

US Patent & Trademark Office

Patent Public Search | Text View

United States Patent
Kind Code
Date of Patent
Inventor(s)

12388978
B2
August 12, 2025
Chen; Lien-Fei et al.

Template-matching based adaptive motion vector resolution (AMVR) for bi-prediction and an affine mode

Abstract

Aspects of the disclosure provide a method and an apparatus including processing circuitry that performs template matching (TM) on motion vector resolution (MVR) pairs of a current block by determining a TM cost corresponding to each one of the MVR pairs. The current block is predicted with an affine adaptive motion vector prediction (Δ MVP) mode. Each MVR pair includes a first MVR in a first plurality of MVRs corresponding to a first reference picture and a second MVR in a second plurality of MVRs corresponding to a second reference picture. Each TM cost is determined based on a current template of the current block and a bi-predictor of the respective MVR pair. The bi-predictor is based on a first reference template in the first reference picture and a second reference template in the second reference picture. An MVR pair is selected based on the determined corresponding TM costs.

Inventors: Chen; Lien-Fei (Hsinchu, TW), Li; Xiang (Saratoga, CA), Liu; Shan (San Jose, CA)

Applicant: Tencent America LLC (Palo Alto, CA)

Family ID: 1000008751385

Assignee: TENCENT AMERICA LLC (Palo Alto, CA)

Appl. No.: 17/965729

Filed: October 13, 2022

Prior Publication Data

Document Identifier	Publication Date
US 20230134017 A1	May. 04, 2023

Related U.S. Application Data

Publication Classification

Int. Cl.: H04N19/00 (20140101); H04N19/105 (20140101); H04N19/139 (20140101); H04N19/159 (20140101); H04N19/176 (20140101); H04N19/513 (20140101)

U.S. Cl.:

CPC H04N19/105 (20141101); H04N19/139 (20141101); H04N19/159 (20141101); H04N19/176 (20141101); H04N19/513 (20141101);

Field of Classification Search

CPC: H04N (19/00)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
2021/0112268	12/2020	Ko et al.	N/A	N/A
2021/0227211	12/2020	Liu et al.	N/A	N/A
2022/0295088	12/2021	Zhang et al.	N/A	N/A
2024/0291997	12/2023	Zhang	N/A	H04N 19/107

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
2021-502038	12/2020	JP	N/A
2021-523604	12/2020	JP	N/A
2018/121506	12/2017	WO	N/A

OTHER PUBLICATIONS

Esenlik et al., “Description of Core Experiment 9 (CE9): Decoder Side Motion Vector Derivation”, Joint Video Experts Team (JVET) of ITU-T SG 16 WP 3 and ISO/IEC JTC 1/SC 29/WG 11, JVET-J1029-v1, 2018, 04 months, 2018, 7 pages. cited by applicant

Office Action received for Japanese Patent Application No. 2023-552245, mailed on Aug. 13, 2024, 8 pages (4 pages of English Translation and 4 pages of Original Document). cited by applicant

High Efficiency Video Coding, Rec. ITU-T H.265 v4 Dec. 2016, pp. 1-664. cited by applicant

ITU-T and ISO/IEC, “Versatile Video Coding”, ITU-T Rec. H.266 and ISO/IEC 23090-3, 2020, pp. 1-516. cited by applicant

V. Seregin, et. al., “Exploration Experiment on Enhanced Compression beyond VVC capability”, ISO/IEC JTC1/SC29/WG11 JVET-U2024, Jan. 2021, pp. 1-19. cited by applicant

Y.-J. Chang, et. al., “Compression efficiency methods beyond VVC”, ISO/IEC JTC1/SC29/WG11 JVET-U0100, Jan. 2021, pp. 1-13. cited by applicant

C.-C. Chen, V. Seregin, Y.-J. Chang, Z. Zhang, H. Huang, Y. Zhang, and M. Karczewicz, “EE2-related: Extension of template matching to Affine, CIIP, GPM merge modes, and boundary sub-blocks”, ISO/IEC JTC1/SC29/WG11 JVET-V0118, Apr. 2021, pp. 1-3. cited by applicant

Y.-W. Chen, et al., “Description of SDR, HDR and 360° video coding technology proposal by Qualcomm and Technicolor—low and high complexity versions”, ISO/IEC JTC1/SC29/WG11

JVET-J0021, Apr. 2018, pp. 1-43. cited by applicant
Esenlik et al., “Description of Core Experiment 9 (CE9): Decoder Side Motion Vector Derivation”, 10. JVET Meeting, San Diego, The Joint Video Exploration Team of ISO/IEC JTC1/SC29/WG11 and ITU-T SG.16, No. JVET-J1029, XP030151328, Apr. 20, 2018, pp. 1-29. cited by applicant
Extended European Search Report and Search Opinion received for European Application No. 22888384.9, mailed on Jan. 27, 2025, 11 pages. cited by applicant

Primary Examiner: Nasri; Maryam A

Attorney, Agent or Firm: ARENTFOX SCHIFF LLP

Background/Summary

INCORPORATION BY REFERENCE (1) The present application claims the benefit of priority to U.S. Provisional Application No. 63/274,273, “TEMPLATE-MATCHING BASED ADAPTIVE MOTION VECTOR RESOLUTION (Δ MVR) FOR BI-PREDICTION AND AFFINE MODE” filed on Nov. 1, 2021, which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

(1) The present disclosure describes embodiments generally related to video coding.

BACKGROUND

(2) 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.

(3) Uncompressed digital images and/or video can include a series of pictures, each picture having a spatial dimension of, for example, 1920×1080 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 image and/or video has specific bitrate requirements. For example, 1080p60 4:2:0 video at 8 bit per sample (1920×1080 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.

(4) One purpose of image and/or video coding and decoding can be the reduction of redundancy in the input image and/or 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. Although the descriptions herein use video encoding/decoding as illustrative examples, the same techniques can be applied to image encoding/decoding in similar fashion without departing from the spirit of the present disclosure. 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.

(5) A video encoder and decoder can utilize techniques from several broad categories, including,

for example, motion compensation, transform processing, quantization, and entropy coding.

(6) 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.

(7) Traditional intra coding used in, for example, MPEG-2 generation coding technologies, does not use intra prediction. However, some newer video compression technologies include techniques that attempt to perform prediction based on, for example, surrounding sample data and/or metadata obtained during the encoding and/or decoding of 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.

(8) 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, a specific technique in use can be coded as a specific intra prediction mode that uses the specific technique. In certain cases, intra prediction modes can have submodes and/or parameters, where the submodes and/or parameters can be coded individually or included in a mode codeword, which defines the prediction mode being used. 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.

(9) 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 of 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.

(10) Referring to FIG. 1A, depicted in the lower right is a subset of nine predictor directions known from the 33 possible predictor directions (corresponding to the 33 angular modes of the 35 intra modes) defined in H.265. 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.

(11) Still referring to FIG. 1A, on the top left there is depicted a square block (104) of 4×4 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 4×4 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.

(12) Intra picture prediction can work by copying reference sample values from the neighboring samples indicated 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 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.

(13) 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.

(14) 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). Currently, JEM/VVC/BMS 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.

(15) 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.

(16) The mapping of intra prediction direction bits that represent the direction in the coded video bitstream can be different from video coding technology to video coding technology. Such mapping can range, for example, from simple direct mappings, to codewords, to complex adaptive schemes involving most probable modes, and similar techniques. In most 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.

(17) Image and/or 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).

(18) 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.

(19) 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 with reference to FIG. 2 is a technique henceforth referred to as “spatial merge”.

(20) 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

(21) Aspects of the disclosure provide methods and apparatuses for video encoding and decoding. In some examples, an apparatus for video decoding includes processing circuitry. The processing circuitry is configured to decode prediction information of a current block in a current picture from a coded video bitstream. The prediction information indicating that the current block is predicted with bi-prediction. The processing circuitry can perform template matching (TM) on motion vector resolution (MVR) pairs by determining a TM cost corresponding to each one of the MVR pairs.

Each MVR pair includes (i) a first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a second MVR in a second plurality of MVRs corresponding to a second reference picture. Each TM cost can be determined based at least on a portion of a current template of the current block and a bi-predictor of the respective MVR pair where the bi-predictor is based on a portion of a first reference template in the first reference picture corresponding to the first MVR of the respective MVR pair and a portion of a second reference template in the second reference picture corresponding to the second MVR of the respective MVR pair. The processing circuitry can select an MVR pair based on the determined corresponding TM costs. The processing circuitry reconstructs the current block based on the selected MVR pair.

(22) In an embodiment, the processing circuitry reorders the MVR pairs based on the determined corresponding TM costs and selects the MVR pair from the reordered MVR pairs.

(23) In an embodiment, all of the current template of the current block comprises the entire current template. For each MVR pair, all of the first reference template comprises the entire first reference template, and all of the second reference template comprises the entire second reference template.

(24) In an example, for each MVR pair, the processing circuitry determines the first reference template based on a first motion vector (MV) having the first MVR in the MVR pair, and determines the second reference template based on a second MV having the second MVR in the MVR pair.

(25) In an example, for each MVR pair, the bi-predictor corresponding to the respective MVR pair is a weighted average of the first reference template corresponding to the first MVR in the respective MVR pair and the second reference template corresponding to the second MVR in the respective MVR pair.

(26) In an example, for each MVR pair, the first MVR in each MVR pair and the second MVR in the respective MVR pair are identical.

(27) In an example, the first MVR of one of the MVR pairs is different from the second MVR of the one of the MVR pairs.

(28) In an embodiment, the prediction information includes a flag indicating that the TM is performed on the MVR pairs.

(29) In an embodiment, the prediction information indicates that the current block is predicted with an affine adaptive motion vector prediction (Δ MVP) mode. The current template includes current subblock templates. For each MVR pair in the MVR pairs, the processing circuitry determines first reference subblock templates in the first reference template based on the current subblock templates and corresponding first motion vectors (MVs), respectively. The first MVs can be based

on positions of the respective current subblock templates and affine parameters of the current block. The processing circuitry determines second reference subblock templates in the second reference template based on the current subblock templates and corresponding second MVs, respectively. The second MVs can be based on the positions of the respective current subblock templates and the affine parameters of the current block. The bi-predictor can be based on the first reference subblock templates and the second reference subblock templates.

(30) In an example, for each MVR pair in the MVR pairs, samples in each of the first reference subblock templates have same motion information.

(31) In an example, for each MVR pair in the MVR pairs, the processing circuitry determines the first reference subblock templates based on a prediction refinement using optical flow (PROF) mode where two samples in one of the first reference subblock templates have different motion information.

(32) In an embodiment, the processing circuitry is configured to decode prediction information of a current block in a current picture from a coded video bitstream. The prediction information can indicate that the current block is predicted using bi-prediction with an affine adaptive motion vector prediction (Δ MVP) mode. The processing circuitry can perform template matching (TM) on motion vector resolution (MVR) pairs by determining a TM cost corresponding to each one of the MVR pairs. Each MVR pair includes (i) a first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a second MVR in a second plurality of MVRs corresponding to a second reference picture. Each TM cost can be determined based at least on a portion or all of a current template of the current block and a bi-predictor of the respective MVR pair. The bi-predictor can be based on a portion or all of a first reference template in the first reference picture corresponding to the first MVR of the respective MVR pair and a portion or all of a second reference template in the second reference picture corresponding to the second MVR of the respective MVR pair. The processing circuitry can perform the TM on the MVR pairs by selecting an MVR pair based on the determined corresponding TM costs. The processing circuitry can reconstruct the current block based on the selected MVR pair.

(33) In an embodiment, the processing circuitry is configured to decode prediction information of a current block in a current picture from a coded video bitstream. The prediction information can indicate that the current block is predicted using bi-prediction with an adaptive motion vector prediction (Δ MVP) mode. The processing circuitry can perform template matching (TM) on motion vector resolution (MVR) pairs by determining a TM cost corresponding to each one of the MVR pairs. Each MVR pair includes (i) a first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a second MVR in a second plurality of MVRs corresponding to a second reference picture. Each TM cost can be determined based at least on a current template of the current block and a bi-predictor of the respective MVR pair. The bi-predictor can be based on a first reference template in the first reference picture corresponding to the first MVR of the respective MVR pair and a second reference template in the second reference picture corresponding to the second MVR of the respective MVR pair. The processing circuitry can perform the TM on the MVR pairs by selecting an MVR pair based on the determined corresponding TM costs. The processing circuitry can reconstruct the current block based on the selected MVR pair.

(34) Aspects of the disclosure also provide a non-transitory computer-readable storage medium storing a program executable by at least one processor to perform the methods for video decoding.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) 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:

- (2) FIG. 1A is a schematic illustration of an exemplary subset of intra prediction modes.
- (3) FIG. 1B is an illustration of exemplary intra prediction directions.
- (4) FIG. 2 shows an example of a current block (201) and surrounding samples.
- (5) FIG. 3 is a schematic illustration of an exemplary block diagram of a communication system (300).
- (6) FIG. 4 is a schematic illustration of an exemplary block diagram of a communication system (400).
- (7) FIG. 5 is a schematic illustration of an exemplary block diagram of a decoder.
- (8) FIG. 6 is a schematic illustration of an exemplary block diagram of an encoder.
- (9) FIG. 7 shows a block diagram of an exemplary encoder.
- (10) FIG. 8 shows a block diagram of an exemplary decoder.
- (11) FIG. 9 shows positions of spatial merge candidates according to an embodiment of the disclosure.
- (12) FIG. 10 shows candidate pairs that are considered for a redundancy check of spatial merge candidates according to an embodiment of the disclosure.
- (13) FIG. 11 shows exemplary motion vector scaling for a temporal merge candidate.
- (14) FIG. 12 shows exemplary candidate positions for a temporal merge candidate of a current coding unit.
- (15) FIG. 13A shows an example of a 4-parameter affine motion model.
- (16) FIG. 13B shows an example of a 6-parameter affine motion model.
- (17) FIG. 14 shows an example of a sub-block based affine transform prediction.
- (18) FIG. 15 shows an example of determining a control point motion vector (CPMV) candidate in an affine merge list of a current CU.
- (19) FIG. 16 shows examples of spatial neighbors and a temporal neighbor of a current block.
- (20) FIG. 17 shows an example of template matching.
- (21) FIG. 18 shows an example of template matching applied to a set of motion vector resolutions (MVRs).
- (22) FIG. 19 shows an example of template matching applied to MVR pairs when a current block is coded using a bi-prediction mode.
- (23) FIG. 20 shows an example of template matching when a current block is coded with an affine mode.
- (24) FIG. 21 shows an example of a bi-prediction template matching when a current block is coded with an affine adaptive motion vector prediction (Δ MVP) mode.
- (25) FIG. 22 shows an example of a prediction refinement using optical flow (PROF) method.
- (26) FIG. 23 shows a flow chart outlining an encoding process according to an embodiment of the disclosure.
- (27) FIG. 24 shows a flow chart outlining a decoding process according to an embodiment of the disclosure.
- (28) FIG. 25 shows a flow chart outlining a decoding process according to an embodiment of the disclosure.
- (29) FIG. 26 shows a flow chart outlining a decoding process according to an embodiment of the disclosure.
- (30) FIG. 27 is a schematic illustration of a computer system in accordance with an embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

(31) FIG. 3 illustrates an exemplary block diagram of a communication system (300). 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.

