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Wu et al.

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(54) **HARDWARE FRIENDLY DESIGN FOR MOTION FIELD PROCESSING AND QUALITY IMPROVEMENT OF MOTION FIELD**

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H04N 19/105 (2014.01)
(Continued)

(52) **U.S. Cl.**
CPC *H04N 19/52* (2014.11); *H04N 19/105* (2014.11); *H04N 19/124* (2014.11);
(Continued)

(58) **Field of Classification Search**
CPC H04N 19/176
See application file for complete search history.

(56) **References Cited**

PUBLICATIONS

Peter de Rivaz, et al., AV1 Bitstream & Decoding Process Specification, Copyright 2018, The Alliance for Open Media, pp. 1-681.

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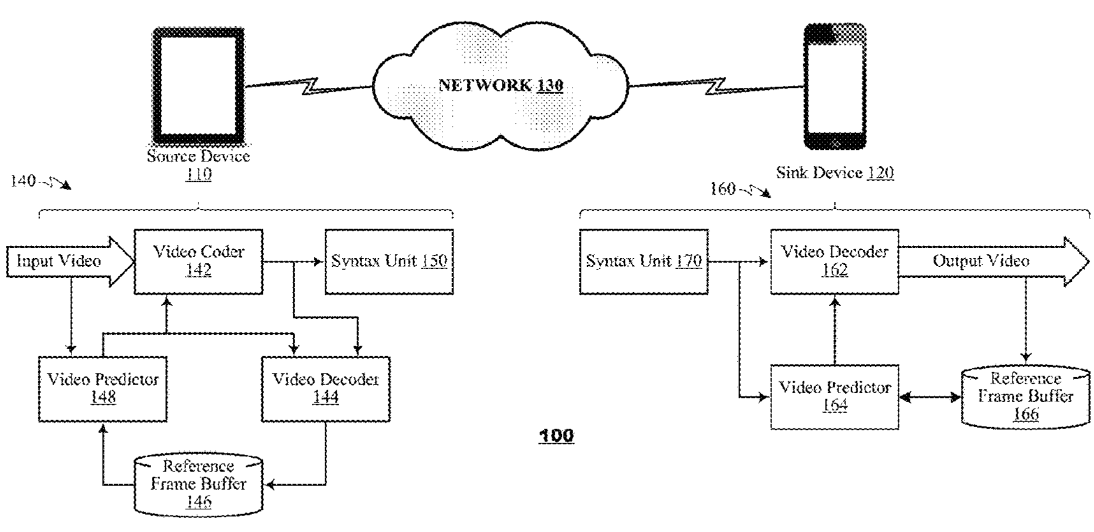
(57) **ABSTRACT**

Techniques are proposed to improve temporal motion projection in video coding. Candidate reference frames available for use in temporal motion projection are sorted in processing order according to scores assigned based on estimates of the reference frames' suitability for prediction. Such estimates may be based on temporal distance between each candidate reference frame and that reference frame's prediction references. Estimates may be based, for each reference frame, based on an estimate of coding quality of a reference frame from which the respective candidate reference frame makes a prediction reference. Once sorted, the candidate reference frames may be processing in the sorting order to supply prediction data to a current frame that is to be coded from the candidate reference frames. Additionally, hardware friendly designs of motion field hole filling and motion vector smoothing operations are proposed. Such designs can reduce hardware implementation complexity and benefit hardware parallel processing in several aspects: by removing the dependency among different processing block rows for hole filling and motion vector smoothing so that it is becomes easier and friendlier to achieve hardware parallel processing; by reducing the hardware bandwidth loading overhead; by improving hardware pipeline throughput; and/or by avoiding adding a line buffer to store the data from the above row since a line buffer will increase hardware cost.

32 Claims, 4 Drawing Sheets



(51) **Int. Cl.**

H04N 19/124	(2014.01)
H04N 19/127	(2014.01)
H04N 19/154	(2014.01)
H04N 19/172	(2014.01)
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H04N 19/52	(2014.01)

(52) **U.S. Cl.**
CPC ***H04N 19/127*** (2014.11); ***H04N 19/154*** (2014.11); ***H04N 19/172*** (2014.11); ***H04N 19/176*** (2014.11)

