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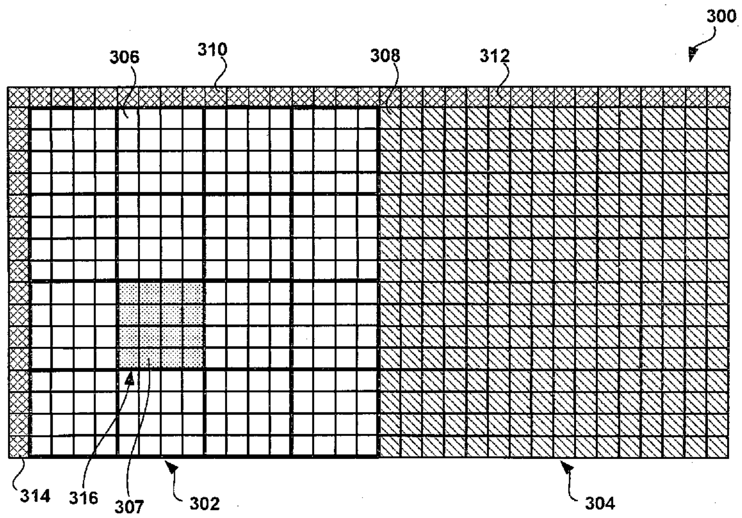
(54) **Title**: METHODS AND SYSTEMS FOR INTRA PREDICTION

FIG. 9



(57) **Abstract**: Aspects of the present invention relate to systems and methods for intra prediction. According to one aspect of the present invention, a macroblock may be partitioned into two, or more, sets of blocks. The pixel values for a block within a first set of blocks may be predicted using reconstructed values from only neighboring macroblocks. The pixel values for a block within another set of blocks may be subsequently predicted using reconstructed values from blocks in previously reconstructed sets of blocks and/or reconstructed values from neighboring macroblocks. A reconstructed block used in the prediction may be above, below, to left of or to the right of the block being predicted. The pixel values for blocks within a set of blocks may be predicted in parallel.

WO 2011/126159 A1

DESCRIPTION

TITLE OF INVENTION: Methods and Systems for Intra Prediction

TECHNICAL FIELD

Embodiments of the present invention relate generally to encoding and decoding of video data and, in particular, to methods and systems for intra prediction.

BACKGROUND ART

State-of-the-art video-coding standards, for example, H.264/AVC and other video-coding standards, may provide higher coding efficiency at the expense of higher computational complexity, which may result in slower encoding and/or decoding speeds. Additionally, computational complexity may increase with increasing quality and resolution requirements. Parallel decoding and parallel encoding may improve decoding and encoding speeds, respectively. Additionally, parallel decoding and parallel encoding may reduce memory bandwidth requirements for decoding and encoding processes, respectively. Furthermore, with advances in multi-core processors, parallel decoding and parallel encoding may be desirable in order to fully use the power of a multi-core processor.

SUMMARY OF THE INVENTION

Some embodiments of the present invention comprise methods and systems for intra prediction.

According to a first aspect of the present invention, a macroblock may be partitioned into two, or more, sets of blocks. A set of blocks may be referred to as a plurality of blocks or a group of blocks. The sets of blocks may be referred to as a partition of the macroblock.

According to a second aspect of the present invention, for a block in a first set of blocks, pixel values may be predicted using reconstructed pixel values from only one or more neighboring macroblocks. The pixel values within a block in another set of blocks may be subsequently predicted using reconstructed pixel values from blocks in previously reconstructed sets of blocks, in the partition of the macroblock, and/or reconstructed pixel values in neighboring macroblocks.

According to a third aspect of the present invention, a reconstructed block used in the prediction may be above, below, to left of or to the right of the block being predicted.

The foregoing and other objectives, features, and advantages of the invention will be more readily understood upon consideration of the following detailed description of the invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a picture depicting the processing order for intra 8x8 prediction and intra 4x4 prediction for H.264/AVC and other coding standards (PRIOR ART);

Fig. 2 is a picture depicting the nine intra-prediction-mode directions of H.264/AVC intra 4x4 prediction and intra 8x8 prediction (PRIOR ART);

Fig. 3A is a picture depicting an exemplary block with neighboring reconstructed samples (PRIOR ART);

Fig. 3B is a picture depicting reconstructed pixel values associated with a vertical intra-prediction mode (PRIOR ART);

Fig. 3C is a picture depicting reconstructed pixel values associated with a horizontal intra-prediction mode (PRIOR ART);

Fig. 3D is a picture depicting an intra-prediction-mode direction associated with a diagonal down left intra-prediction mode (PRIOR ART);

Fig. 3E is a picture depicting an intra-prediction-mode direction associated with a diagonal down right intra-prediction mode (PRIOR ART);

Fig. 3F is a picture depicting an intra-prediction-mode direction associated with a vertical right intra-prediction mode (PRIOR ART);

Fig. 3G is a picture depicting an intra-prediction-mode direction associated with a horizontal down intra-prediction mode (PRIOR ART);

Fig. 3H is a picture depicting an intra-prediction-mode direction associated with a vertical left intra-prediction mode (PRIOR ART);

