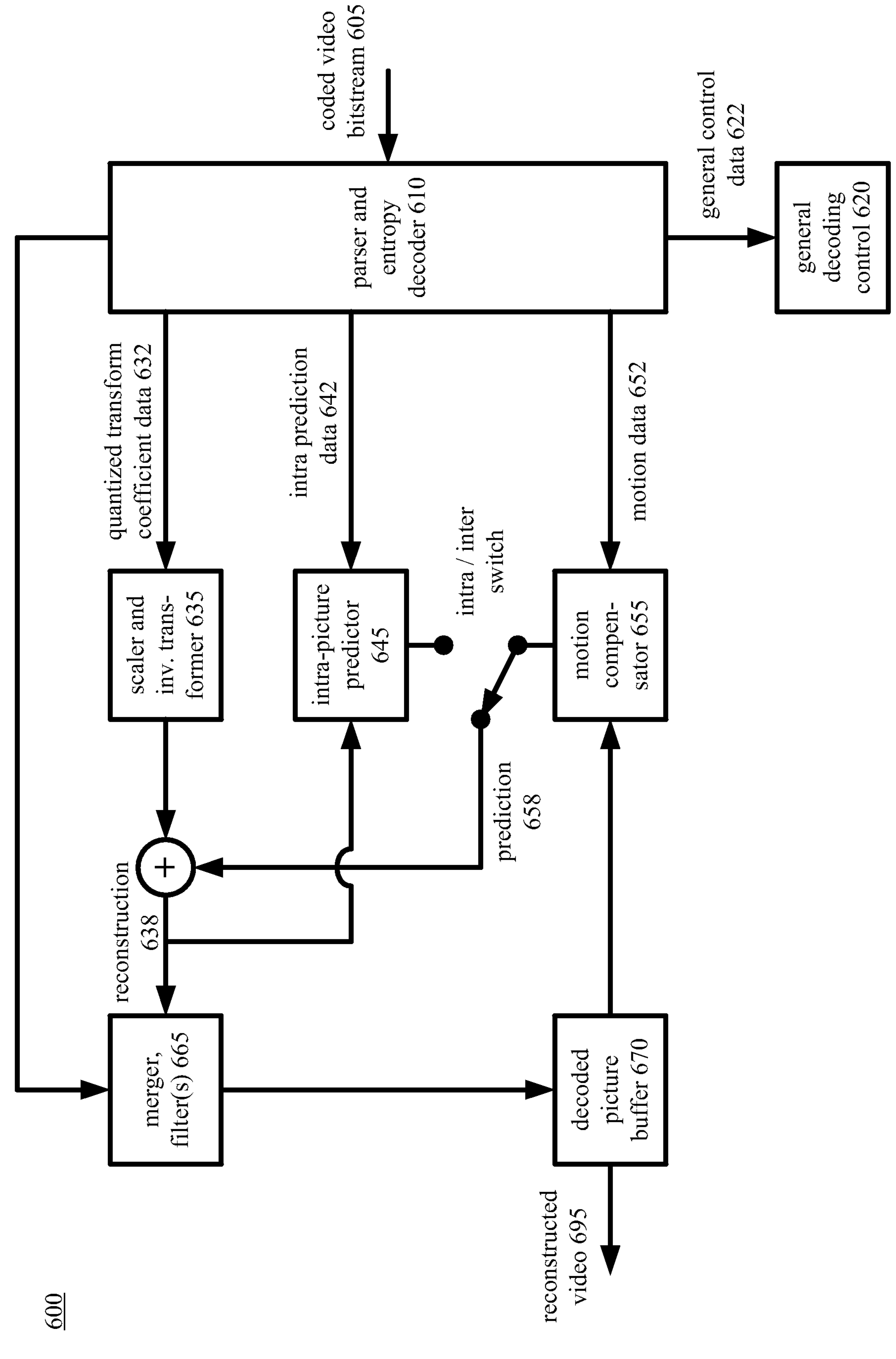

coded video bitstream 605
parser and entropy decoder 610
general control data 622
general decoding control 620
filter control data 662
quantized transform coefficient data 632
intra prediction data 642
motion data 652
scaler and inv. trans-former 635
intra-picture predictor 645
intra / inter switch
motion compen-sator 655
prediction 658
reconstruction 638
merger, filter(s) 665
decoded picture buffer 670
reconstructed video 695