(32) In another example, the communication system (300) includes a second pair of terminal devices (330) and (340) that perform bidirectional transmission of coded video data, 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.

(33) In the example of FIG. 3, the terminal devices (310), (320), (330) and (340) are respectively 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.

(34) FIG. 4 illustrates, as an example of an application for the disclosed subject matter, 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, streaming services, storing of compressed video on digital media including CD, DVD, memory stick and the like, and so on.

(35) 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), 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.

(36) 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.

(37) FIG. 5 shows an exemplary block diagram of a video decoder (510). 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.

(38) The receiver (531) may receive one or more coded video sequences to be decoded by the video decoder (510). In an embodiment, one coded video sequence is received at a time, where the decoding of each coded video sequence is independent from the decoding of 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).

(39) 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 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.

(40) 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).

(41) 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 subgroup control information 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.

(42) 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.

(43) 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).

(44) In some cases, the output samples of the scaler/inverse transform unit (551) can pertain to an intra coded block. The intra coded block 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).

(45) 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.

(46) 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). Video compression 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.

(47) 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.

(48) 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.

(49) The video decoder (510) may perform decoding operations according to a predetermined video compression technology or 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.

(50) 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.

(51) FIG. 6 shows an exemplary block diagram of a video encoder (603). 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.

(52) 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).

(53) 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.

(54) 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. 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.

(55) 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. 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.

(56) 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).

(57) In an embodiment, a decoder technology except the parsing/entropy decoding that is present in a decoder is present, in an identical or a substantially identical functional form, in a corresponding encoder. Accordingly, 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. In certain areas a more detail description is provided below.

(58) 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.

(59) 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 memory (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).

(60) 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).

(61) 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.

(62) 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 applying lossless compression to the symbols according to technologies such as Huffman coding, variable length coding, arithmetic coding, and so forth.

(63) 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 encoder (603) with other data to be transmitted, for example, coded audio data and/or ancillary data streams (sources not shown).

(64) 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:

(65) 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.

(66) 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.

(67) 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.

(68) Source pictures commonly may be subdivided spatially into a plurality of sample blocks (for example, blocks of 4×4, 8×8, 4×8, or 16×16 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.

(69) 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.

(70) 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.

(71) 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.

(72) 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.

(73) Further, a merge mode technique can be used in the inter-picture prediction to improve coding efficiency.

(74) 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 64×64 pixels, 32×32 pixels, or 16×16 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 64×64 pixels can be split into one CU of 64×64 pixels, or 4 CUs of 32×32 pixels, or 16 CUs of 16×16 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 8×8 pixels, 16×16 pixels, 8×16 pixels, 16×8 pixels, and the like.

(75) FIG. 7 shows an exemplary diagram of a video encoder (703). 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.

(76) In an HEVC example, the video encoder (703) receives a matrix of sample values for a processing block, such as a prediction block of 8×8 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.

(77) In the FIG. 7 example, the video encoder (703) includes an 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.

(78) 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.

(79) 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 generate 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.

(80) 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.

(81) 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.

(82) 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 in the bitstream 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.

(83) FIG. 8 shows an exemplary diagram of a video decoder (810). 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.

(84) 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.

(85) 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) and 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. The symbols can also include 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).

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

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

(88) 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 information 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).

(89) The reconstruction module (874) is configured to combine, in the spatial domain, the residual information 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.

(90) 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.

(91) Various inter prediction modes can be used in VVC. For an inter-predicted CU, motion parameters can include MV(s), one or more reference picture indices, a reference picture list usage index, and additional information for certain coding features to be used for inter-predicted sample generation. A motion parameter can be signaled explicitly or implicitly. When a CU is coded with a skip mode, the CU can be associated with a PU and can have no significant residual coefficients, no coded motion vector delta or MV difference (e.g., MVD) or a reference picture index. A merge mode can be specified where the motion parameters for the current CU are obtained from neighboring CU(s), including spatial and/or temporal candidates, and optionally additional information such as introduced in VVC. The merge mode can be applied to an inter-predicted CU,

not only for skip mode. In an example, an alternative to the merge mode is the explicit transmission of motion parameters, where MV(s), a corresponding reference picture index for each reference picture list and a reference picture list usage flag and other information are signaled explicitly per CU.

(92) In an embodiment, such as in VVC, VVC Test model (VTM) reference software includes one or more refined inter prediction coding tools that include: an extended merge prediction, a merge motion vector difference (MMVD) mode, an adaptive motion vector prediction (Δ MVP) mode with symmetric MVD signaling, an affine motion compensated prediction, a subblock-based temporal motion vector prediction (SbTMVP), an adaptive motion vector resolution (Δ MVR), a motion field storage (1/16th luma sample MV storage and 8×8 motion field compression), a bi-prediction with CU-level weights (BCW), a bi-directional optical flow (BDOF), a prediction refinement using optical flow (PROF), a decoder side motion vector refinement (DMVR), a combined inter and intra prediction (CIIP), a geometric partitioning mode (GPM), and the like. Inter predictions and related methods are described in details below.

(93) Extended merge prediction can be used in some examples. In an example, such as in VTM4, a merge candidate list is constructed by including the following five types of candidates in order: spatial motion vector predictor(s) (MVP(s)) from spatial neighboring CU(s), temporal MVP(s) from collocated CU(s), history-based MVP(s) from a first-in-first-out (FIFO) table, pairwise average MVP(s), and zero MV(s).

(94) A size of the merge candidate list can be signaled in a slice header. In an example, the maximum allowed size of the merge candidate list is 6 in VTM4. For each CU coded in the merge mode, an index (e.g., a merge index) of a best merge candidate can be encoded using truncated unary binarization (TU). The first bin of the merge index can be coded with context (e.g., context-adaptive binary arithmetic coding (CABAC)) and a bypass coding can be used for other bins.

(95) Some examples of a generation process of each category of merge candidates are provided below. In an embodiment, spatial candidate(s) are derived as follows. The derivation of spatial merge candidates in VVC can be identical to that in HEVC. In an example, a maximum of four merge candidates are selected among candidates located in positions depicted in FIG. 9. FIG. 9 shows positions of spatial merge candidates according to an embodiment of the disclosure. Referring to FIG. 9, an order of derivation is B1, A1, B0, A0, and B2. The position B2 is considered only when any CU of positions A0, B0, B1, and A1 is not available (e.g. because the CU belongs to another slice or another tile) or is intra coded. After a candidate at the position A1 is added, the addition of the remaining candidates is subject to a redundancy check which ensures that candidates with same motion information are excluded from the candidate list so that coding efficiency is improved.

(96) To reduce computational complexity, not all possible candidate pairs are considered in the mentioned redundancy check. Instead, only pairs linked with an arrow in FIG. 10 are considered and a candidate is only added to the candidate list if the corresponding candidate used for the redundancy check does not have the same motion information. FIG. 10 shows candidate pairs that are considered for a redundancy check of spatial merge candidates according to an embodiment of the disclosure. Referring to FIG. 10, the pairs linked with respective arrows include A1 and B1, A1 and A0, A1 and B2, B1 and B0, and B1 and B2. Thus, candidates at the positions B1, A0, and/or B2 can be compared with the candidate at the position A1, and candidates at the positions B0 and/or B2 can be compared with the candidate at the position B1.

(97) In an embodiment, temporal candidate(s) are derived as follows. In an example, only one temporal merge candidate is added to the candidate list. FIG. 11 shows exemplary motion vector scaling for a temporal merge candidate. To derive the temporal merge candidate of a current CU (1111) in a current picture (1101), a scaled MV (1121) (e.g., shown by a dotted line in FIG. 11) can be derived based on a co-located CU (1112) belonging to a collocated reference picture (1104). A reference picture list used to derive the co-located CU (1112) can be explicitly signaled in a slice

header. The scaled MV(**1121**) for the temporal merge candidate can be obtained as shown by the dotted line in FIG. **11**. The scaled MV (**1121**) can be scaled from the MV of the co-located CU (**1112**) using picture order count (POC) distances tb and td. The POC distance tb can be defined to be the POC difference between a current reference picture (**1102**) of the current picture (**1101**) and the current picture (**1101**). The POC distance td can be defined to be the POC difference between the co-located reference picture (**1104**) of the co-located picture (**1103**) and the co-located picture (**1103**). A reference picture index of the temporal merge candidate can be set to zero.

(98) FIG. **12** shows exemplary candidate positions (e.g., C0 and C1) for a temporal merge candidate of a current CU. A position for the temporal merge candidate can be selected between the candidate positions C0 and C1. The candidate position C0 is located at a bottom-right corner of a co-located CU (**1210**) of the current CU. The candidate position C1 is located at a center of the co-located CU (**1210**) of the current CU (**1210**). If a CU at the candidate position C0 is not available, is intra coded, or is outside of a current row of CTUs, the candidate position C1 is used to derive the temporal merge candidate. Otherwise, for example, the CU at the candidate position C0 is available, intra coded, and in the current row of CTUs, the candidate position C0 is used to derive the temporal merge candidate.

(99) In some examples, a translation motion model is applied for motion compensation prediction (MCP). However, the translational motion model may not be suitable for modeling other types of motions, such as zoom in/out, rotation, perspective motions, and the other irregular motions. In some embodiments, a block-based affine transform motion compensation prediction is applied. In FIG. **13A**, an affine motion field of a block is described by two control point motion vectors (CPMVs), CPMV0 and CPMV1, of two control points (CPs), CP0 and CP1 when a 4-parameter affine model is used. In FIG. **13B**, an affine motion field of a block is described by three CPMVs, CPMV0, CPMV1 and CPMV3, of CPs, CP0, CP1, and CP2 when a 6-parameter affine model is used.

(100) For a 4-parameter affine motion model, a motion vector at a sample location (x, y) in a block is derived as:

$$(101) \quad \begin{cases} mv_x = \frac{mv_{1x} - mv_{0x}}{W}x + \frac{mv_{1y} - mv_{0y}}{W}y + mv_{0x} \\ mv_y = \frac{mv_{1y} - mv_{0y}}{W}x + \frac{mv_{1x} - mv_{0x}}{W}y + mv_{0y} \end{cases} \quad \text{Eq. 1}$$

(102) For a 6-parameter affine motion model, a motion vector at sample location (x, y) in a block is derived as:

$$(103) \quad \begin{cases} mv_x = \frac{mv_{1x} - mv_{0x}}{W}x + \frac{mv_{2x} - mv_{0x}}{H}y + mv_{0x} \\ mv_y = \frac{mv_{1y} - mv_{0y}}{W}x + \frac{mv_{2y} - mv_{0y}}{H}y + mv_{0y} \end{cases} \quad \text{Eq. 2}$$

(104) In Eqs. 1-2, (mv.sub.0x, mv.sub.0y) is a motion vector of the top-left corner control point, (mv.sub.1x, mv.sub.1y) is motion vector of the top-right corner control point, and (mv.sub.2x, mv.sub.2y) is motion vector of the bottom-left corner control point. In addition, the coordinate (x, y) is with respect to the top-left corner of the respective block, and W and H denotes the width and height of the respective block.

(105) In order to simplify the motion compensation prediction, a sub-block based affine transform prediction is applied in some embodiments. For example, in FIG. **14**, the 4-parameter affine motion model is used, and two CPMVs, {right arrow over (v.sub.0)} and {right arrow over (v.sub.1)}, are determined. To derive a motion vector of each 4×4 (samples) luma sub-block (**1402**) partitioned from the current block (**1410**), a motion vector (**1401**) of the center sample of each sub-block (**1402**) is calculated according to Eq. 1, and rounded to a 1/16 fraction accuracy. Then, motion compensation interpolation filters are applied to generate a prediction of each sub-block (**1402**) with the derived motion vector (**1401**). The sub-block size of chroma-components is set to be 4×4. A MV of a 4×4 chroma sub-block is calculated as the average of the MVs of the four corresponding

4×4 luma sub-blocks.

(106) Similar to translational motion inter prediction, two affine motion inter prediction modes, affine merge mode and affine Δ MVP mode, are employed in some embodiments.

(107) In some embodiments, an affine merge mode can be applied for CUs with both width and height larger than or equal to 8. Affine merge candidates of a current CU can be generated based on motion information of spatial neighboring CUs. There can be up to five affine merge candidates and an index is signaled to indicate the one to be used for the current CU. For example, the following three types of affine merge candidates are used to form an affine merge candidate list: (i) Inherited affine merge candidates that are extrapolated from CPMVs of the neighbor CUs; (ii) Constructed affine merge candidates that are derived using the translational MVs of the neighbor CUs; and (iii) Zero MVs.

(108) In some embodiments, there can be at most two inherited affine candidates which are derived from affine motion models of the neighboring blocks, one from left neighboring CUs and one from above neighboring CUs. The candidate blocks, for example, can be located at positions shown in FIG. 9. For the left predictor, the scan order is $A0 > A1$, and for the above predictor, the scan order is $B0 > B1 > B2$. Only the first inherited candidate from each side is selected. No pruning check is performed between two inherited candidates.

