

ADAPTIVE SCANNING WITH MULTIPLE TRANSFORM SELECTION

INCORPORATION BY REFERENCE

[0001] This present application claims the benefit of U.S. Patent Application No. 17/723,256, "ADAPTIVE SCANNING WITH MULTIPLE TRANSFORM SELECTION" filed on April 18, 2022, which claims the benefit of priority to U.S. Provisional Application No. 63/177,280, "ADAPTIVE SCANNING WITH MULTIPLE TRANSFORM SELECTION" filed on April 20, 2021. The disclosures of the prior applications are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

[0002] The present disclosure describes embodiments generally related to video coding.

BACKGROUND

[0003] The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent the work is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

[0004] Uncompressed digital video can include a series of pictures, each picture having a spatial dimension of, for example, 1920 x 1080 luminance samples and associated chrominance samples. The series of pictures can have a fixed or variable picture rate (informally also known as frame rate), of, for example 60 pictures per second or 60 Hz. Uncompressed video has specific bitrate requirements. For example, 1080p60 4:2:0 video at 8 bit per sample (1920x1080 luminance sample resolution at 60 Hz frame rate) requires close to 1.5 Gbit/s bandwidth. An hour of such video requires more than 600 GBytes of storage space.

[0005] One purpose of video coding and decoding can be the reduction of redundancy in the input video signal, through compression. Compression can help reduce the aforementioned bandwidth and/or storage space requirements, in some cases by two orders of magnitude or more. Both lossless compression and lossy compression, as well as a combination thereof can be employed. Lossless compression refers to techniques where an exact copy of the original signal can be reconstructed from the compressed original signal. When using lossy compression, the

reconstructed signal may not be identical to the original signal, but the distortion between original and reconstructed signals is small enough to make the reconstructed signal useful for the intended application. In the case of video, lossy compression is widely employed. The amount of distortion tolerated depends on the application; for example, users of certain consumer streaming applications may tolerate higher distortion than users of television distribution applications. The compression ratio achievable can reflect that: higher allowable/tolerable distortion can yield higher compression ratios.

[0006] A video encoder and decoder can utilize techniques from several broad categories, including, for example, motion compensation, transform, quantization, and entropy coding.

[0007] Video codec technologies can include techniques known as intra coding. In intra coding, sample values are represented without reference to samples or other data from previously reconstructed reference pictures. In some video codecs, the picture is spatially subdivided into blocks of samples. When all blocks of samples are coded in intra mode, that picture can be an intra picture. Intra pictures and their derivations such as independent decoder refresh pictures, can be used to reset the decoder state and can, therefore, be used as the first picture in a coded video bitstream and a video session, or as a still image. The samples of an intra block can be exposed to a transform, and the transform coefficients can be quantized before entropy coding. Intra prediction can be a technique that minimizes sample values in the pre-transform domain. In some cases, the smaller the DC value after a transform is, and the smaller the AC coefficients are, the fewer the bits that are required at a given quantization step size to represent the block after entropy coding.

[0008] Traditional intra coding such as known from, for example MPEG-2 generation coding technologies, does not use intra prediction. However, some newer video compression technologies include techniques that attempt, from, for example, surrounding sample data and/or metadata obtained during the encoding and/or decoding of spatially neighboring, and preceding in decoding order, blocks of data. Such techniques are henceforth called “intra prediction” techniques. Note that in at least some cases, intra prediction is using reference data only from the current picture under reconstruction and not from reference pictures.

[0009] There can be many different forms of intra prediction. When more than one of such techniques can be used in a given video coding technology, the technique in use can be

coded in an intra prediction mode. In certain cases, modes can have submodes and/or parameters, and those can be coded individually or included in the mode codeword. Which codeword to use for a given mode, submode, and/or parameter combination can have an impact in the coding efficiency gain through intra prediction, and so can the entropy coding technology used to translate the codewords into a bitstream.

[0010] A certain mode of intra prediction was introduced with H.264, refined in H.265, and further refined in newer coding technologies such as joint exploration model (JEM), versatile video coding (VVC), and benchmark set (BMS). A predictor block can be formed using neighboring sample values belonging to already available samples. Sample values of neighboring samples are copied into the predictor block according to a direction. A reference to the direction in use can be coded in the bitstream or may itself be predicted.

[0011] Referring to FIG. 1A, depicted in the lower right is a subset of nine predictor directions known from H.265's 33 possible predictor directions (corresponding to the 33 angular modes of the 35 intra modes). The point where the arrows converge (101) represents the sample being predicted. The arrows represent the direction from which the sample is being predicted. For example, arrow (102) indicates that sample (101) is predicted from a sample or samples to the upper right, at a 45 degree angle from the horizontal. Similarly, arrow (103) indicates that sample (101) is predicted from a sample or samples to the lower left of sample (101), in a 22.5 degree angle from the horizontal.

[0012] Still referring to FIG. 1A, on the top left there is depicted a square block (104) of 4 x 4 samples (indicated by a dashed, boldface line). The square block (104) includes 16 samples, each labelled with an "S", its position in the Y dimension (e.g., row index) and its position in the X dimension (e.g., column index). For example, sample S21 is the second sample in the Y dimension (from the top) and the first (from the left) sample in the X dimension. Similarly, sample S44 is the fourth sample in block (104) in both the Y and X dimensions. As the block is 4 x 4 samples in size, S44 is at the bottom right. Further shown are reference samples that follow a similar numbering scheme. A reference sample is labelled with an R, its Y position (e.g., row index) and X position (column index) relative to block (104). In both H.264 and H.265, prediction samples neighbor the block under reconstruction; therefore no negative values need to be used.

[0013] Intra picture prediction can work by copying reference sample values from the neighboring samples as appropriated by the signaled prediction direction. For example, assume the coded video bitstream includes signaling that, for this block, indicates a prediction direction consistent with arrow (102)—that is, samples are predicted from a prediction sample or samples to the upper right, at a 45 degree angle from the horizontal. In that case, samples S41, S32, S23, and S14 are predicted from the same reference sample R05. Sample S44 is then predicted from reference sample R08.

[0014] In certain cases, the values of multiple reference samples may be combined, for example through interpolation, in order to calculate a reference sample; especially when the directions are not evenly divisible by 45 degrees.

[0015] The number of possible directions has increased as video coding technology has developed. In H.264 (year 2003), nine different direction could be represented. That increased to 33 in H.265 (year 2013), and JEM/VVC/BMS, at the time of disclosure, can support up to 65 directions. Experiments have been conducted to identify the most likely directions, and certain techniques in the entropy coding are used to represent those likely directions in a small number of bits, accepting a certain penalty for less likely directions. Further, the directions themselves can sometimes be predicted from neighboring directions used in neighboring, already decoded, blocks.

[0016] FIG. 1B shows a schematic (110) that depicts 65 intra prediction directions according to JEM to illustrate the increasing number of prediction directions over time.

[0017] The mapping of intra prediction directions bits in the coded video bitstream that represent the direction can be different from video coding technology to video coding technology; and can range, for example, from simple direct mappings of prediction direction to intra prediction mode, to codewords, to complex adaptive schemes involving most probable modes, and similar techniques. In all cases, however, there can be certain directions that are statistically less likely to occur in video content than certain other directions. As the goal of video compression is the reduction of redundancy, those less likely directions will, in a well working video coding technology, be represented by a larger number of bits than more likely directions.

[0018] Video coding and decoding can be performed using inter-picture prediction with motion compensation. Motion compensation can be a lossy compression technique and can relate to techniques where a block of sample data from a previously reconstructed picture or part thereof (reference picture), after being spatially shifted in a direction indicated by a motion vector (MV henceforth), is used for the prediction of a newly reconstructed picture or picture part. In some cases, the reference picture can be the same as the picture currently under reconstruction. MVs can have two dimensions X and Y, or three dimensions, the third being an indication of the reference picture in use (the latter, indirectly, can be a time dimension).

[0019] In some video compression techniques, an MV applicable to a certain area of sample data can be predicted from other MVs, for example from those related to another area of sample data spatially adjacent to the area under reconstruction, and preceding that MV in decoding order. Doing so can substantially reduce the amount of data required for coding the MV, thereby removing redundancy and increasing compression. MV prediction can work effectively, for example, because when coding an input video signal derived from a camera (known as natural video) there is a statistical likelihood that areas larger than the area to which a single MV is applicable move in a similar direction and, therefore, can in some cases be predicted using a similar motion vector derived from MVs of neighboring area. That results in the MV found for a given area to be similar or the same as the MV predicted from the surrounding MVs, and that in turn can be represented, after entropy coding, in a smaller number of bits than what would be used if coding the MV directly. In some cases, MV prediction can be an example of lossless compression of a signal (namely: the MVs) derived from the original signal (namely: the sample stream). In other cases, MV prediction itself can be lossy, for example because of rounding errors when calculating a predictor from several surrounding MVs.

[0020] Various MV prediction mechanisms are described in H.265/HEVC (ITU-T Rec. H.265, "High Efficiency Video Coding", December 2016). Out of the many MV prediction mechanisms that H.265 offers, described here is a technique henceforth referred to as "spatial merge".

[0021] Referring to FIG. 2, a current block (201) comprises samples that have been found by the encoder during the motion search process to be predictable from a previous block of the same size that has been spatially shifted. Instead of coding that MV directly, the MV can be

derived from metadata associated with one or more reference pictures, for example from the most recent (in decoding order) reference picture, using the MV associated with either one of five surrounding samples, denoted A0, A1, and B0, B1, B2 (202 through 206, respectively). In H.265, the MV prediction can use predictors from the same reference picture that the neighboring block is using.

SUMMARY

[0022] Aspects of the disclosure provide methods and apparatuses for video encoding/decoding. In some examples, an apparatus for video decoding includes receiving circuitry and processing circuitry. For example, the processing circuitry decodes information of a coding block from a bitstream. The information indicates an intra prediction mode for the coding block, a selection of a separable primary transform from a plurality of separable primary transform candidates, and a selection of a scan pattern from a plurality of scan pattern candidates. The processing circuitry determines whether selectable secondary non-separable transform is not applied to the bitstream and selectable separable primary transform is applied to the bitstream. In response to determining that the secondary non-separable transform is not applied to the bitstream and the selectable separable primary transform is applied to the bitstream, the processing circuitry determines residuals of the coding block from the bitstream based on the selection of the scan pattern and the selection of the separable primary transform. The processing circuitry reconstructs the coding block based on a combination of the residuals with an intra prediction of the coding block. The intra prediction of the coding block is based on the intra prediction mode.

[0023] In some embodiments, the processing circuitry decodes the bitstream to determine transform coefficients in a transform domain based on the selection of the scan pattern, and applies an inverse transform associated with the separable primary transform on the transform coefficients in the transform domain to determine the residuals.

[0024] In some embodiments, the information also indicates an exclusion of a selectable secondary non separable transform and the processing circuitry can determines the residuals of the coding block without an application of an inverse transform associated with the selectable secondary non separable transform.

[0025] In some examples, the scan pattern is applicable respectively with a subset of the plurality of separable primary transform candidates. In some examples, the scan pattern is applicable respectively with each of the plurality of separable primary transform candidates.

[0026] In some examples, the processing circuitry can decode a value of a syntax from the bitstream, and the value of the syntax indicates a combination of the selection of the separable primary transform from the plurality of separable primary transform candidates and the selection of the scan pattern from the plurality of scan pattern candidates.