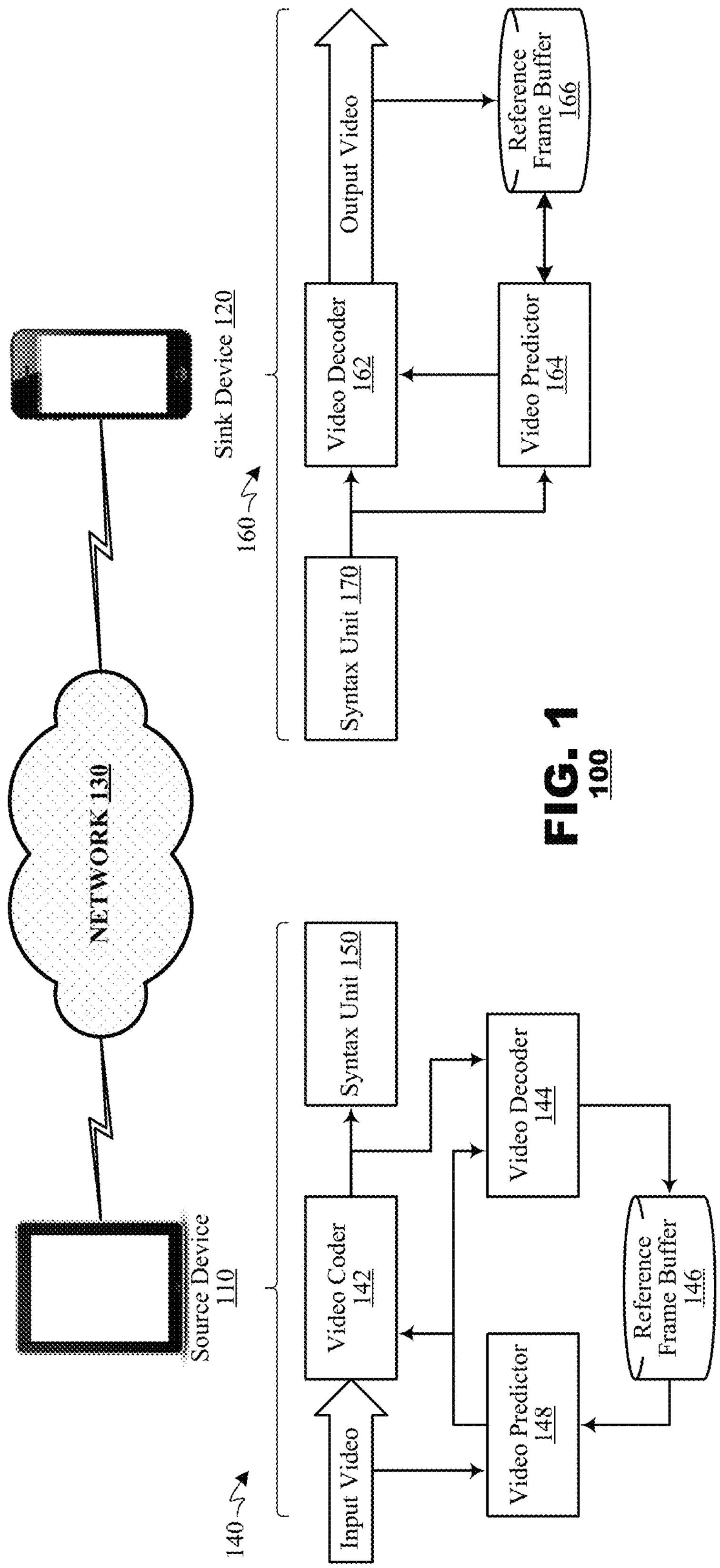
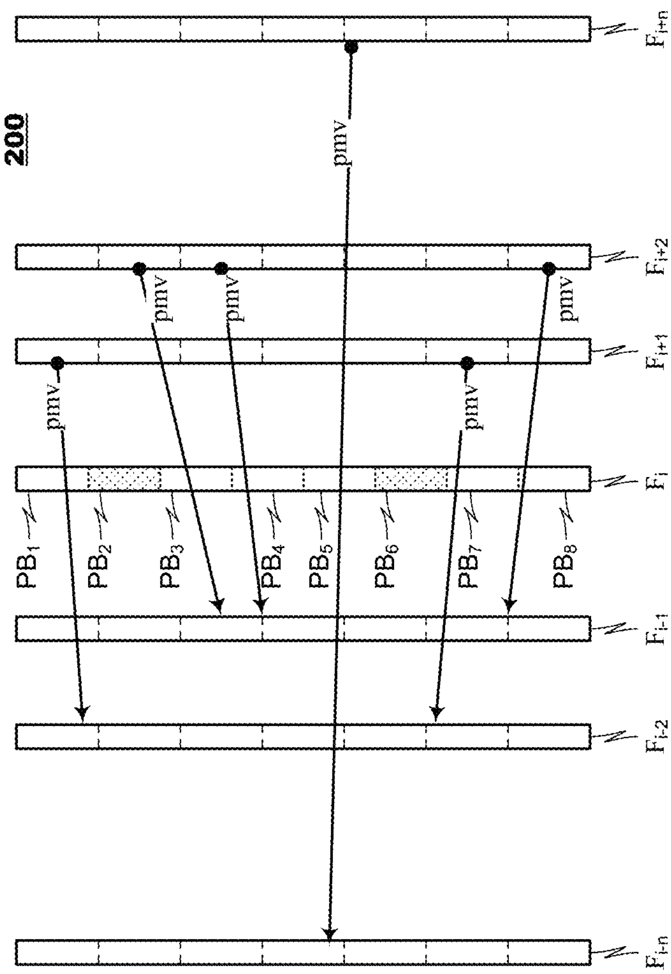

Source Device 110
NETWORK 130
Sink Device 120
140
Input Video
Video Coder 142
Syntax Unit 150
Video Decoder 144
Video Predictor 148
Reference Frame Buffer 146
160
Syntax Unit 170
Video Decoder 162
Video Predictor 164
Output Video
Reference Frame Buffer 166

FIG. 1
100

FIG. 2
200



pmv
pmv
pmv
pmv
pmv
pmv
PB1
PB2
PB3
PB4
PB5
PB6
PB7
PB8
Fi+n
Fi+2
Fi+1
Fi
Fi-1
Fi-2
Fi-n

Score Factor 1: Temporal distance between current frame and candidate ref. frame. 310

↓

Score Factor 2: Coding quality of candidate ref. frame. 320

↓

Score Factor 3: Temporal distance between candidate ref. frame and its ref. frame. 330

↓

Score Factor 3: Motion characteristics of candidate ref. frame (interp. vs. extrap.). 340

↓

Sum score factors for each candidate reference frame. 350

↓

Prioritize candidate reference frames according to score factors. 360

↓

Detect holes according to motion factors of ordered candidate reference frames. 370

FIG. 3
300

FIG. 4
400

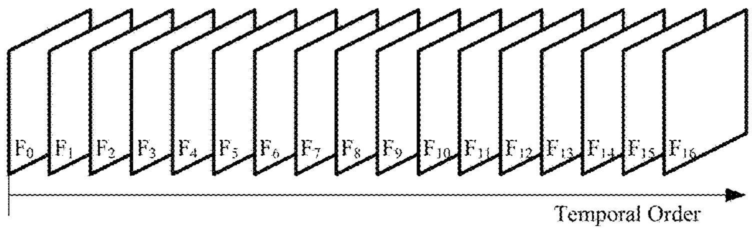


FIG. 5
500

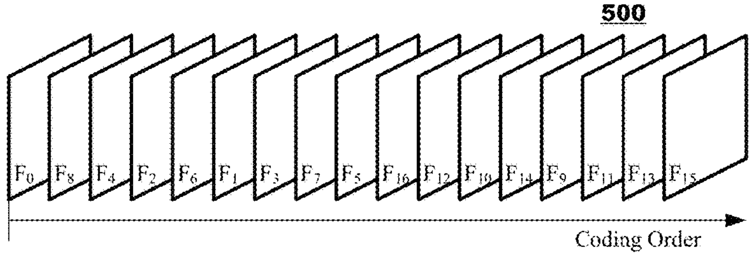
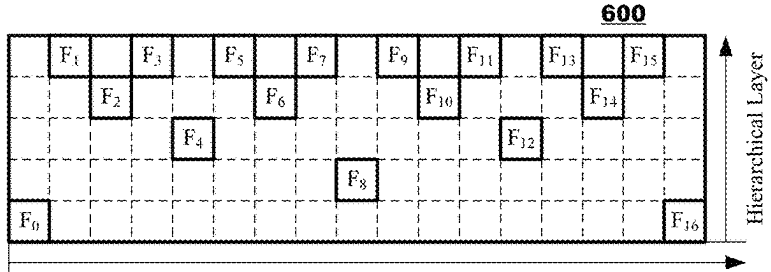