(109) When a neighboring affine CU is identified, CPMVs of the identified neighboring affine CU are used to derive a CPMV candidate in the affine merge list of the current CU. As shown in FIG. 15, a neighbor left bottom block A of a current CU (1510) is coded in an affine mode. Motion vectors, $\{\overrightarrow{v_{sub.2}}\}$, $\{\overrightarrow{v_{sub.3}}\}$ and $\{\overrightarrow{v_{sub.4}}\}$ of the top left corner, above right corner and left bottom corner of a CU (1520) which contains the block A are attained. When block A is coded with a 4-parameter affine model, two CPMVs $\{\overrightarrow{v_{sub.0}}\}$ and $\{\overrightarrow{v_{sub.1}}\}$ of the current CU (1510) are calculated according to $\{\overrightarrow{v_{sub.2}}\}$, and $\{\overrightarrow{v_{sub.3}}\}$. In case that block A is coded with 6-parameter affine model, three CPMVs (not shown) of the current CU are calculated according to $\{\overrightarrow{v_{sub.2}}\}$, $\{\overrightarrow{v_{sub.3}}\}$ and $\{\overrightarrow{v_{sub.4}}\}$.

(110) Constructed affine candidates are constructed by combining neighbor translational motion information of each control point. The motion information for the control points is derived from specified spatial neighbors and temporal neighbor shown in FIG. 16. CPMV_k (k=1, 2, 3, 4) represents the k-th control point. For CPMV1, the $B2 > B3 > A2$ blocks are checked in order and the MV of the first available block is used. For CPMV2, the $B1 > B0$ blocks are checked and for CPMV3, the $A1 > A0$ blocks are checked. A TMVP at block T is used as CPMV4 if available.

(111) After MVs of four control points are attained, affine merge candidates are constructed based on that motion information. The following combinations of control point MVs are used to construct in order: {CPMV1, CPMV2, CPMV3}, {CPMV1, CPMV2, CPMV4}, {CPMV1, CPMV3, CPMV4}, {CPMV2, CPMV3, CPMV4}, {CPMV1, CPMV2}, {CPMV1, CPMV3}.

(112) The combination of 3 CPMVs constructs a 6-parameter affine merge candidate and the combination of 2 CPMVs constructs a 4-parameter affine merge candidate. To avoid a motion scaling process, if the reference indices of control points are different, the related combination of control point MVs is discarded.

(113) After inherited affine merge candidates and constructed affine merge candidates are checked, if the list is still not full, zero MVs are inserted to the end of the merge candidate list.

(114) In some embodiments, affine Δ MVP mode can be applied for CUs with both width and height larger than or equal to 16. An affine flag in CU level is signaled in the bitstream to indicate whether affine Δ MVP mode is used and then another flag is signaled to indicate whether 4-parameter affine or 6-parameter affine is used. A difference of the CPMVs of current CU and their predictors is signaled in the bitstream. An affine AVMP candidate list size is 2, and can be generated by using the following four types of CPVM candidate in order: (i) Inherited affine

Δ MVP candidates that are extrapolated from the CPMVs of the neighbor CUs; (ii) Constructed affine Δ MVP candidates that are derived using the translational MVs of the neighbor CUs; (iii) Translational MVs from neighboring CUs; and (iv) Zero MVs.

(115) The checking order of inherited affine Δ MVP candidates is similar to the checking order of inherited affine merge candidates in an example. The difference is that, for AVMP candidate, the affine CU that has the same reference picture as in current block is considered. No pruning process is applied when inserting an inherited affine motion predictor into the candidate list.

(116) Constructed Δ MVP candidate is derived from the specified spatial neighbors shown in FIG. 16. A same checking order is used as done in affine merge candidate construction. In addition, a reference picture index of a neighboring block is also checked. The first block in the checking order that is inter coded and has the same reference picture as in current CUs is used. When the current CU is coded with a 4-parameter affine model, and CPMV0 and CPMV1 are both available, the available CPMVs are added as one candidate in the affine Δ MVP list. When the current CU is coded with 6-parameter affine mode, and all three CPMVs (CPMV0, CPMV1, and CPMV2) are available, the available CPMVs are added as one candidate in the affine Δ MVP list. Otherwise, constructed Δ MVP candidates are set as unavailable.

(117) If affine Δ MVP list candidates is still less than 2 after inherited affine Δ MVP candidates and constructed Δ MVP candidate are checked, translational motion vectors neighboring the control points will be added to predict all control point MVs of the current CU, when available. Finally, zero MVs are used to fill the affine Δ MVP list if the affine Δ MVP list is still not full.

(118) An adaptive motion vector resolution (Δ MVR) mode can be used in video/image coding, such as in VVC. In some technologies, such as the video coding standards HEVC and AVC/H.264, a fixed motion vector resolution (MVR) of a quarter ($\frac{1}{4}$) luma samples (or $\frac{1}{4}$ -pel) is used. In general, an optimum trade-off between a displacement vector rate and a prediction error rate is chosen to optimize the rate-distortion. In related technologies, such as VVC, the Δ MVR mode is enabled where an MVR can be selected, for example, at a coding block level from a plurality of MVRs, and thus to trade off a bit rate for fidelity of signaling motion parameters. The Δ MVR mode can be signaled at the coding block level, for example, if at least one component of an MVD is not equal to zero. A motion vector predictor (MVP) can be rounded to the given MVR such that a resulting MV (e.g., a sum of the MVP and the MVD) can fall on a grid of the given MVR.

(119) In some examples, a flag, such as an Δ MVR flag (e.g., `amvr_flag`) specifies a resolution (e.g., an MVR) of an MVD. In an example, the Δ MVR flag (e.g., the `amvr_flag`) being equal to 0 specifies that the MVR of the MVD is $\frac{1}{4}$ luma samples ($\frac{1}{4}$ -pel). The Δ MVR flag (e.g., `amvr_flag`) being equal to 1 specifies that the MVR of the MVD is further specified by addition information such as an index (e.g., an Δ MVR precision index). For example, the coding block is predicted with the Δ MVP mode and the Δ MVR flag (e.g., `amvr_flag`) is 1, and thus the MVR is $\frac{1}{2}$ luma samples ($\frac{1}{2}$ -pel), 1 luma sample (1-pel), or 4 luma samples (4-pel) when the Δ MVR precision index is 0, 1, or 2, respectively.

(120) A template matching (TM) technique can be used in video/image coding. To further improve the compression efficiency of VVC standard, for example, TM can be used to refine an MV. In an example, the TM is used at a decoder side. With the TM mode, an MV can be refined by constructing a template (e.g., a current template) of a block (e.g., a current block) in a current picture and determine the closest matching between the template of the block in the current picture and a plurality of possible templates (e.g., a plurality of possible reference templates) in a reference picture. In an embodiment, the template of the block in the current picture can include left neighboring reconstructed samples of the block and above neighboring reconstructed samples of the block. The TM can be used in video/image coding beyond VVC.

(121) FIG. 17 shows an example of template matching (1700). The TM can be used to derive motion information (e.g., deriving final motion information from initial motion information, such as an initial MV 1702) of a current CU (e.g., a current block) (1701) by determining the closest

match between a template (e.g., a current template) (1721) of the current CU (1701) in a current picture (1710) and a template (e.g., a reference template) of a plurality of possible templates (e.g., one of the plurality of possible templates being a template (1725)) in a reference picture (1711). The template (1721) of the current CU (1701) can have any suitable shape and any suitable size. (122) In an embodiment, the template (1721) of the current CU (1701) includes a top template (1722) and a left template (1723). Each of the top template (1722) and the left template (1723) can have any suitable shape and any suitable size.

(123) The top template (1722) can include samples in one or more top neighboring blocks of the current CU (1701). In an example, the top template (1722) includes four rows of samples in one or more top neighboring blocks of the current CU (1701). The left template (1723) can include samples in one or more left neighboring blocks of the current CU (1701). In an example, the left template (1723) includes four columns of samples in the one or more left neighboring blocks of the current CU (1701).

(124) Each one (e.g., the template (1725)) of the plurality of possible templates in the reference picture (1711) corresponds to the template (1721) in the current picture (1710). In an embodiment, the initial MV (1702) points from the current CU (1701) to a reference block (1703) in the reference picture (1711). Each one (e.g., the template (1725)) of the plurality of possible templates in the reference picture (1711) and the template (1721) in the current picture (1710) can have an identical shape and an identical size. For example, the template (1725) of the reference block (1703) includes a top template (1726) in the reference picture (1711) and a left template (1727) in the reference picture (1711). The top template (1726) can include samples in one or more top neighboring blocks of the reference block (1703). The left template (1727) can include samples in one or more left neighboring blocks of the reference block (1703).

(125) A TM cost can be determined based on a pair of templates, such as the template (e.g., the current template) (1721) and the template (e.g., the reference template) (1725). The TM cost can indicate matching between the template (1721) and the template (1725). An optimized MV (or a final MV) can be determined based on a search around the initial MV (1702) of the current CU (1701) within a search range (1715). The search range (1715) can have any suitable shape and any suitable number of reference samples. In an example, the search range (1715) in the reference picture (1711) includes a $[-L, L]$ -pel range where L is a positive integer, such as 8 (e.g., 8 samples). For example, a difference (e.g., $[0, 1]$) is determined based on the search range (1715), and an intermediate MV is determined by a summation of the initial MV (1702) and the difference (e.g., $[0, 1]$). An intermediate reference block and a corresponding template in the reference picture (1711) can be determined based on the intermediate MV. A TM cost can be determined based on the template (1721) and the intermediate template in the reference picture (1711). The TM costs can correspond to the differences (e.g., $[0, 0]$ corresponding to the initial MV (1702), $[0, 1]$, and the like) that are determined based on the search range (1715). In an example, the difference corresponding to the smallest TM cost is selected, and the optimized MV is the summation of the difference corresponding to the smallest TM cost and the initial MV (1702). As described above, the TM can derive the final motion information (e.g., the optimized MV) from the initial motion information (e.g., the initial MV 1702).

(126) The TM can be suitably modified. In an example, a search step size is determined by the Δ MVR mode. In an example, the TM can be cascaded (e.g., used together) with other coding method(s), such as a bilateral matching process.

(127) In related technologies, an MV resolution index (e.g., the Δ MVR precision index) in the Δ MVR mode is encoded according to a fixed order for the bi-prediction and the affine mode (e.g., the affine merge mode, the affine Δ MVP mode, or the like). For example, in the bi-prediction mode, a relationship between (i) each MVR index or each MVR index pair and (ii) each corresponding MVR or pair of MVRs is fixed. Signaling the MVR index (or MVR indices) for the bi-prediction and the affine mode may not be efficient when the MVR index in the Δ MVR mode is

encoded in the fixed order.

(128) A set of MVRs (also referred to as a set of MV precisions) in the Δ MVP mode is available to code a current block. According to an aspect of the disclosure, template matching (TM) can be performed using a plurality of MVRs in the set of MVRs. The TM can be performed by (i) determining TM costs corresponding to each of the plurality of MVRs based on motion information (e.g., the motion information shared by the plurality of MVRs) and each of the plurality of MVRs, (ii) ranking or reordering the plurality of MVRs based on the determined TM costs respectively corresponding to each of the plurality of MVRs, and (iii) selecting an MVR from the ranked or reordered plurality of MVRs. In an example, the motion information indicates MVP information that is used to determine MVP candidate(s) and MVD information. In an example, the motion information shared by the plurality of MVRs includes a candidate index that points to an MVP candidate in a candidate list. MVPs of the plurality of MVRs can be determined based on the MVP candidate indicated by the motion information and the plurality of MVRs, and thus can be different for the plurality of MVRs. MVs of the plurality of MVRs used to determine the TM costs in the TM can be based on the respective MVPs.

(129) For example, for each of the plurality of MVRs, such as $\frac{1}{2}$ -pel for example, an MV or an MVP associated with the MVR (e.g., $\frac{1}{2}$ -pel) can be determined based on the MVR and the motion information (e.g., the candidate index that points to the MVP candidate in the candidate list). The MV and/or the MVP associated with the MVR is determined based on the motion information and the MVR. The MV and/or the MVP associated with the MVR can indicate a reference block associated with the MVR (e.g., $\frac{1}{2}$ -pel) in a reference picture. For example, the determined MV associated with the MVR (e.g., $\frac{1}{2}$ -pel) points from the current block in a current picture to the reference block associated with the MVR (e.g., $\frac{1}{2}$ -pel) in the reference picture. A cost (e.g., a TM cost) corresponding to the MVR (e.g., $\frac{1}{2}$ -pel) can be determined based on a current template of the current block in the current picture and a reference template of the reference block associated with the MVR (e.g., $\frac{1}{2}$ -pel) in the reference picture. The plurality of MVRs can be ranked (e.g., reordered) based on the determined TM costs respectively. In an example, the plurality of MVRs is ranked (e.g., reordered) in an ascending order of the TM costs when a flag (e.g., a `sps_amvr_enabled_flag`) is true.

(130) In an example, the set of MVRs in the Δ MVP mode includes $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel. In an example, the plurality of MVRs is the set of MVRs. In another example, the plurality of MVRs is a subset of the set of MVRs that excludes the highest resolution (e.g., $\frac{1}{4}$ -pel). For example, the plurality of MVRs includes $\frac{1}{2}$ -pel, 1-pel, and 4-pel and excludes $\frac{1}{4}$ -pel.

(131) FIG. 18 shows an example of template matching (1800) applied to the set of MVRs. Template matching can be performed on a current template (1821) of a current block (1801) in a current picture (1810) and reference templates (1851)-(1854) of respective reference blocks (1831)-(1834) in a reference picture (1811). The current template (1821) can have any suitable shape and any suitable size. Shape(s) and size(s) of the reference templates (1851)-(1854) can match the shape and the size of the current template (1821), respectively. In an embodiment, the current template (1821) includes a top template and a left template.

(132) An MV (1841) corresponding to the $\frac{1}{4}$ -pel resolution points from the current block (1801) to the reference block (1831) in the reference picture (1811). An MV (1842) corresponding to the $\frac{1}{2}$ -pel resolution points from the current block (1801) to the reference block (1832) in the reference picture (1811). An MV (1843) corresponding to the 1-pel resolution points from the current block (1801) to the reference block (1833) in the reference picture (1811). An MV (1844) corresponding to the 4-pel resolution points from the current block (1801) to the reference block (1834) in the reference picture (1811).

