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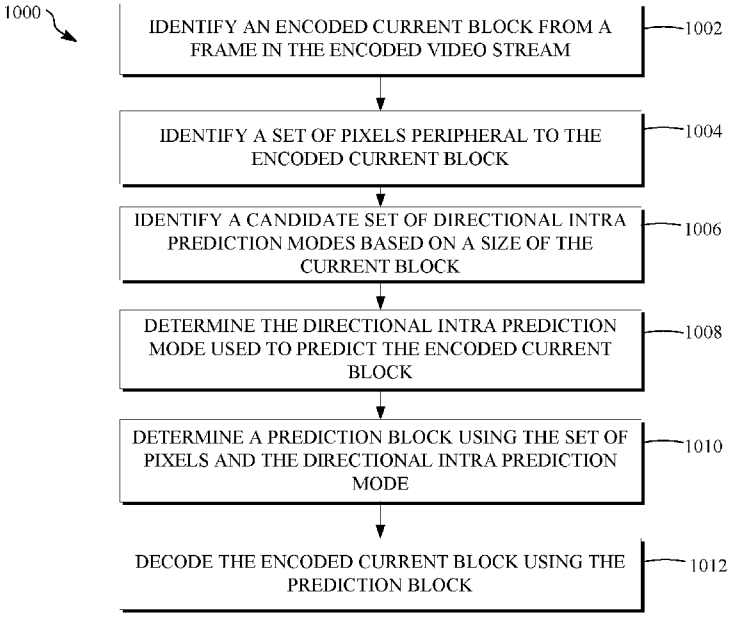


FIG. 10

(57) Abstract: Using directional intra prediction modes for encoding and decoding a video stream are described. A method includes identifying, peripheral to a current block of a frame of the video stream, a set of previously coded pixels in the frame, identifying a candidate set of directional intra prediction modes from a plurality of directional intra prediction modes based on a size of the current block, and selecting, for the current block, an optimal intra prediction mode from the candidate set of directional intra prediction modes. The optimal intra prediction mode is used to predict the current block based on the set of previously coded pixels.

WO 2017/209793 A1

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BLOCK SIZE ADAPTIVE DIRECTIONAL INTRA PREDICTION

BACKGROUND

[0001] Digital video streams may represent video using a sequence of frames or still images. Digital video can be used for various applications including, for example, video conferencing, high definition video entertainment, video advertisements, or sharing of user-generated videos. A digital video stream can contain a large amount of data and consume a significant amount of computing or communication resources of a computing device for processing, transmission or storage of the video data. Various approaches have been proposed to reduce the amount of data in video streams, including compression and other encoding techniques.

SUMMARY

[0002] This disclosure relates generally to encoding and decoding video data and more particularly relates to video coding using directional intra prediction mode. One method for encoding a video stream described herein includes identifying, peripheral to a current block of a frame of the video stream, a set of previously coded (or encoded) pixels in the frame; identifying a candidate set of directional intra prediction modes from a plurality of directional intra prediction modes based on a size of the current block; and selecting, for the current block using a processor, an optimal intra prediction mode from the candidate set of directional intra prediction modes, wherein the optimal intra prediction mode is used to predict the current block based on the set of previously coded pixels.

[0003] Another method described herein is a method for decoding an encoded video bitstream including identifying, peripheral to a current block of a frame of the video stream, a set of previously decoded pixels in the frame; identifying a candidate set of directional intra prediction modes from a plurality of directional intra prediction modes based on a size of the current block; and determining, using a processor, an intra prediction mode previously selected for encoding the current block in the video stream, from the candidate set of directional intra prediction modes, wherein the intra prediction mode is used to predict the current block based on the set of previously decoded pixels.

[0004] An example of an apparatus for decoding a video stream described herein includes a memory and at least one processor. The processor is configured to execute instructions

stored in the memory to identify, peripheral to a current block of a frame of the video stream, a set of previously decoded pixels in the frame; identify a candidate set of directional intra prediction modes from a plurality of directional intra prediction modes based on a size of the current block; and determine an intra prediction mode previously selected for encoding the current block in the video stream, from the candidate set of directional intra prediction modes, wherein the intra prediction mode is used to predict the current block based on the set of previously decoded pixels.

[0005] Another method for decoding a video stream described herein includes identifying, peripheral to a current block of a frame of the video stream, a set of previously decoded pixels in the frame, identifying an intra prediction mode previously selected for encoding the current block from a candidate set of directional intra prediction modes that is based on a size of the current block, determining a prediction block using the intra prediction mode and the set of previously decoded pixels, and decoding the current block using the prediction block.

[0006] In another apparatus for decoding a video stream that includes a memory and a processor, the processor is configured to execute instructions stored in the memory to identify an intra prediction mode previously selected for encoding a current block of a frame from a first candidate set of directional intra prediction modes that is based on a size of the current block, the first candidate set of directional intra prediction modes being different from a second candidate set of directional intra prediction modes for a block having a size different from the current block, determine a prediction block using the inter prediction mode and a set of previously decoded pixels peripheral to the current block, and decode the current block using the prediction block.

[0007] The disclosure also provides computer programs and computer readable media carrying such programs, for putting the described methods and apparatus into effect when executed on one or more suitable computer systems or processors.

[0008] Variations in these and other aspects of the disclosure will be described in additional detail hereafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The description herein makes reference to the accompanying drawings wherein like reference numerals refer to like parts throughout the several views unless otherwise noted.

[0010] FIG. 1 is a schematic of a video encoding and decoding system in accordance with

implementations of this disclosure.

[0011] FIG. 2 is a diagram of an example video stream to be encoded and decoded in accordance with implementations of this disclosure.

[0012] FIG. 3 is a block diagram of an encoder in accordance with implementations of this disclosure.

[0013] FIG. 4 is a block diagram of a decoder in accordance with implementations of this disclosure.

[0014] FIG. 5 is a flow diagram of an example process for encoding a video stream using directional intra prediction modes in accordance with implementations of this disclosure.

[0015] FIG. 6 is a diagram showing a 90 degree directional intra prediction mode that may be used in implementations of the teachings herein.

[0016] FIG. 7 is a diagram showing a 135 degree directional intra prediction mode that may be used in implementations of the teachings herein.

[0017] FIG. 8 is a diagram showing a 90 degree directional intra prediction mode that may be used in implementations of the teachings herein.

[0018] FIG. 9 is a diagram showing an 84 degree directional intra prediction mode that may be used in implementations of the teachings herein.

[0019] FIG. 10 is a flow diagram of an example process for decoding an encoded video stream using directional intra prediction modes in accordance with implementations of this disclosure.

[0020] FIG. 11 is a diagram showing an example implementation of a lookup table for directional intra prediction modes that may be used in implementations of the teachings herein.

[0021] FIG. 12 is a diagram showing an example implementation of a lookup table for directional intra prediction modes that may be used in implementations of the teachings herein.

DETAILED DESCRIPTION

[0022] Compression schemes related to coding video streams may include breaking each image into blocks and generating a digital video output bitstream using one or more techniques to limit the information included in the output. A received bitstream can be decoded to re-create the blocks and the source images from the limited information. Encoding a video stream, or a portion thereof, such as a frame or a block, can include using temporal and spatial similarities in the video stream to improve coding efficiency. For example, a

current block of a video stream may be encoded based on a previously encoded block in the video stream by predicting motion and color information for the current block based on the previously encoded block and identifying a difference (residual) between the predicted values and the current block.

[0023] Intra prediction can include using video data that has been previously encoded and reconstructed to predict the current block in the same frame. The predicted block is deducted from the current block and the difference, i.e., the residual, can be transformed, quantized and entropy encoded to be included in a compressed video stream. In codec schemes that use raster scan order, for example, video data above and to the left of the current block have been previously coded (i.e., coded prior to the current block) is available for use during intra prediction of the current block.

[0024] Codecs may support many different intra prediction modes. Intra prediction modes can include, for example, a horizontal intra prediction mode, a vertical intra prediction mode, and various other directional intra prediction modes, also referred to as angular (intra) prediction modes. A directional (angular) intra prediction mode uses a certain angle, often offset from the horizontal or vertical, for predicting along a direction specified by the angle. Each block can use one of the intra prediction modes to obtain a prediction block that is most similar to the block to minimize the information to be encoded in the residual so as to re-create the block. The directional intra prediction modes, as well as other prediction modes, can be encoded and transmitted so that a decoder can use the same prediction mode(s) to form prediction blocks in the decoding and reconstruction process. Directional intra prediction modes are distinguishable from other intra prediction modes that use a single value (e.g., the quantized DC transform coefficient or a combined pixel value), to populate pixel positions in a prediction block.

[0025] Various directional intra prediction modes can be used to propagate pixel values from previously coded blocks along an angular line, that is, in directions offset from the horizontal and/or the vertical, to predict a block. For example, pixel values being propagated can include peripheral pixels above and/or to the left of the block in the same frame. In implementations of this disclosure, a variable and adaptable number of candidate directional intra prediction modes are considered by a block based on the block size. For example, fewer angles can be used for smaller blocks and more angles can be used for larger blocks, because the differences between predictions using a large number of different angles can be less significant for smaller blocks. When a fewer number of candidate directional intra prediction modes is considered for the smaller blocks, fewer bits need to be used to code the prediction

modes for these blocks, and the overall coding efficiency is improved. Therefore, by varying the number of candidate directional intra prediction modes based on the block size, the total number of bits to be included to signal the directional intra prediction modes can be reduced for the encoded video bitstream, and the overall compression performance can be improved. Other details are described below after first describing an environment in which the disclosure may be implemented.

[0026] FIG. 1 is a schematic of a video encoding and decoding system 100 in which aspects of the disclosure can be implemented. A transmitting station 102 can be, for example, a computer having an internal configuration of hardware including a processor such as a central processing unit (CPU) 104 and a memory 106. The CPU 104 is a controller for controlling the operations of the transmitting station 102. The CPU 104 can be connected to the memory 106 by, for example, a memory bus. The memory 106 can be read only memory (ROM), random access memory (RAM) or any other suitable non-transitory memory or storage device. The memory 106 can store data and program instructions that are used by the CPU 104. Other suitable implementations of the transmitting station 102 are possible. For example, the processing of the transmitting station 102 can be distributed among multiple devices.

[0027] A network 108 connects the transmitting station 102 and a receiving station 110 for encoding and decoding of the video stream. Specifically, the video stream can be encoded in the transmitting station 102 and the encoded video stream can be decoded in the receiving station 110. The network 108 can be, for example, the Internet. The network 108 can also be a local area network (LAN), wide area network (WAN), virtual private network (VPN), a cellular telephone network or any other means of transferring the video stream from the transmitting station 102 to, in this example, the receiving station 110.