[0027] In some examples, the processing circuitry can decode a value of a first syntax and a value of a second syntax from the bitstream. The value of the first syntax indicates the selection of the separable primary transform. The value of the second syntax indicates the selection of the scan pattern.

[0028] In some examples, the processing circuitry infers the selection of the scan pattern. In an example, the processing circuitry infers the selection of the scan pattern based on the intra prediction mode. Further, in an example, the processing circuitry also infer the selection of the separable primary transform. In another example, the processing circuitry decodes a value of a syntax from the bitstream, and the value of the syntax indicates the selection of the separable primary transform.

[0029] Aspects of the disclosure also provide a non-transitory computer-readable medium storing instructions which when executed by a computer for video decoding cause the computer to perform the method for video decoding.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] Further features, the nature, and various advantages of the disclosed subject matter will be more apparent from the following detailed description and the accompanying drawings in which:

[0031] FIG. 1A is a schematic illustration of an exemplary subset of intra prediction modes.

[0032] FIG. 1B is an illustration of exemplary intra prediction directions.

[0033] FIG. 2 is a schematic illustration of a current block and its surrounding spatial merge candidates in one example.

[0034] FIG. 3 is a schematic illustration of a simplified block diagram of a communication system (300) in accordance with an embodiment.

[0035] FIG. 4 is a schematic illustration of a simplified block diagram of a communication system (400) in accordance with an embodiment.

[0036] FIG. 5 is a schematic illustration of a simplified block diagram of a decoder in accordance with an embodiment.

[0037] FIG. 6 is a schematic illustration of a simplified block diagram of an encoder in accordance with an embodiment.

[0038] FIG. 7 shows a block diagram of an encoder in accordance with another embodiment.

[0039] FIG. 8 shows a block diagram of a decoder in accordance with another embodiment.

[0040] FIG. 9 shows a set of three scan patterns of transform coefficients within a transform sub block according to some embodiments of the disclosure.

[0041] FIG. 10 shows a set of two scan patterns of transform sub blocks according to some embodiments of the disclosure.

[0042] FIG. 11 shows a diagram of a residual coding module in some examples.

[0043] FIG. 12 shows transform basis functions in some examples.

[0044] FIG. 13 shows a table for multiple transform selection (MTS) in some examples.

[0045] FIG. 14 shows a diagram of a residual coding module in some examples.

[0046] FIG. 15 shows a diagram of a residual coding module according to some embodiments of the disclosure.

[0047] FIG. 16 shows a table for illustrating a transform and scan signalling mapping table according to some examples.

[0048] FIG. 17 shows another table for illustrating a transform and scan signalling mapping table according to some examples.

[0049] FIG. 18 shows another table for illustrating a transform and scan signalling mapping table according to some examples.

[0050] FIG. 19 shows a flow chart outlining a process according to an embodiment of the disclosure.

[0051] FIG. 20 shows a flow chart outlining a process according to an embodiment of the disclosure.

[0052] FIG. 21 is a schematic illustration of a computer system in accordance with an embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

[0053] FIG. 3 illustrates a simplified block diagram of a communication system (300) according to an embodiment of the present disclosure. The communication system (300) includes a plurality of terminal devices that can communicate with each other, via, for example, a network (350). For example, the communication system (300) includes a first pair of terminal devices (310) and (320) interconnected via the network (350). In the FIG. 3 example, the first pair of terminal devices (310) and (320) performs unidirectional transmission of data. For example, the terminal device (310) may code video data (e.g., a stream of video pictures that are captured by the terminal device (310)) for transmission to the other terminal device (320) via the network (350). The encoded video data can be transmitted in the form of one or more coded video bitstreams. The terminal device (320) may receive the coded video data from the network (350), decode the coded video data to recover the video pictures and display video pictures according to the recovered video data. Unidirectional data transmission may be common in media serving applications and the like.

[0054] In another example, the communication system (300) includes a second pair of terminal devices (330) and (340) that performs bidirectional transmission of coded video data that may occur, for example, during videoconferencing. For bidirectional transmission of data, in an example, each terminal device of the terminal devices (330) and (340) may code video data (e.g., a stream of video pictures that are captured by the terminal device) for transmission to the other terminal device of the terminal devices (330) and (340) via the network (350). Each terminal device of the terminal devices (330) and (340) also may receive the coded video data transmitted by the other terminal device of the terminal devices (330) and (340), and may decode the coded video data to recover the video pictures and may display video pictures at an accessible display device according to the recovered video data.

[0055] In the FIG. 3 example, the terminal devices (310), (320), (330) and (340) may be illustrated as servers, personal computers and smart phones but the principles of the present

disclosure may be not so limited. Embodiments of the present disclosure find application with laptop computers, tablet computers, media players and/or dedicated video conferencing equipment. The network (350) represents any number of networks that convey coded video data among the terminal devices (310), (320), (330) and (340), including for example wireline (wired) and/or wireless communication networks. The communication network (350) may exchange data in circuit-switched and/or packet-switched channels. Representative networks include telecommunications networks, local area networks, wide area networks and/or the Internet. For the purposes of the present discussion, the architecture and topology of the network (350) may be immaterial to the operation of the present disclosure unless explained herein below.

[0056] FIG. 4 illustrates, as an example for an application for the disclosed subject matter, the placement of a video encoder and a video decoder in a streaming environment. The disclosed subject matter can be equally applicable to other video enabled applications, including, for example, video conferencing, digital TV, storing of compressed video on digital media including CD, DVD, memory stick and the like, and so on.

[0057] A streaming system may include a capture subsystem (413), that can include a video source (401), for example a digital camera, creating for example a stream of video pictures (402) that are uncompressed. In an example, the stream of video pictures (402) includes samples that are taken by the digital camera. The stream of video pictures (402), depicted as a bold line to emphasize a high data volume when compared to encoded video data (404) (or coded video bitstreams), can be processed by an electronic device (420) that includes a video encoder (403) coupled to the video source (401). The video encoder (403) can include hardware, software, or a combination thereof to enable or implement aspects of the disclosed subject matter as described in more detail below. The encoded video data (404) (or encoded video bitstream (404)), depicted as a thin line to emphasize the lower data volume when compared to the stream of video pictures (402), can be stored on a streaming server (405) for future use. One or more streaming client subsystems, such as client subsystems (406) and (408) in FIG. 4 can access the streaming server (405) to retrieve copies (407) and (409) of the encoded video data (404). A client subsystem (406) can include a video decoder (410), for example, in an electronic device (430). The video decoder (410) decodes the incoming copy (407) of the encoded video data and creates an outgoing stream of video pictures (411) that can be rendered on a display (412) (e.g., display

screen) or other rendering device (not depicted). In some streaming systems, the encoded video data (404), (407), and (409) (e.g., video bitstreams) can be encoded according to certain video coding/compression standards. Examples of those standards include ITU-T Recommendation H.265. In an example, a video coding standard under development is informally known as Versatile Video Coding (VVC). The disclosed subject matter may be used in the context of VVC.

[0058] It is noted that the electronic devices (420) and (430) can include other components (not shown). For example, the electronic device (420) can include a video decoder (not shown) and the electronic device (430) can include a video encoder (not shown) as well.

[0059] FIG. 5 shows a block diagram of a video decoder (510) according to an embodiment of the present disclosure. The video decoder (510) can be included in an electronic device (530). The electronic device (530) can include a receiver (531) (e.g., receiving circuitry). The video decoder (510) can be used in the place of the video decoder (410) in the FIG. 4 example.

[0060] The receiver (531) may receive one or more coded video sequences to be decoded by the video decoder (510); in the same or another embodiment, one coded video sequence at a time, where the decoding of each coded video sequence is independent from other coded video sequences. The coded video sequence may be received from a channel (501), which may be a hardware/software link to a storage device which stores the encoded video data. The receiver (531) may receive the encoded video data with other data, for example, coded audio data and/or ancillary data streams, that may be forwarded to their respective using entities (not depicted). The receiver (531) may separate the coded video sequence from the other data. To combat network jitter, a buffer memory (515) may be coupled in between the receiver (531) and an entropy decoder / parser (520) ("parser (520)" henceforth). In certain applications, the buffer memory (515) is part of the video decoder (510). In others, it can be outside of the video decoder (510) (not depicted). In still others, there can be a buffer memory (not depicted) outside of the video decoder (510), for example to combat network jitter, and in addition another buffer memory (515) inside the video decoder (510), for example to handle playout timing. When the receiver (531) is receiving data from a store/forward device of sufficient bandwidth and controllability, or from an isosynchronous network, the buffer memory (515) may not be needed,

or can be small. For use on best effort packet networks such as the Internet, the buffer memory (515) may be required, can be comparatively large and can be advantageously of adaptive size, and may at least partially be implemented in an operating system or similar elements (not depicted) outside of the video decoder (510).

[0061] The video decoder (510) may include the parser (520) to reconstruct symbols (521) from the coded video sequence. Categories of those symbols include information used to manage operation of the video decoder (510), and potentially information to control a rendering device such as a render device (512) (e.g., a display screen) that is not an integral part of the electronic device (530) but can be coupled to the electronic device (530), as was shown in FIG. 5. The control information for the rendering device(s) may be in the form of Supplemental Enhancement Information (SEI messages) or Video Usability Information (VUI) parameter set fragments (not depicted). The parser (520) may parse / entropy-decode the coded video sequence that is received. The coding of the coded video sequence can be in accordance with a video coding technology or standard, and can follow various principles, including variable length coding, Huffman coding, arithmetic coding with or without context sensitivity, and so forth. The parser (520) may extract from the coded video sequence, a set of subgroup parameters for at least one of the subgroups of pixels in the video decoder, based upon at least one parameter corresponding to the group. Subgroups can include Groups of Pictures (GOPs), pictures, tiles, slices, macroblocks, Coding Units (CUs), blocks, Transform Units (TUs), Prediction Units (PUs) and so forth. The parser (520) may also extract from the coded video sequence information such as transform coefficients, quantizer parameter values, motion vectors, and so forth.

[0062] The parser (520) may perform an entropy decoding / parsing operation on the video sequence received from the buffer memory (515), so as to create symbols (521).

[0063] Reconstruction of the symbols (521) can involve multiple different units depending on the type of the coded video picture or parts thereof (such as: inter and intra picture, inter and intra block), and other factors. Which units are involved, and how, can be controlled by the subgroup control information that was parsed from the coded video sequence by the parser (520). The flow of such subgroup control information between the parser (520) and the multiple units below is not depicted for clarity.

[0064] Beyond the functional blocks already mentioned, the video decoder (510) can be conceptually subdivided into a number of functional units as described below. In a practical implementation operating under commercial constraints, many of these units interact closely with each other and can, at least partly, be integrated into each other. However, for the purpose of describing the disclosed subject matter, the conceptual subdivision into the functional units below is appropriate.

[0065] A first unit is the scaler / inverse transform unit (551). The scaler / inverse transform unit (551) receives a quantized transform coefficient as well as control information, including which transform to use, block size, quantization factor, quantization scaling matrices, etc. as symbol(s) (521) from the parser (520). The scaler / inverse transform unit (551) can output blocks comprising sample values, that can be input into aggregator (555).