FIG. 6
600



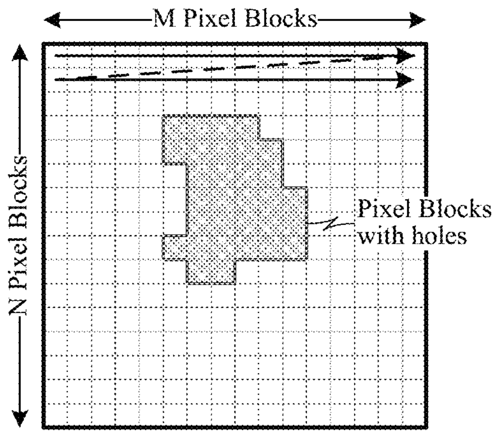


FIG. 7
700

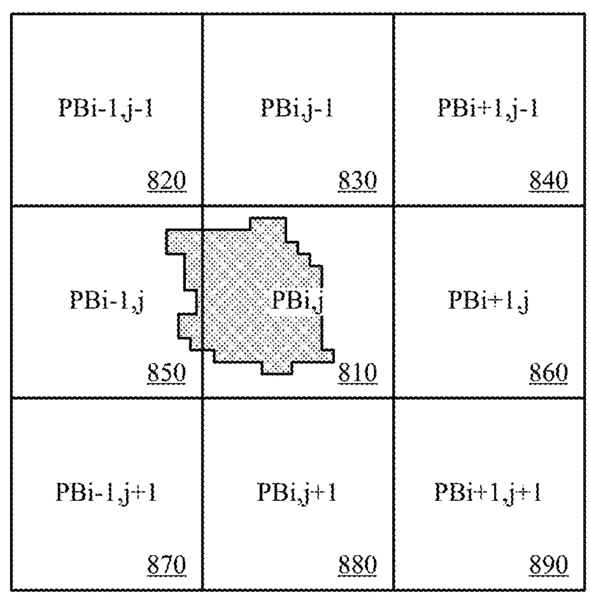


FIG. 8
800

HARDWARE FRIENDLY DESIGN FOR MOTION FIELD PROCESSING AND QUALITY IMPROVEMENT OF MOTION FIELD

CLAIM FOR PRIORITY

The present application benefits from priority of U.S. application Ser. No. 63/494,096, filed Apr. 4, 2023 and entitled "Hardware Friendly Design for Motion Field Processing and Quality Improvement of Motion Field," the disclosure of which is incorporated herein in its entirety.

BACKGROUND

The present disclosure relates to techniques for video coding and decoding and, in particular, to techniques for developing lists of temporal motion vector predictors for predictive coding.

In existing video coding standards, motion vector prediction is used to reduce the bits required to represent motion information that will be sent in bitstreams. Building a high quality motion vector predictor list is an important feature of this technique. Usually, the spatial and temporal correlation of motion vectors in a motion field is exploited. A temporal motion vector predictor (TMVP) is one kind of predictor generated by exploiting the already available motion vectors of reference frames that are coded before a new frame (called a "current" frame) is coded. One method to generate the TMVP is to project the motion vectors of the reference frames, which were used to predictively code content of the reference frames themselves, to the location of current coding frame. The projected motion vectors are then used for the coding process to generate the motion vector prediction (MVP) candidate list, or to create a new reference frame (e.g. temporal interpolation prediction, "TIP"), which helps improve coding efficiency.

The Alliance for Open Media proposes a video model (called "AVM") that selects two highest priority past reference frames and two highest priority future reference frames, if they exist, for a motion vector list to be used when coding a new input frame. Under such techniques, content for a current frame is predicted from the selected reference frames according to a fixed order of selection.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a functional block diagram of a video coding system **100** according to an embodiment of the present disclosure.

FIG. **2** illustrates application of temporal motion vector prediction in the context of an exemplary video sequence.

FIG. **3** illustrates a method according to an embodiment of the present disclosure.

FIG. **4** illustrates an exemplary set of frames on which the method of FIG. **3** may operate arranged in temporal order.

FIG. **5** illustrates an exemplary set of frames on which the method of FIG. **3** may operate arranged in coding order.

FIG. **6** illustrates an exemplary set of frames on which the method of FIG. **3** may operate arranged according to a hierarchy of predictions.

FIG. **7** illustrates application of temporal motion vector prediction in the context of an exemplary frame.

FIG. **8** illustrates granularities of processing blocks for derivation of hole content according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

Current techniques for generating motion prediction lists are sub-optimal because they fail to recognize properties of the candidate reference frames which themselves can provide information regarding their quality for prediction of content for a current frame. For example, these techniques fail to recognize that, when a given reference frame is coded with high quality, other reference frames that refer to the high-quality reference frame also may have high quality. These other reference frames also may be assigned relatively high priority as compared to other candidate reference frames.

Meanwhile, several algorithms are proposed to improve temporal motion projection, therefore, the coding performance, for video coding. To provide flexibility for different applications, achieve best performance, and to also improve error resiliency, high level syntaxes are designed to explicitly signal the motion projection scanning order to the decoder at different levels, such as sequence/frame/tile/slice level.

Additionally, hardware friendly designs of motion field hole filling and MV smoothing operations are proposed. Such designs can reduce hardware implementation complexity and benefit hardware parallel processing in four aspects:

a. By removing the dependency among different processing block rows for hole filling and MV smoothing so that it is becomes easier and friendlier to achieve hardware parallel processing;
b. By reducing the hardware bandwidth loading overhead;
c. By improving hardware pipeline throughput;
d. By avoiding adding a line buffer to store the data from the above row since a line buffer will increase hardware cost.