[0028] The receiving station 110 can, in one example, be a computer having an internal configuration of hardware including a processor such as a CPU 112 and a memory 114. The CPU 112 is a controller for controlling the operations of the receiving station 110. The CPU 112 can be connected to the memory 114 by, for example, a memory bus. The memory 114 can be ROM, RAM or any other suitable non-transitory memory or storage device. The memory 114 can store data and program instructions that are used by the CPU 112. Other suitable implementations of the receiving station 110 are possible. For example, the processing of the receiving station 110 can be distributed among multiple devices.

[0029] A display 116 configured to display a video stream can be connected to the receiving station 110. The display 116 can be implemented in various ways, including by a

liquid crystal display (LCD), a cathode-ray tube (CRT), or a light emitting diode display (LED), such as an organic LED (OLED) display. The display 116 is coupled to the CPU 112 and can be configured to display a rendering 118 of the video stream decoded in the receiving station 110.

[0030] Other implementations of the encoder and decoder system 100 are also possible. For example, one implementation can omit the network 108 and/or the display 116. A video stream can be encoded and then stored for transmission at a later time by the receiving station 110 or any other device having memory. The receiving station 110 can receive (e.g., via the network 108, a computer bus, or some communication pathway) the encoded video stream and store the video stream for later decoding. Additional components can be added to the encoder and decoder system 100. For example, a display or a video camera can be attached to the transmitting station 102 to capture the video stream to be encoded. Other input devices capable of being manipulated by a user may be coupled to the transmitting station 102 the receiving station 110, and/or both.

[0031] FIG. 2 is a diagram of an example video stream 200 to be encoded and decoded. The video stream 200 (also referred to herein as video data) includes a video sequence 204. At the next level, the video sequence 204 includes a number of adjacent frames 206. While three frames are depicted as the adjacent frames 206, the video sequence 204 can include any number of adjacent frames. The adjacent frames 206 can then be further subdivided into individual frames, e.g., a frame 208. Each frame 208 can capture a scene with one or more objects, such as people, background elements, graphics, text, a blank wall, or any other information.

[0032] The frame 208 may be divided into segments. Whether or not the frame 208 is divided into segments, at the next level, the frame 208 can be divided into a set of blocks 210, which can contain data corresponding to, in some of the examples described below, an 8x8 pixel group in the frame 208. The block 210 can also be of any other suitable size such as a block of 16x8 pixels, a block of 8x8 pixels, a block of 16x16 pixels, a block of 4x4 pixels, or of any other size. Unless otherwise noted, the term 'block' can include a macroblock, a subblock (i.e., a subdivision of a macroblock), a segment, a slice, a residual block or any other portion of a frame. A frame, a block, a pixel, or a combination thereof can include display information, such as luminance information, chrominance information, or any other information that can be used to store, modify, communicate, or display the video stream or a portion thereof. The blocks 210 can also be arranged in planes of data. For example, a corresponding block 210 in each plane can respectively contain luminance and chrominance

data for the pixels of the block 210.

[0033] FIG. 3 is a block diagram of an encoder 300 in accordance with implementations of this disclosure. The encoder 300 can be implemented, as described above, in the transmitting station 102 such as by providing a computer software program stored in the memory 106, for example. The computer software program can include machine instructions that, when executed by the CPU 104, cause the transmitting station 102 to encode video data in the manner described in FIG. 3. The encoder 300 can also be implemented as specialized hardware in, for example, the transmitting station 102. The encoder 300 has the following stages to perform the various functions in a forward path (shown by the solid connection lines) to produce an encoded or a compressed bitstream 320 using video stream 200 as input: an intra/inter prediction stage 304, a transform stage 306, a quantization stage 308, and an entropy encoding stage 310. The encoder 300 may include a reconstruction path (shown by the dotted connection lines) to reconstruct a frame for encoding of future blocks. In FIG. 3, the encoder 300 has the following stages to perform the various functions in the reconstruction path: a dequantization stage 312, an inverse transform stage 314, a reconstruction stage 316, and a loop filtering stage 318. Other structural variations of the encoder 300 can be used to encode the video stream 200.

[0034] When the video stream 200 is presented for encoding, the frame 208 within the video stream 200 can be processed in units of blocks. Referring to FIG. 3, at the intra/inter prediction stage 304, each block can be encoded using either intra prediction (i.e., within a single frame) or inter prediction (i.e. from frame to frame). In either case, a prediction block can be formed. The prediction block is then subtracted from the block to produce a residual block (also referred to herein as residual).

[0035] Intra prediction (also referred to herein as intra-prediction or intra-frame prediction) and inter prediction (also referred to herein as inter-prediction or inter-frame prediction) are techniques used in modern image/video compression schemes. In the case of intra-prediction, a prediction block can be formed from samples in the current frame that have been previously encoded and reconstructed. In the case of inter-prediction, a prediction block can be formed from samples in one or more previously constructed reference frames, such as the last frame (i.e., the adjacent frame immediately before the current frame), a golden frame or a constructed or alternative reference frame.

[0036] The prediction block is then subtracted from the current block. The difference, or residual, is encoded and transmitted to decoders. Image or video codecs may support many different intra and inter prediction modes; each block may use one of the prediction modes to

obtain a prediction block that is most similar to the block to minimize the information to be encoded in the residual so as to re-create the block. The prediction mode for each block of transform coefficients can also be encoded and transmitted so a decoder can use the same prediction mode(s) to form prediction blocks in the decoding and reconstruction process.

[0037] The prediction mode may be selected from one of multiple intra-prediction modes. The multiple intra-prediction modes can include, for example, horizontal intra prediction mode, vertical intra prediction mode, and various other directional intra prediction modes, also referred to as angular intra prediction modes, according to implementations of this disclosure. In horizontal intra prediction, each column of a current block can be filled with a copy of a column to the left of the current block. In vertical intra prediction, each row of a current block can be filled with a copy of a row above the current block. Various directional intra prediction modes propagate pixel values from peripheral pixels (e.g., above and/or to the left of the current block) to a block being predicted along an angular line, that is, in directions offset from both the horizontal and the vertical to form a prediction block having the same size as the current block.

[0038] Alternatively, the prediction mode may be selected from one of multiple inter-prediction modes using one or more reference frames including, for example, last frame, golden frame, alternative reference frame, or any other reference frame in an encoding scheme. The bitstream syntax may support three categories of inter prediction modes. The inter prediction modes can include, for example, a mode (sometimes called ZERO_MV mode) in which a block from the same location within a reference frame as the current block is used as the prediction block; a mode (sometimes called a NEW_MV mode) in which a motion vector is transmitted to indicate the location of a block within a reference frame to be used as the prediction block relative to the current block; or a mode (sometimes called a REF_MV mode comprising NEAR_MV or NEAREST_MV mode) in which no motion vector is transmitted and the current block uses the last or second-to-last non-zero motion vector used by neighboring, previously coded blocks to generate the prediction block. Inter-prediction modes may be used with any of the available reference frames.

[0039] Next, still referring to FIG. 3, the transform stage 306 transforms the residual into a block of transform coefficients in, for example, the frequency domain. Examples of block-based transforms include the Karhunen-Loève Transform (KLT), the Discrete Cosine Transform (DCT), Walsh-Hadamard Transform (WHT), the Singular Value Decomposition Transform (SVD), and the Asymmetric Discrete Sine Transform (ADST). In an example, the DCT transforms the block into the frequency domain. In the case of DCT, the transform

coefficient values are based on spatial frequency, with the lowest frequency (e.g., DC) coefficient at the top-left of the matrix and the highest frequency coefficient at the bottom-right of the matrix.

[0040] The quantization stage 308 converts the block of transform coefficients into discrete quantum values, which are referred to as quantized transform coefficients, using a quantizer value or quantization level. The quantized transform coefficients are then entropy encoded by the entropy encoding stage 310. The entropy-encoded coefficients, together with other information used to decode the block, which can include for example the type of prediction used, motion vectors and quantization value, are then output to the compressed bitstream 320. The compressed bitstream 320 can be formatted using various techniques, such as variable length encoding (VLC) and arithmetic coding. The compressed bitstream 320 can also be referred to as an encoded video stream and the terms will be used interchangeably herein.

[0041] The reconstruction path in FIG. 3 (shown by the dotted connection lines) can be used to provide both the encoder 300 and a decoder 400 (described below) with the same reference frames to decode the compressed bitstream 320. The reconstruction path performs functions that are similar to functions that take place during the decoding process that are discussed in more detail below, including dequantizing the quantized transform coefficients at the dequantization stage 312 to generate dequantized transform coefficients and inverse transforming the dequantized transform coefficients at the inverse transform stage 314 to produce a derivative residual block (i.e., derivative residual). At the reconstruction stage 316, the prediction block that was predicted at the intra/inter prediction stage 304 can be added to the derivative residual to create a reconstructed block. In some implementations, the loop filtering stage 318 can be applied to the reconstructed block to reduce distortion such as blocking artifacts.

[0042] Other variations of the encoder 300 can be used. For example, a non-transform based encoder can quantize the residual block directly without the transform stage 3064. In another implementation, an encoder can have the quantization stage 308 and the dequantization stage 312 combined into a single stage.

[0043] FIG. 4 is a block diagram of a decoder 400 in accordance with implementations of this disclosure. The decoder 400 can be implemented, for example, in the receiving station 110, such as by providing a computer software program stored in memory for example. The computer software program can include machine instructions that, when executed by the CPU 112, cause the receiving station 110 to decode video data in the manner described in

FIG. 4. The decoder 400 can also be implemented as specialized hardware or firmware in, for example, the transmitting station 102 or the receiving station 110.

[0044] The decoder 400, similar to the reconstruction path of the encoder 300 discussed above, includes in one example the following stages to perform various functions to produce an output video stream 416 from the compressed bitstream 320: an entropy decoding stage 402, a dequantization stage 404, an inverse transform stage 408, an intra/inter prediction stage 406, a reconstruction stage 410, a loop filtering stage 412, and a deblocking filtering stage 414. Other structural variations of decoder 400 can be used to decode compressed bitstream 320.

[0045] When the compressed bitstream 320 is presented for decoding, the data elements within the compressed bitstream 320 can be decoded by the entropy decoding stage 402 (using, for example, arithmetic coding) to produce a set of quantized transform coefficients. The dequantization stage 404 dequantizes the quantized transform coefficients and the inverse transform stage 408 inverse transforms the dequantized transform coefficients to produce a derivative residual that can be identical to that created by the inverse transform stage 314 in the encoder 300. Using header information decoded from the compressed bitstream 320, the decoder 400 can use the intra/inter prediction stage 406 to create the same prediction block as was created in the encoder 300, e.g., at the intra/inter prediction stage 304. In the case of inter prediction, the reference frame from which the prediction block is generated may be transmitted in the bitstream or constructed by the decoder using information contained within the bitstream.