[0066] In some cases, the output samples of the scaler / inverse transform (551) can pertain to an intra coded block; that is: a block that is not using predictive information from previously reconstructed pictures, but can use predictive information from previously reconstructed parts of the current picture. Such predictive information can be provided by an intra picture prediction unit (552). In some cases, the intra picture prediction unit (552) generates a block of the same size and shape of the block under reconstruction, using surrounding already reconstructed information fetched from the current picture buffer (558). The current picture buffer (558) buffers, for example, partly reconstructed current picture and/or fully reconstructed current picture. The aggregator (555), in some cases, adds, on a per sample basis, the prediction information the intra prediction unit (552) has generated to the output sample information as provided by the scaler / inverse transform unit (551).

[0067] In other cases, the output samples of the scaler / inverse transform unit (551) can pertain to an inter coded, and potentially motion compensated block. In such a case, a motion compensation prediction unit (553) can access reference picture memory (557) to fetch samples used for prediction. After motion compensating the fetched samples in accordance with the symbols (521) pertaining to the block, these samples can be added by the aggregator (555) to the output of the scaler / inverse transform unit (551) (in this case called the residual samples or residual signal) so as to generate output sample information. The addresses within the reference picture memory (557) from where the motion compensation prediction unit (553) fetches

prediction samples can be controlled by motion vectors, available to the motion compensation prediction unit (553) in the form of symbols (521) that can have, for example X, Y, and reference picture components. Motion compensation also can include interpolation of sample values as fetched from the reference picture memory (557) when sub-sample exact motion vectors are in use, motion vector prediction mechanisms, and so forth.

[0068] The output samples of the aggregator (555) can be subject to various loop filtering techniques in the loop filter unit (556). Video compression technologies can include in-loop filter technologies that are controlled by parameters included in the coded video sequence (also referred to as coded video bitstream) and made available to the loop filter unit (556) as symbols (521) from the parser (520), but can also be responsive to meta-information obtained during the decoding of previous (in decoding order) parts of the coded picture or coded video sequence, as well as responsive to previously reconstructed and loop-filtered sample values.

[0069] The output of the loop filter unit (556) can be a sample stream that can be output to the render device (512) as well as stored in the reference picture memory (557) for use in future inter-picture prediction.

[0070] Certain coded pictures, once fully reconstructed, can be used as reference pictures for future prediction. For example, once a coded picture corresponding to a current picture is fully reconstructed and the coded picture has been identified as a reference picture (by, for example, the parser (520)), the current picture buffer (558) can become a part of the reference picture memory (557), and a fresh current picture buffer can be reallocated before commencing the reconstruction of the following coded picture.

[0071] The video decoder (510) may perform decoding operations according to a predetermined video compression technology in a standard, such as ITU-T Rec. H.265. The coded video sequence may conform to a syntax specified by the video compression technology or standard being used, in the sense that the coded video sequence adheres to both the syntax of the video compression technology or standard and the profiles as documented in the video compression technology or standard. Specifically, a profile can select certain tools as the only tools available for use under that profile from all the tools available in the video compression technology or standard. Also necessary for compliance can be that the complexity of the coded video sequence is within bounds as defined by the level of the video compression technology or

standard. In some cases, levels restrict the maximum picture size, maximum frame rate, maximum reconstruction sample rate (measured in, for example megasamples per second), maximum reference picture size, and so on. Limits set by levels can, in some cases, be further restricted through Hypothetical Reference Decoder (HRD) specifications and metadata for HRD buffer management signaled in the coded video sequence.

[0072] In an embodiment, the receiver (531) may receive additional (redundant) data with the encoded video. The additional data may be included as part of the coded video sequence(s). The additional data may be used by the video decoder (510) to properly decode the data and/or to more accurately reconstruct the original video data. Additional data can be in the form of, for example, temporal, spatial, or signal noise ratio (SNR) enhancement layers, redundant slices, redundant pictures, forward error correction codes, and so on.

[0073] FIG. 6 shows a block diagram of a video encoder (603) according to an embodiment of the present disclosure. The video encoder (603) is included in an electronic device (620). The electronic device (620) includes a transmitter (640) (e.g., transmitting circuitry). The video encoder (603) can be used in the place of the video encoder (403) in the FIG. 4 example.

[0074] The video encoder (603) may receive video samples from a video source (601) (that is not part of the electronic device (620) in the FIG. 6 example) that may capture video image(s) to be coded by the video encoder (603). In another example, the video source (601) is a part of the electronic device (620).

[0075] The video source (601) may provide the source video sequence to be coded by the video encoder (603) in the form of a digital video sample stream that can be of any suitable bit depth (for example: 8 bit, 10 bit, 12 bit, ...), any colorspace (for example, BT.601 Y CrCb, RGB, ...), and any suitable sampling structure (for example Y CrCb 4:2:0, Y CrCb 4:4:4). In a media serving system, the video source (601) may be a storage device storing previously prepared video. In a videoconferencing system, the video source (601) may be a camera that captures local image information as a video sequence. Video data may be provided as a plurality of individual pictures that impart motion when viewed in sequence. The pictures themselves may be organized as a spatial array of pixels, wherein each pixel can comprise one or more samples depending on the sampling structure, color space, etc. in use. A person skilled in the art

can readily understand the relationship between pixels and samples. The description below focuses on samples.

[0076] According to an embodiment, the video encoder (603) may code and compress the pictures of the source video sequence into a coded video sequence (643) in real time or under any other time constraints as required by the application. Enforcing appropriate coding speed is one function of a controller (650). In some embodiments, the controller (650) controls other functional units as described below and is functionally coupled to the other functional units. The coupling is not depicted for clarity. Parameters set by the controller (650) can include rate control related parameters (picture skip, quantizer, lambda value of rate-distortion optimization techniques, ...), picture size, group of pictures (GOP) layout, maximum motion vector search range, and so forth. The controller (650) can be configured to have other suitable functions that pertain to the video encoder (603) optimized for a certain system design.

[0077] In some embodiments, the video encoder (603) is configured to operate in a coding loop. As an oversimplified description, in an example, the coding loop can include a source coder (630) (e.g., responsible for creating symbols, such as a symbol stream, based on an input picture to be coded, and a reference picture(s)), and a (local) decoder (633) embedded in the video encoder (603). The decoder (633) reconstructs the symbols to create the sample data in a similar manner as a (remote) decoder also would create (as any compression between symbols and coded video bitstream is lossless in the video compression technologies considered in the disclosed subject matter). The reconstructed sample stream (sample data) is input to the reference picture memory (634). As the decoding of a symbol stream leads to bit-exact results independent of decoder location (local or remote), the content in the reference picture memory (634) is also bit exact between the local encoder and remote encoder. In other words, the prediction part of an encoder "sees" as reference picture samples exactly the same sample values as a decoder would "see" when using prediction during decoding. This fundamental principle of reference picture synchronicity (and resulting drift, if synchronicity cannot be maintained, for example because of channel errors) is used in some related arts as well.

[0078] The operation of the "local" decoder (633) can be the same as of a "remote" decoder, such as the video decoder (510), which has already been described in detail above in conjunction with FIG. 5. Briefly referring also to FIG. 5, however, as symbols are available and

encoding/decoding of symbols to a coded video sequence by an entropy coder (645) and the parser (520) can be lossless, the entropy decoding parts of the video decoder (510), including the buffer memory (515), and parser (520) may not be fully implemented in the local decoder (633).

[0079] An observation that can be made at this point is that any decoder technology except the parsing/entropy decoding that is present in a decoder also necessarily needs to be present, in substantially identical functional form, in a corresponding encoder. For this reason, the disclosed subject matter focuses on decoder operation. The description of encoder technologies can be abbreviated as they are the inverse of the comprehensively described decoder technologies. Only in certain areas a more detail description is required and provided below.

[0080] During operation, in some examples, the source coder (630) may perform motion compensated predictive coding, which codes an input picture predictively with reference to one or more previously coded picture from the video sequence that were designated as "reference pictures." In this manner, the coding engine (632) codes differences between pixel blocks of an input picture and pixel blocks of reference picture(s) that may be selected as prediction reference(s) to the input picture.

[0081] The local video decoder (633) may decode coded video data of pictures that may be designated as reference pictures, based on symbols created by the source coder (630). Operations of the coding engine (632) may advantageously be lossy processes. When the coded video data may be decoded at a video decoder (not shown in FIG. 6), the reconstructed video sequence typically may be a replica of the source video sequence with some errors. The local video decoder (633) replicates decoding processes that may be performed by the video decoder on reference pictures and may cause reconstructed reference pictures to be stored in the reference picture cache (634). In this manner, the video encoder (603) may store copies of reconstructed reference pictures locally that have common content as the reconstructed reference pictures that will be obtained by a far-end video decoder (absent transmission errors).

[0082] The predictor (635) may perform prediction searches for the coding engine (632). That is, for a new picture to be coded, the predictor (635) may search the reference picture memory (634) for sample data (as candidate reference pixel blocks) or certain metadata such as reference picture motion vectors, block shapes, and so on, that may serve as an appropriate

prediction reference for the new pictures. The predictor (635) may operate on a sample block-by-pixel block basis to find appropriate prediction references. In some cases, as determined by search results obtained by the predictor (635), an input picture may have prediction references drawn from multiple reference pictures stored in the reference picture memory (634).

[0083] The controller (650) may manage coding operations of the source coder (630), including, for example, setting of parameters and subgroup parameters used for encoding the video data.

[0084] Output of all aforementioned functional units may be subjected to entropy coding in the entropy coder (645). The entropy coder (645) translates the symbols as generated by the various functional units into a coded video sequence, by lossless compressing the symbols according to technologies such as Huffman coding, variable length coding, arithmetic coding, and so forth.

[0085] The transmitter (640) may buffer the coded video sequence(s) as created by the entropy coder (645) to prepare for transmission via a communication channel (660), which may be a hardware/software link to a storage device which would store the encoded video data. The transmitter (640) may merge coded video data from the video coder (603) with other data to be transmitted, for example, coded audio data and/or ancillary data streams (sources not shown).

[0086] The controller (650) may manage operation of the video encoder (603). During coding, the controller (650) may assign to each coded picture a certain coded picture type, which may affect the coding techniques that may be applied to the respective picture. For example, pictures often may be assigned as one of the following picture types:

[0087] An Intra Picture (I picture) may be one that may be coded and decoded without using any other picture in the sequence as a source of prediction. Some video codecs allow for different types of intra pictures, including, for example Independent Decoder Refresh (“IDR”) Pictures. A person skilled in the art is aware of those variants of I pictures and their respective applications and features.

[0088] A predictive picture (P picture) may be one that may be coded and decoded using intra prediction or inter prediction using at most one motion vector and reference index to predict the sample values of each block.

[0089] A bi-directionally predictive picture (B Picture) may be one that may be coded and decoded using intra prediction or inter prediction using at most two motion vectors and reference indices to predict the sample values of each block. Similarly, multiple-predictive pictures can use more than two reference pictures and associated metadata for the reconstruction of a single block.

[0090] Source pictures commonly may be subdivided spatially into a plurality of sample blocks (for example, blocks of 4x4, 8x8, 4x8, or 16x16 samples each) and coded on a block-by-block basis. Blocks may be coded predictively with reference to other (already coded) blocks as determined by the coding assignment applied to the blocks' respective pictures. For example, blocks of I pictures may be coded non-predictively or they may be coded predictively with reference to already coded blocks of the same picture (spatial prediction or intra prediction). Pixel blocks of P pictures may be coded predictively, via spatial prediction or via temporal prediction with reference to one previously coded reference picture. Blocks of B pictures may be coded predictively, via spatial prediction or via temporal prediction with reference to one or two previously coded reference pictures.