FIG. **1** is a functional block diagram of a video coding system **100** according to an embodiment of the present disclosure. The system **100** may include a source device **110** provided in communication with a sink device **120** over a network **130**. The source device **110** may provide a stream of coded video data to the sink device **120** over the network. The sink device **120** may decoded the coded video data, which may recover a stream of output video data that may be consumed by the sink device **120**. Typically, recovered video data is consumed by displaying the recovered video on a display device, by storing the recovered video for later review, or by outputting the recovered video to an application (not shown) executing on the sink device **120** for its use.

A source device **110** may possess a video coding system **140** that generates coded video data from input video. FIG. **1** illustrates typical elements of a video coding system **140** at a high level. A video coding system **140** may have a video coder **142**, a video decoder, a reference frame buffer **146**, and a video predictor **148**. The video coder **142** may generate coded video data from the input video and may output the coded video data to a syntax unit **150** that formats the coded video data for transmission to the sink device **120**. The video coder **142** may partition individual frames of video into blocks, sometimes recursively, and may code the blocks on a block-by-block basis. The video coder **142** may code the blocks differentially with reference to predicted blocks that are supplied to the video coder by the video predictor **148**. The video predictor **148** may select predicted blocks for use by the video coder **142** by searching among a set of reference frames that are stored in the reference frame buffer **146** for a candidate prediction block that matches content of a block currently being coded by the video coder **142**.

The video coding system **140** may select certain coded frames (called "reference frames") to serve as candidates for prediction of blocks for other frames that will be coded later. The video decoder **144** may decode the coded video data generated by the video coder **142** and store recovered frames assembled therefrom in the reference frame buffer **146**. The video decoder **144** typically inverts coding operations that are applied by the video coder **142**. For blocks coded predictively with reference to prediction block, the video decoder **144** may receive prediction blocks from the video predictor **148** and integrate content of the prediction blocks into decoded blocks prior to output. The video coder's coding operations can be lossy processing operations; thus application of the video coder **142** and the video decoder **144** can result in recovery of a frame that resembles the input frame from which it as derived but with some coding errors.

The syntax unit **150** may integrate coded video data from the video coder **142** with other content streams such as audio streams. The syntax unit **150** typically formats the coded video data according to a protocol determined by a coding standard (e.g., ITU H.265, H264, H.263, or the like) under which the video coding system **140** operates. For blocks where the video coder **142** codes the block differentially with respect to a predicted block, the coded block data may include an identifier of the prediction block that was selected (often by a "motion vector") and its motion type (e.g., translation, zoom, rotation, affine, etc.) as compared to the block being coded. Coded video data may include other identifiers of coding parameters that were selected by the video coder **142** such as identifications of block partitioning, transform type, quantization parameters, designation of select frames as reference frames, and the like. And, of course, coded video data identifies, for each block, the temporal location of the frame from which the block was derived.

A sink device **120** may possess a video decoding system **160** that generates recovered video from the coded video data received from the source device **110**. Again, FIG. **1** illustrates typical elements of a video decoding system **160** at a high level. The video decoding system **160** may have a video decoder **162**, a video predictor **164**, and a reference frame buffer **166**. The video decoder **162** may receive coded video data from a syntax unit **170**, which parses the coded video data from perhaps other content elements included in the media stream received from the source device **120**. The video decoder **162** may invert coding operations applied by the video coder **142** of the source device **120** just as the source device's video decoder **144** does. The video decoder **162** may output a stream of recovered video from the video decoder system **160**.

For blocks coded predictively, the video decoder **162** may receive prediction blocks from the video predictor **164** and integrate content of the prediction blocks into decoded blocks prior to output. The video predictor **164** may retrieve prediction blocks from the reference frame buffer according to the motion information, e.g., the motion vectors and motion type identifiers, provided in coded video data.

For frames that are designated to serve reference frames, recovered frame data may be stored in the reference frame buffer **166** for use in decoding later-received coded frames. Operation of the video decoders **144** and **162** between the video coding system **140** and the video decoding system **160** are synchronized so that, in the absence of transmission errors or other communication artifacts that cause a loss of coded video data, the reference frame buffers **146** and **166** of the two systems **140**, **160** should have the same state during coding and decoding of a common block of a common frame.

FIG. **2** illustrates application of temporal motion vector prediction in the context of an exemplary coded video sequence. In this example, a "current frame" F_i to be coded may draw prediction references from any number of previously coded frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n} that are candidates to serve as prediction references for blocks (PB_1-PB_8) of the current frame F_i. These reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n} are already coded at the time a video coding system **140** (FIG. **1**) begins work to code the frame F_i. Thus, the video coding system **140** has access not only to the recovered video data corresponding to these candidate reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n}, it also has access to the prediction data, the motion vectors, identifications of reference frames, and identification of motion type, that the video coding system **140** used to predictively code frames F_{i-2}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n}. FIG. **2** illustrates exemplary prediction references for the reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n} as pmv. As illustrated in FIG. **2**, a projection of the prediction references pmv may intersect certain pixel blocks PB_1-PB_8 of the current frame F_i. Although not illustrated in FIG. **2**, it may occur that, for certain pixel blocks PB_1-PB_8 of the current frame F_i, there are multiple prediction references from the reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n} that intersect the pixel blocks PB_1-PB_8.

FIG. **3** illustrates a method **300** according to an embodiment of the present disclosure to select, from among a plurality of candidate reference frames, a reference frame to serve as a prediction reference for a pixel block to be coded. The method **300** may be performed, for example, by a video coder **142** (FIG. **1**). The method **300** may assign scores individually to candidate reference frames according to a variety of factors. A first score factor may be assigned based on a temporal distance between the frame being coded (e.g., frame F_i in FIG. **2**) and a candidate reference frame (box **310**). A second score factor may be assigned based on a quality of coding that was used to code each candidate reference frame (box **320**). Another score factor may be assigned based on a temporal distance between each candidate reference frame and its own prediction references (box **330**). Another score factor may be assigned based on characteristics of motion prediction references among the candidate reference frames (box **340**).

The method **300** may sum the score factors assigned to the candidate reference frames (box **350**) and organize the candidate reference frames in a scanning order (box **360**) for construction of a motion projection list. The method may predict content for the current frame from a list of candidate reference frames sorted by priority (box. **370**). The method **300** thereafter may identify the presence of pixel block holes in a frame being coded by reviewing prediction references among the candidate reference frames as ordered in the motion projection list (box **380**).