Figure 7

700

Block (8x8) of pixel values 710

	P_0	P_1	P_2	P_3	P_4	P_5		P_7
	(50,0,0)	(60,25,0)	(85,12,120)	(50,0,0)	(60,25,0)	(27,55,8)	(122,0,36)	(5,45,72)
P_8	(72,0,0)	(68,35,0)	(70,28,0)	(41,5,0)	(118,8,6)	(31,38,8)	(88,4,30)	(12,23,84)
	...							
	(50,0,0)	(60,25,0)	(85,12,120)	(50,0,0)	(60,25,0)	(27,55,8)	(122,0,36)	(5,45,72)

$\Downarrow$

Encode pixel values using 1-D dictionary mode 720

After encoding first three pixel values 730

1-D dictionary: [(50,0,0), (60,25,0), (85,12,120)]

Encoded bit stream: P_0(direct) P_1(direct) P_2(direct)

After encoding first five pixel values 740

1-D dictionary: [(50,0,0), (60,25,0), (85,12,120), (50,0,0), (60,25,0)]

Encoded bit stream: P_0(direct) P_1(direct) P_2(direct) P_3-P_4(offset:2, length:1)

Offset and length reduced by one for zero-based numbering

Figure 8

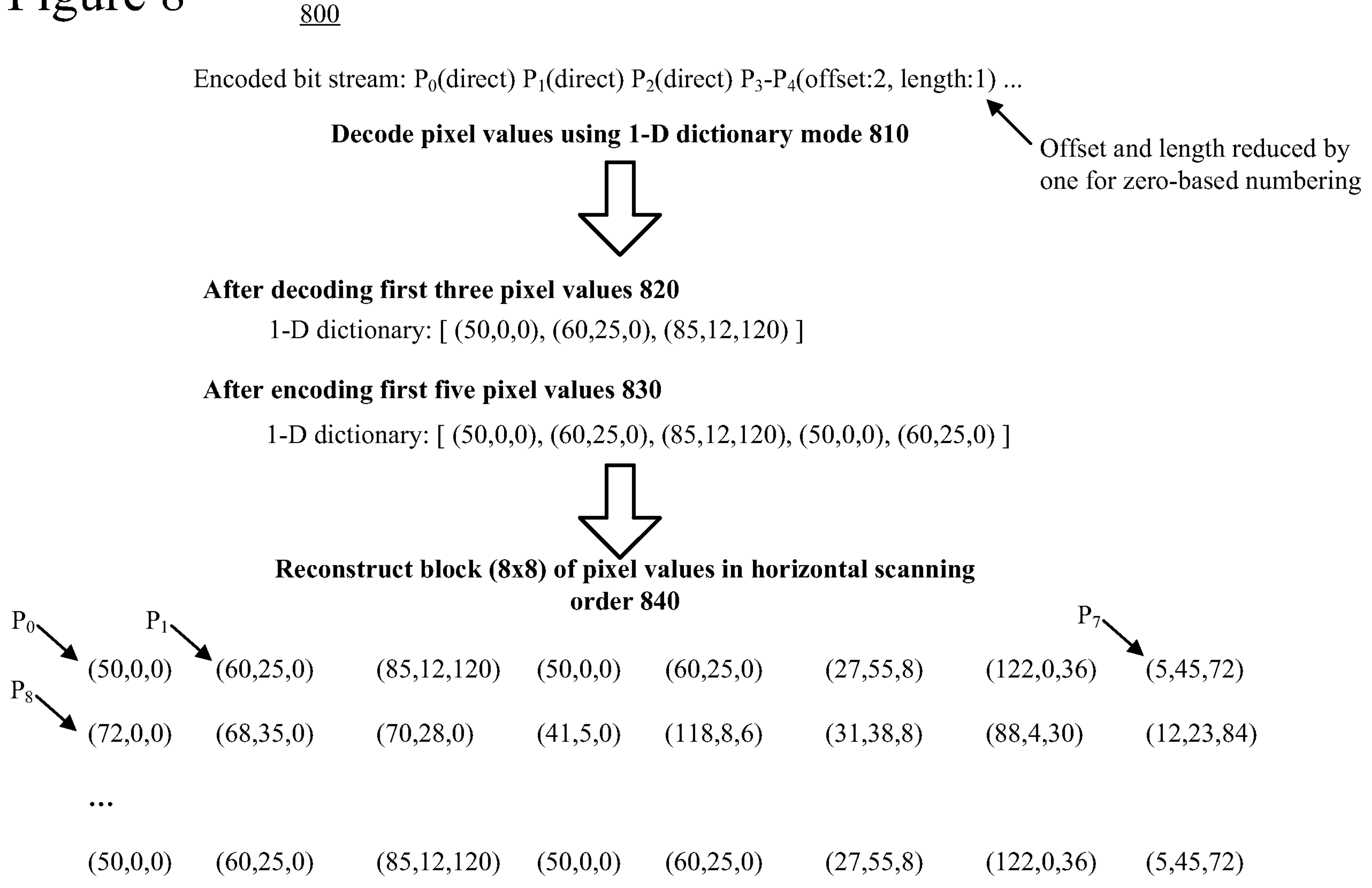

800
Encoded bit stream: P_0(direct) P_1(direct) P_2(direct) P_3-P_4(offset:2, length:1) ...
Offset and length reduced by one for zero-based numbering
Decode pixel values using 1-D dictionary mode 810
After decoding first three pixel values 820
1-D dictionary: [(50,0,0), (60,25,0), (85,12,120)]
After encoding first five pixel values 830
1-D dictionary: [(50,0,0), (60,25,0), (85,12,120), (50,0,0), (60,25,0)]
Reconstruct block (8x8) of pixel values in horizontal scanning order 840
P_0
P_1
P_7
P_8
(50,0,0) (60,25,0) (85,12,120) (50,0,0) (60,25,0) (27,55,8) (122,0,36) (5,45,72)
(72,0,0) (68,35,0) (70,28,0) (41,5,0) (118,8,6) (31,38,8) (88,4,30) (12,23,84)
...
(50,0,0) (60,25,0) (85,12,120) (50,0,0) (60,25,0) (27,55,8) (122,0,36) (5,45,72)