[0046] At the reconstruction stage 410, the prediction block can be added to the derivative residual to create a reconstructed block that can be identical to the block created by the reconstruction stage 316 in the encoder 300. In some implementations, the loop filtering stage 412 can be applied to the reconstructed block to reduce blocking artifacts. The deblocking filtering stage 414 can be applied to the reconstructed block to reduce blocking distortion, and the result is output as output video stream 416. The output video stream 416 can also be referred to as a decoded video stream and the terms will be used interchangeably herein.

[0047] Other variations of the decoder 400 can be used to decode the compressed bitstream 320. For example, the decoder 400 can produce the output video stream 416 without the deblocking filtering stage 414.

[0048] FIG. 5 is a flow diagram showing a process 500 for encoding a video stream using directional intra prediction modes in accordance with an implementation of this

disclosure. The process 500 can be implemented in an encoder such as the encoder 300 (shown in FIG. 3) and can be implemented, for example, as a software program that can be executed by computing devices such as the transmitting station 102 or the receiving station 110 (shown in FIG. 1). For example, the software program can include machine-readable instructions that can be stored in a memory such as the memory 106 or the memory 114, and that can be executed by a processor, such as the CPU 104, to cause the computing device to perform the process 500.

[0049] The process 500 can be implemented using specialized hardware or firmware. Some computing devices can have multiple memories, multiple processors, or both. The operations or steps of the process 500 can be distributed using different processors, memories, or both. Use of the terms "processor" or "memory" in the singular encompasses computing devices that have one processor or one memory as well as devices that have multiple processors or multiple memories that can each be used in the performance of some or all of the recited steps. For simplicity of explanation, the process 500 is depicted and described as a series of steps. However, steps in accordance with this disclosure can occur in various orders and/or concurrently. Additionally, steps in accordance with this disclosure may occur with other steps not presented and described herein. Furthermore, not all illustrated steps may be required to implement a method in accordance with the disclosed subject matter.

[0050] The process 500 assumes that a stream of video data having multiple frames, each having multiple blocks, is being encoded using a video encoder such as the encoder 300 executing on a computing device such as the transmitting station 102. The video data or stream can be received by the computing device in any number of ways, such as by receiving the video data over a network, over a cable, or by reading the video data from a primary memory or other storage device, including a disk drive or removable media such as a CompactFlash (CF) card, Secure Digital (SD) card, or any other device capable of communicating video data. In some implementations, video data can be received from a video camera connected to the computing device operating the encoder. At least some of the blocks within frames are encoded using intra prediction as described in more detail below.

[0051] At operation 502, a video stream including a frame having multiple blocks of video data including a current block can be received by a computing device, such as the transmitting station 102. At operation 504, the process 500 identifies a set of pixels peripheral to the current block from the frame. By identify, this disclosure means distinguish, determine, select, or otherwise identify in any manner whatsoever. The set of pixels can include pixels

from previously coded blocks in the frame. The set of pixels identified can be based on the scan order of the blocks within the frame such that the identified pixels are previously encoded and decoded. For example, the set of pixels can be identified from a block above, to the left, or to the above-left of the current block in the frame when the scan order is a raster scan order. Other scan orders, such as wavefront, spiral, zig-zag, etc., are possible. The set of pixels can be, for example, a set of reconstructed pixels determined using the reconstruction path in FIG. 3 at the encoder 300.

[0052] The set of pixels can be identified from a single block, or multiple blocks peripheral to the current block. The set of pixels can include one or more rows of pixel values above the current block, or one or more columns of pixel values to the left of the current block, or a pixel from a block to the top-left of the current block, or any combination thereof. Data from rows or columns not immediately adjacent to the current block, including data from blocks that are not adjacent to the current block, can be included in the set of pixels.

[0053] At operation 506, based on a size of the current block, the process 500 identifies a candidate set of directional intra prediction modes from a plurality of directional intra prediction modes that may be used to predict the current block.

[0054] As mentioned briefly above, directional intra prediction can be used to form prediction blocks by propagating pixels peripheral to the current block along an angular direction, that is, in a direction offset from both the horizontal and the vertical, to populate a prediction block. The prediction block is then subtracted from the original block to form the residual. In directional intra prediction (also called angular intra prediction), the current block can be predicted by projecting reference pixels from neighboring blocks, typically on the left and top boundaries of the current block, in a certain angle or direction offset from the horizontal and the vertical lines. The reference pixels can be, for example, actual pixel values of the peripheral pixels or combinations of the pixel values (such as averaging or weighted averaging) of the peripheral pixels. For example, some example directional intra prediction modes can include propagating the reference pixel values along directions such as 45 degree lines ("45 degree intra prediction mode"), 63 degree lines ("63 degree intra prediction mode"), 117 degree lines ("117 degree intra prediction mode"), 135 degree lines ("135 degree intra prediction mode"), 153 degree lines ("153 degree intra prediction mode"), 207 degree lines ("207 degree intra prediction mode"), etc., to form the prediction block.

[0055] FIGS. 6 and 7 illustrate some example intra prediction modes including a vertical intra prediction mode and a 135 degree intra prediction mode. FIG. 6 is a diagram that illustrates a 90 degree (vertical) intra prediction mode, which propagates peripheral pixels A

through E down the columns of the prediction block such that each pixel in a column has its value set equal to that of the adjacent peripheral pixel A through E in the direction of the arrows. FIG. 7 is a diagram that illustrates a 135 degree intra prediction mode, which propagates peripheral pixel values along 135 degree line (e.g., lines 706) to the right and down through the prediction block. The peripheral pixel values can include, for example, the reference data 708 provided by peripheral pixels A through S from blocks adjacent to a current 4x4 block of a frame 700 to be encoded. The propagated pixels are used to form a prediction block 702 for the block.

[0056] Although the 135 degree intra prediction mode in FIG. 7 is illustrated using the pixel values of the reference data 708 to generate the prediction block 702, in this example, a linear combination (e.g., weighted average) of two or three of the peripheral pixels can be used to predict pixel values of the prediction block along lines extending through the block. For example, the value of the pixel 704 to be propagated along line 706 can be formed from an average of pixel values B and N and, or can be formed from a weighted average of pixel values L, M, and N when another angular intra prediction mode is used. The pixel values along the lines can be formed of combinations of the reference data 708 propagated along a single line using a formula instead of propagating a single value. For the labeled line 706 of FIG. 7, for example, the value of the pixel above the pixel 704 may be an average of the pixel values of the pixels M and B, and the value of the pixel beside the pixel 704 may be an average of the pixel values of the pixels N and C. Other variations are possible.

[0057] The plurality of directional intra prediction modes can include, for example, angular intra prediction modes using angles (in degrees) shown in FIGS. 11 and 12. For example, FIG. 11 shows 40 angles (in degrees) that can be used as directional intra prediction modes, and FIG. 12 shows another 56 angles (in degrees) that can be used as directional intra prediction modes.

[0058] Referring again to the operation 506 of FIG. 5, the process 500 identifies a candidate set (subset) of directional intra prediction modes from the plurality of directional intra prediction modes based on the size of the current block. The number of directional intra prediction modes in the candidate set of directional intra prediction modes is variable and adaptive to the size of the current block. When the number of angles is not unnecessarily large, the more angles the encoder supports, the better the compression performance. However, the more angles the encoder supports, the slower the encoding speed.

[0059] The difference between predictions using different angles is often less significant for smaller prediction blocks than for larger prediction blocks. For example, FIG. 8 is a

diagram that illustrates a 90 degree (vertical) intra prediction mode for a 4x4 block resulting in a prediction block 804 and an 8x8 block resulting in a prediction block 806 using reconstructed values 802 of a frame 800, and FIG. 9 is a diagram that illustrates an 84 degree intra prediction mode for a 4x4 block resulting in a prediction block 904 and an 8x8 block resulting in a prediction block 906 using reconstructed values 902 of a frame 900. The root mean square difference between the predicted values of the 4x4 prediction block 904 using the 84 degree intra prediction mode and the 4x4 prediction block 804 using the vertical intra prediction mode is 0.32. The root mean square difference between the predicted values of the 8x8 prediction block 906 using the 84 degree intra prediction mode and the 8x8 prediction block 806 using the vertical intra prediction mode in this illustrated example is 0.50. As can be seen from this example, the difference between predictions between the 84 degree angle and the 90 degree angle is less significant for 4x4 blocks than for 8x8 blocks.

[0060] Therefore, to improve the quality of prediction for larger prediction blocks, more angles can be considered by the current block as candidate intra prediction modes. For smaller blocks, and hence smaller prediction blocks, fewer angles can be considered so that the encoder can be substantially faster without sacrificing much compression efficiency. Overall, using a variable subset of directional intra prediction modes as the candidate set of directional intra prediction modes can reduce the number of directional intra prediction modes considered for smaller prediction blocks. This can increase encoding speed, and improve overall compression performance. By reducing the number of bits used to signal the prediction angle used, further optimization and bandwidth efficiency can be achieved.

[0061] The number of directional intra prediction modes in the candidate set of directional intra prediction modes can include a predetermined number of angles for the particular size of the current block, and the angles can be approximately evenly distributed between, for example, 0 degrees and 270 degrees. The number of angles for the candidate set of directional intra prediction modes can also be reduced by grouping angles that are close together.

[0062] A lookup table can be constructed for the size of the block to be encoded using, for example, a predetermined number of approximately evenly spaced angles as entries in the lookup table. For example, FIG. 11 illustrates an example implementation of a lookup table for blocks of size 4x4 and 8x8, where the lookup table includes 40 angles (in degrees) that are identified for 4x4 and 8x8 blocks, which correspond to 40 directional intra prediction modes in the candidate set of intra prediction modes identified for 4x4 and 8x8 blocks. FIG. 12 illustrates an example implementation of a lookup table for blocks of size 16x16, 32x32, and

larger, where the lookup table includes 56 angles (in degrees) that are identified for 16x16, 32x32, and larger blocks, which correspond to 56 directional intra prediction modes in the candidate set of intra prediction modes identified for 16x16, 32x32, and larger blocks. While the lookup tables may be used solely by the encoder for providing the available intra prediction modes for a block size, in some cases, an index may be added to the entries (e.g., the angles of the intra prediction modes) in the lookup tables, which are shared with a decoder. In this way, the index of the optimal intra prediction mode, described below, may be transmitted in the encoded bitstream so as to optimal intra prediction mode to the decoder.

[0063] It is possible that the angles are not approximately evenly spaced as shown in the examples of FIGS. 11 and 12. The number of angles for each block size (also referred to as block dimensions) does not have to be predetermined and can be dynamically adjusted, and signaled to the decoder. Smaller blocks have fewer choices of intra prediction angles, and hence intra prediction modes. In the examples shown, two smaller block sizes share a first set of intra prediction modes, and three larger block sizes share a second set of intra prediction modes, where the first and second sets do not overlap. This is not required. The candidate sets may have some overlapping intra prediction modes. For example, the second set of intra prediction modes may include all of the intra prediction modes of the first set of intra prediction modes and some additional intra prediction modes. Different block sizes may not share candidate sets. For example, if there are five prediction block sizes, there may be five different candidate sets with increasing numbers of intra prediction modes as the sizes increase.