The score factors may be assigned in a variety of ways. In box **310**, reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n} that have shorter temporal distances to the frame F_i being coded may be assigned relatively higher scores than reference frames that have higher temporal distances to the frame F_i being coded. Exceptions may be made for frames that are designated as being on an opposite side from a scene cut than the frame F_i being coded; in such cases, candidate reference frames on the other side of a scene cut may be assigned lower scores in box **310** than otherwise be assigned based on the temporal distance between those frames and the frame F_i being coded.

In box **320**, candidate reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n} that are coded with relatively high quality may be assigned relatively higher scores than candidate reference frames coded with lower quality. Coding quality may be assessed from a variety of factors. For example, scores may be assigned based on the values of quantization parameters used for quantization of pixel blocks in the candidate reference frames, based on the bit size of the candidate reference frames when coded, based on an estimate of coding distortion when a decoded candidate reference frame is compared to its counterpart in an input video sequence, based on a determination of coefficient thresholding applied, and the like.

In another embodiment, coding quality scores in box **320** may be derived from a candidate reference frame's position in a coding hierarchy defined by prediction references among the candidate reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n}. This is discussed hereinbelow with reference to FIG. **6**.

In box **330**, candidate reference frames that have relatively short temporal distances to their closest reference frames with the interpolation property may be assigned higher scores than other candidate reference frames that have relatively long temporal distances to their closest reference frames with the interpolation property.

In box **340**, scores may be assigned based on characteristics of motion prediction references among the candidate reference frames. For example, motion prediction references that extend between reference frames at opposite temporal locations from the frame being coded (e.g., motion vectors that lead to interpolation of pixel block content) may be assigned higher scores than motion prediction references that extend between reference frames that are located on the same side of the frame being coded. With reference to FIG. **2**, the exemplary motion vectors pmv illustrated in FIG. **2** each extend from reference frames F_{i+1}, F_{i+2}, and F_{i+n} that temporally are located on one side of the frame F_i being coded to other reference frames F_{i-n}, F_{i-2}, and/or F_{i-1} that are located on the other side of the frame F_i being coded. If a prediction motion vector extended between frames that both are on the same side as the frame F_i being coded, for example, from frame F_{i+2} to frame F_{i+1} (not shown), such a prediction vector may be given a lower score than those prediction motion vectors illustrated in FIG. **2**.

FIGS. **4-6** illustrate an exemplary set of frames to which the method of FIG. **3** may be applied. FIG. **4** illustrates a set **400** of frames F_0-F_{16} in temporal order; this is the order in which frames may appear in input video or in recovered output video (FIG. **1**). Video coding and decoding systems **140**, **160** (FIG. **1**), however, often process frames in an encoding order that is different from the frames' presentation order. FIG. **5** illustrates a coding sequence **500** that may be applied to the frames F_0-F_{16} when they are coded by, for example, a video coder **142** (FIG. **1**). Finally, owing to temporal prediction references that extend between the coded frames, the frames F_0-F_{16} may be organized into a coding hierarchy **600** of prediction references as shown in FIG. **6**.

FIG. **6** assigns the frames F_0-F_{16} to different levels of the hierarchy **600** according to the number of prediction references that extend from each frame to a base frame F_0 in the sequence. The base frame F_0 is shown in a base level of the hierarchy because it makes reference to no other frame in the video sequence. Frame F_5 may be coded predictively with reference to frame F_0, however, which places frame F_5 in a second level of the hierarchy. Frame F_4 may be coded predictively with reference frames F_0 and/or F_8, and therefore it is shown at a third level of the hierarchy. Other frames are assigned to other levels of the hierarchy to show possible permutations of prediction references among the frames.

Operation of the method **300** will be discussed with reference to exemplary frame F_5. Assume for purposes of discussion that, at the time frame F_5 is processed for coding, reference frames F_3, F_4, F_6, and F_8 are available to serve as prediction references. The score factors developed in boxes **310-340** (FIG. **3**) will be discussed in context of frame F_5.

When coding frame F_5, frames F_4 and F_6 have the shortest temporal distance from frame F_5 which are the same as each other. Frames F_3 and F_8 have longer temporal distances to frame F_5. Thus, the score factors assigned to frames F_4 and F_6 by box **310** may be the same as each other and they may be greater than the score factors assigned to frames F_3 and F_8 by box **310**. The score factors assigned to frames F_3 and F_8 by box **310** also may be the same as each other.

When coding frame F_5, assessments of coding quality may consider not only the coding parameters assigned for the candidate reference frames but also the coding parameters of those candidate reference frames' parent frames. Consider an example where frame F_4 is coded using coding parameters such as quantization parameters that indicate frame F_4 is a high quality frame. In this circumstance, frame F_4 may be given a relatively high score based on the quality of coding assigned to frame F_4. If frame F_6 is coded predictively with reference to the high-quality frame F_4, it, too, may be given a relatively high score based on the quality of coding assigned to frame F_4.

As discussed, in box **320**, scores may be assigned based on a candidate reference frame's position in a coding hierarchy developed by prediction references among the candidate reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n}. The example of FIG. **6** shows that frame F_4 is contained in a third layer of a hierarchy **600** among frames, which may arise because frame F_4 is coded predictively with reference to frame F_8 and frame F_8 is coded predictively with reference to frame F_0. FIG. **6** shows that frame F_6 is contained in a fourth layer of the hierarchy **600**, which may arise because frame F_6 is coded predictively with reference to frame F_4. In such a circumstance, frame F_4 may be assigned a higher score in box **320** than frame F_6 because it is placed in a lower layer of the hierarchy as compared to frame F_6.

In box **330**, scores may be assigned based on a temporal distance between a candidate reference frame and the reference frame to which the candidate reference frame refers in prediction. Continuing with the foregoing example where frame F_4 is coded predictively with reference to frame F_8 and frame F_6 is coded predictively with reference to frame F_4, there is a larger temporal distance between frame F_4 and its reference frame F_8 than between frame F_6 and its reference frame F_4. In this circumstance, frame F_6 may be assigned a higher score than frame F_4 in box **330** owing to its shorter temporal distance to its parent reference frame.