[0091] The video encoder (603) may perform coding operations according to a predetermined video coding technology or standard, such as ITU-T Rec. H.265. In its operation, the video encoder (603) may perform various compression operations, including predictive coding operations that exploit temporal and spatial redundancies in the input video sequence. The coded video data, therefore, may conform to a syntax specified by the video coding technology or standard being used.

[0092] In an embodiment, the transmitter (640) may transmit additional data with the encoded video. The source coder (630) may include such data as part of the coded video sequence. Additional data may comprise temporal/spatial/SNR enhancement layers, other forms of redundant data such as redundant pictures and slices, SEI messages, VUI parameter set fragments, and so on.

[0093] A video may be captured as a plurality of source pictures (video pictures) in a temporal sequence. Intra-picture prediction (often abbreviated to intra prediction) makes use of spatial correlation in a given picture, and inter-picture prediction makes uses of the (temporal or other) correlation between the pictures. In an example, a specific picture under

encoding/decoding, which is referred to as a current picture, is partitioned into blocks. When a block in the current picture is similar to a reference block in a previously coded and still buffered reference picture in the video, the block in the current picture can be coded by a vector that is referred to as a motion vector. The motion vector points to the reference block in the reference picture, and can have a third dimension identifying the reference picture, in case multiple reference pictures are in use.

[0094] In some embodiments, a bi-prediction technique can be used in the inter-picture prediction. According to the bi-prediction technique, two reference pictures, such as a first reference picture and a second reference picture that are both prior in decoding order to the current picture in the video (but may be in the past and future, respectively, in display order) are used. A block in the current picture can be coded by a first motion vector that points to a first reference block in the first reference picture, and a second motion vector that points to a second reference block in the second reference picture. The block can be predicted by a combination of the first reference block and the second reference block.

[0095] Further, a merge mode technique can be used in the inter-picture prediction to improve coding efficiency.

[0096] According to some embodiments of the disclosure, predictions, such as inter-picture predictions and intra-picture predictions are performed in the unit of blocks. For example, according to the HEVC standard, a picture in a sequence of video pictures is partitioned into coding tree units (CTU) for compression, the CTUs in a picture have the same size, such as 64x64 pixels, 32x32 pixels, or 16x16 pixels. In general, a CTU includes three coding tree blocks (CTBs), which are one luma CTB and two chroma CTBs. Each CTU can be recursively quadtree split into one or multiple coding units (CUs). For example, a CTU of 64x64 pixels can be split into one CU of 64x64 pixels, or 4 CUs of 32x32 pixels, or 16 CUs of 16x16 pixels. In an example, each CU is analyzed to determine a prediction type for the CU, such as an inter prediction type or an intra prediction type. The CU is split into one or more prediction units (PUs) depending on the temporal and/or spatial predictability. Generally, each PU includes a luma prediction block (PB), and two chroma PBs. In an embodiment, a prediction operation in coding (encoding/decoding) is performed in the unit of a prediction block. Using a luma prediction block as an example of a prediction block, the prediction block includes a matrix of

values (e.g., luma values) for pixels, such as 8x8 pixels, 16x16 pixels, 8x16 pixels, 16x8 pixels, and the like.

[0097] FIG. 7 shows a diagram of a video encoder (703) according to another embodiment of the disclosure. The video encoder (703) is configured to receive a processing block (e.g., a prediction block) of sample values within a current video picture in a sequence of video pictures, and encode the processing block into a coded picture that is part of a coded video sequence. In an example, the video encoder (703) is used in the place of the video encoder (403) in the FIG. 4 example.

[0098] In an HEVC example, the video encoder (703) receives a matrix of sample values for a processing block, such as a prediction block of 8x8 samples, and the like. The video encoder (703) determines whether the processing block is best coded using intra mode, inter mode, or bi-prediction mode using, for example, rate-distortion optimization. When the processing block is to be coded in intra mode, the video encoder (703) may use an intra prediction technique to encode the processing block into the coded picture; and when the processing block is to be coded in inter mode or bi-prediction mode, the video encoder (703) may use an inter prediction or bi-prediction technique, respectively, to encode the processing block into the coded picture. In certain video coding technologies, merge mode can be an inter picture prediction submode where the motion vector is derived from one or more motion vector predictors without the benefit of a coded motion vector component outside the predictors. In certain other video coding technologies, a motion vector component applicable to the subject block may be present. In an example, the video encoder (703) includes other components, such as a mode decision module (not shown) to determine the mode of the processing blocks.

[0099] In the FIG. 7 example, the video encoder (703) includes the inter encoder (730), an intra encoder (722), a residue calculator (723), a switch (726), a residue encoder (724), a general controller (721), and an entropy encoder (725) coupled together as shown in FIG. 7.

[0100] The inter encoder (730) is configured to receive the samples of the current block (e.g., a processing block), compare the block to one or more reference blocks in reference pictures (e.g., blocks in previous pictures and later pictures), generate inter prediction information (e.g., description of redundant information according to inter encoding technique, motion vectors, merge mode information), and calculate inter prediction results (e.g., predicted

block) based on the inter prediction information using any suitable technique. In some examples, the reference pictures are decoded reference pictures that are decoded based on the encoded video information.

[0101] The intra encoder (722) is configured to receive the samples of the current block (e.g., a processing block), in some cases compare the block to blocks already coded in the same picture, generate quantized coefficients after transform, and in some cases also intra prediction information (e.g., an intra prediction direction information according to one or more intra encoding techniques). In an example, the intra encoder (722) also calculates intra prediction results (e.g., predicted block) based on the intra prediction information and reference blocks in the same picture.

[0102] The general controller (721) is configured to determine general control data and control other components of the video encoder (703) based on the general control data. In an example, the general controller (721) determines the mode of the block, and provides a control signal to the switch (726) based on the mode. For example, when the mode is the intra mode, the general controller (721) controls the switch (726) to select the intra mode result for use by the residue calculator (723), and controls the entropy encoder (725) to select the intra prediction information and include the intra prediction information in the bitstream; and when the mode is the inter mode, the general controller (721) controls the switch (726) to select the inter prediction result for use by the residue calculator (723), and controls the entropy encoder (725) to select the inter prediction information and include the inter prediction information in the bitstream.

[0103] The residue calculator (723) is configured to calculate a difference (residue data) between the received block and prediction results selected from the intra encoder (722) or the inter encoder (730). The residue encoder (724) is configured to operate based on the residue data to encode the residue data to generate the transform coefficients. In an example, the residue encoder (724) is configured to convert the residue data from a spatial domain to a frequency domain, and generate the transform coefficients. The transform coefficients are then subject to quantization processing to obtain quantized transform coefficients. In various embodiments, the video encoder (703) also includes a residue decoder (728). The residue decoder (728) is configured to perform inverse-transform, and generate the decoded residue data. The decoded residue data can be suitably used by the intra encoder (722) and the inter encoder (730). For

example, the inter encoder (730) can generate decoded blocks based on the decoded residue data and inter prediction information, and the intra encoder (722) can generate decoded blocks based on the decoded residue data and the intra prediction information. The decoded blocks are suitably processed to generate decoded pictures and the decoded pictures can be buffered in a memory circuit (not shown) and used as reference pictures in some examples.

[0104] The entropy encoder (725) is configured to format the bitstream to include the encoded block. The entropy encoder (725) is configured to include various information according to a suitable standard, such as the HEVC standard. In an example, the entropy encoder (725) is configured to include the general control data, the selected prediction information (e.g., intra prediction information or inter prediction information), the residue information, and other suitable information in the bitstream. Note that, according to the disclosed subject matter, when coding a block in the merge submode of either inter mode or bi-prediction mode, there is no residue information.

[0105] FIG. 8 shows a diagram of a video decoder (810) according to another embodiment of the disclosure. The video decoder (810) is configured to receive coded pictures that are part of a coded video sequence, and decode the coded pictures to generate reconstructed pictures. In an example, the video decoder (810) is used in the place of the video decoder (410) in the FIG. 4 example.

[0106] In the FIG. 8 example, the video decoder (810) includes an entropy decoder (871), an inter decoder (880), a residue decoder (873), a reconstruction module (874), and an intra decoder (872) coupled together as shown in FIG. 8.

[0107] The entropy decoder (871) can be configured to reconstruct, from the coded picture, certain symbols that represent the syntax elements of which the coded picture is made up. Such symbols can include, for example, the mode in which a block is coded (such as, for example, intra mode, inter mode, bi-predicted mode, the latter two in merge submode or another submode), prediction information (such as, for example, intra prediction information or inter prediction information) that can identify certain sample or metadata that is used for prediction by the intra decoder (872) or the inter decoder (880), respectively, residual information in the form of, for example, quantized transform coefficients, and the like. In an example, when the prediction mode is inter or bi-predicted mode, the inter prediction information is provided to the

inter decoder (880); and when the prediction type is the intra prediction type, the intra prediction information is provided to the intra decoder (872). The residual information can be subject to inverse quantization and is provided to the residue decoder (873).

[0108] The inter decoder (880) is configured to receive the inter prediction information, and generate inter prediction results based on the inter prediction information.

[0109] The intra decoder (872) is configured to receive the intra prediction information, and generate prediction results based on the intra prediction information.

[0110] The residue decoder (873) is configured to perform inverse quantization to extract de-quantized transform coefficients, and process the de-quantized transform coefficients to convert the residual from the frequency domain to the spatial domain. The residue decoder (873) may also require certain control information (to include the Quantizer Parameter (QP)), and that information may be provided by the entropy decoder (871) (data path not depicted as this may be low volume control information only).

[0111] The reconstruction module (874) is configured to combine, in the spatial domain, the residual as output by the residue decoder (873) and the prediction results (as output by the inter or intra prediction modules as the case may be) to form a reconstructed block, that may be part of the reconstructed picture, which in turn may be part of the reconstructed video. It is noted that other suitable operations, such as a deblocking operation and the like, can be performed to improve the visual quality.

[0112] It is noted that the video encoders (403), (603), and (703), and the video decoders (410), (510), and (810) can be implemented using any suitable technique. In an embodiment, the video encoders (403), (603), and (703), and the video decoders (410), (510), and (810) can be implemented using one or more integrated circuits. In another embodiment, the video encoders (403), (603), and (603), and the video decoders (410), (510), and (810) can be implemented using one or more processors that execute software instructions.

[0113] Aspects of the disclosure provide techniques for adaptive scanning with multiple transform selection. During residual coding, the scanning of transform coefficients with multiple transform selection can be adaptively performed. The scanned transform coefficients can be quantized, and entropy coded.

[0114] According to some aspects of the disclosure, to code residuals after prediction, a CU is suitably divided into transform units (TUs) which can be separated into luma transform blocks (e.g., including residuals after prediction of luma component) and chroma transform blocks (e.g., including residuals after prediction of chroma components) according to luma and chroma components. A transform block before transform can include residuals in the spatial domain and the transform block in the spatial domain can be transformed into transform block in the transform domain. The transform block in the transform domain includes transform coefficients in the transform domain. The transform block in the transform domain can be scanned according to a scan pattern to convert transform coefficients of two dimensional (2D) form into transform coefficients of one dimensional (1D) form. Then, the transform coefficients of 1D form can be quantized and entropy coded into bits, and the bits can be combined with other suitable information into a bitstream that carries the coded video.