Figure 9

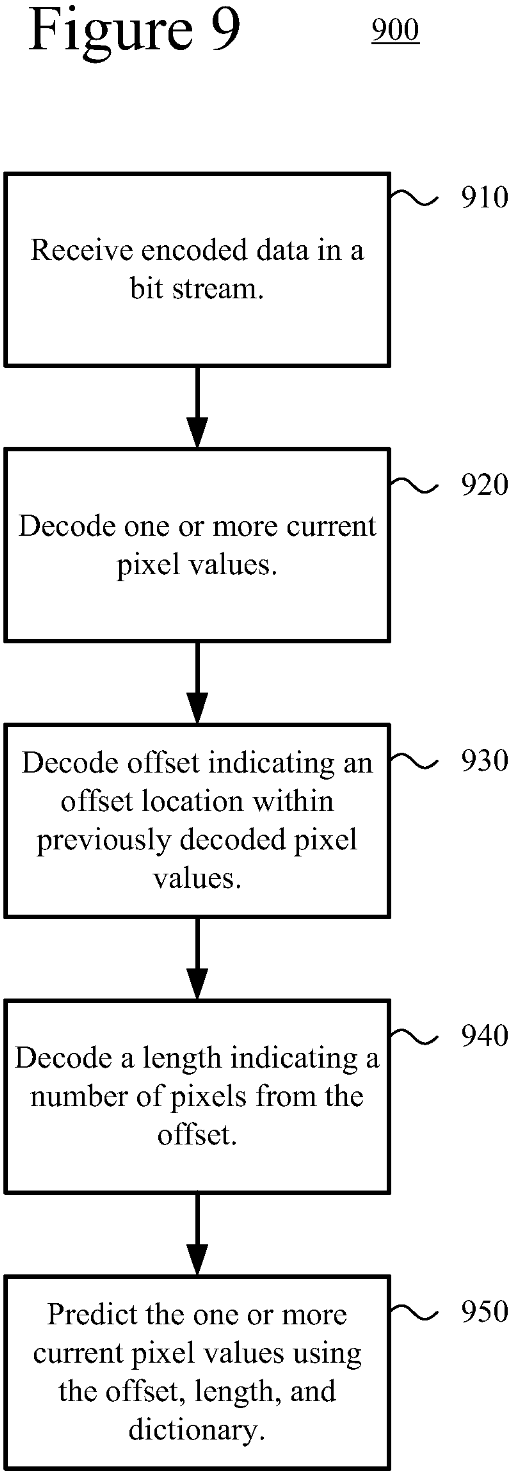

900
Receive encoded data in a bit stream.
910
Decode one or more current pixel values.
920
Decode offset indicating an offset location within previously decoded pixel values.
930