A similar analytical approach may be applied for frames F_9, F_{10}, and F_{13} in the example of FIGS. **4-6**. It may occur that, when the method **300** of FIG. **3** considers quality contributions based in candidate reference frames' locations in hierarchical layers and/or their reference to other frames of high quality, that different priority assignments may be achieved using the techniques proposed in FIG. **3** than according to prioritization schemes define by other techniques such as:

TABLE 1

Correct priority assignment for the highest priority of past and future reference frames when building the motion projection list

	Current Design		Proposed Design	
Frame Index	1st priority	2nd priority	1st priority	2nd priority
5	4	6	6	4
10	8	12	12	8
9	8	10	10	8
13	12	14	14	12

In the foregoing table, the current design refers to priority assignments that might be reached by predecessor AOM proposals whereas the proposed design refers to priority assignments that might be reached by the embodiment disclosed in FIG. **3**.

For the score-based adaptive motion projection order, besides considering the relationship between the reference frames to the current frame, like the temporal distance, interpolation/extrapolation, and pixel quality, the method **300** also may consider the relationship between the reference frames. As discussed, if two reference frames F_4, F_6 have the same temporal distance to the current frame F_5 and have the same interpolation/extrapolation property, and if one reference frame F_6 uses the other reference frame F_4 as its reference frame, then the reference frame F_6 that uses another reference F_4 frame as its reference frame should be assigned with a higher priority compared to the other one F_4.

The motion projection order can be achieved by ranking the score of each reference frame:

Score=Function(temporal distance between current frame to the reference frame, the relationship between two highest priority reference frames, interpolation/extrapolation, pixel_quality, light change, occlusion/disocclusion)

Another issue with the AOM score-based adaptive motion projection order is that it does not consider the relationship between the reference frame and its own reference frames. For example, when coding frame F_5, frame F_3 is the second highest priority past reference frame and frame F_5 is the second highest priority future reference frame for frame F_5. With the current score based adaptive motion projection order algorithm, frame F_8 is assigned with higher priority than frame F_3 when building the motion projection list for frame F_5 due to the high pixel quality of frame F_8 (low hierarchical layer). However, the first reference frame with interpolation property for frame F_8 is frame F_0 when coding frame F_5, the temporal distance is F_8 and half of the GOP size. Temporal correlation often reduces with the increase of temporal distance. For reference frame F_3, its first reference frame with interpolation property is frame $_6$, the temporal distance between frame F_3 and frame F_6 is much less than the temporal distance between frame F_8 and frame F_0. Thus, reference frame F_3 should be assigned a higher priority than frame F_8 when building the motion projection list for frame F_5. A similar improvement can be applied to frames F_3, F_6, F_7, F_{10}, F_{11}, F_{13} as shown in Table 2.

TABLE 2

Correct priority assignment for the second highest priority of past and future reference frames when building the motion projection list

	Current Design		Proposed Design	
Frame Index	3rd priority	4th priority	3rd priority	4th priority
3	8	1	1	8
6	16	2	2	16
5	8	3	3	8
7	16	5	5	16
10	16	8	8	16
11	16	9	9	16
13	16	11	11	16

In an embodiment, the method **300** may consider relationships between the reference frames and their own first reference frame with interpolation property relative to the current frame. When coding a frame, if one reference has higher priority than another reference frame, but the temporal distance between this reference frame to its own first reference frame with interpolation property is much larger than another reference frame to its own first reference frame with interpolation property, then another reference frame with small temporal distance to its own first reference frame with interpolation property should be assigned with high priority. For example, as in the example shown in FIG. **6**, frame F_3 and frame F_8 are two reference frames when coding frame F_5, and based on the current score based adaptive motion projection order algorithm, frame F_8 will be assigned with high priority since it has high pixel quality. However, the temporal distance of frame F_5 to its own first reference frame with interpolation property, frame F_0, is much larger than the temporal distance of frame F_3 to its own first reference frame with interpolation property, frame F_6. Therefore, instead of assigning high priority for frame F_8, frame F_3 should be assigned higher priority than frame F_8 when building the motion projection list for coding frame F_5.

In a particular embodiment of the proposed algorithm, the motion projection list may be generated as follows:

Scan Order:

temporal_dist_2nd_past=temporal distance between 2nd closest past reference to its own first reference frame with interpolation property

temporal_dist_2nd_future=temporal distance between 2nd closest future reference to its own first reference frame with interpolation property

```
if ( closest past is the reference frame of the closest future) {
  if (temporal__dist__2nd__past < temporal__dist__2nd__future) {
    Scan Order: closest future, closest past, 2nd closest past, 2nd
    closest future
  } else {
    Scan Order: closest future, closest past, 2nd closest future, 2nd
    closest past
  }
} else {
  if (temporal__dist__2nd__past < temporal__dist__2nd__future) {
    Scan Order: closest past, closest future, 2nd closest past, 2nd
    closest future
} else {
    Scan Order: closest past, closest future, 2nd closest future, 2nd
    closest past
  }
}
```

The algorithm may apply a maximum allowed number of predictors, for example, three predictors. Moreover, the algorithm may operate according to an overwrite rule in which a motion vector from a lower priority reference frame will not overwrite the motion information assigned by a higher priority reference frame.

Adaptive TMVP motion projection order can be achieved by assigning and ranking scores of each reference frame using functions that consider:

a. Temporal distance between the reference frame to the current frame
b. Temporal distance between the reference frame and its own first reference frame with interpolation property
c. The relationship between two reference frames: is one reference frame a reference of another reference frame
d. Interpolation or extrapolation
e. Pixel quality of the reference frame
f. Light change
g. Occlusion or disocclusion

The score can be modeled as a function of, but not limited to, the temporal distance between the current frame to its reference frame, temporal distance between the reference frame and its own first reference frame with interpolation property, the relationship between two reference frames: is one reference frame a reference of another reference frame, interpolation/extrapolation, pixel_quality, light change, and occlusion/disocclusion. The function can be, but not limited to linear models, nonlinear models, decision tree, neural network, SVM (support vector machine) models, etc.

In an embodiment, a video coder **142** (FIG. **1**) may explicitly signal the motion projection scanning order to the decoder **162**. The signaling can be done at a sequence, frame, tile, or slice level of a governing coding protocol.