Fig. 3I is a picture depicting an intra-prediction-mode direction associated with a horizontal up intra-prediction mode (PRIOR ART);

Fig. 4 is a picture depicting an exemplary partitioning of a macroblock into two sets of blocks according to embodiments of the present invention;

Fig. 5A is a picture depicting an exemplary partitioning of a macroblock into two sets of blocks according to embodiments of the present invention;

Fig. 5B is a picture depicting an exemplary partitioning of a macroblock into two sets of blocks according to embodiments of the present invention;

Fig. 5C is a picture depicting an exemplary partitioning of a macroblock into two sets of blocks according to embodiments of the present invention;

Fig. 5D is a picture depicting an exemplary partitioning of a macroblock into two sets of blocks according to embodiments of the present invention;

Fig. 5E is a picture depicting an exemplary partitioning of a macroblock into two sets of blocks according to embodiments of the present invention;

Fig. 6A is a picture depicting an exemplary partitioning of a macroblock into three sets of blocks according to embodiments of the present invention;

Fig. 6B is a picture depicting an exemplary partitioning of a macroblock into three sets of blocks according to embodiments of the present invention;

Fig. 7A is a picture depicting an exemplary partition of 4x4 blocks in a 32x32 macroblock according to embodiments of the present invention;

Fig. 7B is a picture depicting an exemplary partition of 4x4 blocks in a 32x32 macroblock according to embodiments of the present invention;

Fig. 8 is a picture depicting an exemplary partitioning of a macroblock into four sets of blocks according to embodiments of the present invention;

Fig. 9 is a picture depicting an exemplary portion of an image comprising two 16x16 macroblocks and neighboring macroblock pixels;

Fig. 10 is a picture depicting an exemplary partitioning of a macroblock into two sets of blocks according to embodiments of the present invention and neighboring blocks used for mode prediction;

Fig. 11 is a picture depicting an exemplary macroblock and neighboring pixels;

Fig. 12 is a picture depicting 18 intra-prediction-mode directions according to embodiments of the present invention;

Fig. 13A is a picture depicting an intra-prediction-mode direction, according to embodiments of the present invention, in a direction opposite to a diagonal down left intra-prediction-mode direction;

Fig. 13B is a picture depicting intra prediction, according to embodiments of the present invention, in an intra-prediction-mode direction opposite to a diagonal down left intra-prediction-mode direction through rotation and use of the "mode 4" prediction equations;

Fig. 14A is a picture depicting an intra-prediction-mode direction, according to embodiments of the present invention, in a direction opposite to a diagonal down right intra-prediction-mode direction;

Fig. 14B is a picture depicting intra prediction, according to embodiments of the present invention, in an intra-prediction-mode direction opposite to a diagonal down right intra-prediction-mode direction through rotation and use of the "mode 4" prediction equations;

Fig. 15A is a picture depicting an intra-prediction-mode direction, according to embodiments of the present invention, in a direction opposite to a vertical right intra-prediction-mode direction;

Fig. 15B is a picture depicting intra prediction, according to embodiments of the present invention, in an intra-prediction-mode direction opposite to a vertical right intra-prediction-mode direction through rotation and use of the "mode 5" prediction equations;

Fig. 16A is a picture depicting an intra-prediction-mode direction, according to embodiments of the present invention, in a direction opposite to a horizontal down intra-prediction-mode direction;

Fig. 16B is a picture depicting intra prediction, according to embodiments of the present invention, in an intra-prediction-mode direction opposite to a horizontal down intra-prediction-mode direction through rotation and use of the "mode 6" prediction equations;

Fig. 17A is a picture depicting an intra-prediction-mode direction, according to embodiments of the present invention, in a direction opposite to a vertical left intra-prediction-mode direction;

Fig. 17B is a picture depicting intra prediction, according to embodiments of the present invention, in an intra-prediction-mode direction opposite to a vertical left intra-prediction-mode direction through rotation and use of the "mode 6" prediction equations;

Fig. 18A is a picture depicting an intra-prediction-mode direction, according to embodiments of the present invention, in a direction opposite to a horizontal up intra-prediction-mode direction;

Fig. 18B is a picture depicting intra prediction, according to embodiments of the present invention, in an intra-prediction-mode direction opposite to a horizontal up intra-prediction-mode direction through flipping and use of the “mode 6” prediction equations; and

Fig. 19 is a picture depicting an exemplary block in which predicting block pixel values using an opposite-direction prediction mode may be advantageous.

Fig. 20 illustrates a video encoder, according to embodiments of the present invention.

Fig. 21 illustrates a video decoder, according to embodiments of the present invention.

Fig. 22 illustrates a codeword video encoding technique, according to embodiments of the present invention.

DESCRIPTION OF EMBODIMENTS

Embodiments of the present invention will be best understood by reference to the drawings, wherein like parts are designated by like numerals throughout. The figures listed above are expressly incorporated as part of this detailed description.

It will be readily understood that the components of the present invention, as generally described and illustrated in the figures herein, could be arranged and designed in a wide variety of different configurations. Thus, the following more detailed description of the embodiments of the methods and systems of the present invention is not intended to limit the scope of the invention but it is merely representative of the presently preferred embodiments of the invention.