(133) The template matching between the current template (1821) of the current block (1801) and the respective reference templates (1851)-(1854) in the reference picture (1811) can be performed as follows. A TM cost (TM0) is calculated based on the reference template (1851) and the current

template (**1821**). A TM cost (TM1) is calculated based on the reference template (**1852**) and the current template (**1821**). A TM cost (TM2) is calculated based on the reference template (**1853**) and the current template (**1821**). A TM cost (TM4) is calculated based on the reference template (**1854**) and the current template (**1821**). The TM costs can be determined based on a sum of absolute difference (SAD) between the current template (**1821**) and the respective reference template (e.g., (**1851**)). Other functions, such as sum of squared errors (SSE), a variance, a partial SAD, or the like can also be used to determine the TM costs.

(134) Subsequently, the MVRs can be ranked (e.g., reordered) based on the TM costs, for example, in an ascending order of the corresponding TM costs between the current template (**1821**) and the reference templates (**1851**)-(**1854**) that correspond to the set of MVRs. In an example, the set of MVRs includes $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel, and the TM costs in the ascending order is TM2, TM1, TM3, and TM0. TM2 is the smallest of TM0-TM3. The set of MVRs can be ranked (e.g., reordered) as 1-pel, $\frac{1}{2}$ -pel, 4-pel, and $\frac{1}{4}$ -pel.

(135) A flag, such as a TM- Δ MVR flag (e.g., a `tm_amvr_flag`) can be used to indicate which MVR is selected for the current block (**1801**). In an example, the TM- Δ MVR flag (e.g., the `tm_amvr_flag`) being false indicates that a first MVR (e.g., 1-pel) corresponding to the smallest TM cost (e.g., TM2) in the TM costs (e.g., TM0-TM3) is selected. When the TM- Δ MVR flag (e.g., the `tm_amvr_flag`) is true, an index, such as a TM- Δ MVR precision index (e.g., a `tm_amvr_precision_idx`) is further signaled, for example, to indicate which MVR is selected for the current block (**1801**). The MVR can be selected from remaining MVRs (e.g., TM0, TM1, and TM3) in the set of MVRs that exclude the first MVR (e.g., 1-pel). For example, the ranked remaining MVRs is TM1, TM3, and TM0. The Δ MVR precision index (e.g., a `tm_amvr_precision_idx`) of 0, 1, or 2 indicates that the MVR is TM1, TM3, or TM0, respectively.

(136) An exemplary pseudo syntax is shown as follows in Table 1. When certain conditions are met, such as the Δ MVR mode being enabled (e.g., the `sps_amvr_enabled_flag` being true), the affine mode not being enabled (e.g., an `inter_affine_flag` being false), and at least one component of an MVD of the current block (**1801**) not equal to zero, the TM- Δ MVR flag (e.g., the `tm_amvr_flag`) is signaled. When the TM- Δ MVR flag (e.g., the `tm_amvr_flag`) is false, the first MVR corresponding to the smallest TM cost in the TM costs is selected, and the TM- Δ MVR precision index (e.g., the `tm_amvr_precision_idx`) is not signaled. Otherwise, when the TM- Δ MVR flag (e.g., the `tm_amvr_flag`) is true, the TM- Δ MVR precision index (e.g., the `tm_amvr_precision_idx`) is signaled.

(137) TABLE-US-00001 TABLE 1 if(`sps_amvr_enabled_flag` && `inter_affine_flag`[`x0`][`y0`] = 0 && (`MvdL0`[`x0`][`y0`][0] != 0 || `MvdL0`[`x0`][`y0`][1] != 0 || `MvdL1`[`x0`][`y0`][0] != 0 || `MvdL1`[`x0`][`y0`][1] != 0)) { `tm_amvr_flag`[`x0`][`y0`] if(`tm_amvr_flag`[`x0`][`y0`]) `tm_amvr_precision_idx`[`x0`][`y0`] }

(138) In an embodiment, the TM is applied to all or some of the MVRs in the set of MVRs. For example, the set of MVRs includes $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel, and the plurality of MVRs to which TM is applied includes $\frac{1}{2}$ -pel, 1-pel, and 4-pel and excludes $\frac{1}{4}$ -pel. In this case, when a flag, such as the Δ MVR flag, is false, $\frac{1}{4}$ -pel is used to code the current block (**1801**).

(139) The template matching can be performed on the plurality of MVRs (e.g., $\frac{1}{2}$ -pel, 1-pel, and 4-pel) as a variation of FIG. 18. For example, the TM costs TM1, TM2, and TM3 corresponding to $\frac{1}{2}$ -pel, 1-pel, and 4-pel, respectively are calculated as described in FIG. 18 and TM0 is not calculated. Subsequently, the plurality of MVRs (e.g., $\frac{1}{2}$ -pel, 1-pel, and 4-pel) are reordered in an ascending order (e.g., TM2, TM1, and TM3 with TM2 being the smallest of TM1, TM2, and TM3) of the corresponding TM costs between the current template (**1821**) in the current picture (**1810**) and the reference blocks (e.g., (**1832**)-(**1834**)) in the reference picture (**1811**). The plurality of MVRs can be ranked (e.g., reordered) as 1-pel, $\frac{1}{2}$ -pel, and 4-pel. An index, such as the TM- Δ MVR precision index (e.g., the `tm_amvr_precision_idx`) is signaled, for example, to indicate which MVR is selected for the current block. The MVR can be selected from the plurality of MVRs (e.g., TM1-

TM3). The TM-ΔMVR precision index (e.g., the `tm_amvr_precision_idx`) of 0, 1, or 2 indicates that the MVR is TM2, TM1, or TM3, respectively.

(140) An exemplary pseudo syntax is shown as follows in Table 2. When certain conditions are met, such as the ΔMVR mode being enabled (e.g., the `sps_amvr_enabled_flag` being true), the affine mode not being enabled (e.g., the `inter_affine_flag` being false), and at least one component of an MVD of the current block (**1801**) not equal to zero, the ΔMVR flag (e.g., the `amvr_flag`) is signaled. When the ΔMVR flag (e.g., the `amvr_flag`) is false, ¼-pel is selected, and the TM-ΔMVR precision index (e.g., the `tm_amvr_precision_idx`) is not signaled. Otherwise, when the ΔMVR flag (e.g., the `amvr_flag`) is true, the TM-ΔMVR precision index (e.g., the `tm_amvr_precision_idx`) is signaled.

(141) TABLE-US-00002 TABLE 2 if((`sps_amvr_enabled_flag` && `inter_affine_flag`[`x0`][`y0`] = 0 && (`MvdL0`[`x0`][`y0`][0] != 0 || `MvdL0`[`x0`][`y0`][1] != 0 || `MvdL1`[`x0`][`y0`][0] != 0 || `MvdL1`[`x0`][`y0`][1] != 0))) { `amvr_flag`[`x0`][`y0`] if(`amvr_flag`[`x0`][`y0`]) `tm_amvr_precision_idx`[`x0`][`y0`] }

(142) In an embodiment, the TM is applied to the set of MVRs. For example, the set of MVRs includes ¼-pel, ½-pel, 1-pel, and 4-pel. The template matching can be performed on the set of MVRs. For example, the TM costs TM0-TM3 corresponding to ¼-pel, ½-pel, 1-pel, and 4-pel, respectively are calculated as described in FIG. 18. Subsequently, the set of MVRs are reordered in the ascending order (e.g., TM2, TM1, TM3, and TM0 with TM2 being the smallest of TM0-TM3) of the corresponding TM costs between the current template (**1821**) in the current picture (**1810**) and the reference templates (e.g., (**1851**)-(**1854**)) in the reference picture (**1811**). The set of MVRs can be ranked (e.g., reordered) as 1-pel, ½-pel, 4-pel, and ¼-pel.

(143) The TM-ΔMVR flag (e.g., the `tm_amvr_flag`) can be set as true when the MVR (e.g., 1-pel) with the smallest TM cost (e.g., TM2) is chosen. Otherwise, the TM-ΔMVR flag (e.g., the `tm_amvr_flag`) can be set as false and the regular ΔMVR signaling is used. In the regular ΔMVR signaling, the ΔMVR flag is signaled. If the ΔMVR flag is false, ¼-pel is used to code the current block. If the ΔMVR flag is true, the ΔMVR precision index (e.g., the `amvr_precision_idx`) is signaled, for example, to indicate which MVR in the plurality of MVRs (e.g., TM1-TM3) is selected for the current block. The MVR can be selected from the plurality of MVRs (e.g., TM1-TM3). The ΔMVR precision index (e.g., the `amvr_precision_idx`) of 0, 1, or 2 indicates that the MVR is TM1, TM2, or TM3, respectively.

(144) An exemplary pseudo syntax is shown as follows in Table 3. When certain conditions are met, such as the ΔMVR mode being enabled (e.g., the `sps_amvr_enabled_flag` being true), the affine mode not being enabled (e.g., the `inter_affine_flag` being false), and at least one component of an MVD of the current block not equal to zero, the TM-ΔMVR flag (e.g., the `tm_amvr_flag`) is signaled. When the TM-ΔMVR flag (e.g., the `tm_amvr_flag`) is false, the following is performed. For example, the ΔMVR flag (e.g., the `amvr_flag`) is signaled. When the ΔMVR flag (e.g., the `amvr_flag`) is false, ¼-pel is selected, and the ΔMVR precision index (e.g., the `amvr_precision_idx`) is not signaled. Otherwise, when the ΔMVR flag (e.g., the `amvr_flag`) is true, the ΔMVR precision index (e.g., the `amvr_precision_idx`) is signaled.

(145) TABLE-US-00003 TABLE 3 if((`sps_amvr_enabled_flag` && `inter_affine_flag`[`x0`][`y0`] = 0 && (`MvdL0`[`x0`][`y0`][0] != 0 || `MvdL0`[`x0`][`y0`][1] != 0 || `MvdL1`[`x0`][`y0`][0] != 0 || `MvdL1`[`x0`][`y0`][1] != 0))) { `tm_amvr_flag`[`x0`][`y0`] if(`tm_amvr_flag`[`x0`][`y0`] == 0) { `amvr_flag`[`x0`][`y0`] if(`amvr_flag`[`x0`][`y0`]) `amvr_precision_idx`[`x0`][`y0`] }

(146) In an embodiment, the ΔMVR flag (e.g., the `amvr_flag`) is signaled to indicate whether the ΔMVR mode is enabled or not.

(147) If the ΔMVR mode is not enabled (e.g., the ΔMVR flag is false), ¼-pel can be selected.

(148) If the ΔMVR mode is enabled (e.g., the ΔMVR flag is true), the TM-ΔMVR flag (e.g., the `tm_amvr_flag`) is signaled to indicate whether the MVR with the smallest TM cost is selected.

(149) When the TM-ΔMVR flag (e.g., the `tm_amvr_flag`) is true, the template matching is applied to the plurality of MVRs (e.g., ½-pel, 1-pel, and 4-pel) that excludes ¼-pel. For example, the TM costs **TM1**, **TM2**, and **TM3** corresponding to ½-pel, 1-pel, and 4-pel, respectively are calculated as described in FIG. 18 and **TM0** is not calculated. Subsequently, the plurality of MVRs (e.g., ½-pel, 1-pel, and 4-pel) are reordered in an ascending order (e.g., **TM2**, **TM1**, and **TM3** with **TM2** being the smallest of **TM1**-**TM3**) of the corresponding TM costs between the current template (**1821**) in the current picture (**1810**) and the reference templates (e.g., (**1852**)-(**1854**)) in the reference picture (**1811**). The plurality of MVRs can be ranked (e.g., reordered) as the 1-pel, the ½-pel, and the 4-pel. The MVR (e.g., 1-pel) is selected corresponding to the smallest TM cost (e.g., **TM2**) in the plurality of MVRs (e.g., ½-pel, 1-pel, and 4-pel) that excludes ¼-pel.

(150) When the TM-ΔMVR flag (e.g., the `tm_amvr_flag`) is set as false, the ΔMVR precision index is signaled and the MVR is selected based on the ΔMVR precision index and without reordering the MVRs. For example, the MVR is ½-pel, 1-pel, or 4-pel when the ΔMVR precision index is 0, 1, or 2, respectively.

(151) TABLE-US-00004 TABLE 4 if((`sps_amvr_enabled_flag` && `inter_affine_flag`[`x0`][`y0`] = 0 && (`MvdL0`[`x0`][`y0`][0] != 0 || `MvdL0`[`x0`][`y0`][1] != 0 || `MvdL1`[`x0`][`y0`][0] != 0 || `MvdL1`[`x0`][`y0`][1] != 0)) { `amvr_flag`[`x0`][`y0`] if(`amvr_flag`[`x0`][`y0`]) { `tm_amvr_flag`[`x0`][`y0`] if(`tm_amvr_flag`[`x0`][`y0`] == 0) `amvr_precision_idx`[`x0`][`y0`] }

(152) An exemplary pseudo syntax is shown as follows in Table 4. When certain conditions are met, such as the ΔMVR mode being enabled (e.g., the `sps_amvr_enabled_flag` being true), the affine mode not being enabled (e.g., the `inter_affine_flag` being false), and at least one component of an MVD of the current block not equal to zero, the ΔMVR flag (e.g., the `amvr_flag`) is signaled. When the ΔMVR flag (e.g., the `amvr_flag`) is true, the following is performed. For example, the TM-ΔMVR flag (e.g., the `tm_amvr_flag`) is signaled. When the TM-ΔMVR flag (e.g., the `tm_amvr_flag`) is false, the ΔMVR precision index (e.g., the `amvr_precision_idx`) is signaled. Otherwise, when the TM-ΔMVR flag (e.g., the `tm_amvr_flag`) is true, the ΔMVR precision index (e.g., the `amvr_precision_idx`) is not signaled.

(153) The above descriptions can be applied to a block that is coded with a uni-prediction. The above descriptions can be adapted to scenarios where a block is coded with the bi-prediction. In an example, when the bi-prediction mode is used, a current block in a current picture can be coded using a first reference picture from a reference list 0 (**L0**) and a second reference picture from a reference list 1 (**L1**).