Decode a length indicating a number of pixels from the offset.
940
Predict the one or more current pixel values using the offset, length, and dictionary.
950

Figure 10

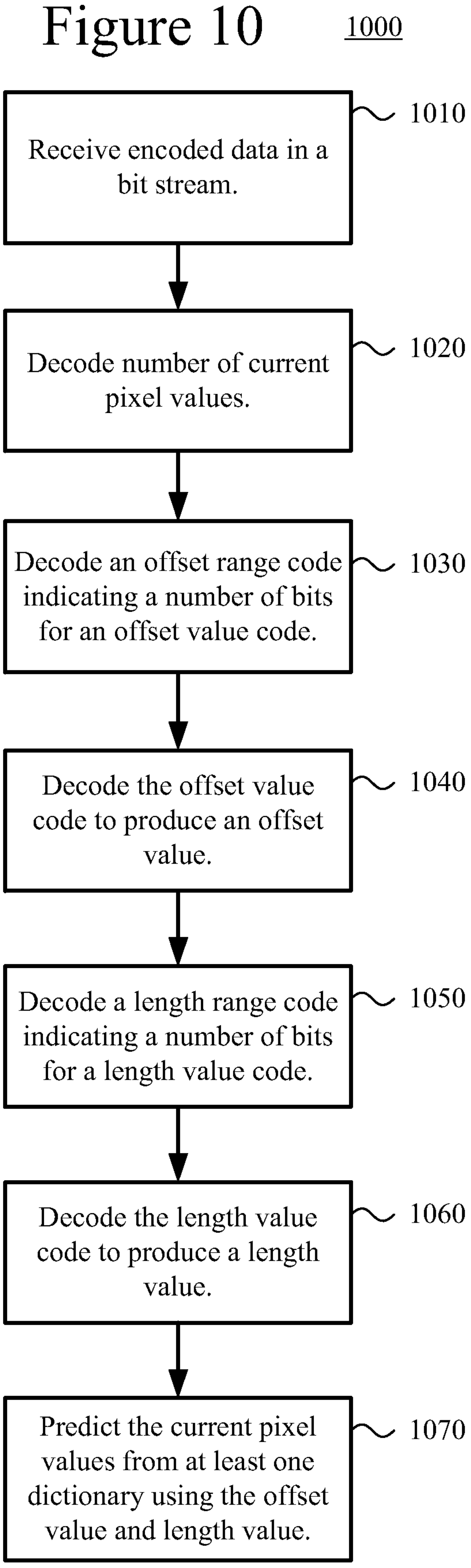
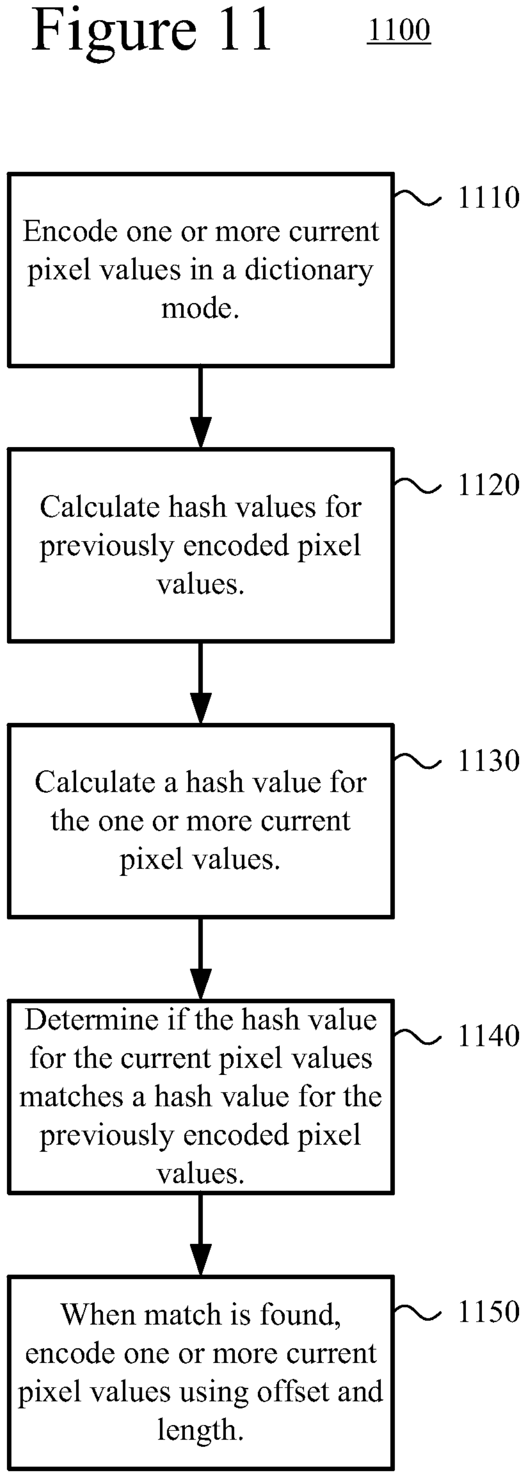