[0064] Returning to FIG. 5, the process 500 selects, for the current block, an optimal intra prediction mode from the candidate set of directional intra prediction modes at operation 508. The optimal intra prediction mode is used to predict the current block based on the set of previously coded pixels. For example, an optimal directional intra prediction mode can be selected to predict the current block by testing each directional intra prediction mode in the candidate set of directional intra prediction modes using the set of previously coded pixels to predict the current block, and selecting the directional intra prediction mode that provides the best compression (e.g., the fewest bits, including bits required to specify the intra prediction mode in the encoded video bitstream) with the least distortion (that is, the least amount of error in the predicted and subsequently reconstructed block). This can be referred to as the lowest rate-distortion cost or value. The selection process can occur in a rate distortion loop. In cases where the blocks are better predicted by inter prediction, the best inter prediction mode can be selected as the optimal prediction mode for the current block.

[0065] Referring to FIGS. 11 and 12 to explain an example of the operation 508, the optimal intra prediction mode can be selected from, for example, a candidate set of directional intra prediction modes shown in FIG. 11, when the current block is a 4x4 block or an 8x8 block. For example, the optimal intra prediction mode can be selected as a 94 degree directional intra prediction mode. When the current blocks is 16x16 block or larger, the optimal intra prediction mode can be selected from a candidate set of directional intra prediction modes shown in FIG. 12. For example, optimal intra prediction mode can be selected as a 93 degree directional intra prediction mode. Some of the directional intra prediction modes that have close angular values can be grouped together, or combined into one directional intra prediction mode. For example, a 93 degree directional intra prediction mode can be combined with a 94 degree directional intra prediction mode. The angular values that are grouped together can come from, for example, same or different candidate sets. As discussed above, the optimal intra prediction mode can be selected in a rate distortion loop that identifies a prediction mode resulting in an optimal (i.e., a lowest) rate distortion value.

[0066] At operation 510, the process 500 encodes the optimal directional intra prediction mode used for the current block before processing begins again for the next block of the current frame. In addition, the current block can be encoded according to the process described with respect to FIG. 3.

[0067] FIG. 10 is a flow diagram of a process 1000 for decoding an encoded video stream using directional intra prediction modes in accordance with implementations of this disclosure. The decoder can identify the particular directional intra prediction mode that was selected in the process 500, shown in FIG. 5, to encode a block. The decoder can read the index of the bitstream to determine the particular directional intra prediction mode to use from a plurality of directional intra prediction modes. The process 1000 can be implemented, for example, as a software program that may be executed by computing devices such as transmitting station 102 or receiving station 110. For example, the software program can include machine-readable instructions that may be stored in a memory such as the memory 106 or the memory 114, and that, when executed by a processor, such as the CPU 104 or the CPU 112, may cause the computing device to perform the process 1000. The process 1000 can be implemented using specialized hardware or firmware. As explained above, some computing devices may have multiple memories or processors, and the operations or steps of the process 1000 can be distributed using multiple processors, memories, or both.

[0068] For simplicity of explanation, the process 1000 is depicted and described as a

series of operations or steps. However, steps in accordance with this disclosure can occur in various orders and/or concurrently. Additionally, steps in accordance with this disclosure may occur with other steps not presented and described herein. Furthermore, not all illustrated steps may be required to implement a method in accordance with the disclosed subject matter.

[0069] Desirably, the process 1000 substantially conforms to the process 500. There are some differences, however, that are pointed out in the following description of the process 1000. Where steps are substantially similar to those in the process 500, reference will be made to the description above.

[0070] A computing device such as the receiving station 110 may receive the encoded video stream, such as the compressed bitstream 320. The encoded video stream (which may be referred to herein as the encoded video data) can be received in any number of ways, such as by receiving the video data over a network, over a cable, or by reading the video data from a primary memory or other storage device, including a disk drive or a removable media such as a DVD, CompactFlash (CF) card, Secure Digital (SD) card, or any other device capable of communicating a video stream.

[0071] At operation 1002, an encoded current block can be identified from a frame in the encoded video stream. The encoded current block can be, for example, a block that has been encoded at the encoder 300 using any of the directional intra prediction modes described herein, such as the 90 degree (vertical) intra prediction mode of FIG. 6 or the 135 degree intra prediction mode of FIG. 7, or any other angular intra prediction mode such as one shown in FIG. 11 or FIG. 12.

[0072] At operation 1004, the process 1000 identifies a set of pixels peripheral to the encoded current block from the frame in the video stream. The set of pixels can include pixels from previously decoded blocks in the frame, such as a block from the same frame as the current block that has been decoded prior to the current block. For example, the set of pixels can be identified from a block above, a block to the left, or a block to the above-left of the current block in the same frame. The set of pixels can be identified from a single block in the frame, or multiple blocks peripheral to the current block in the same frame. For example, the set of pixels can include pixels from multiple blocks, such as blocks to the left of the current block, blocks above the current block, and/or blocks to the above-left of the current block.

[0073] In some implementations, the set of pixels can include one or more rows of pixel values above the current block, or one or more columns of pixel values to the left of the

current block, or one or more columns of pixel values to the above-left of the current block, or any combination thereof. For example, the set of pixels can include one of a column of pixels from the block to the left of the current block, a row of pixels from a block above the current block, a pixel from a block to the top-left of the current block, or any combination thereof. In other implementations, data from rows or columns not immediately adjacent to the current block, including data from blocks that are not adjacent to the current block, can be included in the set of pixels.

[0074] At the operation 1006, the process 1000 identifies a candidate set of directional intra prediction modes from a plurality of directional intra prediction modes based on a size of the current block. Similar to the operation 506, the number of directional intra prediction modes in the candidate set of directional intra prediction modes can be variable and adaptive to the size of the current block.

[0075] At operation 1008, the process 1000 determines the directional intra prediction mode used to predict the encoded current block. The directional intra prediction mode can be previously selected from the candidate set of directional intra prediction modes at the operation 508, and used to predict the current block during the encoding process based on the set of previously coded pixels. The directional intra prediction mode can be determined at least partially by, for example, reading bits from one or more headers such as a header associated with the current block or a frame header. This information can be communicated by reading and decoding bits from the encoded video stream that indicate to the decoder the use of a directional intra prediction mode and information about the directional intra prediction mode (e.g., index or some other indication) according to one of the techniques disclosed above. Using the candidate set of directional intra prediction modes identified at the operation 1006 and the decoded information regarding the directional intra prediction mode, the directional intra prediction mode can be determined.

[0076] When the direction or angle can be decoded directly from the information about the directional intra prediction mode in the encoded bitstream, identifying the candidate set of directional intra prediction modes at the operation 1006 may be omitted. The set of pixels peripheral to the encoded current block within a frame identified at the operation 1002 can be identified at the operation 1004 after the directional intra prediction mode is determined at the operation 1008. That is, the directional intra prediction mode itself can be used to identify the second of pixels.

[0077] At operation 1010, the process 1000 determines a prediction block using the set of pixels and the particular directional intra prediction mode used to encode the current block.

The process 1000 generally forms the prediction block by propagating the pixel values along the angular direction of the particular directional intra prediction mode identified at the operation 1008 as described with regard to the operations of FIG. 5. At operation 1012, the encoded current block can be decoded using the prediction block. For example, the encoded current block (i.e., its encoded residual) can be entropy decoded at the entropy decoding stage 402, dequantized at the dequantization stage 404, and inverse transformed at the inverse transform stage 408 to determine the derivative residual. The derivative residual can be added to the prediction block determined for the current block at the operation 1010 to reconstruct the current block at the reconstruction stage 410. A frame can be reconstructed from the reconstructed blocks and the output can be an output video stream, such as the output video stream 416 shown in FIG. 4, and may be referred to as a decoded video stream.

[0078] The aspects of encoding and decoding described above illustrate some encoding and decoding techniques. However, it is to be understood that encoding and decoding, as those terms are used in the claims, could mean compression, decompression, transformation, or any other processing or change of data.

[0079] The words "example" or "aspect" are used herein to mean serving as an example, instance, or illustration. Any aspect or design described herein as "example" or "aspect" is not necessarily to be construed as preferred or advantageous over other aspects or designs. Rather, use of the words "example" or "aspect" is intended to present concepts in a concrete fashion. As used in this application, the term "or" is intended to mean an inclusive "or" rather than an exclusive "or". That is, unless specified otherwise, or clear from context, "X includes A or B" is intended to mean any of the natural inclusive permutations. That is, if X includes A; X includes B; or X includes both A and B, then "X includes A or B" is satisfied under any of the foregoing instances. In addition, the articles "a" and "an" as used in this application and the appended claims should generally be construed to mean "one or more" unless specified otherwise or clear from context to be directed to a singular form. Moreover, use of the term "an implementation" or "an example" throughout is not intended to mean the same embodiment or implementation unless described as such.

[0080] Implementations of the transmitting station 102 and/or the receiving station 110 (and the algorithms, methods, instructions, etc., stored thereon and/or executed thereby, including by the encoder 300 and the decoder 400) can be realized in hardware, software, or any combination thereof. The hardware can include, for example, computers, intellectual property (IP) cores, application-specific integrated circuits (ASICs), programmable logic arrays, optical processors, programmable logic controllers, microcode, microcontrollers,

servers, microprocessors, digital signal processors or any other suitable circuit. In the claims, the term "processor" should be understood as encompassing any of the foregoing hardware, either singly or in combination. The terms "signal" and "data" are used interchangeably. Further, portions of transmitting station 102 and receiving station 110 do not necessarily have to be implemented in the same manner.

[0081] Further, in one aspect, for example, the transmitting station 102 or the receiving station 110 can be implemented using a general purpose computer or general purpose processor with a computer program that, when executed, carries out any of the respective methods, algorithms and/or instructions described herein. In addition or alternatively, for example, a special purpose computer/processor can be utilized which can contain other hardware for carrying out any of the methods, algorithms, or instructions described herein.

[0082] The transmitting station 102 and the receiving station 110 can, for example, be implemented on computers in a video conferencing system. Alternatively, the transmitting station 102 can be implemented on a server and the receiving station 110 can be implemented on a device separate from the server, such as a hand-held communications device. In this instance, the transmitting station 102 can encode content using an encoder into an encoded video signal and transmit the encoded video signal to the communications device. In turn, the communications device can then decode the encoded video signal using a decoder. Alternatively, the communications device can decode content stored locally on the communications device, for example, content that was not transmitted by the transmitting station 102. Other suitable transmitting station 102 and receiving station 110 implementation schemes are available. For example, the receiving station 110 can be a generally stationary personal computer rather than a portable communications device and/or a device including the encoder 300 may also include the decoder 400.