(154) FIG. 19 shows an example of template matching (**1900**) when the current block (**1801**) is predicted using the bi-prediction mode. The current block (**1801**), the current picture (**1810**), the current template (**1821**), the MVs (**1841**)-(**1844**), the reference templates (**1851**)-(**1854**), the reference blocks (**1831**)-(**1834**), and the reference picture (**1811**) in FIG. 19 are described in FIG. 18.

(155) Referring to FIG. 19, the reference picture (**1811**) is referred to as the first reference picture (**1811**) and is associated with a first plurality of MVRs. The MVs (**1841**)-(**1844**), the reference templates (**1851**)-(**1854**), and the reference blocks (**1831**)-(**1834**) that correspond to the first plurality of MVRs are referred to as the first MVs (**1841**)-(**1844**), the first reference templates (**1851**)-(**1854**), and the first reference blocks (**1831**)-(**1834**), respectively. The first plurality of MVRs can include any suitable MVR and any suitable number of MVRs. In an example, the first plurality of MVRs includes ¼-pel, ½-pel, 1-pel, and 4-pel. In an example, the first plurality of MVRs includes a subset of ¼-pel, ½-pel, 1-pel, and 4-pel.

(156) Referring to FIG. 19, a second reference picture (**1911**) is associated with a second plurality of MVRs. Second MVs (**1941**)-(**1944**) can correspond to the second plurality of MVRs, such as ¼-pel, ½-pel, 1-pel, and 4-pel, respectively. The second MVs (**1941**)-(**1944**) can point from the current block (**1801**) to second reference blocks (**1931**)-(**1934**) in the second reference picture

(1911), respectively. Second reference templates (1951)-(1954) are associated with the second reference blocks (1931)-(1934), respectively.

(157) The second plurality of MVRs can include any suitable MVR and any suitable number of MVRs. In an example, the second plurality of MVRs includes ¼-pel, ½-pel, 1-pel, and 4-pel. In an example, the second plurality of MVRs includes a subset of ¼-pel, ½-pel, 1-pel, and 4-pel.

(158) A first number of MVRs in the first plurality of MVRs can be identical to or different from a second number of MVRs in the second plurality of MVRs.

(159) The current block (1801) can be predicted based on the first reference picture (1811) from L0 and the second reference picture (1911) from L1.

(160) According to an embodiment of the disclosure, TM can be performed on MVR pairs. The MVR pairs can include any suitable combinations of the first plurality of MVRs and the second plurality of MVRs. In an embodiment, an MVR pair in the MVR pairs includes (i) a first MVR (e.g., ½-pel) from the first plurality of MVRs and (ii) a second MVR (e.g., 1-pel) from the second plurality of MVRs. The TM can include determining a TM cost corresponding to each MVR pair in the MVR pairs, for example, the MVR pair includes ½-pel as the first MVR and 1-pel as the second MVR. A TM cost can be determined based on a portion of the current template (1821) of the current block (1801) and a bi-predictor of the respective MVR pair. The bi-predictor can be based on a portion of a first reference template (e.g., (1851)) in the first reference picture (1811) corresponding to the first MVR of the respective MVR pair and a portion of a second reference template (e.g., (1951)) in the second reference picture (1911) corresponding to the second MVR of the respective MVR pair. In an embodiment, the TM includes ranking or reordering the MVR pairs based on the determined corresponding TM costs and selecting an MVR pair from the ranked or reordered MVR pairs. The current block (1801) can be reconstructed based on the selected MVR pair.

(161) As described above, the TM can be applied to a bi-predicted CU, such as a bi-predicted current block (e.g., the current block (1801)) where the MVR pairs in the ΔMVP mode can be reordered. Referring to FIG. 19, each of the TM costs can be calculated according to a distortion (e.g., a difference) between the current template (1821) and the corresponding bi-predictor that is based on reference templates (e.g., (1851) and (1951)).

(162) In an embodiment, such as shown in FIG. 19, for the MVR pair including the first MVR (e.g., ½-pel) and the second MVR (e.g., 1-pel), the bi-predictor is determined based on a first reference template (e.g., (1851)) corresponding to the first MVR and a second reference template (e.g., (1951)) corresponding to the second MVR. The bi-predictor can be an average of the first reference template (e.g., (1851)) and the second reference template (e.g., (1951)). In an example, the bi-predictor is a weighted average of the first reference template (e.g., (1851)) and the second reference template (e.g., (1951)). In an example, the bi-predictor is modified by an offset.

(163) In an example, the bi-predictor (denoted as TP.sub.b (i,j)) corresponding to the MVR pair is calculated using Eq. 3.

$$TP_{\text{sub.b}}(i,j) = (TP0_{\text{sub.i}} + TP1_{\text{sub.j}} + 1) \gg 1 \quad \text{Eq. 3}$$

(164) A parameter TP0.sub.i and a parameter TP1.sub.j can respectively represent the first reference template (e.g., (1851)) for the reference list L0 and the second reference template (e.g., (1951)) for the reference list L1. Integers i and j represent the first MVR and the second MVR in the MVR pair, respectively. Based on Eq. 3, a value of a predictor sample in the bi-predictor TP.sub.b (i,j) can be an average of a first reference sample value in the first reference template and a second reference sample value in the second reference template.

(165) The TM cost (denoted as the TM cost (i, j)) corresponding to the MVR pair can be calculated based on the current template (denoted as TC) and the bi-predictor TP.sub.b (i,j), for example, using Eq. 4 below.

$$TM \text{ cost}(i,j) = SAD(TP_{\text{sub.b}}(i,j) - TC) \quad \text{Eq. 4}$$

(166) A parameter TC represents the current template (1821) of the current block (1801). A sum of

absolute difference (SAD) denotes a function of sum of absolute difference, for example, between sample values in the current template (**1821**) and corresponding values of predictor samples in the bi-predictor TP.sub.b (i, j).

(167) Other functions, such as an SSE, a variance, a partial SAD, or the like may be used to determine the TM cost. In an example of a partial SAD, a portion of the current template (**1821**), a corresponding portion of the first reference template (e.g., **1851**), and a corresponding portion of the second reference template (e.g., **1951**) are used to determine the TM cost.

(168) In an example of a partial SAD, a portion of or the entire current template (**1821**), a portion of or the entire first reference template (e.g., **1851**), and a portion of or the entire second reference template (e.g., **1951**) are down-sampled before being used to determine the TM cost.

(169) As described above, the MVR pair to be used to code the current block (**1801**) can be derived according to the TM costs of the reordered MVR pairs in the ascending order of the TM costs.

(170) In an embodiment, the first MVR and the second MVR in the MVR pair are identical (e.g., $i=j$ in Eq. 3) when the current block is coded (e.g., encoded and/or decoded) in the bi-prediction mode. For example, the first plurality of MVRs and the second plurality of MVRs are identical. $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel in the first plurality of MVRs correspond to i being 0, 1, 2, and 3, respectively. $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel in the second plurality of MVRs correspond to j being 0, 1, 2, and 3, respectively. The first MVs (**1841**)-(**1844**) correspond to $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel, respectively. The second MVs (**1941**)-(**1944**) correspond to $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel, respectively. Accordingly, the MVR pairs include four MVR pairs: a first MVR pair, a second MVR pair, a third MVR pair, a fourth MVR pair, as shown in Table 5. For example, the first MVR pair includes a first MVR of $\frac{1}{4}$ -pel with i being 0 and a second MVR of $\frac{1}{4}$ -pel with j being 0.

(171) TABLE-US-00005 TABLE 5 MVR pairs when the first MVR is equal to the second MVR
First MVR Second MVR First MVR pair $\frac{1}{4}$ -pel ($i = 0$) $\frac{1}{4}$ -pel ($j = 0$) Second MVR pair $\frac{1}{2}$ -pel ($i = 1$) $\frac{1}{2}$ -pel ($j = 1$) Third MVR pair 1-pel ($i = 2$) 1-pel ($j = 2$) Fourth MVR pair 4-pel ($i = 3$) 4-pel ($j = 3$)

(172) Four bi-predictors TP.sub.b (0,0), TP.sub.b (1,1), TP.sub.b (2,2), and TP.sub.b (3,3) corresponding to the four MVR pairs can be determined based on Eq. 3. For example, the bi-predictor TP.sub.b (0,0) is determined based on the first reference template (**1851**) (e.g., TP0.sub.i with $i=0$) and the corresponding second reference template (**1951**) (e.g., TP1; with $j=0$). In an example, TP.sub.b (0,0) is an average of TP0.sub.0 and TP1.sub.0.

(173) Four TM costs (e.g., a TM cost (0, 0), a TM cost (1, 1), a TM cost (2, 2), and a TM cost (3, 3)) corresponding to the four MVR pairs can be determined based on the current template (**1821**) and the bi-predictors TP.sub.b (0,0), TP.sub.b (1,1), TP.sub.b (2,2), and TP.sub.b (3,3), respectively. For example, the TM cost (0, 0) is determined using Eq. 4 where the TM cost (0, 0) is an SAD between the bi-predictor TP.sub.b (0,0) and the current template (**1821**).

(174) The four MVR pairs can be ranked (e.g., reordered differently from the order shown in Table 5 based on the corresponding four TM costs, such as an ascending order of the four TM costs. In an example, the ascending order of the four TM costs is the TM cost (1, 1), the TM cost (2, 2), the TM cost (0, 0), and the TM cost (3, 3). The ranked MVR pairs corresponding to the TM cost (1, 1), the TM cost (2, 2), the TM cost (0, 0), and the TM cost (3, 3) include the second MVR pair, the third MVR pair, the first MVR pair, and the fourth MVR pair.

(175) An MVR pair can be selected from the ranked MVR pairs. In an example, the selected MVR pair is the MVR pair corresponding to the smallest TM cost, such as the second MVR pair corresponding to the TM cost (1, 1). In an embodiment, no index is signaled when the selected MVR pair is the MVR pair corresponding to the smallest TM cost.

(176) In an example, an index is signaled to indicate which MVR pair in the ranked MVR pairs is selected. For example, based on the ranked (e.g., reordered) MVR pairs, an index of 0, 1, 2, or 3 indicates the selected MVR pair to be the second MVR pair, the third MVR pair, the first MVR pair, or the fourth MVR pair, respectively.

(177) In an embodiment, the first MVR and the second MVR in one of the MVR pairs are identical (e.g., $i=j$ in Eq. 3), and the first MVR and the second MVR in another of the MVR pairs are different (e.g., $i \neq j$ in Eq. 3) when the current block is coded (e.g., encoded and/or decoded) in the bi-prediction mode. In an example, the first plurality of MVRs has $N_{\text{sub.1}}$ first MVRs, and the second plurality of MVRs has $N_{\text{sub.2}}$ second MVRs where $N_{\text{sub.1}}$ and $N_{\text{sub.2}}$ are positive integers. $N_{\text{sub.1}}$ and $N_{\text{sub.2}}$ can be identical or different. In an example, $N_{\text{sub.1}}$ and $N_{\text{sub.2}}$ are 4, and 16 MVR pairs or 16 different combinations of the first MVRs and the second MVRs are associated with the bi-predicted current block. Table 6 shows an example of the 16 MVR pairs.

(178) TABLE-US-00006 TABLE 6 Exemplary MVR pairs

First MVR	Second MVR
1.sup.st MVR pair $\frac{1}{4}$ -pel ($i = 0$) $\frac{1}{4}$ -pel ($j = 0$)	2.sup.nd MVR pair $\frac{1}{4}$ -pel ($i = 0$) $\frac{1}{2}$ -pel ($j = 1$)
3.sup.rd MVR pair $\frac{1}{4}$ -pel ($i = 0$) 1-pel ($j = 2$)	4.sup.th MVR pair $\frac{1}{4}$ -pel ($i = 0$) 4-pel ($j = 3$)
5.sup.th MVR pair $\frac{1}{2}$ -pel ($i = 1$) $\frac{1}{4}$ -pel ($j = 0$)	6.sup.th MVR pair $\frac{1}{2}$ -pel ($i = 1$) $\frac{1}{2}$ -pel ($j = 1$)
7.sup.th MVR pair $\frac{1}{2}$ -pel ($i = 1$) 1-pel ($j = 2$)	8.sup.th MVR pair $\frac{1}{2}$ -pel ($i = 1$) 4-pel ($j = 3$)
9.sup.th MVR pair 1-pel ($i = 2$) $\frac{1}{4}$ -pel ($j = 0$)	10.sup.th MVR pair 1-pel ($i = 2$) $\frac{1}{2}$ -pel ($j = 1$)
11.sup.th MVR pair 1-pel ($i = 2$) 1-pel ($j = 2$)	12.sup.th MVR pair 1-pel ($i = 2$) 4-pel ($j = 3$)
13.sup.th MVR pair 4-pel ($i = 3$) $\frac{1}{4}$ -pel ($j = 0$)	14.sup.th MVR pair 4-pel ($i = 3$) $\frac{1}{2}$ -pel ($j = 1$)
15.sup.th MVR pair 4-pel ($i = 3$) 1-pel ($j = 2$)	16.sup.th MVR pair 4-pel ($i = 3$) 4-pel ($j = 3$)

(179) In an example, the first MVs **(1841)-(1844)** correspond to $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel, respectively. The second MVs **(1941)-(1944)** correspond to $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel, respectively.

(180) 16 bi-predictors $TP_{\text{sub.b}}(i, j)$ (e.g., $TP_{\text{sub.b}}(0, 0)$ - $TP_{\text{sub.b}}(3, 3)$) corresponding to the 16 MVR pairs in Table 6 can be determined based on Eq. 3. For example, the bi-predictor $TP_{\text{sub.b}}(1, 3)$ corresponding to the 8th MVR pair in Table 6 is determined based on the first reference template **(1852)** (e.g., $TP0_{\text{sub.i}}$ with $i=1$) and the corresponding second reference template **(1954)** (e.g., $TP1$; with $j=3$). In an example, $TP_{\text{sub.b}}(1, 3)$ is an average of **TP01** and **TP13**.