Elements of embodiments of the present invention may be embodied in hardware, firmware and/or software. While exemplary embodiments revealed herein may only describe one of these forms, it is to be understood that one skilled in the art would be able to effectuate these elements in any of these forms while resting within the scope of the present invention.

State-of-the-art video-coding standards, for example, H.264/AVC and other video-coding standards, may provide higher coding efficiency at the expense of higher computational complexity, which may result in slower encoding and/or decoding speeds. Additionally, computational complexity may increase with increasing quality and resolution requirements. Parallel decoding and parallel encoding may improve decoding and encoding speeds, respectively. Additionally, parallel decoding and parallel encoding may reduce memory bandwidth requirements for decoding and encoding processes, respectively. Furthermore, with advances in multi-core processors, parallel decoding and parallel encoding may be desirable in order to fully use the power of a multi-core processor.

Intra prediction may be an important contributing factor in video-coding inefficiency. Many state-of-the-art video codecs (coder/decoders) use intra prediction to reduce spatial redundancy. In the encoder and the decoder, intra prediction may use reconstructed neighboring blocks to predict a current block. Thus, the encoder need signal only the prediction mode and the prediction residual. However, the dependency on reconstructed neighboring blocks prevents intra prediction from being parallelized. The serial dependency may be more problematic for the intra-prediction modes of smaller block sizes. Many video codecs organize blocks of pixels into larger blocks referred to as macroblocks. For example, if a 16x16 macroblock uses intra 8x8 prediction, then the four 8x8 blocks which make up the macroblock must be processed sequentially. However, if a 16x16 macroblock uses intra 4x4 prediction, then the sixteen 4x4 blocks must be processed sequentially. The serial design of current intra-prediction schemes may result in unbalanced loads when processing macroblocks associated with different prediction modes, for example, intra 4x4 decoding, intra 8x8 decoding and intra 16x16 may take different decoding cycles. Further, if all macroblocks are intra 4x4 coded, all blocks must be processed sequentially.

Some embodiments of the present invention comprise methods and systems for intra prediction that allow parallel implementation with negligible impact on coding efficiency.

Some embodiments of the present invention may be described herein in relation to luminance-channel signals. This is for purposes of illustration and not limitation. As readily appreciated by a person having ordinary skill in the art, embodiments of the present invention, described herein in relation to luminance-channel signals, may be used in conjunction with chrominance-channel, disparity-channel and other signal sources.

Embodiments of the present invention may relate to a video device. Exemplary video devices may include a video encoder, a video decoder, a video transcoder and other video devices.

Some embodiments of the present invention may be described in relation to H.264/AVC. The following section provides a brief introduction to intra prediction in H.264/AVC.

Introduction to Intra Prediction in H.264/AVC

Intra prediction exploits spatial relationships within a frame, or an image. At an encoder, a current block may be predicted from neighboring previously encoded blocks, also considered reconstructed blocks, located above and/or to the left of the current block, and the prediction mode and the prediction residual may be coded for the block. At a decoder, a current block may be predicted, according to a prediction mode, from neighboring reconstructed blocks located above and/or to the left of the current block, and the decoded prediction residual for the block may be added to the prediction to obtain the block signal values. There are three types of intra luma prediction, for example, defined in H.264/AVC: intra 4x4, intra 8x8 and intra 16x16 prediction. Larger block sizes also may be desirable.

In a 16x16 macroblock, there are four 8x8 blocks or sixteen 4x4 blocks. Figure 1 depicts the processing order for intra 8x8 **2** prediction and intra 4x4 **4** prediction for H.264/AVC, and other coding standards. This processing order may be referred to as a zig-zag processing order. In these standards, a current block may be predicted using previously reconstructed neighboring blocks. Thus, the processing of previous blocks in the scan order must be completed before a current block may be processed. Intra 4x4 prediction has more serial dependency compared to intra 8x8 and 16x16 prediction. This serial dependency may cause an increase of operating cycles, a slowdown of intra prediction, an uneven throughput of different intra-prediction types and other undesirable processing characteristics.

In H.264/AVC, intra 4x4 prediction and intra 8x8 prediction have nine prediction modes **10** as shown in Figure 2. Pixel values in a current block may be predicted from pixel values in a reconstructed upper and/or left neighboring block(s) relative to the current block. The direction of the arrow depicting a mode indicates the prediction direction for the mode. In Figure 2, the center point **11** does not represent a direction so this point may be associated with a DC prediction mode, also referred to as "mode 2." A horizontal arrow **12** extending to the right from the center point **11** may represent a horizontal prediction mode, also referred to as "mode 1." A vertical arrow **13** extending down from the center point **11** may represent a vertical prediction mode, also referred to as "mode 0." An arrow **14** extending from the center point **11** diagonally downward to the right at approximately a 45 degree angle from horizontal may represent a diagonal down-right (DDR) prediction mode, also referred to as "mode 4." An arrow **15** extending from the center point **11** diagonally downward to the left at approximately a 45 degree angle from horizontal may represent a diagonal down-left (DDL) prediction mode, also referred to as "mode 3." Both the DDR and DDL prediction modes may be referred to as diagonal prediction modes. An arrow **16** extending from the center point **11** diagonally upward to the right at approximately a 22.5 degree angle from horizontal may represent a horizontal up (HU) prediction mode, also referred to as "mode 8."