[0083] Further, all or a portion of implementations of the present disclosure can take the form of a computer program product accessible from, for example, a tangible computer-usable or computer-readable medium. A computer-usable or computer-readable medium can be any device that can, for example, tangibly contain, store, communicate, or transport the program for use by or in connection with any processor. The medium can be, for example, an electronic, magnetic, optical, electromagnetic, or a semiconductor device. Other suitable mediums are also available.

[0084] The above-described embodiments, implementations and aspects have been described in order to allow easy understanding of the present disclosure and do not limit the present disclosure. On the contrary, the disclosure is intended to cover various modifications

and equivalent arrangements included within the scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structure as is permitted under the law.

What is claimed is:

1. A method of encoding a video stream, comprising:

identifying, peripheral to a current block of a frame of the video stream, a set of previously coded pixels in the frame;

identifying a candidate set of directional intra prediction modes from a plurality of directional intra prediction modes based on a size of the current block; and

selecting, for the current block, an optimal intra prediction mode from the candidate set of directional intra prediction modes, wherein the optimal intra prediction mode is used to predict the current block based on the set of previously coded pixels.

2. The method of claim 1, wherein each of the plurality of directional intra prediction modes is associated with a defined angle for predicting the current block along a direction specified by the defined angle using the set of previously coded pixels.

3. The method of claim 2, further comprising:

storing the defined angles in a lookup table associated with the size of the current block.

4. The method of any preceding claim, wherein a number of the directional intra prediction modes in the candidate set of directional intra prediction modes varies based on the size of the current block.

5. The method of any preceding claim, wherein the candidate set of directional intra prediction modes comprises: a first candidate set of directional intra prediction modes comprising a first number of the directional intra prediction modes when the size of the current block is a first size; and a second candidate set of directional intra prediction modes comprising a second number of the directional intra prediction modes when the size of the current block is a second size larger than the first size, the second number being larger than the first number.

6. The method of any preceding claim, wherein a first candidate set of directional intra prediction modes identified for a first block in the frame comprises a fewer number of

directional intra prediction modes than a second candidate set of directional intra prediction modes identified for a second block in the frame, when the size of the first block is less than a size of the second block.

7. The method of any preceding claim, wherein selecting the optimal intra prediction mode comprises:

selecting a directional intra prediction mode from the candidate set of directional intra prediction modes that results in a smallest rate-distortion cost.

8. The method of any preceding claim, further comprising:

identifying a subset of previously coded pixels from the set of previously coded pixels based on the optimal intra prediction mode; and

determining, for the current block, a prediction block using the subset of previously coded pixels.

9. The method of any preceding claim, wherein the candidate set of directional intra prediction modes is stored as entries within a lookup table including an index for each entry, the method further comprising:

transmitting an index for the optimal intra prediction mode within an encoded bitstream.

10. A method of decoding a video stream, comprising:

identifying, at pixel positions peripheral to a current block of a frame of the video stream, a set of previously decoded pixels in the frame;

identifying an intra prediction mode previously selected for encoding the current block from a candidate set of directional intra prediction modes that is based on a size of the current block;

determining a prediction block using the intra prediction mode and the set of previously decoded pixels; and

decoding the current block using the prediction block.

11. The method of claim 10, wherein the candidate set of directional intra prediction modes comprises a quantity of intra prediction modes, each associated with a

respective angle for predicting the current block along a direction specified by the angle using the set of previously decoded pixels.

12. The method of claim 10 or 11, wherein the candidate set of directional intra prediction modes is stored in a lookup table, and identifying the intra prediction mode comprises:

identifying an index within the lookup table, the index associated with the intra prediction mode.

13. The method of claim 10 or 11, wherein the candidate set of directional intra prediction modes comprises a first candidate set of a plurality of candidate sets of directional intra prediction modes, and identifying the intra prediction mode comprises selecting the first candidate set of the plurality of candidate sets based on the size of the current block.

14. The method of claim 13, wherein:

each of the plurality of candidate sets has a different number of intra prediction modes, an increasing number of directional intra prediction modes associated with a candidate set for a block size as the block size increases.

15. The method of any of claims 10 to 14, wherein:

the candidate set is: a first candidate set of at least two candidate sets of directional intra prediction modes, the size of the current block being a first size, and a second candidate set of the at least two candidate sets of directional intra prediction modes associated with a second size, the second size being larger than the first size and a number of intra prediction modes in the first candidate set being smaller than a number of intra prediction modes in the second candidate set.

16. An apparatus for decoding a video stream, comprising:

a memory; and

a processor configured to execute instructions stored in the memory to:

identify an intra prediction mode previously selected for encoding a current block of a frame from a first candidate set of directional intra prediction modes that is based on a size of the current block, the first candidate set of directional intra

prediction modes being different from a second candidate set of directional intra prediction modes for a block having a size different from the current block;

determine a prediction block using the inter prediction mode and a set of previously decoded pixels peripheral to the current block; and

decode the current block using the prediction block.

17. The apparatus of claim 16, wherein the processor is configured to execute instructions stored in the memory to:

decode, from an encoder, an index identifying the intra prediction mode within a first lookup table including angles identifying each of the directional intra prediction modes of the first candidate set.

18. The apparatus of claim 16 or 17, wherein:

the first candidate set has a first number of directional intra prediction modes;

the second candidate set has a second number of directional intra prediction modes that is higher than the first number when the size of the current block is smaller than the size different from the current block; and

the second candidate set has a second number of directional intra prediction modes that is lower than the first number when the size of the current block is larger than the size different from the current block.

19. The apparatus of any of claims 16 to 18, wherein each directional intra prediction mode in the first candidate set of directional intra prediction modes is different from each directional intra prediction mode in the second candidate set of directional intra prediction modes.

20. The apparatus of any of claims 16 to 18, wherein at least some of the intra prediction modes in the first candidate set of directional intra prediction modes are identical to intra prediction modes in the second candidate set of directional intra prediction modes.

21. Apparatus for encoding a video stream, the apparatus being arranged to:

identify, at pixel positions peripheral to a current block of a frame of the video stream, a set of previously encoded pixels in the frame;

identify a candidate set of directional intra prediction modes from a plurality of directional intra prediction modes based on a size of the current block; and

select, for the current block, an optimal intra prediction mode from the candidate set of directional intra prediction modes, wherein the optimal intra prediction mode is used to predict the current block based on the set of previously encoded pixels.