(181) 16 TM costs (e.g., TM cost $(0, 0)$ -TM cost $(3, 3)$) corresponding to the 16 MVR pairs can be determined based on the current template **(1821)** and the bi-predictors $TP_{\text{sub.b}}(0, 0)$ - $TP_{\text{sub.b}}(3, 3)$, respectively. For example, the TM cost $(1, 3)$ is determined using Eq. 4 where the TM cost $(1, 3)$ is an SAD between the bi-predictor $TP_{\text{sub.b}}(1, 3)$ and the current template **(1821)**.

(182) The 16 MVR pairs in Table 6 can be ranked (e.g., reordered) based on the corresponding 16 TM costs, such as an ascending order of the 16 TM costs. An MVR pair can be selected from the ranked 16 MVR pairs. In an example, the selected MVR pair is the MVR pair corresponding to the smallest TM cost in the 16 TM costs. For example, no index is signaled when the selected MVR pair is the MVR pair corresponding to the smallest TM cost in the 16 TM costs. In an example, an index is signaled to indicate which MVR pair in the ranked (e.g., reordered) 16 MVR pairs is selected.

(183) For purposes of brevity, the MVR pairs shown in Table 5 are referred to as a first set of MVR pairs. The MVR pairs shown in Table 6 are referred to as a second set of MVR pairs.

(184) In an embodiment, a flag is signaled in a video bitstream, such as in a sequence parameter set (SPS), a picture parameter set (PPS), a picture header (PH), a slice header, or the like, to indicate whether the TM is performed on the MVR pairs (e.g., the first set or the second set of MVR pairs).

(185) Embodiments associated with the bi-prediction are described with respect to the first plurality of MVRs and the second plurality of MVRs that include $\frac{1}{4}$ -pel, $\frac{1}{2}$ -pel, 1-pel, and 4-pel. The descriptions related to bi-prediction can be adapted when the first plurality of MVRs and/or the second plurality of MVRs include less or more MVRs.

(186) A TM can be applied in an affine mode, such as the affine Δ MVP mode, the affine merge mode, and can be referred to as an affine TM. FIG. 20 shows an example of TM **(2000)**, such as in an affine merge mode. A template **(2021)** of a current block (e.g., a current CU) **(2001)** can correspond to a template (e.g., the template **(1721)** in FIG. 17) in a TM applied to a translational motion model. A reference template **(2025)** of a reference block in a reference picture can include

multiple subblock templates (e.g., 4×4 subblocks) that are pointed by control point MV (CPMV)-derived MVs of neighboring subblocks (e.g., A.sub.0-A.sub.3 and L.sub.0-L.sub.3 as shown in FIG. 20) at block boundaries.

(187) A search process of the TM that is applied in the affine mode (e.g., the affine merge mode) can start from a CPMV0, while keeping other CPMV(s) (e.g., (i) CPMV1 if a 4-parameter model is used or (ii) CPMV1 and CPMV2 if a 6-parameter model is used) constant. The search can be performed toward a horizontal direction and a vertical direction. In an example, the search is followed by diagonal direction(s) only if a zero vector is not the best difference vector found from the horizontal search and the vertical search. The affine TM can repeat the same search process for the CPMV1. The affine TM can repeat the same search process for CPMV2 if a 6-parameter model is used. Based on the refined CPMVs, the whole search process can restart from the refined CPMV0, if the zero vector is not the best difference vector from the previous iteration and the search process has iterated less than 3 times.

(188) The bi-prediction TM described in FIG. 19 can be adapted to a subblock based TM, such as a bi-prediction TM used in an affine mode, such as the affine ΔMVP mode. FIG. 21 shows an example of a subblock based bi-prediction TM (2100), for example, in the affine ΔMVP mode.

(189) In the affine ΔMVP mode, referring to FIG. 21, a current block (2110) includes multiple subblocks (2101). The current block (2110) can be coded with the subblock based bi-prediction mode. The TM can be applied to MVR pairs available for the current block (2110), such as the first set of MVR pairs or the second set of MVR pairs. Referring to FIG. 21, a first reference block (2111) can be obtained based on a first MVR (e.g., ¼-pel) in an MVR pair of the MVR pairs, and a second reference block (2113) can be obtained based on a second MVR (e.g., ½-pel) in the MVR pair.

(190) In an example, each subblock (2101) in the current block (2110) is associated with an MV pair including a first MV pointing to a first reference subblock (2103) in the first reference block (2111) in a first reference picture and a second MV pointing to a second reference subblock (2105) in the second reference block (2113) in a second reference picture.

(191) The MV pair associated with each subblock (2101) can be determined based on affine parameters of the current block (2110) and positions of the respective subblock (2101), such as described in FIG. 14. In an example, the affine parameters of the current block (2110) are determined based on the CPMVs (e.g., CPMV.sub.0-CPMV.sub.1 or CPMV.sub.0-CPMV2) of the current block (2110). The first MVs that point from the subblocks (2101) to the corresponding first reference subblocks (2103) are associated with the first MVR (e.g., ¼-pel), and the second MVs that point from the subblocks (2101) to the corresponding second reference subblocks (2105) are associated with the second MVR (e.g., ½-pel).

(192) The current template (2121) of the current block (2110) can include multiple subblocks (also referred to as subblock templates). The current template (2121) can include any suitable number of subblocks at any suitable positions. Each of the multiple subblock templates can have any suitable size, such as N×N. N can be a positive integer, such as 4. In an example, the multiple subblock templates include top subblock template(s) (e.g., A.sub.0-A.sub.3) and/or left subblock template(s) (e.g., L.sub.0-L.sub.3). For example, the current template (2121) can include (i) a top template that includes the top subblock template(s) and/or (ii) a left template that includes the left subblock template(s). In the example of FIG. 21, the current template (2121) includes the top subblock templates A.sub.0-A.sub.3 and the left subblock templates L.sub.0-L.sub.3.

(193) Each subblock template in the current template (2121) (e.g., one of A.sub.0-A.sub.3 or one of L.sub.0-L.sub.3) can be associated with an MV pair including a first MV and a second MV. The MV pairs associated with the subblock templates can be determined based on the affine parameters of the current block (2110) and respective positions of the subblock templates, such as described in FIG. 14, and thus the MV pairs associated with the subblock templates can be different.

(194) A first reference template (2123) associated with the first reference block (2111) can be

determined based on the multiple subblock templates and the associated MV pairs (e.g., the associated first MVs), respectively. Referring to FIG. 21, first reference subblock templates (e.g., first top reference subblock templates A.sub.00-A.sub.03 and/or first left reference subblock templates L.sub.00-L.sub.03) in the first reference template (2123) can be determined based on the multiple subblock templates (e.g., A.sub.0-A.sub.3 and/or L.sub.0-L.sub.3) and the associated MV pairs, respectively. In an example, a shape of the first reference template (2123) is different from the current template (2121) when the first MVs associated with the multiple subblock templates are different.

(195) Similarly, a second reference template (2125) associated with the second reference block (2113) can be determined based on the multiple subblock templates and the associated MV pairs (e.g., the associated second MVs), respectively. Referring to FIG. 21, second reference subblock templates (e.g., second top reference subblock templates A.sub.10-A.sub.13 and/or second left reference subblock templates L.sub.10-L.sub.13) in the second reference template (2125) can be determined based on the multiple subblock templates (e.g., A.sub.0-A.sub.3 and/or L.sub.0-L.sub.3) and the associated MV pairs, respectively. In an example, a shape of the second reference template (2125) is different from the current template (2121) when the second MVs associated with the multiple subblock templates are different.

(196) For example, an MV pair of a subblock template (e.g., A.sub.0) includes a first MV (e.g., with the first MVR of $\frac{1}{4}$ -pel) pointing to a first reference subblock template (e.g., A.sub.00) in the first reference template (2123) and a second MV (e.g., with the second MVR of $\frac{1}{2}$ -pel) pointing to a second reference subblock template (e.g., A.sub.10) of a second reference template (2125).

(197) Various embodiments of the TM described in FIG. 19 can be applied to the MVR pairs when the current block (2110) is coded with the affine mode, such as the affine Δ MVP mode. For each MVR pair in the MVR pairs, a TM cost can be determined based on a portion of the current template (2121) and a bi-predictor of the respective MVR pair. The bi-predictor can be based on a portion of the first reference template (2123) corresponding to the first MVR of the MVR pair and a portion of the second reference template (2125) corresponding to the second MVR of the MVR pair. In an embodiment, for each MVR pair in the MVR pairs, the bi-predictor is determined based on the first reference template (2123) and the second reference template (2125), and the TM cost is determined based on the current template (2121) and the bi-predictor, for example, using Eqs. 3-4. In an embodiment, the TM includes ranking the MVR pairs based on the determined corresponding TM costs and selecting an MVR pair from the ranked MVR pairs. The current block (2110) can be reconstructed based on the selected MVR pair.

(198) A difference between embodiments in FIGS. 19 and 21 is described below.

(199) In the example of FIG. 19, the current block (1801) is coded with a non-subblock based mode, such as the translational motion mode. Thus, for a MVR pair, the first reference template (1851) is determined based on a single MV (e.g., the MV (1841)), and the shape of the first reference template (1851) is identical to the current template (1821). Similarly, the second reference template (1951) is determined based on a single MV (e.g., the MV (1941)), and the shape of the second reference template (1951) is identical to the current template (1821).

(200) In the example of FIG. 21, the current block (2110) is coded with the affine mode (e.g., the affine Δ MVP mode). Thus, for a MVR pair including a first MVR and a second MVR, the first reference template (2123) can be determined based on different MVs having the first MVR, and the shape of the first reference template (2123) (e.g., including A.sub.00-A.sub.03 and L.sub.00-L.sub.03) can be different from the current template (2121) (e.g., including A.sub.0-A.sub.3 and L.sub.0-L.sub.3). In an example, the second reference template (2125) is determined based on different MVs having the second MVR, and the shape of the second reference template (2125) (e.g., including A.sub.10-A.sub.13 and L.sub.10-L.sub.13) is different from the current template (2121).

(201) As the current template (2121) includes the multiple subblock templates (e.g., including

A.sub.0-A.sub.3 and L.sub.0-L.sub.3), the TM cost calculated using Eq. 4 can be rewritten based on subblock based TM costs where each subblock based TM cost is based on a corresponding subblock based bi-predictor and a corresponding subblock template.

(202) For each MVR pair, such as the 2.sup.nd MVR pair in Table 6 that includes ¼-pel as the first MVR (i being 0) and ½-pel as the second MVR (j being 1), a corresponding subblock based bi-predictor (e.g., a k.sup.th subblock based bi-predictor) TP.sub.b,k (i, j) can be determined based on a k.sup.th first reference subblock template TP0.sub.k,i (e.g., A.sub.00) and a second reference subblock template TP1.sub.k,j (e.g., A.sub.10) that are associated with a subblock template (e.g., A.sub.0) using Eq. 5. The k.sup.th first reference subblock template TP0.sub.k,i (e.g., A.sub.00) corresponds to the first MVR (e.g., ¼-pel indicated by i), and the k.sup.th second reference subblock template TP1.sub.k,j (e.g., A.sub.10) corresponds to the second MVR (e.g., ½-pel indicated by j).

$$TP_{sub.b,k}(i,j) = ((TP_{0.sub.k,i} + TP_{1.sub.k,j+1}) \gg 1) \quad \text{Eq. 5}$$

(203) A subblock based TM cost (e.g., a k.sup.th subblock based TM cost TM.sub.k (i, j)) can be determined based on the k.sup.th subblock based bi-predictor TP.sub.b,k (i, j) and the corresponding subblock template (e.g., A.sub.0) of the current template (2121). For example, TM.sub.k (i, j) = SAD (TC.sub.k - TP.sub.b,k (i, j)) where a parameter TC.sub.k represents a k.sup.th subblock template (e.g., A.sub.0) in the current template (2121).

(204) The TM cost corresponding to the MVR pair TM cost (i, j) can be determined based on (i) the entirety or a subset of the first reference template (2123) and (ii) the entirety or a subset of the second reference template (2125). The TM cost (TM cost (i, j)) can be accumulated based on the subblock based TM costs of the subblock templates, such as shown in Eq. 6.

$$TM\ cost(i,j) = \sum_{sub.k} SAD(TM_{sub.k}(i,j)) \quad \text{Eq. 6}$$

(205) Eq. 6 can be adapted to Eq. 7 below. In an example, the TM cost corresponding to the MVR pair (TM cost (i, j)) is rewritten as follows.

$$TM\ cost(i,j) = \sum_{sub..} Math.SAD(TC_{sub.Ap} - ((TP_{0.sub.Ap,i} + TP_{1.sub.Ap,j+1}) \gg 1)) + \sum_{sub.m} SAD(TC_{sub.Lm} - ((TP_{0.sub.Lm,i} + TP_{1.sub.Lm,j+1}) \gg 1)) \quad \text{Eq. 7}$$

(206) A parameter TC.sub.Ap represents an p.sup.th top subblock template (e.g., A.sub.0 with p being 0) in the current template (2121), a parameter TP0.sub.Ap,i represents an p.sup.th first top reference subblock template (e.g., A.sub.00 with p being 0) corresponding to the first MVR (indicated by i), and a parameter TP1.sub.Ap,j represents an p.sup.th second top reference subblock template (e.g., A.sub.10 with p being 0) corresponding to the second MVR (indicated by j). The first summation in Eq. 7 is performed on the top subblock templates in the current template (2121), such as A.sub.0-A.sub.3 with a parameter p in Eq. 7 being from 0 to 3.

(207) A parameter TC.sub.Lm represents an m.sup.th left subblock template (e.g., L.sub.0 with m being 0) in the current template (2121), a parameter TP0.sub.Lm,i represents an m.sup.th first left reference subblock template (e.g., Loo with m being 0) corresponding to the first MVR (indicated by i), and a parameter TP1.sub.Lm,j represents an m.sup.th second left reference subblock template (e.g., L.sub.10 with 1 being 0) corresponding to the second MVR (indicated by j). The second summation in Eq. 7 is performed on the left subblock templates in the current template (2121), such as L.sub.0-L.sub.3 with a parameter m in Eq. 7 being from 0 to 3.