An arrow **17** extending from the center point **11** diagonally downward to the right at approximately a 22.5 degree angle from horizontal may represent a horizontal down (HD) prediction mode, also referred to as "mode 6." An arrow **18** extending from the center point **11** diagonally downward to the right at approximately a 67.5 degree angle from horizontal may represent a vertical right (VR) prediction mode, also referred to as "mode 5." An arrow **19** extending from the center point **11** diagonally downward to the left at approximately a 67.5 degree angle from horizontal may represent a vertical left (VL) prediction mode, also referred to as "mode 7." The HU, HD, VR and VL prediction modes may be referred to collectively as intermediate-angle prediction modes.

Figure 3A shows an exemplary 4x4 block **20** of samples, labeled a-p, that may be predicted from reconstructed, neighboring samples, labeled A-M. When samples E-H are not available, in some implementations of the standard, the unavailable samples may be replaced by sample D. In alternative implementations, unavailable samples may be replaced with a fixed, default value, which may be related to the bit depth of the data. For example, for 8-bit data, the default value may be 128, for 10-bit data, the default value may be 512 and, in general, the default value may be 2^{b-1} where b is the bit depth of the image data. Alternative implementations may use other values, as defined by the specification of the standard, to replace unavailable samples.

Intra-prediction mode 0 (prediction-mode direction indicated as **13** in Figure 2) may be referred to as vertical-mode intra prediction. In mode 0, or vertical-mode intra prediction, the samples of a current block may be predicted in the vertical direction from the reconstructed samples in the block above the current block. Figure 3B illustrates an exemplary vertical-mode intra prediction **21** of the samples in a 4x4 block. In Figure 3B, the samples labeled a-p in Figure 3A are shown replaced with the label of the sample label from Figure 3A from which they are predicted.

Intra-prediction mode 1 (prediction-mode direction indicated as **12** in Figure 2) may be referred to as horizontal-mode intra prediction. In mode 1, or horizontal-mode intra prediction, the samples of a block may be predicted in the horizontal direction from the reconstructed samples in the block to the left of the current block. Figure 3C illustrates an exemplary horizontal prediction **22** of the samples in a 4x4 block. In Figure 3C, the samples labeled a-p in Figure 3A are shown replaced with the label of the sample label from Figure 3A from which they are predicted.

Intra-prediction mode 3 (prediction-mode direction indicated as **15** in Figure 2) may be referred to as diagonal-down-left-mode intra prediction. In mode 3, the samples of a block **23** may be predicted from neighboring blocks in the direction shown in Figure 3D.

Intra-prediction mode 4 (prediction-mode direction indicated as **14** in Figure 2) may be referred to as diagonal-down-right-mode intra prediction. In mode 4, the samples of a block **24** may be predicted from neighboring blocks in the direction shown in Figure 3E.

Intra-prediction mode 5 (prediction-mode direction indicated as **18** in Figure 2) may be referred to as vertical-right-mode intra prediction. In mode 5, the samples of a block **25** may be predicted from neighboring blocks in the direction shown in Figure 3F.

Intra-prediction mode 6 (prediction-mode direction indicated as **17** in Figure 2) may be referred to as horizontal-down-mode intra prediction. In mode 6, the samples of a block **26** may be predicted from neighboring blocks in the direction shown in Figure 3G.

Intra-prediction mode 7 (prediction-mode direction indicated as **19** in Figure 2) may be referred to as vertical-left-mode intra prediction. In mode 7, the samples of a block **27** may be predicted from neighboring blocks in the direction shown in Figure 3H.

Intra-prediction mode 8 (prediction-mode direction indicated as **16** in Figure 2) may be referred to as horizontal-up-mode intra prediction. In mode 8, the samples of a block **28** may be predicted from neighboring blocks in the direction shown in Figure 3I.

In intra-prediction mode 2, which may be referred to as DC mode, all samples labeled a-p in Figure 3A may be replaced with the average of samples labeled A-D and I-L in Figure 3A.

The nine intra-prediction modes described above correspond to the nine intra-prediction modes for luminance samples in the 4x4 sub-blocks of a 16x16 macroblock in H.264/AVC.

H.264/AVC also supports four 16x16 luma intra prediction modes in which the 16x16 samples of the macroblock are extrapolated from the upper and/or left-hand encoded and reconstructed samples adjacent to the macroblock. The samples may be extrapolated vertically, mode 0 (similar to mode 0 for the 4x4 size block), or the samples may be extrapolated horizontally, mode 1 (similar to mode 1 for the 4x4 size block). The samples may be replaced by the mean, mode 2 (similar to the DC mode for the 4x4 size block), or a mode 3, referred to as plane mode, may be used in which a linear plane function is fitted to the upper and left-hand samples. This concludes the brief introduction to H.264/AVC intra prediction.