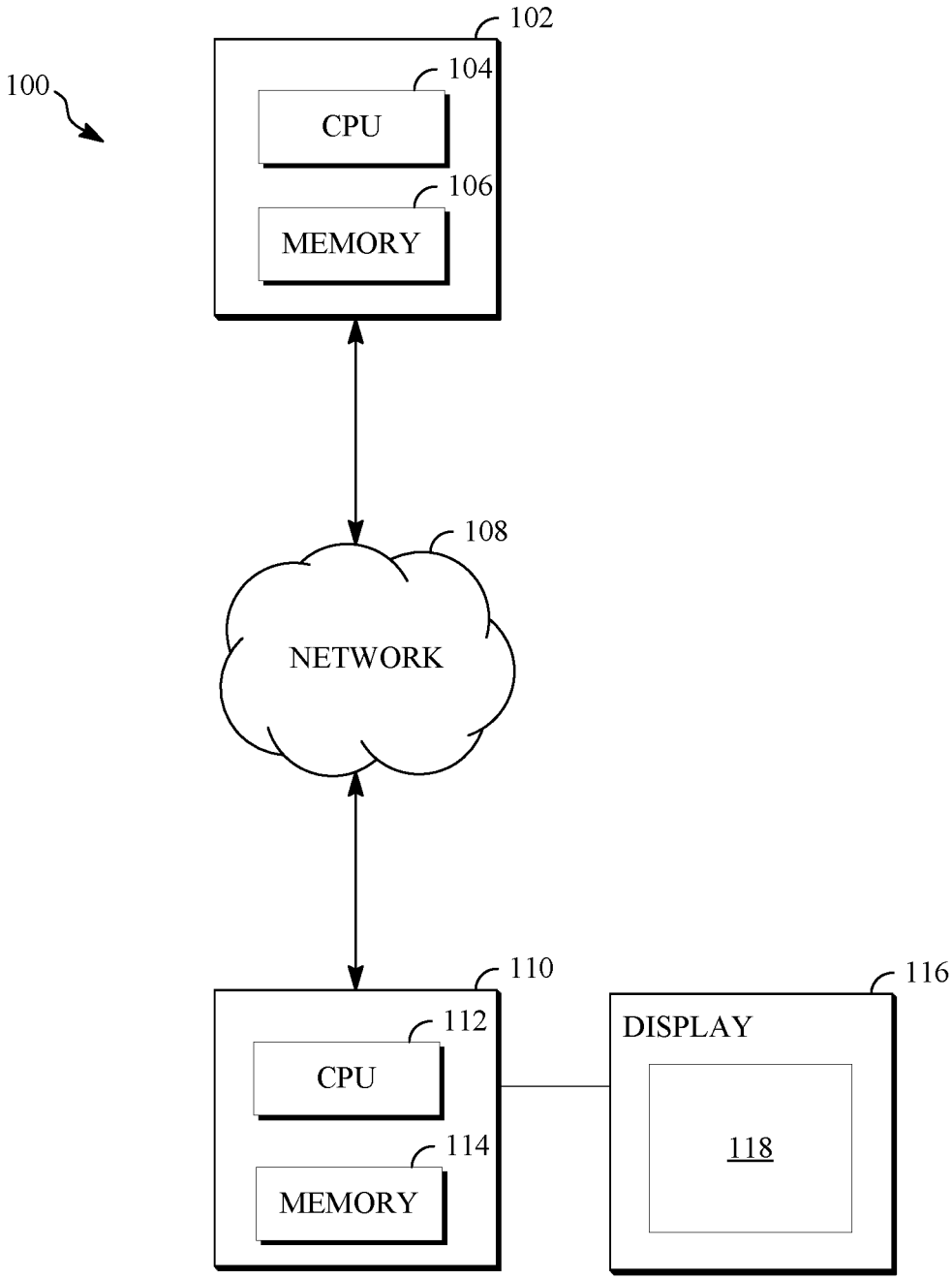

100
102
104
CPU
106
MEMORY
108
NETWORK
110
112
CPU
114
MEMORY
116
DISPLAY
118

FIG. 1

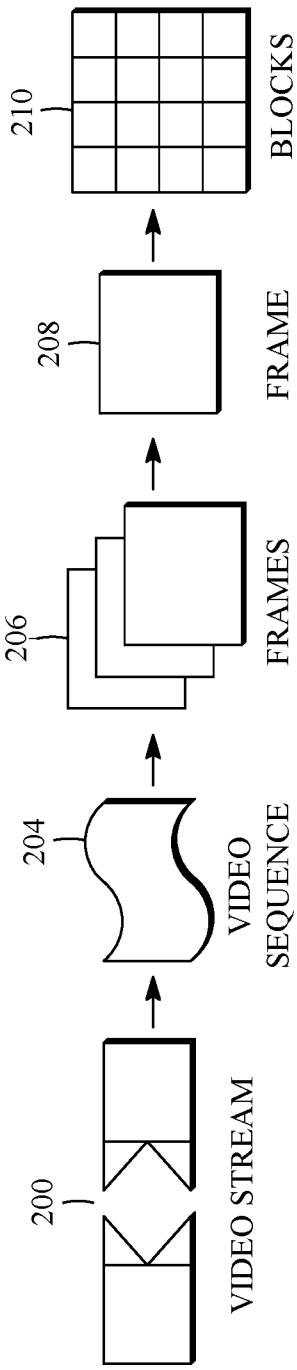

200
VIDEO STREAM
204
VIDEO SEQUENCE
206
FRAMES
208
FRAME
210
BLOCKS

FIG. 2

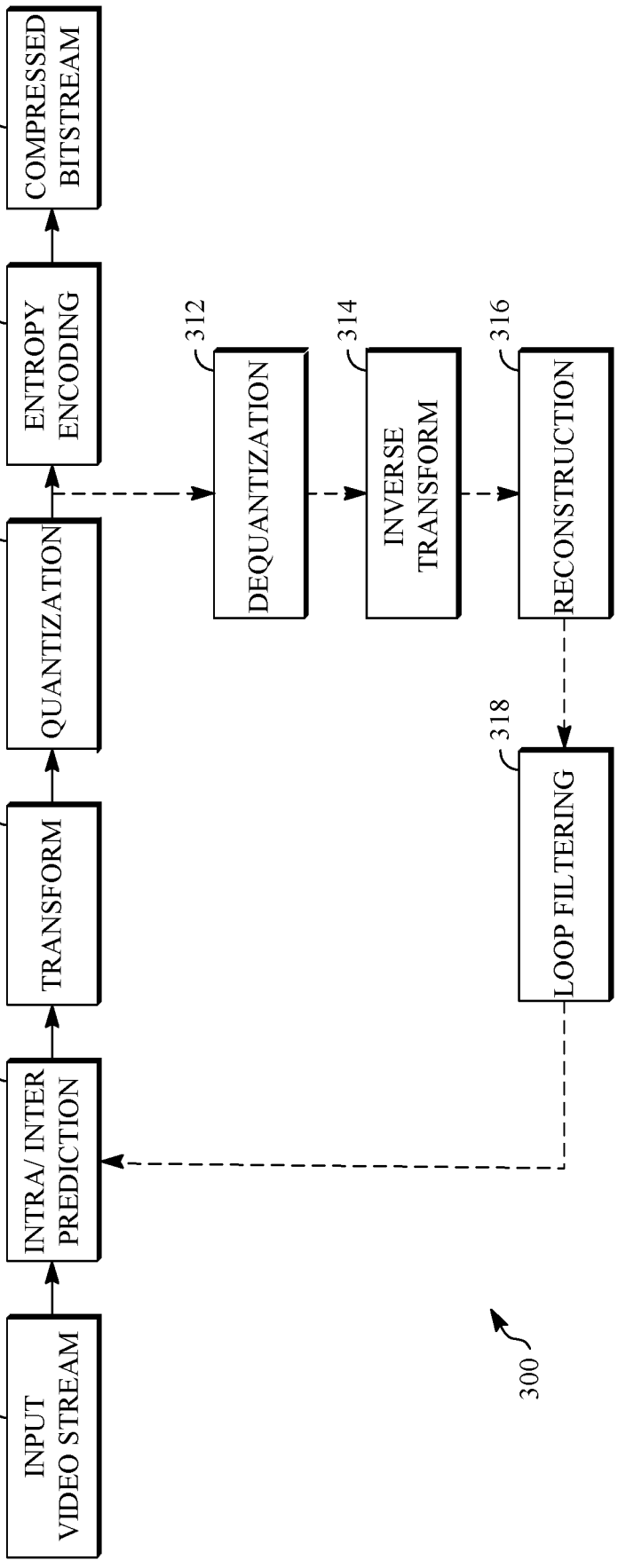

200
INPUT VIDEO STREAM
304
INTRA/ INTER PREDICTION
306
TRANSFORM
308
QUANTIZATION
310
ENTROPY ENCODING
320
COMPRESSED BITSTREAM
312
DEQUANTIZATION
314
INVERSE TRANSFORM
316
RECONSTRUCTION
318
LOOP FILTERING
300

FIG. 3

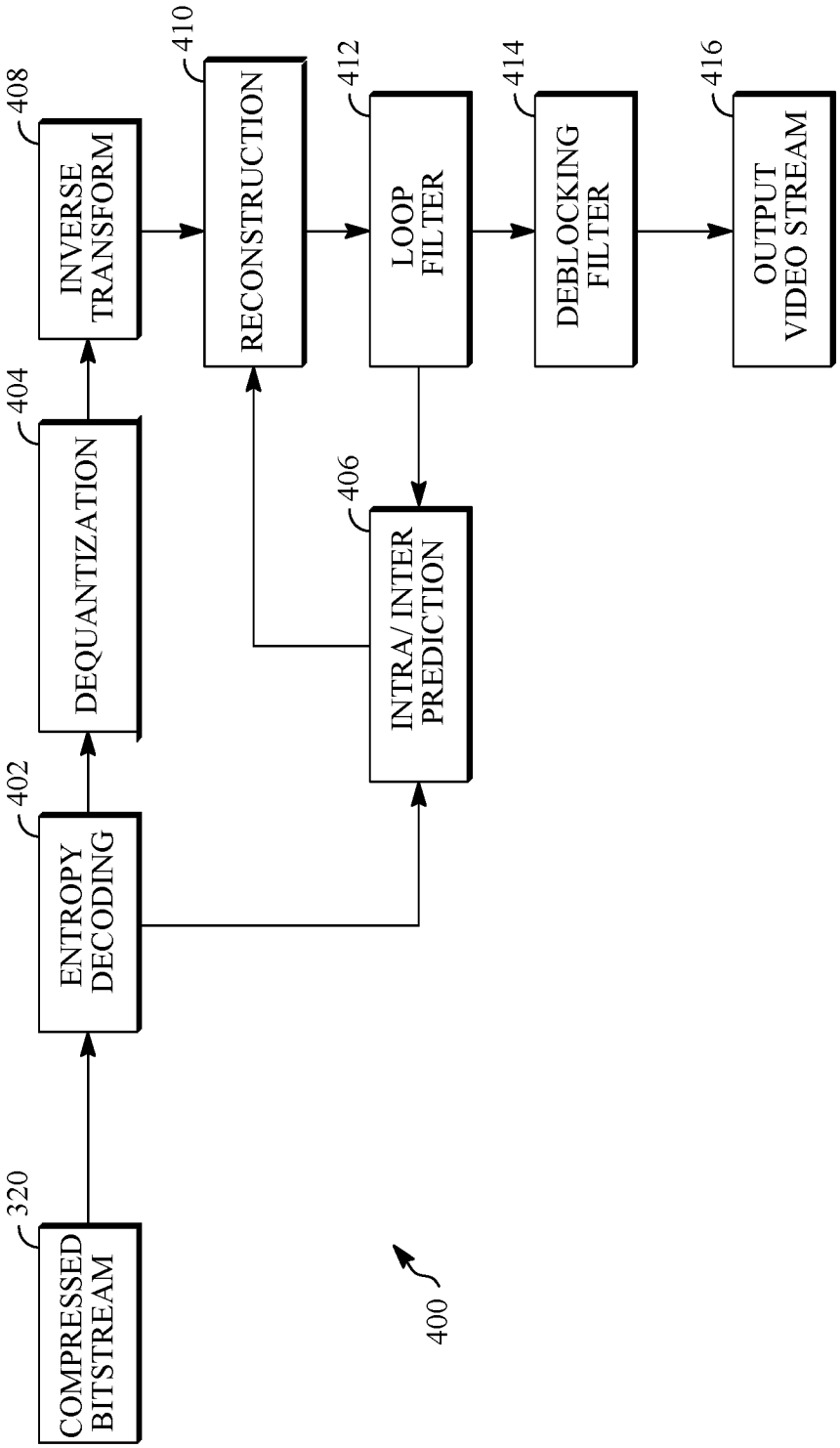

COMPRESSED BITSTREAM
320
ENTROPY DECODING
402
DEQUANTIZATION
404
INVERSE TRANSFORM
408
INTRA/ INTER PREDICTION
406
RECONSTRUCTION
410
LOOP FILTER
412
DEBLOCKING FILTER
414
OUTPUT VIDEO STREAM
416
400