(208) Other functions, such as an SSE, a variance, a partial SAD, or the like may be used to determine the TM cost (e.g., TM cost (i, j) in Eq. 6 or Eq. 7).

(209) In an example of a partial SAD, a portion (e.g., A.sub.0-A.sub.3) of the current template (2121), a corresponding portion (e.g., A.sub.00-A.sub.03) of the first reference template (2123), and a corresponding portion (e.g., A.sub.10-A.sub.13) of the second reference template (2125) are used to determine the TM cost.

(210) In an example of a partial SAD, a portion of or the entire current template (2121), a portion of or the entire first reference template (2123), and a portion of or the entire second reference

template (2125) are down-sampled before being used to determine the TM cost.

(211) In the example shown in FIG. 21, a first number (e.g., 4) of the top subblock templates is equal to a second number (e.g., 4) of the left subblock templates.

(212) In another example, the first number of the top subblock templates is different from the second number of the left subblock templates.

(213) In an embodiment, the inherited affine parameter(s) of the current block (2110) can be directly applied to a reference template, such as the first reference template (2123) and/or the second reference template (2125) in the subblock based TM. For example, for each MVR pair in the MVR pairs, each of the first reference subblock templates (e.g., A.sub.00-A.sub.03 and L.sub.00-L.sub.03) in the first reference template (2123) is determined based on the affine parameters (e.g., the inherited affine parameter(s)) of the current block (2110) where samples in the respective first reference subblock template (e.g., one of A.sub.00-A.sub.03 or one of L.sub.00-L.sub.03) can have same motion information (e.g., the same MV).

(214) FIG. 22 shows an example of the PROF method. In some embodiments, the PROF method is implemented to improve the subblock-based affine motion compensation to have a finer granularity of motion compensation. According to the PROF method, after the subblock-based affine motion compensation is performed (such as shown in FIG. 14), predicted samples (e.g., luma predicted samples) can be refined by adding a set of adjustment values derived by an optical flow equation.

(215) Referring to FIG. 22, a current block (2210) is divided into four sub-blocks (2212, 2214, 2216, and 2218). In an example, each one of the sub-blocks (2212, 2214, 2216, and 2218) has a size of 4×4 pixels. A sub-block MV.sub.SB for the sub-block (2212) can be derived according to the affine prediction and point to a reference sub-block (2232). Initial sub-block predicted samples can be determined according to the reference sub-block (2232). Refinement values to be applied to the initial sub-block predicted samples can be calculated as if each predicted sample is at a position (e.g., a position (2232a) for sample (2212a)) indicated by a refined MV (e.g., a pixel MV) (2242) that is determined according to the sub-block MV.sub.SB for the sub-block 2212 adjusted by an adjustment vector ΔMV. Referring to FIG. 22, an initial sub-block predicted sample (2252) based on the MV.sub.SB is refined to be the refined sample at the position (2232a) that is based on the pixel MV (2242).

(216) In some embodiments, the PROF method may begin with performing the subblock-based affine motion compensation to generate an initial sub-block predicted sample I (i1, i2) (2252), where (i1, i2) corresponds to a particular sample in a current sub-block. Next, the spatial gradients g.sub.x (i1, i2) and g.sub.y (i1, i2) of the initial sub-block predicted sample I (i1, i2) (2252) can be calculated using a 3-tap filter [-1, 0, 1] according to

$$g_{\text{sub.x}}(i1, i2) = (i1+1, i2) - (i1-1, i2) \quad \text{Eq. 8}$$

$$g_{\text{sub.y}}(i1, i2) = I(i1, i2+1) - I(i1, i2-1) \quad \text{Eq. 9}$$

(217) The sub-block prediction is extended by one pixel on each side for the gradient calculation. In some embodiments, to reduce the memory bandwidth and complexity, the pixels on the extended borders can be copied from the nearest integer pixel position in the reference picture. Therefore, additional interpolation for a padding region is avoided.

(218) The prediction refinement can be calculated by an optical flow equation.

$$\Delta I(i1, i2) = g_{\text{sub.x}}(i1, i2) * \Delta mv_{\text{sub.x}}(i1, i2) + g_{\text{sub.y}}(i1, i2) * \Delta mv_{\text{sub.y}}(i1, i2) \quad \text{Eq. 10}$$

(219) The Δmv (i1, i2) (e.g., ΔMV) is the difference between the pixel MV (2242) for the sample location (i1, i2) and the sub-block MV.sub.SB for the sub-block to which the pixel location (i1, i2) belongs. Since the affine model parameters and the pixel location relative to the sub-block center are not changed from sub-block to sub-block, Δmv (i1, i2) can be calculated for a first sub-block (e.g., (2212)), and reused for other sub-blocks (e.g., (2214), (2216), and (2218)) in the same coding block or CU (e.g., (2210)). In some examples, let x and y be the horizontal and vertical position of Δmv (i1, i2) with respect to the center of the sub-block (2212), Δmv (i1, i2) can be derived by the following equation,

$$(220) \quad \begin{cases} \Delta mv_x(x, y) = a * x + b * y \\ \Delta mv_y(x, y) = c * x + d * y \end{cases} \quad \text{Eq. 11}$$

where $\Delta mv_{\text{sub}.x}(x, y)$ is the x component of $\Delta mv(i1, i2)$, and $\Delta mv_{\text{sub}.y}(x, y)$ is the y component of $\Delta mv(i1, i2)$.

(221) For a 4-parameter affine model,

$$(222) \quad \begin{cases} a = d = \frac{v_{1x} - v_{0x}}{w} \\ c = -b = \frac{v_{1y} - v_{0y}}{w} \end{cases} \quad \text{Eq. 12}$$

(223) For a 6-parameter affine model,

$$(224) \quad \begin{cases} a = \frac{v_{1x} - v_{0x}}{w} \\ b = \frac{v_{2x} - v_{0x}}{h} \\ c = \frac{v_{1y} - v_{0y}}{w} \\ d = \frac{v_{2y} - v_{0y}}{h} \end{cases} \quad \text{Eq. 13}$$

(225) $(v_{\text{sub}.0x}, v_{\text{sub}.0y})$, $(v_{\text{sub}.1x}, v_{\text{sub}.1y})$, and $(v_{\text{sub}.2x}, v_{\text{sub}.2y})$ are the upper-left, upper-right, and lower-left control point motion vectors, and w and h are the width and height of the coding block or CU.

(226) The prediction refinement can be added to the initial sub-block predicted sample $I(i1, i2)$. The final predicted sample I' according to the PROF method can be generated using Eq. 14.

$$I'(i1, i2) = I(i1, i2) + \Delta I(i1, i2) \quad \text{Eq. 14}$$

(227) In an embodiment, referring back to FIG. 21, the PROF is applied to each subblock template, for example, to determine each first reference subblock template (e.g., one of A.sub.00-A.sub.03 or one of L.sub.00-L.sub.03) in the first reference template (2123) or each second reference subblock template (e.g., one of A.sub.10-A.sub.13 or one of L.sub.10-L.sub.13) in the second reference template (2125). For example, for each MVR pair in the MVR pairs, the first reference subblock template (e.g., one of A.sub.00-A.sub.03 or one of L.sub.00-L.sub.03) is determined using the PROF mode where two samples in the same first reference subblock template can have different motion information (e.g., two different MVs).

(228) In an embodiment, the first MVR associated with L.sub.0 and the second MVR associated with L.sub.1 in the MVR pair can be different, such as described in Table 6.

(229) In an embodiment, a flag is signaled in a video bitstream, such as in an SPS, a PPS, a PH, a slice header, or the like, to indicate whether the subblock based TM is performed on the MVR pairs (e.g., the first set of MVR pairs in Table 5 or the second set of MVR pairs in Table 6).

(230) FIG. 23 shows a flow chart outlining an encoding process (2300) according to an embodiment of the disclosure. In various embodiments, the process (2300) is executed by processing circuitry, such as the processing circuitry in the terminal devices (310), (320), (330) and (340), processing circuitry that performs functions of a video encoder (e.g., (403), (603), (703)), or the like. In some embodiments, the process (2300) is implemented in software instructions, thus when the processing circuitry executes the software instructions, the processing circuitry performs the process (2300). The process starts at (S2301), and proceeds to (S2310).

(231) At (S2310), template matching (TM) (e.g., TM I) on motion vector resolution (MVR) pairs can be performed for a current block by determining a TM cost corresponding to each one of the MVR pairs where each MVR pair includes (i) a first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a second MVR in a second plurality of MVRs corresponding to a second reference picture. Each TM cost can be determined based at least on a portion or all of a current template of the current block and a bi-predictor of the respective MVR pair. The bi-predictor can be based on a portion or all of a first reference template in the first reference picture corresponding to the first MVR of the respective MVR pair and a portion or all of

a second reference template in the second reference picture corresponding to the second MVR of the respective MVR pair. The TM can include selecting an MVR pair based on the determined corresponding TM costs. For example, the TM includes ranking or reordering the MVR pairs based on the determined corresponding TM costs and selecting an MVR pair from the ranked or reordered MVR pairs.

(232) In an embodiment, all of the current template of the current block comprises the entire current template. For each MVR pair, all of the first reference template comprises the entire first reference template, and all of the second reference template comprises the entire second reference template.

(233) In an example, for each MVR pair, the first reference template is determined based on a first motion vector (MV) having the first MVR in the MVR pair, and the second reference template is determined based on a second MV having the second MVR in the MVR pair.

(234) In an example, for each MVR pair, the bi-predictor corresponding to the respective MVR pair is a weighted average of the first reference template corresponding to the first MVR in the respective MVR pair and the second reference template corresponding to the second MVR in the respective MVR pair.

(235) In an example, for each MVR pair, the first MVR in each MVR pair and the second MVR in the respective MVR pair are identical.

(236) In an example, the first MVR of one of the MVR pairs is different from the second MVR of the one of the MVR pairs.

(237) At (S2320), the current block can be encoded based on the selected MVR pair using bi-prediction. Prediction information indicating that the current block is predicted with the bi-prediction can be encoded.

(238) In an example, the prediction information includes a flag indicating that template matching (TM) (e.g., TM I) is performed on the MVR pairs.

(239) At (S2330), the encoded current block and/or the prediction information can be included in a video bitstream.

(240) The process (2300) then proceeds to (S2399), and terminates.

(241) The process (2300) can be suitably adapted to various scenarios and steps in the process (2300) can be adjusted accordingly. One or more of the steps in the process (2300) can be adapted, omitted, repeated, and/or combined. Any suitable order can be used to implement the process (2300). Additional step(s) can be added.

(242) In an embodiment, the prediction information indicates that the current block is predicted with an affine adaptive motion vector prediction (Δ MVP) mode and the current template includes current subblock templates. For each MVR pair in the MVR pairs, first reference subblock templates in the first reference template can be determined based on the current subblock templates and corresponding first motion vectors (MVs), respectively. The first MVs can be based on positions of the respective current subblock templates and affine parameters of the current block. Second reference subblock templates in the second reference template can be determined based on the current subblock templates and corresponding second MVs, respectively. The second MVs can be based on the positions of the respective current subblock templates and the affine parameters of the current block. The bi-predictor can be based on the first reference subblock templates and the second reference subblock templates.

(243) In an example, for each MVR pair in the MVR pairs, samples in each of the first reference subblock templates have the same motion information.

(244) In an example, for each MVR pair in the MVR pairs, the first reference subblock templates can be determined based on a prediction refinement using optical flow (PROF) mode where two samples in one of the first reference subblock templates have different motion information.

(245) FIG. 24 shows a flow chart outlining a decoding process (2400) according to an embodiment of the disclosure. In various embodiments, the process (2400) 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 decoder (410), the processing circuitry that performs functions of the video decoder (510), the processing circuitry that performs functions of the video encoder (603), and the like. In some embodiments, the process (2400) is implemented in software instructions, thus when the processing circuitry executes the software instructions, the processing circuitry performs the process (2400). The process starts at (S2401), and proceeds to (S2410). (246) At (S2410), prediction information of a current block in a current picture can be decoded from a coded video bitstream. The prediction information can indicate that the current block is predicted with the bi-prediction.

(247) In an example, the prediction information includes a flag indicating that template matching (TM) (e.g., TM I) is performed on the MVR pairs.

(248) At (S2420), the TM can be performed on motion vector resolution (MVR) pairs by determining a TM cost corresponding to each one of the MVR pairs where each MVR pair can include (i) a first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a second MVR in a second plurality of MVRs corresponding to a second reference picture. Each TM cost can be determined based at least on a portion or all of a current template of the current block and a bi-predictor of the respective MVR pair. The bi-predictor can be based on a portion or all of a first reference template in the first reference picture corresponding to the first MVR of the respective MVR pair and a portion or all of a second reference template in the second reference picture corresponding to the second MVR of the respective MVR pair. The TM can include selecting an MVR pair based on the determined corresponding TM costs. For example, the TM includes ranking or reordering the MVR pairs based on the determined corresponding TM costs and selecting an MVR pair from the ranked or reordered MVR pairs.

(249) In an embodiment, all of the current template of the current block comprises the entire current template. For each MVR pair, all of the first reference template comprises the entire first reference template, and all of the second reference template comprises the entire second reference template.

(250) In an example, for each MVR pair, the first reference template is determined based on a first motion vector (MV) having the first MVR in the MVR pair, and the second reference template is determined based on a second MV having the second MVR in the MVR pair.

(251) In an example, for each MVR pair, the bi-predictor corresponding to the respective MVR pair is a weighted average of the first reference template corresponding to the first MVR in the respective MVR pair and the second reference template corresponding to the second MVR in the respective MVR pair.

(252) In an example, for each MVR pair, the first MVR in each MVR pair and the second MVR in the respective MVR pair are identical.

(253) In an example, the first MVR of one of the MVR pairs is different from the second MVR of the one of the MVR pairs.

(254) At (S2430), the current block can be reconstructed based on the selected MVR pair. The process (2400) proceeds to (S2499), and terminates.

(255) The process (2400) can be suitably adapted to various scenarios and steps in the process (2400) can be adjusted accordingly. One or more of the steps in the process (2400) can be adapted, omitted, repeated, and/or combined. Any suitable order can be used to implement the process (2400). Additional step(s) can be added.