[0115] According to some aspects of the disclosure, various transform and scanning techniques can be applied for residual coding.

[0116] In some examples, for a transform block, only one transform candidate is available to transform the residual signals into the transform domain. In an example (e.g., HEVC), a type of transform that is referred to as type 2 discrete cosine transform (DCT-2) is used to transform residual signals into the transform domain. For example, DCT-2 can be implemented by applying transform basis functions of DCT-2 in horizontal direction and vertical direction. In some examples, DCT-2 can be implemented using transform matrices. In some examples, transform blocks can have four sizes, such as 4×4 , 8×8 , 16×16 , and 32×32 , then four integer DCT-2 transform matrices respectively for the four sizes of transform blocks, are used for transform during residual coding. Elements of the transform matrices can be represented using 8-bit integers, and thus those transform matrices are referred to as 8-bit transform cores in some examples.

[0117] It is noted that, in an example, residual coding for intra predicted 4×4 blocks may use a different transform matrix from the 4×4 matrix of DCT-2, such as a matrix that is referred as 4×4 integer DST-6 matrix.

[0118] To scan the transform coefficients of the transform blocks in the transform domain, in some examples, transform blocks larger than 4×4 are partitioned into non-

overlapping transform sub blocks (TSBs) that are of 4×4 transform coefficients each. For ease of description, a transform block of 4×4 transform coefficients can be referred to as a transform sub block. In some examples, a scan pattern of transform coefficients in a transform block in the transform domain can be determined based on a scan pattern of transform coefficients within a transform sub block, and a scan pattern of transform sub blocks in the transform block.

[0119] FIG. 9 shows a set of three scan patterns (910), (920) and (930) of transform coefficients within a transform sub block according to some embodiments of the disclosure.

[0120] In FIG. 9, the scan pattern (910) can be referred to as a reverse diagonal scan pattern in a transform sub block. In the scan pattern (910), each small square represents a transform coefficient in the transform sub block, the number in the small square represents a scan order in a diagonal scan that scans diagonally from a top left corner of the transform block to a bottom right corner, such as from 0-15. The reverse diagonal scan pattern scans the transform coefficients in a reverse order of the diagonal scan, such as from 15-0 as shown by arrows.

[0121] In FIG. 9, the scan pattern (920) can be referred to as a reverse horizontal scan pattern in a transform sub block. In the scan pattern (920), each small square represents a transform coefficient in the transform sub block, the number in the small square represents a scan order in a horizontal raster scan that scans from left to right and top to bottom, such as from 0-15. The reverse horizontal scan pattern scans the transform coefficients in a reverse order of the horizontal raster scan, such as from 15-0 as shown by arrows.

[0122] In FIG. 9, the scan pattern (930) can be referred to as a reverse vertical scan pattern in a transform sub block. In the scan pattern (930), each small square represents a transform coefficient in the transform sub block, the number in the small square represents a scan order in a vertical raster scan that scans from top to bottom, and left to right, such as from 0-15. The reverse vertical scan pattern scans the transform coefficients in a reverse order of the vertical raster scan, such as from 15-0 as shown by arrows.

[0123] FIG. 10 shows a set of two scan patterns (1010) and (1020) of transform sub blocks according to some embodiments of the disclosure.

[0124] In FIG. 10, the scan pattern (1010) can be referred to as a reverse diagonal (or vertical) scan pattern of four transform sub blocks in an 8×8 transform block. In the scan pattern (1010), each small square represents a transform sub block in the transform block, the number in

the small square represents a scan order of transform sub blocks in a diagonal (vertical raster) scan that scans diagonally (or in vertical raster order) from a top left corner of the transform block to a bottom right corner of the transform block, such as from 0-3. The reverse diagonal (vertical) scan pattern scans the transform sub blocks in the transform block in a reverse order of the diagonal (vertical) scan, such as from 3-0 as shown by arrows.

[0125] In FIG. 10, the scan pattern (1020) can be referred to as a reverse horizontal scan pattern of four transform sub blocks in an 8x8 transform block. In the scan pattern (1020), each small square represents a transform sub block in the transform block, the number in the small square represents a scan order of transform sub blocks in a horizontal raster scan that scans the transform sub blocks from left to right and top to bottom, such as from 0-3. The reverse horizontal scan pattern scans the transform sub blocks in the transform block in a reverse order of the horizontal raster scan, such as from 3-0 as shown by arrows.

[0126] In some embodiments, for inter coded blocks, a reverse diagonal scan is used for all block sizes. For all block sizes, the scan order of the transform sub blocks in the transform block follows the same pattern as the coefficients scan within the TSB. For example, the scan pattern (910) of transform coefficients in a TSB and the scan pattern (1010) of TSBs can be used for transform block of 8x8 inter coded block.

[0127] For intra coded blocks of size 4×4 or 8×8 , the three scan patterns (910) (920) and (930) are available. In some embodiments, one of the three scan patterns (910), (920) and (930) can be selected based on the direction of the intra prediction mode. It is noted that the ordering of the transform sub-blocks in the transform block follows the same pattern as the coefficients scan within the TSB. In an example, the scan pattern (910) of transform coefficients in a TSB and the scan pattern (1010) of TSBs can be used for transform block of 8x8 intra coded block. In another example, the scan pattern (920) of transform coefficients in a TSB and the scan pattern (1020) of TSBs can be used for transform block of 8x8 intra coded block. In another example, the scan pattern (930) of transform coefficients in a TSB and the scan pattern (1010) of TSBs can be used for transform block of 8x8 intra coded block.

[0128] In some embodiments, for intra coded blocks of size 16×16 and 32×32 , a reverse diagonal scan is used for all block sizes. In some examples, the scan order of the transform sub blocks in the transform block follows the same pattern as the coefficients scan

within the TSB. For example, the scan pattern (910) of transform coefficients in a TSB and a scan pattern similar to (910) for scanning TSBs (e.g., 4×4 TSBs) can be used for a transform block of 16x16 intra coded block.

[0129] FIG. 11 shows a diagram of a residual coding module (1100) in some examples. For example, the residual coding module (1100) can be used for coding transform coefficients from intra predicted residual(s) in HEVC. For an intra coded block of a size, the transform (e.g., transform matrix) is fixed based on the size of the intra coded block and the scan pattern can be varied depending on the intra prediction mode.

[0130] Specifically, in the FIG. 11 example, the residual coding module (1100) includes a transform module (1110), a selectable scan module (1170), a quantizer module (1180), and an entropy coding module (1190) coupled together as shown in FIG. 11.

[0131] The transform module (1110) receives the intra predicted residuals (e.g., generated by subtracting the intra prediction from the original samples), and divides the intra predicted residuals into TBs in the spatial domain. The transform module (1110) can perform a transform (e.g., a fixed transform matrix, DCT-2 in horizontal direction and vertical direction) that converts a TB in the spatial domain to a TB in the transform domain.

[0132] The selectable scan module (1170) receives the TB in the transform domain, and a select scan signal that is indicative of a selected scan pattern. The TB in the transform domain includes transform coefficients in 2D form. The scan module (1170) can use the selected scan pattern to convert transform coefficients in the 2D form to transform coefficients in 1D form.

[0133] The quantizer module (1180) can perform quantization and scaling to compress the transform coefficients to generate transform coefficient levels.

[0134] The entropy coding module (1190) can perform binarization of the transform coefficient levels and generate coded bits representing the transform coefficient levels.

[0135] In some examples, the modules in the FIG. 11 can be respectively implemented using integrated circuits (ICs) to perform the functions of the modules. In some examples, the modules in the FIG. 11 can be respectively implemented as software instructions that can be executed by one or more processors to perform the functions of the modules.

[0136] While in the above example (e.g., HEVC), the transform for encoding intra coded blocks and inter coded blocks is fixed, in some other examples, a technique that is referred to as

multiple transform selection (MTS) can be used for residual coding of both inter and intra coded blocks with transform selected from multiple transform candidates (e.g., transform matrices of the same size, transform basis functions). In some examples, the multiple transform candidates can include DCT-2, type 7 discrete sine transform (DST-7) and type 8 discrete cosine transform (DCT-8). In some examples, MTS is applied only for residual coding of luma blocks.

[0137] FIG. 12 shows transform basis functions of DCT-2, DST-7 and DCT-8 in some examples. In some examples, a separable transform refers to a transform that can be applied separately as a horizontal direction transform and a vertical direction transform. In some examples, the horizontal direction transform can be selected from DCT-2, DST-7 and DCT-8 transform basis functions, and the vertical direction transform can be selected from DCT-2, DST-7 and DCT-8 transform basis functions. In some examples, a non-separable transform refers to a transform that cannot be separated as a vertical transform and a horizontal transform.

[0138] According to an aspect of the disclosure, the selection of the transform from the transform candidates can be signaled implicitly or explicitly from the encoder side to the decoder side. In an example of implicit MTS, a combination of DCT-2 and DST-7 can be derived based on the width and the height of a current TB. In an example, when the value of the width is larger than the value of the height of the current TB, DCT-2 is used to perform transform in the horizontal direction, and the DST-7 is used to perform transform in the vertical direction; when the value of the width is smaller than the value of the height of the current TB, DCT-2 is used to perform transform in the vertical direction, and the DST-7 is used to perform transform in the horizontal direction. In another example, when the value of the width is larger than the value of the height of the current TB, DST-7 is used to perform transform in the horizontal direction, and the DCT-2 is used to perform transform in the vertical direction; when the value of the width is smaller than the value of the height of the current TB, DST-7 is used to perform transform in the vertical direction, and the DCT-2 is used to perform transform in the horizontal direction.

[0139] In some examples, in order to control MTS scheme, separate enabling flags are specified at SPS level for intra and inter, respectively. In some embodiments, when MTS is enabled at SPS, a CU level flag denoted by `mts_idx` is signaled to indicate how MTS is applied.

[0140] FIG. 13 shows a table (1300) for an application of MTS based on a CU level flag `mts_idx` in some examples. Each value of `mts_idx` is associated with a horizontal direction

transform and a vertical direction transform. For example, when value of `mts_idx` is 0, MTS is not applied, DCT-2 is used to perform transform in the horizontal direction and in the vertical direction; when value of `mts_idx` is 1, DST-7 is used to perform transform in the horizontal direction, and DST-7 is used to perform transform in the vertical direction; when value of `mts_idx` is 2, DCT-8 is used to perform transform in the horizontal direction, and DST-7 is used to perform transform in the vertical direction; when value of `mts_idx` is 3, DST-7 is used to perform transform in the horizontal direction, and DCT-8 is used to perform transform in the vertical direction; and when value of `mts_idx` is 4, DCT-8 is used to perform transform in the horizontal direction, and DCT-8 is used to perform transform in the vertical direction.

[0141] It is noted that, in some embodiments, MTS is applied only for residual coding of luma blocks. For example, only DCT-2 is used for residual coding of chroma blocks.

[0142] According to an aspect of the disclosure, the MTS signaling can be skipped in some examples. In an example, when the position of the last significant coefficient for the luma TB is less than 1 (e.g., has DC component only), the MTS signaling is skipped. In another example, when the last significant coefficient of the luma TB is located inside a MTS zero-out region (e.g., a region in the luma TB with coefficients being set to zero by video coder), the MTS signaling is skipped.