In some embodiments of the present invention, the blocks within a macrobock may be partitioned into a first plurality of blocks, also considered a first group of blocks or a first set of blocks, and a second plurality of blocks, also considered a second group of blocks or a second set of blocks, in order to break the serial dependency, among blocks, of intra prediction. A block may be an m x n size block of pixels. In some of these embodiments, the blocks within the first plurality of blocks may be encoded using reconstructed pixel values from only one or more previously encoded neighboring macroblocks, and then the blocks within the second plurality of blocks may be encoded using the reconstructed pixel values from previously encoded blocks associated with the first plurality of blocks and/or neighboring macroblocks.

Correspondingly, in some embodiments of the present invention, the blocks within the first plurality of blocks may be decoded using reconstructed pixel values from only neighboring macroblocks, and then the blocks within the second plurality of blocks may be decoded using the reconstructed pixel values from reconstructed blocks associated with the first plurality of blocks and/or neighboring macroblocks.

Blocks within the first plurality of blocks may be encoded, fully or partially, in parallel, and blocks within the second plurality of blocks may be encoded, fully or partially, in parallel. Blocks within the first plurality of blocks may be decoded, fully or partially, in parallel, and blocks within the second plurality of blocks may be decoded, fully or partially, in parallel.

In some embodiments of the present invention, all of the blocks within a macrobock may be encoded using reconstructed pixel values from only one or more previously encoded neighboring macroblocks. Thus, the blocks within the macroblock may be encoded, fully or partially, in parallel.

Correspondingly, in some embodiments of the present invention, all of the blocks within a macroblock may be decoded using reconstructed pixel values from only one or more neighboring macroblocks. Thus, the blocks within the macroblock may be decoded, fully or partially, in parallel.

For a macroblock with N blocks, the degree of parallelism may be $\frac{N}{2}$. For example, the speed up for 4x4 intra prediction for a 16x16 macroblock may be close to a factor of eight.

One exemplary partition **40**, for $\frac{M}{4} \text{x} \frac{N}{4}$ intra prediction of an M x N macroblock, is shown in Figure 4. In some embodiments, M and N may be equal. In other embodiments,

M and N may be unequal. In this exemplary partition, the sixteen blocks **41-56** may be grouped into two sets of eight blocks each according to a checker-board pattern. The eight blocks in one set are shown in white **41, 44, 45, 48, 49, 52, 53, 56**, and the eight blocks in the other set are shown in cross-hatch **42, 43, 46, 47, 50, 51, 54, 55**. One set of blocks may be decoded, or encoded, in parallel first using previously reconstructed macroblocks, and then the second set of blocks may be decoded, or encoded, in parallel using the reconstructed blocks associated with the first set and/or previously reconstructed macroblocks. Either set may be the first set in the processing order. In some embodiments, the first set to be processed may be predefined, which may not require bitstream signaling. In alternative embodiments, the choice of which set to process first may be signaled in the bitstream.

Bitstream signaling may refer to signaling information in a bitstream or signaling information in a stored memory.

Alternative exemplary partitions **60, 80, 100, 120,A1** are shown in Figures 5A-5E. In the exemplary partition **60** shown in Figure 5A, the blocks **61-76** within a macroblock may be grouped into two sets of blocks: one set **61-64, 69-72** shown in white; and another set **65-68, 73-76** shown in cross-hatch. In the exemplary partition **80** shown in Figure 5B, the blocks **81-96** within a macroblock may be grouped into two sets of blocks: one set **81, 84, 86, 87, 90, 91, 93, 96** shown in white; and another set **82, 83, 85, 88, 89, 92, 94, 95** shown in cross-hatch. In the exemplary partition **100** shown in Figure 5C, the blocks **101-116** within a macroblock may be grouped into two sets of blocks: one set **101-108** shown in white; and another set **109-116** shown in cross-hatch. In the exemplary partition **120** shown in Figure 5D, the blocks **121-136** within a macroblock may be grouped into two sets of blocks: a one set **121, 123, 125, 127, 129, 131, 133, 135** shown in white; and another set **122, 124, 126, 128, 130, 132, 134, 136** shown in cross-hatch. In the exemplary partition **A1** of four 4x4 blocks in a 8x8 macroblock shown in Figure 5E, the blocks **A2-A5** may be grouped into two sets of blocks: a one set **A2-A3** shown in white; and another set **A4-A5** shown in negative-slope hatching. As appreciated by a person of ordinary skill in the art, the exemplary partitions shown in Figure 4 and Figures 5A-5E may be readily extended to other macroblock and block sizes.

In alternative embodiments of the present invention, a macrobock may be partitioned into three pluralities of blocks. In some of these embodiments, a first plurality of blocks may be predicted in the encoding process using reconstructed pixel values from only previously encoded neighboring macroblocks. A second plurality of blocks may be subsequently predicted in the encoding process using reconstructed pixel values from the previously encoded blocks associated with the first plurality of blocks and/or using reconstructed pixel values from previously encoded neighboring macroblocks. Then a third plurality of blocks may be subsequently predicted in the encoding process using reconstructed pixel values from the previously encoded blocks associated with the first plurality of blocks, reconstructed pixel values from the previously encoded blocks associated with the second plurality of blocks and/or reconstructed pixel values from previously encoded neighboring macroblocks. In some embodiments, the blocks within a plurality of blocks may be encoded, fully or partially, in parallel.