FIG. 4

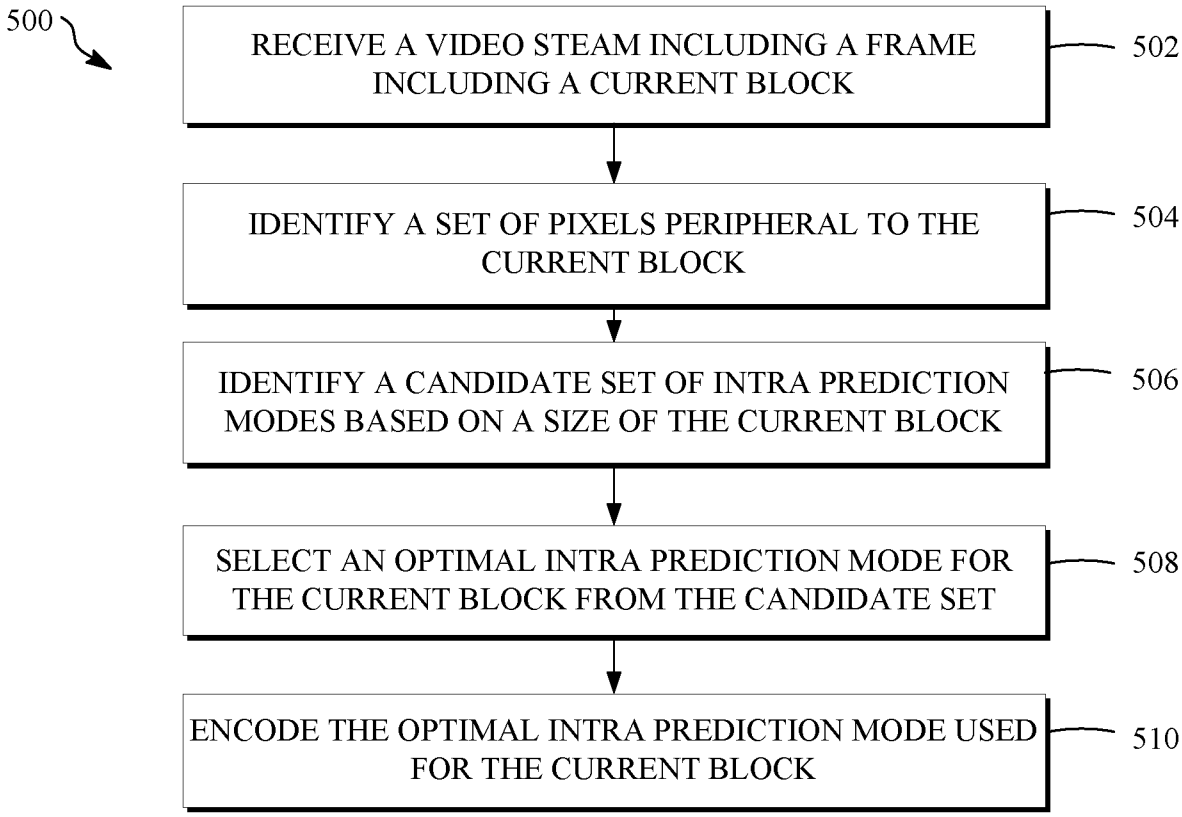

500
RECEIVE A VIDEO STEAM INCLUDING A FRAME INCLUDING A CURRENT BLOCK
502
IDENTIFY A SET OF PIXELS PERIPHERAL TO THE CURRENT BLOCK
504
IDENTIFY A CANDIDATE SET OF INTRA PREDICTION MODES BASED ON A SIZE OF THE CURRENT BLOCK
506
SELECT AN OPTIMAL INTRA PREDICTION MODE FOR THE CURRENT BLOCK FROM THE CANDIDATE SET
508
ENCODE THE OPTIMAL INTRA PREDICTION MODE USED FOR THE CURRENT BLOCK
510

FIG. 5

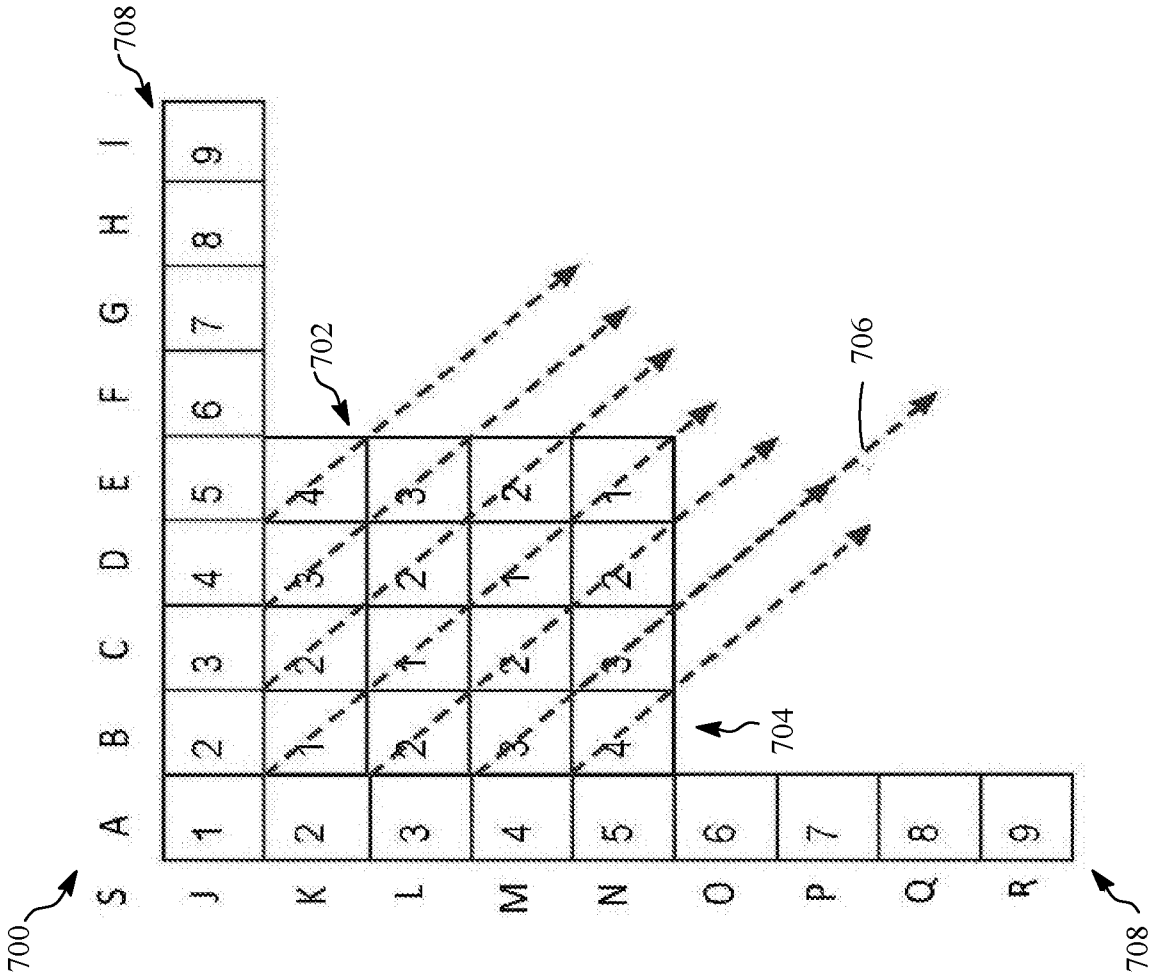

700
708
702
704
706
S A B C D E F G H I
J 1 2 3 4 5 6 7 8 9
K 2
L 3
M 4
N 5
O 6
P 7
Q 8
R 9

FIG. 7

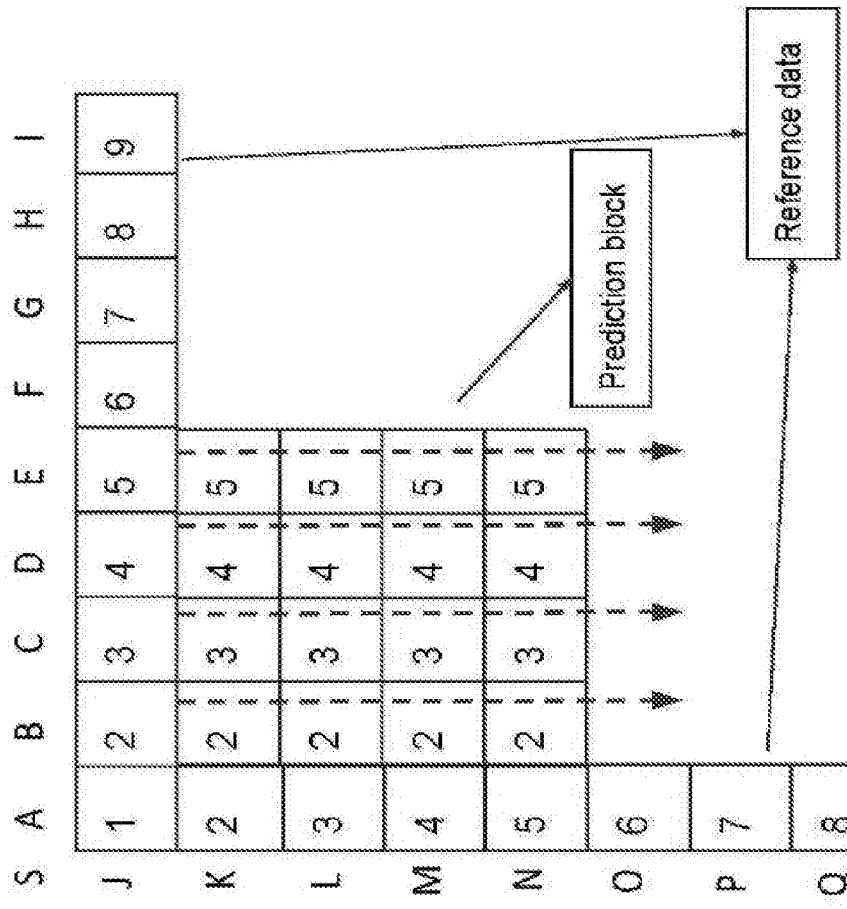

Prediction block
Reference data
S A B C D E F G H I
J 1 2 3 4 5 6 7 8 9
K 2
L 3
M 4
N 5
O 6
P 7
Q 8
R 9