[0143] According to some aspects of the disclosure, coding of residual signals can include primary transform and secondary transform. In some examples (e.g., VVC), DCT-2 is applied, for example, to intra coded blocks (in horizontal and vertical directions) as the primary transform to generate frequency components, and low-frequency non-separable transform (LFNST) is applied as secondary transform to the low-frequency components output from the primary transform to better exploit the directionality characteristics of the intra coded blocks.

[0144] It is noted that LFNST is a non-separable transform that cannot be separated as a vertical transform and a horizontal transform. Generally, using a separable transform that is performed as a horizontal transform and a vertical transform can catch the correlations in the horizontal direction and vertical direction; and using non-separable transform can additionally catch the correlations in other directions, such as diagonal directions, and the like.

[0145] According to an aspect of the disclosure, LFNST can be mode dependent, a transform (e.g., e.g., matrix) to apply for LFNST can be selected based on intra-picture

prediction modes of the intra coded blocks. The LFNST can be applied, at the encoder side, between the primary transform (also referred to as forward primary transform at the encoder side) and quantization, and the LFNST can be applied, at the decoder side, between the inverse quantization and inverse primary transform. In some examples, when LFNST is applied, the CU level flag `mts_idx` is not signaled and `mts_idx` is inferred to be 0 to indicate that DCT2 is used for both horizontal and vertical transformation (in the primary transform).

[0146] FIG. 14 shows a diagram of a residual coding module (1400) in some examples. For example, the residual coding module (1400) can be used for coding transform coefficients from intra predicted residuals in VVC. The residual coding module (1400) can apply selectable primary transform to intra predicted residuals (residuals after intra prediction) or can apply non-selectable primary transform and selectable secondary transform to the intra predicted residuals. The residual coding module (1400) can apply a fixed scan, such as reverse diagonal scan, to convert 2D transform coefficients to 1D transform coefficients.

[0147] Specifically, in the FIG. 14 example, the residual coding module (1400) includes a selectable primary transform module (1410), a fixed primary transform module (1420), a selectable secondary transform module (1430), a fixed scan module (1470), a quantizer module (1480), and an entropy coding module (1490) coupled together as shown in FIG. 14.

[0148] The selectable primary transform module (1410) can receive the intra predicted residuals (e.g., generated by subtracting the intra prediction from the original samples), and divide the intra predicted residuals into TBs in the spatial domain. The selectable primary transform module (1410) also receives a select transform signal that indicates selected transforms, such as transform functions to be applied in the horizontal direction and vertical direction. The selectable primary transform module (1410) can perform transforms according to the select transform signal to convert a TB in the spatial domain to a TB in the transform domain.

[0149] The fixed primary transform module (1420) can receive the intra predicted residuals (e.g., generated by subtracting the intra prediction from the original samples), and divide the intra predicted residual into TBs in the spatial domain. The fixed primary transform module (1420) can perform a fixed transform, such as DCT-2 in horizontal direction and vertical

direction, that converts a TB in the spatial domain to an intermediate TB in the frequency domain.

[0150] In some examples, the selectable secondary transform module (1430) is configured to perform LFNST. The selectable secondary transform module (1430) can receive the intermediate TB, and also a select secondary transform signal that indicates a selected secondary transform, such as a selected LFNST. The selectable secondary transform module (1430) can perform the selected LFNST on the intermediate TB and generate TB in the transform domain.

[0151] The fixed scan module (1470) can receive the TB in the transform domain from the selectable primary transform module (1410) or from the selectable secondary transform module (1430). The fixed scan module (1470) applies a fixed scan pattern, such as the reverse diagonal scan patterns shown by (910) and (1010) to convert transform coefficients in the 2D form to transform coefficients in the 1D form.

[0152] The quantizer module (1480) can perform quantization and scaling to compress the transform coefficients to generate transform coefficient levels.

[0153] The entropy coding module (1490) can perform binarization of the transform coefficient levels and generate coded bits representing the transform coefficient levels.

[0154] In some examples, the modules in the FIG. 14 can be respectively implemented using integrated circuits (ICs) to perform the functions of the modules. In some examples, the modules in the FIG. 14 can be respectively implemented as software instructions that can be executed by one or more processors to perform the functions of the modules.

[0155] In the FIG. 14 examples, transform coefficients of a coding block are coded by categorizing them into transform sub blocks (TSB). The TSB size can be 4×4 , 1×16 , 16×1 , 2×8 , 8×2 , 2×4 , and 4×2 . In some examples (e.g., VVC), Intra Sub-Partition (ISP) may be applied that can result narrow luma TBs, and small chroma TBs. The transform coefficients within a TSB are coded following a single reverse diagonal scan order, such as shown by (910), and TSBs inside a TB are coded following a single reverse diagonal scan order, such as shown by (1010).

[0156] It is noted that, in some examples (e.g., residual coding for intra predicted block by HEVC), the transform is fixed for a given block size and the scanning pattern can be varied

depending on the intra prediction mode. Since the transform is fixed, the scanning pattern is not adaptive to the transform. In some other examples (e.g., residual coding from intra predicted block by VVC), the scanning pattern is fixed (not adaptive) but multiple transformation selection can be applied to improve coding efficiency for both intra coded blocks and inter coded blocks.

[0157] According to an aspect of the disclosure, under certain conditions (e.g., VVC common test condition with VTM-11), certain values of `mts_idx`, such as `mts_idx` equal 0 or `mts_idx` equal 1, are used with high probability, and the other values of `mts_idx` are rarely used. In some embodiments, computation can be saved at encoder for evaluating the rate-distortion performance of certain values of `mts_idx`, but not all values of `mts_idx`. Some aspects of the disclosure can improve the coding efficiency of video codec.

[0158] FIG. 15 shows a diagram of a residual coding module (1500) according to some embodiments of the disclosure. For example, the residual coding module (1500) can be used for coding transform coefficients from intra predicted residual at an encoder. The residual coding module (1500) can include multiple transform and scan process paths for applying suitable transform and scan techniques to intra predicted residuals (residuals after intra prediction) to form 1D transform coefficients. For example, the residual coding module (1500) includes a first transform and scan processing path (1501) that can apply selectable primary transform and selectable scan to intra predicted residuals to form 1D transform coefficients; and includes a second transform and scan processing path (1502) that can apply a fixed primary transform, a selectable secondary transform and a fixed scan on to intra predicted residuals to form 1D transform coefficients.

[0159] Specifically, in the FIG. 15 example, the residual coding module (1500) includes a selectable primary transform module (1510), a selectable scan module (1560), a fixed primary transform module (1520), a selectable secondary transform module (1530), a fixed scan module (1570), a quantizer module (1580), and an entropy coding module (1590) coupled together as shown in FIG. 15.

[0160] The selectable primary transform module (1510) can receive the intra predicted residuals (e.g., generated by subtracting the intra prediction from the original samples), and divide the intra predicted residuals into TBs in the spatial domain. The selectable primary transform module (1510) also receives a select transform signal that indicates selected

transforms, such as transform functions to be applied in the horizontal direction and vertical direction. The selectable primary transform module (1510) can perform transforms according to the select transform signal to convert a TB in the spatial domain to a TB in the transform domain.

[0161] The selectable scan module (1560) receives the TB in the transform domain output from the selectable primary transform module (1510), and a select scan signal that is indicative of a selected scan pattern. The TB in the transform domain includes transform coefficients in 2D form. The selectable scan module (1560) can use the selected scan pattern to convert transform coefficients in the 2D form to transform coefficients in 1D form.

[0162] The fixed primary transform module (1520) can receive the intra predicted residual (e.g., generated by subtracting the intra prediction from the original samples), and divide the intra predicted residuals into TBs in the spatial domain. The fixed primary transform module (1520) can perform a fixed transform, such as DCT-2 in horizontal direction and vertical direction, that converts a TB in the spatial domain to an intermediate TB in frequency domain.

[0163] In some examples, the selectable secondary transform module (1530) is configured to perform LFNST. The selectable secondary transform module (1530) can receive the intermediate TB, and a select secondary transform signal that indicates a selected secondary transform, such as a selected LFNST. The selectable secondary transform module (1530) can perform the selected LFNST on the intermediate TB and generate TB in the transform domain.

[0164] The fixed scan module (1570) can receive the TB in the transform domain output from the selectable secondary transform module (1530). The fixed scan module (1570) applies a fixed scan pattern, such as the reverse diagonal scan patterns shown by (910) and (1010) to convert transform coefficients in the 2D form to transform coefficients in the 1D form.

[0165] The quantizer module (1580) can receive the transform coefficients in the 1D form output from the selectable scan module (1560) or the fixed scan module (1570). The quantizer module (1580) can perform quantization and scaling to compress the transform coefficients to generate transform coefficient levels.

[0166] The entropy coding module (1590) can perform binarization of the transform coefficient levels and generate coded bits representing the transform coefficient levels.

[0167] In some examples, the modules in the FIG. 15 can be respectively implemented using integrated circuits (ICs) to perform the functions of the modules. In some examples, the modules in the FIG. 15 can be respectively implemented as software instructions that can be executed by one or more processors to perform the functions of the modules.

[0168] As shown in FIG. 15, the first transform and scan processing path (1501) can apply adaptive scanning (selectable scan) to the coding of intra predicted residual block when the primary transform is selectable and the secondary transform is not enabled. When the primary separable transform is selectable and the secondary transform is not enabled, a scan pattern from multiple scan patterns is selected to apply to the output of at least one of the selected primary transform to re-order the two-dimensional transform coefficients into one dimension before sending the transform coefficients for quantization.

[0169] According to an aspect of the disclosure, the scan selection can be signaled implicitly or explicitly. When the scan selection is signaled explicitly, the selection of the scan for a TB is encoded in the bitstream for each TB. When the scan selection is signaled implicitly, the scan selection can be derived from the direction of the intra prediction mode and/or the selection of the primary transform in some examples.

[0170] In some embodiments, the primary transform selection and scan selection are signaled separately.

[0171] In some embodiments, the primary transform selection and scan selection are signaled jointly.

[0172] In an embodiment, the transform selection and the scan selection are signalled jointly and the scan selection is applicable to a subset of the selectable primary transforms. For example, reverse diagonal scan pattern, reverse horizontal scan pattern and reverse vertical scan pattern, such as shown in FIG. 9 and FIG. 10 can be used for scanning. The transform selection and the scan selection can be encoded jointly by encoding `mts_idx`, such as based on a transform and scan signaling mapping table.

[0173] FIG. 16 shows a table (1600) for illustrating a transform and scan signalling mapping table according to some examples. In some examples, the statistics of the intra coding (e.g., in VVC) with explicit MTS indicate that most blocks were encoded with either DCT-2 for both horizontal and vertical transforms or DST-7 for both horizontal and vertical transforms.

The example in the table (1600) takes advantage of the statistics and includes two transform selections, a first selection of DCT-2 for both horizontal and vertical transforms and a second selection of DST-7 for both horizontal and vertical transforms.

[0174] In the FIG. 16, in the table (1600), corresponding to the first selection of using DCT-2 for both horizontal and vertical transforms, a fixed scan is used. Further, corresponding to the second selection of using DST7 for both horizontal and vertical transforms, three scan pattern candidates can be applied. In the FIG. 16 example, selectable scan is only applicable to a subset of the selectable transforms.

[0175] In another embodiment, the primary transform selection and the scan selection are signaled jointly and the scan selection is applicable to each transform selection in the selectable primary transform.