Correspondingly, in some embodiments of the present invention, a first plurality of blocks may be predicted in the decoding process using reconstructed pixel values in only neighboring macroblocks. A second plurality of blocks may be subsequently predicted in the decoding process using the reconstructed pixel values in the reconstructed blocks associated with the first plurality of blocks and/or reconstructed pixel values in neighboring macroblocks. Then a third plurality of blocks may be subsequently predicted in the decoding process using reconstructed pixel values from the previously decoded blocks associated with the first plurality of blocks, reconstructed pixel values from the previously decoded blocks associated with the second plurality of blocks and/or reconstructed pixel values from previously decoded neighboring macroblocks. In some embodiments, the blocks with a plurality of blocks may be decoded, fully or partially, in parallel.

Figure 6A and Figure 6B depict exemplary three-group partitions **140**, **160** of a macroblock. In the exemplary partition **140** shown Figure 6A, the blocks shown in negative-slope hatching **146**, **148**, **154**, **156** are allocated to a one group of blocks; the blocks shown in white **141**, **143**, **149**, **151** are allocated to another group of blocks; and the blocks shown in cross-hatch **142**, **144**, **145**, **147**, **150**, **152**, **153**, **155** are allocated to yet another group of blocks. In the exemplary partition **160** shown Figure 6B, the blocks shown negative-slope hatching **166**, **167**, **168**, **170**, **174** are allocated to one group of blocks; the blocks shown in cross-hatch **162**, **164**, **165**, **172**, **173**, **175** are allocated to a another group of blocks; and the blocks shown in white **161**, **163**, **169**, **171**, **176** are allocated to yet another group of blocks.

In alternative embodiments of the present invention, a macrobock may be partitioned into two or more pluralities of blocks. In some of these embodiments, a first plurality of blocks may be predicted at the encoder using reconstructed pixel values from only previously encoded neighboring macroblocks. A subsequent plurality of blocks may be predicted at the encoder using reconstructed pixel values from previously encoded blocks from previously encoded partitions and/or reconstructed pixel values from previously encoded neighboring macroblocks. Correspondingly, in some embodiments of the present invention, the first plurality of blocks may be predicted at the decoder using reconstructed pixel values from only neighboring macroblocks, and a subsequent plurality of blocks associated with a partition may be predicted at the decoder using reconstructed pixels from previously decoded blocks, from previously decoded partitions and/or previously decoded reconstructed pixel values in neighboring macroblocks. In some embodiments, the blocks with a plurality of blocks may be encoded, fully or partially, in parallel. In some embodiments, the blocks with a plurality of blocks may be decoded, fully or partially, in parallel.

Figure 7 shows an exemplary partition **200** of 4x4 blocks in a 32x32 macroblock. In this exemplary partition **200**, the sixty-four 4x4 blocks **201-264** are partitioned into four 32x8 sub-macroblocks: a first sub-macroblock **270** consisting of sixteen 4x4 blocks **201-216** shown in negative-slope hatching; a second sub-macroblock **272** consisting of sixteen 4x4 blocks **217-232** shown in cross-hatch; a third sub-macroblock **274** consisting of sixteen 4x4 blocks **233-248** shown in positive-slope hatching; and a fourth sub-macroblock **276** consisting of sixteen 4x4 blocks **249-264** shown in vertical-hatch. Each sub-macroblock **270, 272, 274, 276** may be partitioned into three sets of blocks: a first set of blocks shown with light shading (blocks **210, 212, 214, 216** in the first sub-macroblock **270**; blocks **226, 228, 230, 232** in the second sub-macroblock **272**; blocks **242, 244, 246, 248** in the third sub-macroblock **274**; blocks **258, 260, 262, 264** in the fourth sub-macroblock **276**); a second set of blocks shown with dark shading (blocks **201, 203, 205, 207** in the first sub-macroblock **270**; blocks **217, 219, 221, 223** in the second sub-macroblock **272**; blocks **233, 235, 237, 239** in the third sub-macroblock **274**; blocks **249, 251, 253, 255** in the fourth sub-macroblock **276**); and a third set of blocks shown with no shading (blocks **202, 204, 206, 208, 209, 211, 213, 215** in the first sub-macroblock **270**; blocks **218, 220, 222, 224, 225, 227, 229, 231** in the second sub-macroblock **272**; blocks **234, 236, 238, 240, 241, 243, 245, 247** in the third sub-macroblock **274**; blocks **250, 252, 254, 256, 257, 259, 261, 263** in the fourth sub-macroblock **276**).