A hierarchical layer structure can also be utilized to signal the motion projection scanning order to improve signaling efficiency. The scanning order of motion projection can be simultaneously controlled at different levels of a coding syntax, such as in a VPS (video parameter set), SPS (sequence parameter set) or PPS (picture parameter set) layers, and/or at the frame level and slice or tile level. A highest level can signal the scanning order of all reference frames in the motion projection list, but then the lower levels can signal the scanning order of a subset of reference frames to refine the overall scanning order of motion projection. In this instance, the remaining part may use the motion projection scanning order signaled in the higher level. For example, the motion projection scanning order of all N possible reference frames could be signaled in the SPS, then, in the PPS, the scanning order of the first M reference frames could be further refined, where M<N. In this example, the scanning order of the remaining N−M reference frames will just use the scanning order as defined in the SPS. A similar approach can be applied to the slice or tile level, where, at the slice and tile level, only a part of the scanning order from the PPS or SPS will be refined.

In an alternative embodiment, a video coder **142** may define several different scanning order sets and signal them in a higher level syntax, and then, at lower levels, the video coder **142** can select a set by using a set index. This can help reduce the signaling cost at lower levels compared to explicitly signaling the scanning order.

Returning to FIG. **2**, the motion vectors of reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n} may be used to derive content of pixel blocks PB_1-PB_8 of the current frame F_i. It is not guaranteed, however, that prediction references pmv from the candidate reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n} will intersect all pixel blocks PB_1-PB_8 of the current frame F_i. In the example of FIG. **2**, pixel blocks PB_2 and PB_6 are illustrated as having no intersection with the prediction references pmv from the candidate reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n}. A pixel block (say, PB_2 and PB_6) that does not intersect with the field of prediction references pmv from the candidate reference frames F_{i-n}, F_{i-2}, F_{i-1}, F_{i+1}, F_{i+2}, and F_{i+n} is deemed to present a “hole” in this field of prediction references pmv.

FIG. **2** illustrates a one-dimensional projection of exemplary pixel blocks in a current frame F_i. FIG. **7** illustrates the phenomenon of holes in a two dimensional representation **700** of a current frame F_i. In cases where content of pixel blocks cannot be derived through temporal motion prediction, some other derivation technique is used.

Embodiments of the present invention apply hole derivation techniques in which hole content for a processing block **810**, shown in FIG. **8**, is derived from predicted portions of a frame that are selected to have a predetermined size. Thus, instead of utilizing the projected motion fields of an entire frame for hole filling and motion vector smoothing, only the projected motion fields within the processing block **810** of a predetermined size are utilized. In one embodiment, the size of the processing block **810** may be aligned with the size of the largest coding units available in a governing coding standard, such as a superblock (SB) or a coding tree unit (CTU). For example, the maximum allowed SB size in AOM AV1 and the AVM is 128×128 pixels. Thus, in the example shown in FIG. **8**, the processing block **810** may be constrained to be of size 128×128 pixels and the unit size of each TMVP block (not shown) within the processing block is set to 8×8 pixels.

It is expected that, by restricting hole derivation techniques to processing blocks **810** of predetermined sizes, the operation of such hole derivation techniques will be improved by reducing processing dependency issues that can arise in microprocessor programming environments. As compared to implementations in which hole derivation techniques utilize content from processing blocks proximate **820-890** to the processing block **810** at issue, an embodiment that restricts hole filling to a processing block **810** of predetermined size can reduce processing dependency issues that arise when a processing pipeline that operates on a first number of pixel blocks (say, pixel blocks **820-840**). Other fixed specific processing block sizes can also be defined for hardware parallel processing.

In an embodiment, processing block sizes may be selected to be slightly larger than the largest coding unit size that is supported by a coding protocol. For example, in a coding environment where a largest coding unit is 128×128 pixels, the processing block size may be selected to be 144×144 pixels, which accommodates motion fields from and near the current processing block, and especially around the boundary of the processing block.

In a further embodiment, the constraint can be relaxed by allowing the processing block **810** to utilize the motion fields from the current block's left and right processing blocks **850**, **860**. As show in FIG. **8**, the left and right processing blocks **850**, **860** can be utilized for hole filling and MV smoothing of the current processing block **810** since oftentimes they will not affect the hardware parallel processing, and content from those blocks **850**, **860** improve the motion field quality especially around the current processing block's **810** vertical boundary.

In an alternative embodiment, if the hardware can tolerate the complexity of accessing above and bottom processing blocks **830**, **880**, the constraint can be relaxed to allow the access of the motion fields from casual above and bottom blocks **830**, **880**, which can increase coding gain.

In an alternative embodiment, processing block constraints may allow utilization of motion fields from the current **810** and the left processing block **850** for hole filling and MV smoothing since it can mitigate the waiting cycles while maintaining coding gains.

Additional processing blocks on the left and/or right can also be considered for hole filling and MV smoothing. The coding specification and consequently any hardware implementations of encoders and decoders of such specification can be designed based on a desired waiting cycle and coding gain tradeoff, which can help determine how many processing blocks on the left and/or right can be utilized for hole filling and MV smoothing, or some blocks from above and bottom might also be allowed.

The processing block size can also be different for hole filing and MV smoothing. This can be signaled at a different level (e.g. frame level, sequence level, etc.). It can be the same or different from the processing block size used for motion projection.

The foregoing discussion has described operation of the video coders and video decoders of the present disclosure in the context of source and sink devices. Commonly, these components are provided as electronic devices. Video coders and decoders can be embodied in integrated circuits, such as application specific integrated circuits, field programmable gate arrays and/or digital signal processors. Alternatively, they can be embodied in computer programs that execute on personal computers, notebook computers, tablet computers, mobile devices, media players and other consumer devices. Such computer programs typically are embodied as program instructions stored in physical storage media such as electronic-, magnetic- and/or optically-based storage devices, where they are read to a processor and executed. And, of course, these components may be provided as hybrid systems that distribute functionality across dedicated hardware components and programmed general-purpose processors, as desired.

The foregoing description has been presented for purposes of illustration and description. It is not exhaustive and does not limit embodiments of the disclosure to the precise forms disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from the practicing embodiments consistent with the disclosure. Unless described otherwise herein, any of the methods may be practiced in any combination.