[0176] FIG. 17 shows a table (1700) for illustrating a transform and scan signalling mapping table according to some examples. In some examples, the statistics of the intra coding (e.g., in VVC) with explicit MTS indicate that most blocks were encoded with either DCT-2 for both horizontal and vertical transforms or DST-7 for both horizontal and vertical transforms. The example in the table (1700) takes advantage of the statistics and includes two transform selections, a first selection of DCT-2 for both horizontal and vertical transforms and a second selection of DST-7 for both horizontal and vertical transforms.

[0177] In the FIG. 17, in the table (1700), corresponding to the first selection of using DCT-2 for both horizontal and vertical transforms, a scan pattern can be selected from three scan pattern candidates (e.g., reverse diagonal scan pattern, reverse vertical scan pattern and reverse horizontal scan pattern). Similarly, corresponding to the second selection of using DST7 for both horizontal and vertical transforms, a scan pattern can be selected from three scan pattern candidates (e.g., reverse diagonal scan pattern, reverse vertical scan pattern and reverse horizontal scan pattern).

[0178] In some embodiments, the transform selection is explicitly signaled and the scan selection is implicitly signaled based on the intra prediction mode.

[0179] FIG. 18 shows a table (1800) for illustrating a transform and scan signalling mapping table according to some examples. In some examples, the statistics of the intra coding (e.g., in VVC) with explicit MTS indicate that most blocks were encoded with either DCT-2 for

both horizontal and vertical transforms or DST-7 for both horizontal and vertical transforms. The example in the table (1800) takes advantage of the statistics and includes two transform selections, a first selection of DCT-2 for both horizontal and vertical transforms and a second selection of DST-7 for both horizontal and vertical transforms.

[0180] In the FIG. 18, in the table (1800), 1 bit is used to signal `mts_idx` to indicate one of a first selection of using DCT-2 for both horizontal and vertical transforms and a second selection of using DST7 for both horizontal and vertical transforms. The scan pattern is selected based on the intra prediction mode. In some examples, at the encoder side, the encoder can perform rate-distortion optimization on two choices of `mts_idx` instead of 5 choices shown in table (1300), and thus the encoder complexity can be lower.

[0181] In some embodiments, the scan pattern is determined based on intra prediction mode, such as denoted by `predModeIntra` in VVC.

[0182] In an example, the reverse horizontal scan can be selected when $|\text{preModeIntra} - 50| \leq 10$ or the value of `preModeIntra` ≤ -5 ; the reverse vertical scan is used when $|\text{preModeIntra} - 18| \leq 10$ or the value of `preModeIntra` ≥ 70 ; for other value of `predModeIntra`, reverse diagonal scan is used.

[0183] FIG. 19 shows a flow chart outlining a process (1900) according to an embodiment of the disclosure. The process (1900) can be used in a video encoder. In various embodiments, the process (1900) is executed by processing circuitry, such as the processing circuitry in the terminal devices (310), (320), (330) and (340), the processing circuitry that performs functions of the video encoder (403), the processing circuitry that performs functions of the video encoder (603), the processing circuitry that performs functions of the video encoder (703), and the like. In some embodiments, the process (1900) is implemented in software instructions, thus when the processing circuitry executes the software instructions, the processing circuitry performs the process (1900). The process starts at (S1901) and proceeds to (S1910).

[0184] At (S1910), an intra prediction of a coding block is performed based on an intra prediction mode.

[0185] At (S1920), a selection of a separable primary transform from a plurality of separable primary transform candidates and a selection of a scan pattern from a plurality of scan pattern candidates are determined for encoding residuals of the coding block from the intra

prediction. In some examples, the video encoder takes advantages of the statistics of most of the intra coded blocks are coded with transform function DCT-2 or DST-7. In an example, the video encoder performs rate distortion performance evaluation based on transform function DCT-2 or DST-7, and applicable scan patterns to determine the selection of the separable primary transform from the plurality of separable primary transform candidates and the selection of the scan pattern from the plurality of scan pattern candidates.

[0186] In some examples, an exclusion of an application of a selectable secondary non separable transform is determined, and thus no selectable secondary non separable transform is applied.

[0187] In some examples, the scan pattern is applicable respectively with a subset of the plurality of separable primary transform candidates, such as in table (1600).

[0188] In some examples, the scan pattern is applicable respectively with each of the plurality of separable primary transform candidates, such as in table (1700).

[0189] At (S1930), the residuals of the coding block are encoded based on the selection of the separable primary transform and the selection of the scan pattern.

[0190] In some examples, the separable primary transform is applied on the residuals to generate transform coefficients in the transform domain. Then, the transform coefficients in the transform domain can be converted from 2D to 1D based on the scan pattern. The transform coefficients in the 1D can be quantized and entropy encoded into bits in a bitstream.

[0191] At (S1940), the selection of the separable primary transform and the selection of the scan pattern are signaled. Then, the process proceeds to (S1999) and terminates.

[0192] In some examples, the selection of the separable primary transform and the selection of the scan pattern are signaled jointly and explicitly. In an example, a value of a syntax (e.g., `mts_idx`) is selected to indicate a combination of the selection of the separable primary transform from the plurality of separable primary transform candidates and the selection of the scan pattern from the plurality of scan pattern candidates, such as using table (1600), table (1700), and the like. The value of the syntax is encoded into the bitstream.

[0193] In some examples, the selection of the separable primary transform and the selection of the scan pattern are signaled separately and explicitly. In an example, a value of a first syntax is determined to indicate the selection of the separable primary transform, and a

value of a second syntax is determined to indicate the selection of the scan pattern. The first syntax and the second syntax are encoded into the bitstream.

[0194] In some examples, the selection of the separable primary transform is signaled explicitly, and the selection of the scan pattern is signaled implicitly. For example, the selection of the scan pattern is based on the intra prediction mode.

[0195] In some examples, the selection of the separable primary transform is signaled implicitly, and the selection of the scan pattern is signaled implicitly. For example, the selection of the scan pattern is based on the intra prediction mode.

[0196] The process (1900) can be suitably adapted. Step(s) in the process (1900) can be modified and/or omitted. Additional step(s) can be added. Any suitable order of implementation can be used.

[0197] FIG. 20 shows a flow chart outlining a process (2000) according to an embodiment of the disclosure. The process (2000) can be used in a video decoder. In various embodiments, the process (2000) is executed by processing circuitry, such as the processing circuitry in the terminal devices (310), (320), (330) and (340), the processing circuitry that performs functions of the video decoder (410), the processing circuitry that performs functions of the video decoder (510), and the like. In some embodiments, the process (1800) is implemented in software instructions, thus when the processing circuitry executes the software instructions, the processing circuitry performs the process (2000). The process starts at (S2001) and proceeds to (S2010).

[0198] At (S2010), information of a coding block is decoded from a bitstream. The information indicates an intra prediction mode for the coding block, a selection of a separable primary transform from a plurality of separable primary transform candidates, and a selection of a scan pattern from a plurality of scan pattern candidates.

[0199] In an example, the scan pattern is applicable respectively with a subset of the plurality of separable primary transform candidates. In another example, the scan pattern is applicable respective with the plurality of separable primary transform candidates.

[0200] In some examples, the selection of the separable primary transform and the selection of the scan pattern are signaled jointly and explicitly. For example, a value of a syntax is decoded from the bitstream, the value of the syntax indicates a combination of the selection of

the separable primary transform from the plurality of separable primary transform candidates and the selection of the scan pattern from the plurality of scan pattern candidates.

[0201] In some examples, the selection of the separable primary transform and the selection of the scan pattern are signaled separately and explicitly. For example, a value of a first syntax is decoded from the bitstream, the value of the first syntax indicates the selection of the separable primary transform; and a value of a second syntax is decoded from the bitstream, the value of the second syntax indicates the selection of the scan pattern.

[0202] In some examples, the selection of the separable primary transform is signaled explicitly, and the selection of the scan pattern is signaled implicitly, thus the selection of the scan pattern can be inferred, and the selection of the separable primary transform can be determined based on a syntax decoded from the bitstream. In some examples, both the selection of the separable primary transform and the selection of the scan pattern are signaled implicitly, thus both of the selection of the separable primary transform and the selection of the scan pattern can be inferred. In an example, the selection of the scan pattern can be inferred based on the direction of the intra prediction mode.

[0203] At (S2020), residuals of the coding block from the bitstream are determined based on the selection of the scan pattern and the selection of the separable primary transform.

[0204] In some examples, the transform coefficients in a transform domain are decoded from the bitstream based on the selection of the scan pattern. Then, an inverse transform associated with the separable primary transform is applied on the transform coefficients in the transform domain to determine the residuals.

[0205] In some examples, the decoded information of the coding block indicates an exclusion of a selectable secondary non separable transform. Thus, an application of an inverse transform associated with the selectable secondary non separable transform is excluded from the processing for determining the residuals of the coding block.

[0206] At (S2030), the coding block is reconstructed based on a combination of the residuals with an intra prediction of the coding block, the intra prediction of the coding block is based on the intra prediction mode.

[0207] Then, the process proceeds to (S2099) and terminates.

[0208] The process (2000) can be suitably adapted. Step(s) in the process (2000) can be modified and/or omitted. Additional step(s) can be added. Any suitable order of implementation can be used.

[0209] The techniques described above, can be implemented as computer software using computer-readable instructions and physically stored in one or more computer-readable media. For example, FIG. 21 shows a computer system (2100) suitable for implementing certain embodiments of the disclosed subject matter.

[0210] The computer software can be coded using any suitable machine code or computer language, that may be subject to assembly, compilation, linking, or like mechanisms to create code comprising instructions that can be executed directly, or through interpretation, micro-code execution, and the like, by one or more computer central processing units (CPUs), Graphics Processing Units (GPUs), and the like.

[0211] The instructions can be executed on various types of computers or components thereof, including, for example, personal computers, tablet computers, servers, smartphones, gaming devices, internet of things devices, and the like.

[0212] The components shown in FIG. 21 for computer system (2100) are exemplary in nature and are not intended to suggest any limitation as to the scope of use or functionality of the computer software implementing embodiments of the present disclosure. Neither should the configuration of components be interpreted as having any dependency or requirement relating to any one or combination of components illustrated in the exemplary embodiment of a computer system (2100).

[0213] Computer system (2100) may include certain human interface input devices. Such a human interface input device may be responsive to input by one or more human users through, for example, tactile input (such as: keystrokes, swipes, data glove movements), audio input (such as: voice, clapping), visual input (such as: gestures), olfactory input (not depicted). The human interface devices can also be used to capture certain media not necessarily directly related to conscious input by a human, such as audio (such as: speech, music, ambient sound), images (such as: scanned images, photographic images obtain from a still image camera), video (such as two-dimensional video, three-dimensional video including stereoscopic video).

[0214] Input human interface devices may include one or more of (only one of each depicted): keyboard (2101), mouse (2102), trackpad (2103), touch screen (2110), data-glove (not shown), joystick (2105), microphone (2106), scanner (2107), camera (2108).

[0215] Computer system (2100) may also include certain human interface output devices. Such human interface output devices may be stimulating the senses of one or more human users through, for example, tactile output, sound, light, and smell/taste. Such human interface output devices may include tactile output devices (for example tactile feedback by the touch-screen (2110), data-glove (not shown), or joystick (2105), but there can also be tactile feedback devices that do not serve as input devices), audio output devices (such as: speakers (2109), headphones (not depicted)), visual output devices (such as screens (2110) to include CRT screens, LCD screens, plasma screens, OLED screens, each with or without touch-screen input capability, each with or without tactile feedback capability—some of which may be capable to output two dimensional visual output or more than three dimensional output through means such as stereographic output; virtual-reality glasses (not depicted), holographic displays and smoke tanks (not depicted)), and printers (not depicted).