1000
Receive encoded data in a bit stream.
1010
Decode number of current pixel values.
1020
Decode an offset range code indicating a number of bits for an offset value code.
1030
Decode the offset value code to produce an offset value.
1040
Decode a length range code indicating a number of bits for a length value code.
1050
Decode the length value code to produce a length value.
1060
Predict the current pixel values from at least one dictionary using the offset value and length value.
1070

Figure 11


1100
Encode one or more current pixel values in a dictionary mode.
1110
Calculate hash values for previously encoded pixel values.
1120
Calculate a hash value for the one or more current pixel values.
1130
Determine if the hash value for the current pixel values matches a hash value for the previously encoded pixel values.
1140
When match is found, encode one or more current pixel values using offset and length.
1150

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2014/072774

A. CLASSIFICATION OF SUBJECT MATTER

H04N 19/50 (2014.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI;EPODOC;CNKI;CNPAT;IEEE: video, image, encod+, decod+, pixel, offset, length, predict+

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/0142132 A1 (DOLBY LABORATORIES LICENSING CORPORATION) 16 June 2011 (2011-06-16) description, paragraphs 0027-0073, 0089-0096 and figures 1-17	1-24
Y	US 2011/0142132 A1 (DOLBY LABORATORIES LICENSING CORPORATION) 16 June 2011 (2011-06-16) description, paragraphs 0027-0073, 0089-0096 and figures 1-17	17-24
Y	CN 103281538 A (UNIVERSITY SHANGHAI JIAOTONG) 04 September 2013 (2013-09-04) description, paragraphs 0011-0069, figures 1-5	17-24
A	CN 101420606 A (QINGDAO HISENSE ELECTRIC CO. LT.) 29 April 2009 (2009-04-29) the whole documents	1-24
A	US 7023924 B1 (EMC CORPORATION) 04 April 2006 (2006-04-04) the whole documents	1-24

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:

"A"	document defining the general state of the art which is not considered to be of particular relevance
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"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search **11 October 2014**	Date of mailing of the international search report **05 December 2014**
Name and mailing address of the ISA/CN **STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA(ISA/CN)** **6,Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088 China** Facsimile No. **(86-10)62019451**	Authorized officer **LI,Nan** Telephone No. **(86-10)62413690**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2014/072774

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
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		WO 2010/017166 A2	11 February 2010
CN 103281538 A	04 September 2013	None	
CN 101420606 A	29 April 2009	None	
US 7023924 B1	04 April 2006	None	