(256) In an embodiment, the prediction information indicates that the current block is predicted with an affine adaptive motion vector prediction (Δ MVP) mode and the current template includes current subblock templates. For each MVR pair in the MVR pairs, first reference subblock templates in the first reference template can be determined based on the current subblock templates and corresponding first motion vectors (MVs), respectively. The first MVs can be based on

positions of the respective current subblock templates and affine parameters of the current block. Second reference subblock templates in the second reference template can be determined based on the current subblock templates and corresponding second MVs, respectively. The second MVs can be based on the positions of the respective current subblock templates and the affine parameters of the current block. The bi-predictor can be based on the first reference subblock templates and the second reference subblock templates.

(257) In an example, for each MVR pair in the MVR pairs, samples in each of the first reference subblock templates have the same motion information.

(258) In an example, for each MVR pair in the MVR pairs, the first reference subblock templates can be determined based on a prediction refinement using optical flow (PROF) mode where two samples in one of the first reference subblock templates have different motion information.

(259) FIG. 25 shows a flow chart outlining a decoding process (2500) according to an embodiment of the disclosure. In various embodiments, the process (2500) 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 decoder (410), the processing circuitry that performs functions of the video decoder (510), the processing circuitry that performs functions of the video encoder (603), and the like. In some embodiments, the process (2500) is implemented in software instructions, thus when the processing circuitry executes the software instructions, the processing circuitry performs the process (2500). The process starts at (S2501), and proceeds to (S2510).

(260) At (S2510), prediction information of a current block in a current picture can be decoded from a coded video bitstream. The prediction information can indicate that the current block is predicted using the bi-prediction with an affine adaptive motion vector prediction (Δ MVP) mode.

(261) At (S2520), the TM can be performed on motion vector resolution (MVR) pairs by determining a TM cost corresponding to each one of the MVR pairs where each MVR pair can include (i) a first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a second MVR in a second plurality of MVRs corresponding to a second reference picture. Each TM cost can be determined based at least on a portion or all of a current template (i.e., the entire current template) of the current block and a bi-predictor of the respective MVR pair. The bi-predictor can be based on a portion or all of a first reference template (i.e., the entire first reference template) in the first reference picture corresponding to the first MVR of the respective MVR pair and a portion or all of a second reference template (i.e., the entire second reference template) in the second reference picture corresponding to the second MVR of the respective MVR pair. The TM can include selecting an MVR pair based on the determined corresponding TM costs. For example, the TM includes ranking or reordering the MVR pairs based on the determined corresponding TM costs and selecting an MVR pair from the ranked or reordered MVR pairs.

(262) At (S2530), the current block can be reconstructed based on the selected MVR pair. The process (2500) proceeds to (S2599), and terminates.

(263) The process (2500) can be suitably adapted to various scenarios and steps in the process (2500) can be adjusted accordingly. One or more of the steps in the process (2500) can be adapted, omitted, repeated, and/or combined. Any suitable order can be used to implement the process (2500). Additional step(s) can be added.

(264) FIG. 26 shows a flow chart outlining a decoding process (2600) according to an embodiment of the disclosure. In various embodiments, the process (2600) 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 decoder (410), the processing circuitry that performs functions of the video decoder (510), the processing circuitry that performs functions of the video encoder (603), and the like. In some embodiments, the process (2600) is implemented in software instructions, thus when the processing circuitry executes the software instructions, the processing

circuitry performs the process (2600). The process starts at (S2601), and proceeds to (S2610). (265) At (S2610), prediction information of a current block in a current picture can be decoded from a coded video bitstream. The prediction information can indicate that the current block is predicted using the bi-prediction with an adaptive motion vector prediction (Δ MVP) mode. (266) At (S2620), the TM can be performed on motion vector resolution (MVR) pairs by determining a TM cost corresponding to each one of the MVR pairs where each MVR pair can include (i) a first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a second MVR in a second plurality of MVRs corresponding to a second reference picture. Each TM cost can be determined based at least on a current template of the current block and a bi-predictor of the respective MVR pair. The bi-predictor can be based on a first reference template in the first reference picture corresponding to the first MVR of the respective MVR pair and a second reference template in the second reference picture corresponding to the second MVR of the respective MVR pair. The TM can include selecting an MVR pair based on the determined corresponding TM costs. For example, the TM includes ranking or reordering the MVR pairs based on the determined corresponding TM costs and selecting an MVR pair from the ranked or reordered MVR pairs.

(267) At (S2630), the current block can be reconstructed based on the selected MVR pair. The process (2600) proceeds to (S2699), and terminates.

(268) The process (2600) can be suitably adapted to various scenarios and steps in the process (2600) can be adjusted accordingly. One or more of the steps in the process (2600) can be adapted, omitted, repeated, and/or combined. Any suitable order can be used to implement the process (2600). Additional step(s) can be added.

(269) Embodiments in the disclosure may be used separately or combined in any order. Further, each of the methods (or embodiments), an encoder, and a decoder may be implemented by processing circuitry (e.g., one or more processors or one or more integrated circuits). In one example, the one or more processors execute a program that is stored in a non-transitory computer-readable medium.

(270) 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. 27 shows a computer system (2700) suitable for implementing certain embodiments of the disclosed subject matter.

(271) 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.

(272) 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.

(273) The components shown in FIG. 27 for computer system (2700) 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 (2700).

(274) Computer system (2700) 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).

(275) Input human interface devices may include one or more of (only one of each depicted): keyboard (2701), mouse (2702), trackpad (2703), touch-screen (2710), data-glove (not shown), joystick (2705), microphone (2706), scanner (2707), camera (2708).

(276) Computer system (2700) 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 (2710), data-glove (not shown), or joystick (2705), but there can also be tactile feedback devices that do not serve as input devices), audio output devices (such as: speakers (2709), headphones (not depicted)), visual output devices (such as screens (2710) 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).

(277) Computer system (2700) can also include human accessible storage devices and their associated media such as optical media including CD/DVD ROM/RW (2720) with CD/DVD or the like media (2721), thumb-drive (2722), removable hard drive or solid state drive (2723), 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.

(278) 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.

(279) Computer system (2700) can also include an interface (2754) to one or more communication networks (2755). 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 (2749) (such as, for example USB ports of the computer system (2700)); others are commonly integrated into the core of the computer system (2700) 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 (2700) 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.

(280) Aforementioned human interface devices, human-accessible storage devices, and network interfaces can be attached to a core (2740) of the computer system (2700).

(281) The core (2740) can include one or more Central Processing Units (CPU) (2741), Graphics Processing Units (GPU) (2742), specialized programmable processing units in the form of Field Programmable Gate Areas (FPGA) (2743), hardware accelerators for certain tasks (2744), graphics adapters (2750), and so forth. These devices, along with Read-only memory (ROM) (2745), Random-access memory (2746), internal mass storage such as internal non-user accessible hard drives, SSDs, and the like (2747), may be connected through a system bus (2748). In some

computer systems, the system bus (2748) 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 (2748), or through a peripheral bus (2749). In an example, the screen (2710) can be connected to the graphics adapter (2750). Architectures for a peripheral bus include PCI, USB, and the like.

(282) CPUs (2741), GPUs (2742), FPGAs (2743), and accelerators (2744) can execute certain instructions that, in combination, can make up the aforementioned computer code. That computer code can be stored in ROM (2745) or RAM (2746). Transitional data can be stored in RAM (2746), whereas permanent data can be stored for example, in the internal mass storage (2747). 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 (2741), GPU (2742), mass storage (2747), ROM (2745), RAM (2746), and the like.

(283) 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.

(284) As an example and not by way of limitation, the computer system having architecture (2700), and specifically the core (2740) 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 (2740) that are of non-transitory nature, such as core-internal mass storage (2747) or ROM (2745). The software implementing various embodiments of the present disclosure can be stored in such devices and executed by core (2740). A computer-readable medium can include one or more memory devices or chips, according to particular needs. The software can cause the core (2740) 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 (2746) 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 (2744)), 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

(285) 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 R-D: Rate-Distortion

(286) 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.

Claims

1. A method for video decoding in a video decoder, comprising: decoding prediction information of a current block in a current picture from a coded video bitstream, the prediction information indicating that the current block is predicted using bi-prediction with an affine adaptive motion vector prediction (Δ MVP) mode; performing template matching (TM) on motion vector resolution (MVR) pairs by determining a TM cost corresponding to each one of the MVR pairs, each MVR pair including (i) a respective first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a respective second MVR in a second plurality of MVRs corresponding to a second reference picture, each TM cost being determined based at least on a portion or all of a current template of the current block and a bi-predictor of the respective MVR pair, the bi-predictor being based on a portion or all of a first reference template in the first reference picture corresponding to the first MVR of the respective MVR pair and a portion or all of a second reference template in the second reference picture corresponding to the second MVR of the respective MVR pair; and selecting an MVR pair from the MVR pairs based on the determined corresponding TM costs; and reconstructing the current block based on the selected MVR pair, wherein the first MVR of one of the MVR pairs is different from the second MVR of the one of the MVR pairs.
2. The method of claim 1, wherein the performing the TM includes reordering the MVR pairs based on the determined corresponding TM costs; and the selecting includes selecting the MVR pair from the reordered MVR pairs.
3. The method of claim 2, wherein all of the current template of the current block is used to determine the TM costs; and for each MVR pair, all of the first reference template is used to determine the bi-predictor, and all of the second reference template is used to determine the bi-predictor.
4. The method of claim 1, wherein the prediction information includes a flag indicating that the TM is performed on the MVR pairs.
5. The method of claim 3, wherein the current template includes current subblock templates, and for each MVR pair in the MVR pairs, the determining the TM cost includes: determining first reference subblock templates in the first reference template based on the current subblock templates and corresponding first motion vectors (MVs), respectively, the first MVs being based on positions of the respective current subblock templates and affine parameters of the current block, and determining second reference subblock templates in the second reference template based on the current subblock templates and corresponding second MVs, respectively, the second MVs being based on the positions of the respective current subblock templates and the affine parameters of the current block, the bi-predictor being based on the first reference subblock templates and the second reference subblock templates.
6. The method of claim 5, wherein for each MVR pair in the MVR pairs, samples in each of the first reference subblock templates have same motion information.
7. The method of claim 5, wherein the determining the first reference subblock templates comprises: for each MVR pair in the MVR pairs, determining the first reference subblock templates based on a prediction refinement using optical flow (PROF) mode, two samples in one of the first reference subblock templates having different motion information.
8. A method for video decoding in a video decoder, comprising: decoding prediction information of a current block in a current picture from a coded video bitstream, the prediction information

indicating that the current block is predicted using bi-prediction with an adaptive motion vector prediction (Δ MVP) mode; performing template matching (TM) on motion vector resolution (MVR) pairs by determining a TM cost corresponding to each one of the MVR pairs, each MVR pair including (i) a respective first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a respective second MVR in a second plurality of MVRs corresponding to a second reference picture, each TM cost being determined based at least on a current template of the current block and a bi-predictor of the respective MVR pair, the bi-predictor being based on a first reference template in the first reference picture corresponding to the first MVR of the respective MVR pair and a second reference template in the second reference picture corresponding to the second MVR of the respective MVR pair; and selecting an MVR pair from the MVR pairs based on the determined corresponding TM costs; and reconstructing the current block based on the selected MVR pair, wherein the first MVR of one of the MVR pairs is different from the second MVR of the one of the MVR pairs.

9. The method of claim 8, wherein the performing the TM includes reordering the MVR pairs based on the determined corresponding TM costs; and the selecting includes selecting the MVR pair from the reordered MVR pairs.

10. The method of claim 9, wherein the determining the TM cost comprises: for each MVR pair, determining the first reference template based on a first motion vector (MV) having the first MVR in the MVR pair, and determining the second reference template based on a second MV having the second MVR in the MVR pair.

11. The method of claim 10, wherein for each MVR pair, the bi-predictor corresponding to the respective MVR pair is a weighted average of the first reference template corresponding to the first MVR in the respective MVR pair and the second reference template corresponding to the second MVR in the respective MVR pair.

12. The method of claim 8, wherein the prediction information includes a flag indicating that the TM is performed on the MVR pairs.

13. A method for video encoding, comprising: performing template matching (TM) on motion vector resolution (MVR) pairs for a current block in a current picture that is predicted using bi-prediction with an affine adaptive motion vector prediction (AMVP) mode by determining a TM cost corresponding to each one of the MVR pairs, each MVR pair including (i) a respective first MVR in a first plurality of MVRs corresponding to a first reference picture and (ii) a respective second MVR in a second plurality of MVRs corresponding to a second reference picture, each TM cost being determined based at least on a portion or all of a current template of the current block and a bi-predictor of the respective MVR pair, the bi-predictor being based on a portion or all of a first reference template in the first reference picture corresponding to the first MVR of the respective MVR pair and a portion or all of a second reference template in the second reference picture corresponding to the second MVR of the respective MVR pair; and selecting an MVR pair from the MVR pairs based on the determined corresponding TM costs; encoding the current block based on the selected MVR pair using the bi-prediction; and encoding, in a bitstream, information indicating that the current block is predicted using the bi-prediction with the Δ MVP mode, wherein the first MVR of one of the MVR pairs is different from the second MVR of the one of the MVR pairs.

14. The method of claim 13, wherein the performing the TM includes reordering the MVR pairs based on the determined corresponding TM costs; and the selecting includes selecting the MVR pair from the reordered MVR pairs.

15. The method of claim 14, wherein all of the current template of the current block is used to determine the TM costs; and for each MVR pair, all of the first reference template is used to determine the bi-predictor, and all of the second reference template is used to determine the bi-predictor.

16. The method of claim 15, wherein the current template includes current subblock templates, and

for each MVR pair in the MVR pairs, the determining the TM cost includes: determining first reference subblock templates in the first reference template based on the current subblock templates and corresponding first motion vectors (MVs), respectively, the first MVs being based on positions of the respective current subblock templates and affine parameters of the current block, and determining second reference subblock templates in the second reference template based on the current subblock templates and corresponding second MVs, respectively, the second MVs being based on the positions of the respective current subblock templates and the affine parameters of the current block, the bi-predictor being based on the first reference subblock templates and the second reference subblock templates.