FIG. 6

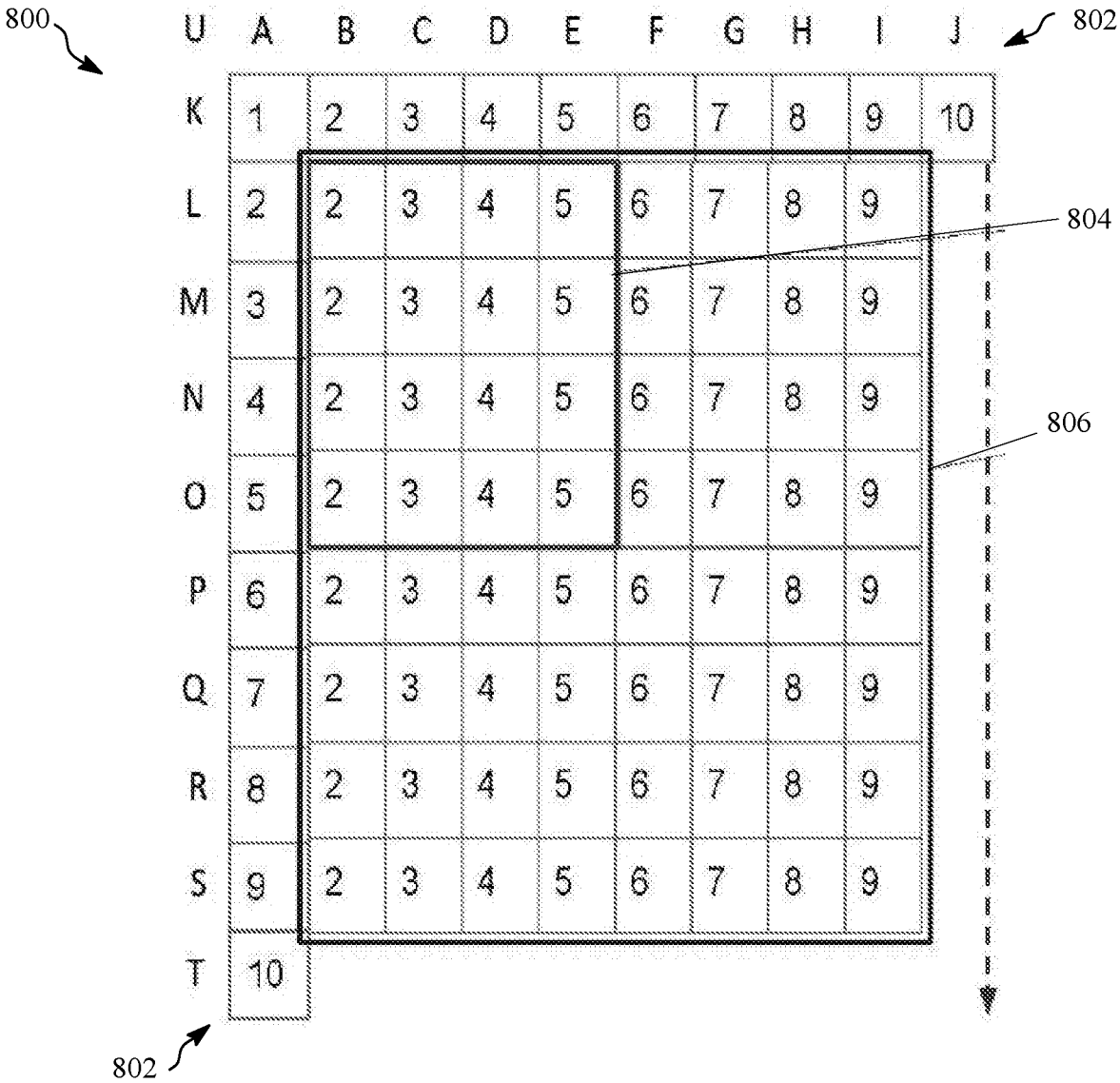

800
802
804
806
802
U A B C D E F G H I J
K 1 2 3 4 5 6 7 8 9 10
L 2 2 3 4 5 6 7 8 9
M 3 2 3 4 5 6 7 8 9
N 4 2 3 4 5 6 7 8 9
O 5 2 3 4 5 6 7 8 9
P 6 2 3 4 5 6 7 8 9
Q 7 2 3 4 5 6 7 8 9
R 8 2 3 4 5 6 7 8 9
S 9 2 3 4 5 6 7 8 9
T 10

FIG. 8

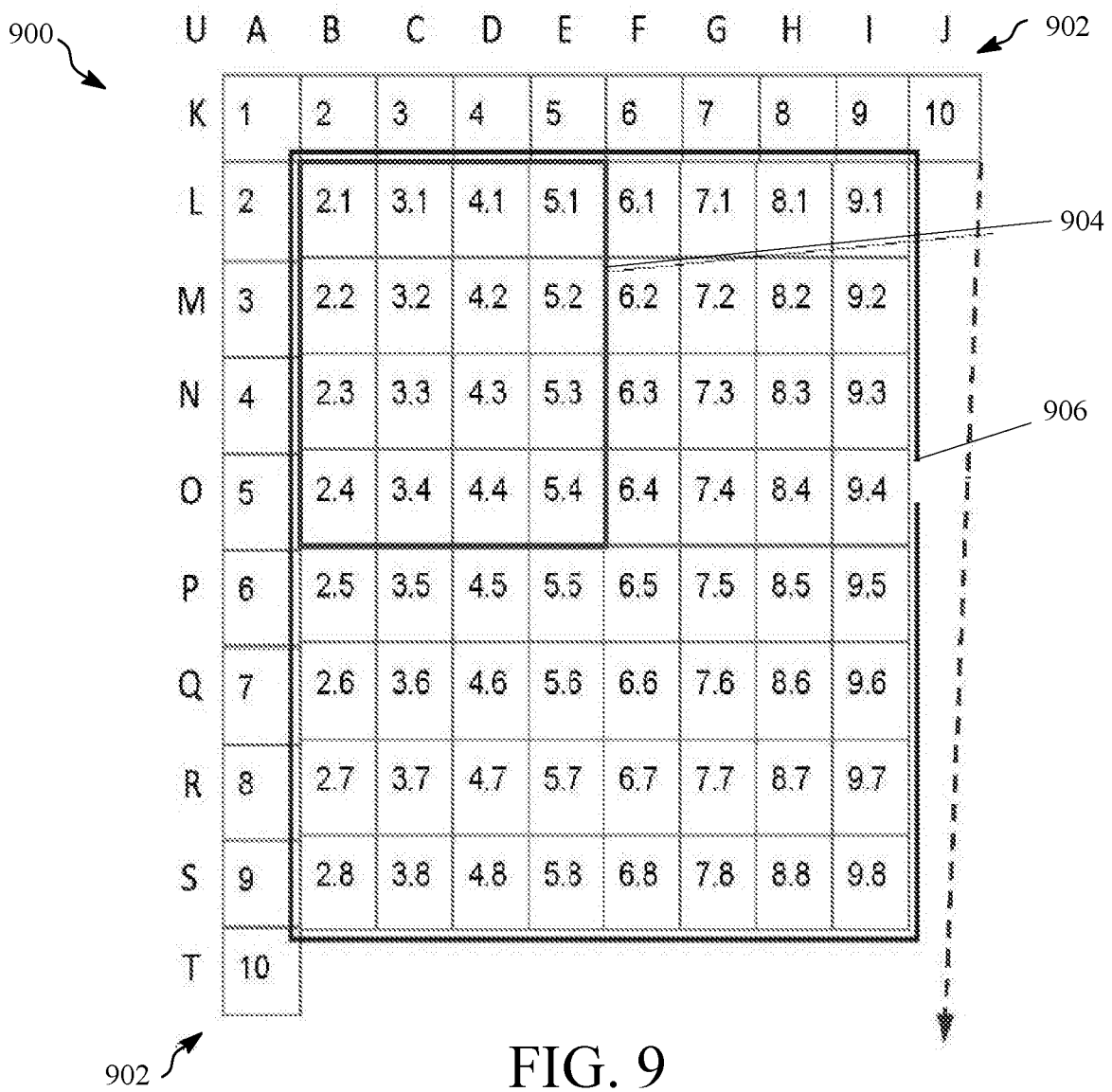


FIG. 9

37	59	82	103	127	149	172	195
41	63	86	107	131	153	176	199
45	67	90	111	135	157	180	203
49	71	94	115	139	161	184	207
53	75	98	119	143	165	188	211

FIG. 11

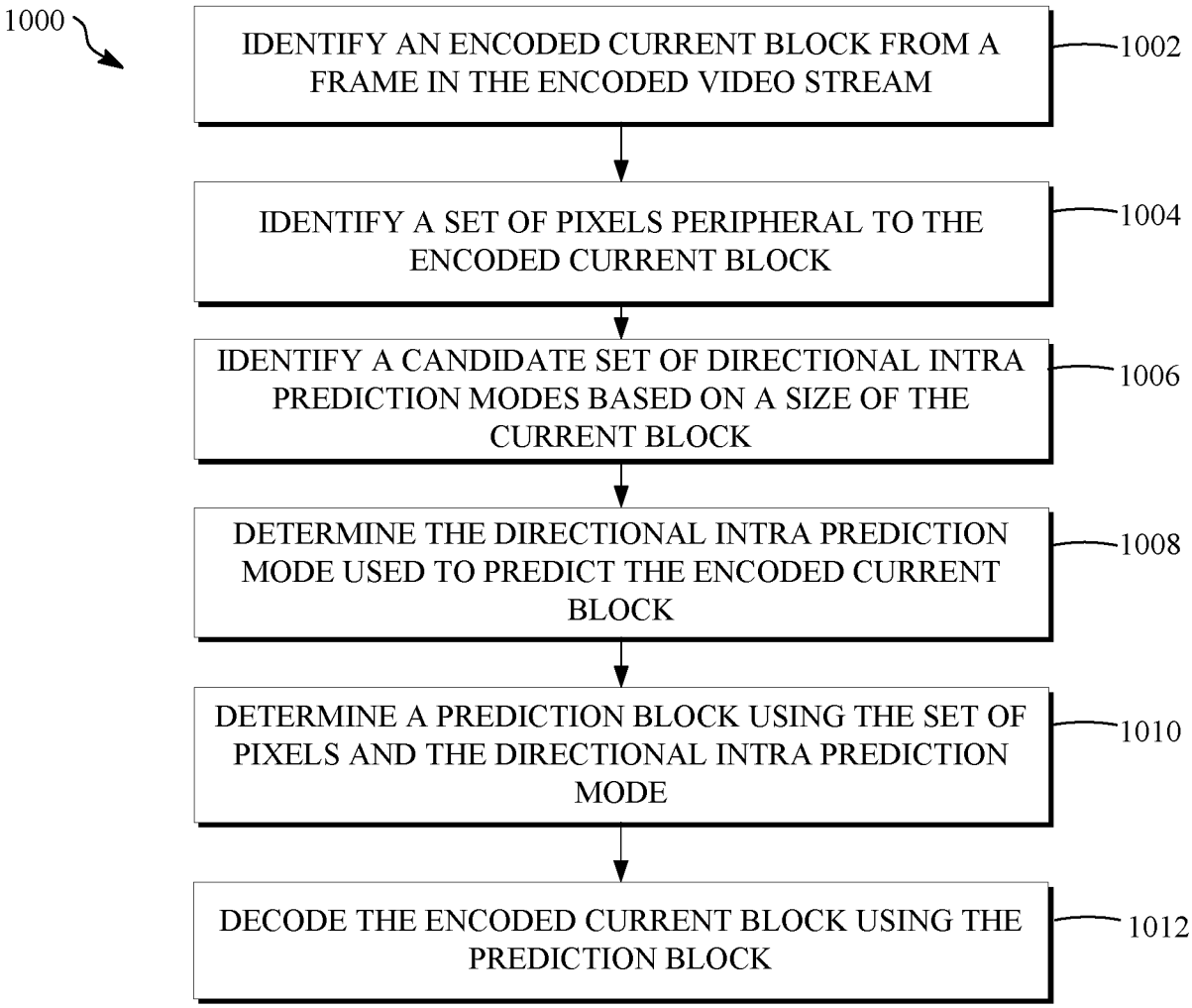


FIG. 10

36	58	81	102	126	148	171	194
39	61	84	105	129	151	174	197
42	64	87	108	132	154	177	200
45	67	90	111	135	157	180	203
48	70	93	114	138	160	183	206
51	73	96	117	141	163	186	209
54	76	99	120	144	166	189	212

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/068328

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04N19/11 H04N19/157 H04N19/176
ADD.

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)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 661 880 A1 (MEDIATEK SINGAPORE PTE LTD [SG]) 13 November 2013 (2013-11-13) paragraphs [0003], [0015]; figures 1, 5; table 1 -----	1-21

☐ 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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Date of the actual completion of the international search	Date of mailing of the international search report
24 February 2017	08/03/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Oelbaum, Tobias

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2016/068328

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2661880 A1	13-11-2013	AU 2011354441 A1	02-05-2013
		CN 103299622 A	11-09-2013
		EP 2661880 A1	13-11-2013
		US 2012177113 A1	12-07-2012
		US 2015131722 A1	14-05-2015
		WO 2012092763 A1	12-07-2012