[0216] Computer system (2100) can also include human accessible storage devices and their associated media such as optical media including CD/DVD ROM/RW (2120) with CD/DVD or the like media (2121), thumb-drive (2122), removable hard drive or solid state drive (2123), legacy magnetic media such as tape and floppy disc (not depicted), specialized ROM/ASIC/PLD based devices such as security dongles (not depicted), and the like.

[0217] Those skilled in the art should also understand that term “computer readable media” as used in connection with the presently disclosed subject matter does not encompass transmission media, carrier waves, or other transitory signals.

[0218] Computer system (2100) can also include an interface (2154) to one or more communication networks (2155). Networks can for example be wireless, wireline, optical. Networks can further be local, wide-area, metropolitan, vehicular and industrial, real-time, delay-tolerant, and so on. Examples of networks include local area networks such as Ethernet, wireless LANs, cellular networks to include GSM, 3G, 4G, 5G, LTE and the like, TV wireline or wireless wide area digital networks to include cable TV, satellite TV, and terrestrial broadcast TV, vehicular and industrial to include CANBus, and so forth. Certain networks commonly require

external network interface adapters that attached to certain general purpose data ports or peripheral buses (2149) (such as, for example USB ports of the computer system (2100)); others are commonly integrated into the core of the computer system (2100) by attachment to a system bus as described below (for example Ethernet interface into a PC computer system or cellular network interface into a smartphone computer system). Using any of these networks, computer system (2100) can communicate with other entities. Such communication can be uni-directional, receive only (for example, broadcast TV), uni-directional send-only (for example CANbus to certain CANbus devices), or bi-directional, for example to other computer systems using local or wide area digital networks. Certain protocols and protocol stacks can be used on each of those networks and network interfaces as described above.

[0219] Aforementioned human interface devices, human-accessible storage devices, and network interfaces can be attached to a core (2140) of the computer system (2100).

[0220] The core (2140) can include one or more Central Processing Units (CPU) (2141), Graphics Processing Units (GPU) (2142), specialized programmable processing units in the form of Field Programmable Gate Areas (FPGA) (2143), hardware accelerators for certain tasks (2144), graphics adapters (2150), and so forth. These devices, along with Read-only memory (ROM) (2145), Random-access memory (2146), internal mass storage such as internal non-user accessible hard drives, SSDs, and the like (2147), may be connected through a system bus (2148). In some computer systems, the system bus (2148) can be accessible in the form of one or more physical plugs to enable extensions by additional CPUs, GPU, and the like. The peripheral devices can be attached either directly to the core's system bus (2148), or through a peripheral bus (2149). In an example, the screen (2110) can be connected to the graphics adapter (2150). Architectures for a peripheral bus include PCI, USB, and the like.

[0221] CPUs (2141), GPUs (2142), FGAs (2143), and accelerators (2144) can execute certain instructions that, in combination, can make up the aforementioned computer code. That computer code can be stored in ROM (2145) or RAM (2146). Transitional data can be also be stored in RAM (2146), whereas permanent data can be stored for example, in the internal mass storage (2147). Fast storage and retrieve to any of the memory devices can be enabled through the use of cache memory, that can be closely associated with one or more CPU (2141), GPU (2142), mass storage (2147), ROM (2145), RAM (2146), and the like.

[0222] The computer readable media can have computer code thereon for performing various computer-implemented operations. The media and computer code can be those specially designed and constructed for the purposes of the present disclosure, or they can be of the kind well known and available to those having skill in the computer software arts.

[0223] As an example and not by way of limitation, the computer system having architecture (2100), and specifically the core (2140) can provide functionality as a result of processor(s) (including CPUs, GPUs, FPGA, accelerators, and the like) executing software embodied in one or more tangible, computer-readable media. Such computer-readable media can be media associated with user-accessible mass storage as introduced above, as well as certain storage of the core (2140) that are of non-transitory nature, such as core-internal mass storage (2147) or ROM (2145). The software implementing various embodiments of the present disclosure can be stored in such devices and executed by core (2140). A computer-readable medium can include one or more memory devices or chips, according to particular needs. The software can cause the core (2140) and specifically the processors therein (including CPU, GPU, FPGA, and the like) to execute particular processes or particular parts of particular processes described herein, including defining data structures stored in RAM (2146) and modifying such data structures according to the processes defined by the software. In addition or as an alternative, the computer system can provide functionality as a result of logic hardwired or otherwise embodied in a circuit (for example: accelerator (2144)), which can operate in place of or together with software to execute particular processes or particular parts of particular processes described herein. Reference to software can encompass logic, and vice versa, where appropriate. Reference to a computer-readable media can encompass a circuit (such as an integrated circuit (IC)) storing software for execution, a circuit embodying logic for execution, or both, where appropriate. The present disclosure encompasses any suitable combination of hardware and software.

Appendix A: Acronyms

JEM: joint exploration model

VVC: versatile video coding

BMS: benchmark set

MV: Motion Vector

HEVC: High Efficiency Video Coding
SEI: Supplementary Enhancement Information
VUI: Video Usability Information
GOPs: Groups of Pictures
TUs: Transform Units,
PUs: Prediction Units
CTUs: Coding Tree Units
CTBs: Coding Tree Blocks
PBs: Prediction Blocks
HRD: Hypothetical Reference Decoder
SNR: Signal Noise Ratio
CPUs: Central Processing Units
GPUs: Graphics Processing Units
CRT: Cathode Ray Tube
LCD: Liquid-Crystal Display
OLED: Organic Light-Emitting Diode
CD: Compact Disc
DVD: Digital Video Disc
ROM: Read-Only Memory
RAM: Random Access Memory
ASIC: Application-Specific Integrated Circuit
PLD: Programmable Logic Device
LAN: Local Area Network
GSM: Global System for Mobile communications
LTE: Long-Term Evolution
CANBus: Controller Area Network Bus
USB: Universal Serial Bus
PCI: Peripheral Component Interconnect
FPGA: Field Programmable Gate Areas
SSD: solid-state drive

IC: Integrated Circuit

CU: Coding Unit

[0224] While this disclosure has described several exemplary embodiments, there are alterations, permutations, and various substitute equivalents, which fall within the scope of the disclosure. It will thus be appreciated that those skilled in the art will be able to devise numerous systems and methods which, although not explicitly shown or described herein, embody the principles of the disclosure and are thus within the spirit and scope thereof.

WHAT IS CLAIMED IS:

1. A method of video processing in a decoder, comprising:
decoding information of a coding block from a bitstream, the information indicating an intra prediction mode for the coding block, a selection of a separable primary transform from a plurality of separable primary transform candidates, and a selection of a scan pattern from a plurality of scan pattern candidates;
determining whether selectable secondary non-separable transform is not applied to the bitstream and selectable separable primary transform is applied to the bitstream;
in response to determining that the secondary non-separable transform is not applied to the bitstream and the selectable separable primary transform is applied to the bitstream, determining residuals of the coding block from the bitstream based on the selection of the scan pattern; and
reconstructing the coding block based on a combination of the residuals with an intra prediction of the coding block, the intra prediction being based on the intra prediction mode.
2. The method of claim 1, wherein the determining the residuals of the coding block further comprises:
decoding the bitstream to determine transform coefficients in a transform domain based on the selection of the scan pattern; and
applying an inverse transform associated with the separable primary transform on the transform coefficients in the transform domain to determine the residuals.
3. The method of claim 1, wherein the information indicates an exclusion of a selectable secondary non separable transform and the determining the residuals of the coding block excludes an application of an inverse transform associated with the selectable secondary non separable transform.
4. The method of claim 1, wherein the scan pattern is applicable respectively with a subset of the plurality of separable primary transform candidates.

5. The method of claim 1, wherein the scan pattern is applicable respectively with each of the plurality of separable primary transform candidates.

6. The method of claim 1, further comprising:
decoding a value of a syntax from the bitstream, the value of the syntax indicating a combination of the selection of the separable primary transform from the plurality of separable primary transform candidates and the selection of the scan pattern from the plurality of scan pattern candidates.

7. The method of claim 1, further comprising:
decoding a value of a first syntax from the bitstream, the value of the first syntax indicating the selection of the separable primary transform; and
decoding a value of a second syntax from the bitstream, the value of the second syntax indicating the selection of the scan pattern.

8. The method of claim 1, further comprising:
inferring the selection of the scan pattern.

9. The method of claim 8, further comprising:
inferring the selection of the scan pattern based on the intra prediction mode.

10. The method of claim 8, further comprising at least one of:
inferring the selection of the separable primary transform; and
decoding a value of a syntax from the bitstream, the value of the syntax indicating the selection of the separable primary transform.

11. An apparatus for video decoding, comprising processing circuitry configured to:
decode information of a coding block from a bitstream, the information indicating an intra prediction mode for the coding block, a selection of a separable primary transform from a

plurality of separable primary transform candidates, and a selection of a scan pattern from a plurality of scan pattern candidates;

determine whether selectable secondary non-separable transform is not applied to the bitstream and selectable separable primary transform is applied to the bitstream;

in response to determining that the secondary non-separable transform is not applied to the bitstream and the selectable separable primary transform is applied to the bitstream, determine residuals of the coding block from the bitstream based on the selection of the scan pattern and the selection of the separable primary transform; and

reconstruct the coding block based on a combination of the residuals with an intra prediction of the coding block, the intra prediction being based on the intra prediction mode.

12. The apparatus of claim 11, wherein the processing circuitry is further configured to:

decode the bitstream to determine transform coefficients in a transform domain based on the selection of the scan pattern; and

apply an inverse transform associated with the separable primary transform on the transform coefficients in the transform domain to determine the residuals.

13. The apparatus of claim 11, wherein the information indicates an exclusion of a selectable secondary non separable transform and the processing circuitry is configured to determine the residuals of the coding block without an application of an inverse transform associated with the selectable secondary non separable transform.

14. The apparatus of claim 11, wherein the scan pattern is applicable respectively with a subset of the plurality of separable primary transform candidates.

15. The apparatus of claim 11, wherein the scan pattern is applicable respectively with each of the plurality of separable primary transform candidates.

16. The apparatus of claim 11, wherein the processing circuitry is configured to:

decode a value of a syntax from the bitstream, the value of the syntax indicating a combination of the selection of the separable primary transform from the plurality of separable primary transform candidates and the selection of the scan pattern from the plurality of scan pattern candidates.

17. The apparatus of claim 11, wherein the processing circuitry is configured to:
decode a value of a first syntax from the bitstream, the value of the first syntax indicating the selection of the separable primary transform; and
decode a value of a second syntax from the bitstream, the value of the second syntax indicating the selection of the scan pattern.

18. The apparatus of claim 11, wherein the processing circuitry is configured to:
infer the selection of the scan pattern.

19. The apparatus of claim 18, wherein the processing circuitry is configured to:
infer the selection of the scan pattern based on the intra prediction mode.

20. The apparatus of claim 18, wherein the processing circuitry is configured to perform at least one of:
inferring the selection of the separable primary transform; and
decoding a value of a syntax from the bitstream, the value of the syntax indicating the selection of the separable primary transform.