Figure 7B shows an exemplary partition B0 of sixteen 4x4 blocks in a 16x16 macroblock. In this exemplary partition **B0**, the sixteen 4x4 blocks **B1-B16** are partitioned into four 8x8 sub-macroblocks: a first sub-macroblock consisting of four 4x4 blocks **B1-B4** shown in positive-slope hatching; a second sub-macroblock consisting of four 4x4 blocks **B5-B8** shown in cross-hatch; a third sub-macroblock consisting of four 4x4 blocks **B9-B12** shown in negative-slope hatching; and a fourth sub-macroblock consisting of four 4x4 blocks **B13-B16** shown in dotted-hash. Each sub-macroblock may be partitioned into two sets of blocks: a first set of blocks (blocks **B1-B2** in the first sub-macroblock; blocks **B5-B8** in the second sub-macroblock; blocks **B9-B10** in the third sub-macroblock; blocks **B13-B14** in the fourth sub-macroblock); and a second set of blocks (blocks **B3-B4** in the first sub-macroblock; blocks **B11-B12** in the third sub-macroblock; blocks **B15-B16** in the fourth sub-macroblock).

In some embodiments, the set processing order may be predefined, which may not require bitstream signaling. In alternative embodiments, the choice of processing order may be signaled in the bitstream.

In some embodiments of the present invention, sub-macroblocks may be processed, fully or partially, in parallel. In some embodiments, at the encoder, the first plurality of blocks in each sub-macroblock may be predicted from pixel values in only previously encoded neighboring macroblocks. Subsequent groups of blocks may be predicted from pixel values in previously encoded groups of blocks and/or pixel values in previously encoded neighboring macroblocks. In some embodiments, at the decoder, the first plurality of blocks in each sub-macroblocks may be decoded using pixel values from only previously reconstructed neighboring macroblocks. Subsequent groups of blocks may be reconstructed from pixel values in previously reconstructed groups of blocks and/or pixel values in previously reconstructed neighboring macroblocks.

One exemplary partition **280**, for $\frac{M}{4} \text{x} \frac{N}{4}$ intra prediction of an M x N macroblock, is shown in Figure 8. In some embodiments, M and N may be equal. In other embodiments, M and N may be unequal. In this exemplary partition, the sixteen blocks **281-296** of the macroblock may be grouped into four sets of four blocks each according to an alternating row, alternating pattern. The four blocks: in one set are shown in white **281**, **283**, **289**, **291**; in a second set are shown in cross-hatch **282**, **284**, **290**, **292**; in a third set are shown in negative-slope cross-hatch **286**, **288**, **294**, **296**; and in a fourth set are shown in vertical hatching **285**, **287**, **293**, **295**. One set of blocks may be decoded first, followed by a second set of blocks, then a third set and finishing with a fourth set. In some embodiments, the blocks within a set of blocks may be decoded, fully or partially, in parallel. In some embodiments, the set processing order may be predefined, which may not require bitstream signaling. In alternative embodiments, the choice of processing order may be signaled in the bitstream.

According to exemplary embodiments of the present invention, at the encoder, the pixel values in the blocks in a first plurality of blocks may be predicted using the pixel values from only the neighboring left and/or upper encoded macroblocks using the nine prediction modes defined for H.264/AVC. The mode for each block in the first plurality of blocks may be selected according to mode-selection methods known in the art, and the residual for each block may be encoded. Correspondingly, at the decoder, the pixel values in the blocks in the first plurality of blocks may be predicted using the pixel values from only the reconstructed neighboring left and/or upper macroblocks. In alternative embodiments, the first plurality of blocks may be predicted using the pixel values from only the neighboring left and/or upper encoded macroblocks using prediction modes available in the encoder.

The encoding and decoding of the blocks in the set of blocks processed first may be understood in relation to Figure 9. Figure 9 depicts an exemplary portion **300** of an image comprising two 16x16 macroblocks **302**, **304**. In the encoding and decoding of the macroblock on the left **302** (pixels shown in white, for example, **306** and pixels shown in dotted-hash, for example, **307**), the pixel values in the macroblock on the right **304** (pixels shown in negative-slope hatching, for example, **308**) are unavailable since this macroblock **304** has not been reconstructed. However, the pixels in the neighboring macroblocks above and to the left of the current macroblock **302** are available. The pixels in the neighboring macroblocks above and to the left, for example, **310**, **312**, **314**, of the current macroblock **302** are shown in cross-hatch. For a block, for example, **316** (shown in dotted-hatch), in the set of blocks encoded first, the pixel values may be predicted from the available pixel values in the neighboring macroblocks above and to the left of the current macroblock (for example, the pixels shown in cross-hatch). In some embodiments of the present invention, at the encoder, the values may be predicted for each prediction mode, and the mode yielding the smallest residual error may be selected. In alternative embodiments, other mode selection methods known in the art may be used to select the prediction mode.

In some embodiments of the present invention, the predicted pixel values may be determined according to H.264/AVC 4x4 prediction equations extended to a macroblock.