We claim:

1. A method of building a motion projection list for use in temporal prediction of video coding, comprising, for a number of candidate reference frames available for coding of a current frame:

assigning relative first scores to each candidate reference frame based on a temporal distance between the respective candidate reference frame and the current frame,

assigning relative second scores to each candidate reference frame based on a temporal distance between the respective candidate reference frame and the respective candidate reference frame's reference frame,

sorting the candidate reference frames within the motion projection list based on aggregate scores developed from the first and second scores;

developing prediction content for the current frame from motion vector predictions of the candidate reference frames so ordered.

2. The method of claim **1**, wherein the method operates within a video coder of a source device.

3. The method of claim **1**, wherein the method operates within a video decoder of a sink device.

4. The method of claim **1**, wherein first scores of candidate reference frames that have shorter temporal distances to the current frame are higher than first scores of other candidate reference frames that have longer temporal distances to the current frame.

5. The method of claim **1**, wherein second scores of candidate reference frames that have shorter temporal distances to their reference frames are higher than second scores of other candidate reference frames that have longer temporal distances to their reference frames.

6. The method of claim **1**, further comprising:

assigning a third score to each candidate reference frame based on the respective candidate reference frame's position within a hierarchy of prediction references formed among previously-coded candidate reference frames, wherein the aggregate scores of the candidate reference frames include contribution from the respectively assigned third scores.

7. The method of claim **1**, further comprising:

assigning a third score to each candidate reference frame based on a type of prediction extending from the respective candidate reference frame to the current frame, wherein the aggregate scores of the candidate reference frames include contribution from the respectively assigned third scores.

8. The method of claim **1**, further comprising:

assigning a third score to each candidate reference frame based on an estimate of coding quality of the respective candidate reference frame.

9. The method of claim **8**, wherein the estimate of each candidate reference frame's quality is based on quantization parameter(s) used to code the respective candidate reference frame.

10. The method of claim **8**, wherein the estimate of each candidate reference frame's quality is based on an estimate of distortion of the respective candidate reference frame when decoded.

11. The method of claim **8**, wherein the estimate of each candidate reference frame's quality is based on quantization parameter(s) used to code the candidate reference frame.

12. The method of claim **8**, wherein the estimate of each candidate reference frame's quality is based on an estimate of coding quality of a parent frame from the respective reference frame was coded.

13. The method of claim **1**, further comprising:

estimating, from motion vector predictors of the candidate reference frames, whether a content hole exists for the current frame, and

when a content hole is determined to exist, on a processing block by processing block basis, deriving content for a portion of the content hole present in each respective processing block from other content of the respective processing block,

wherein the processing block has a predetermined size.

14. The method of claim **13**, wherein the size of the processing block aligns with a size of a largest coding unit of a governing video coding protocol.

15. The method of claim **13**, wherein the size of the processing block is greater than a size of a largest coding unit of a governing video coding protocol.

16. The method of claim **13**, wherein the size of the processing block encompasses multiple instances of a largest coding unit of a governing video coding protocol but confined to a common row in which the coding unit exists.

17. A computer readable medium storing program instructions that, when executed by a processing device, cause the processing device to execute a method of building a motion projection list for use in temporal prediction of video coding in which, for a number of candidate reference frames available for coding of a current frame, the method:

assigns relative first scores to each candidate reference frame based on a temporal distance between the respective candidate reference frame and the current frame,

assigns relative second scores to each candidate reference frame based on a temporal distance between the respective candidate reference frame and the respective candidate reference frame's reference frame,

sorts the candidate reference frames within the motion projection list based on aggregate scores developed from the first and second scores;

develops prediction content for the current frame from motion vector predictions of the candidate reference frames so ordered.

18. The medium of claim **17**, wherein the processing device operates within a video coder of a source device.

19. The medium of claim **17**, wherein the processing device operates within a video decoder of a sink device.

20. The medium of claim **17**, wherein first scores of candidate reference frames that have shorter temporal distances to the current frame are higher than first scores of other candidate reference frames that have longer temporal distances to the current frame.

21. The medium of claim **17**, wherein second scores of candidate reference frames that have shorter temporal distances to their reference frames are higher than second scores of other candidate reference frames that have longer temporal distances to their reference frames.

22. The medium of claim **17**, wherein the method further:

assigns a third score to each candidate reference frame based on the respective candidate reference frame's position within a hierarchy of prediction references formed among previously-coded candidate reference frames, wherein the aggregate scores of the candidate reference frames include contribution from the respectively assigned third scores.

23. The medium of claim **17**, wherein the method further:

assigns a third score to each candidate reference frame based on a type of prediction (interpolation vs. extrapolation) extending from the candidate reference frame to the current frame, wherein the aggregate scores of the candidate reference frames include contribution from the respectively assigned third scores.

24. The medium of claim **17**, wherein the method further:

assigns a third score to each candidate reference frame based on an estimate of coding quality of the respective candidate reference frame.

25. The medium of claim **24**, wherein the estimate of each candidate reference frame's quality is based on quantization parameter(s) used to code the respective candidate reference frame.

26. The medium of claim **24**, wherein the estimate of each candidate reference frame's quality is based on an estimate of distortion of the respective candidate reference frame when decoded.

27. The medium of claim **24**, wherein the estimate of each candidate reference frame's quality is based on quantization parameter(s) used to code the candidate reference frame.

28. The medium of claim **24**, wherein the estimate of each candidate reference frame's quality is based on an estimate of coding quality of a parent frame from the respective reference frame was coded.

29. The medium of claim **17**, wherein the method further:

estimates, from motion vector predictors of the candidate reference frames, whether a content hole exists for the current frame, and

when a content hole is determined to exist, on a processing block by processing block basis, derives content for a portion of the content hole present in each respective processing block from other content of the respective processing block,

wherein the processing block has a predetermined size.

30. The medium of claim **29**, wherein the size of the processing block aligns with a size of a largest coding unit of a governing video coding protocol.

31. The medium of claim **29**, wherein the size of the processing block is greater than a size of a largest coding unit of a governing video coding protocol.

32. The medium of claim **29**, wherein the size of the processing block encompasses multiple instances of a largest coding unit of a governing video coding protocol but confined to a common row in which the coding unit exists.

* * * * *