In some embodiments of the present invention, prediction, for an N x N block, according to mode 0 – vertical-mode intra prediction – may be performed according to the pseudo code, where pred[y][x] denotes the predicted pixel value, y denotes the row index and x denotes the column index:

// Vertical

```
// pU array holds upper neighbors
BLOCK_SIZE = N ;
for (y=0; y<BLOCK_SIZE; y++)
  for  (x=0; x<BLOCK_SIZE; x++)
    pred[y][x] = pU[x];
// end pseudo code.
```

In some embodiments of the present invention, prediction, for an N x N block, according to mode 1 – horizontal-mode intra prediction – may be performed according to the pseudo code, where pred[y][x] denotes the predicted pixel value, y denotes the row index and x denotes the column index:

```
// Horizontal
// pL array holds left neighbors
BLOCK_SIZE = N ;
for (y=0; y<BLOCK_SIZE; y++)
  for  (x=0; x<BLOCK_SIZE; x++)
                 pred[y][x] = pL[y];
// end pseudo code.
```

In some embodiments of the present invention, prediction, for an N x N block, where $N = 2^n$, according to mode 2 – DC-mode intra prediction – may be performed according to the pseudo code, where pred[y][x] denotes the predicted pixel value, y denotes the row index and x denotes the column index:

```
// DC
// pU array holds upper neighbors
// pL array holds left neighbors
BLOCK_SIZE = N ;
if all pU samples and all pL samples are available then
  for (y=0; y<BLOCK_SIZE; y++)
    for  (x=0; x<BLOCK_SIZE; x++)
    {
      pred[y][x] = (pU[0] + pU[1] + … + pU[N -1] +
```

```
pL[0] + pL[1] + … + pL[N-1] + (1<<n)) >> (n+1);
}
if any pU samples are unavailable and all pL samples are available then
 for (y=0; y<BLOCK_SIZE; y++)
  for (x=0; x<BLOCK_SIZE; x++)
  {
   pred[y][x] = (pL[0] + pL[1] + … + pL[N-1] + (1<<(n-1))) >> n
  }
if all pU samples are available and any pL samples are unavailable then
 for (y=0; y<BLOCK_SIZE; y++)
  for (x=0; x<BLOCK_SIZE; x++)
  {
   pred[y][x] = (pU[0] + pU[1] + … + pU[N-1] + (1<<(n-1))) >> n;
  }
if any pU samples are unavailable and any pL samples are unavailable then
 for (y=0; y<BLOCK_SIZE; y++)
  for (x=0; x<BLOCK_SIZE; x++)
  {
   pred[y][x] = DefaultValue;  // DefaultValue = 2^(b-1) for an image with bitdepth = b
  }
// end pseudo code.
```

In some embodiments of the present invention, prediction, for an $N \times N$ block, according to mode 3 – diagonal-down-left-mode intra prediction – may be performed according to the pseudo code, where pred[y][x] denotes the predicted pixel value, y denotes the row index and x denotes the column index:

```
// Diagonal Down Left
// pU array holds upper neighbors
// pL array holds left neighbors
BLOCK_SIZE = N;
```

```
bound = BLOCK_SIZE-1;
for (y=0; y<BLOCK_SIZE; y++)
 for  (x=0; x<BLOCK_SIZE; x++)
 {
    if (x!=bound||y!=bound)
       pred[y][x] = (pU[x+y] + 2*pU[x+y+1] + pU[x+y+2] +2) >> 2;
   else
      pred[y][x] = (pU[bound*2] + 3*pU[bound*2+1] +2) >> 2;
 }
// end pseudo code.
```

In some embodiments of the present invention, prediction, for an N x N block, according to mode 4 – diagonal-down-right-mode intra prediction – may be performed according to the pseudo code, where pred[y][x] denotes the predicted pixel value, y denotes the row index and x denotes the column index:

```
// Diagonal Down Right
// pU array holds upper neighbors
// pL array holds left neighbors
BLOCK_SIZE = N;
bound = BLOCK_SIZE-1;
if (x>y)
  pred[y][x]  = (pU[x-y-2] + 2*pU[x-y-1] + pU[x-y] +2) >> 2;
else if (x<y)
  pred[y][x]  = (pL[y-x-2] + 2*pL[y-x-1] + pL[y-x] +2) >> 2;
 else
  pred[y][x]  = (pU[0] + 2*pU[-1] + pL[0] +2) >> 2;
// end pseudo code.
```

In some embodiments of the present invention, prediction, for an N x N block, according to mode 5 – vertical-right-mode intra prediction – may be performed according to the pseudo code, where pred[y][x] denotes the predicted pixel value, y denotes the row index and x denotes the column index:

```
// Vertical Right
// pU array holds upper neighbors
// pL array holds left neighbors
BLOCK_SIZE = N;
bound = BLOCK_SIZE-1;
zVR = 2*x-y;
if ( ((zVR&0x1) == 0) && (zVR>=0) && zVR<=2*bound )
  pred[y][x] = (pU[x-(y>>1)-1] + pU[x-(y>>1)] +1) >> 1;
else if ( ((zVR&0x1) == 1) && (zVR> 0) && zVR<2*bound)
  pred[y][x]  = (pU[x-(y>>1)-2] + 2*pU[x-(y>>1)-1] + pU[x-(y>>1)] +2) >> 2;
else if (zVR == -1)
  pred[y][x]  = (pL[0] + 2*pU[-1] + pU[0] +2) >> 2;
else
  pred[y][x]  = (pL[y-(x<<1)-1] + 2*pL[y-(x<<1)-2] + pL[y-(x<<1)-3] +2) >> 2;
// end pseudo code.
```

In some embodiments of the present invention, prediction, for an N x N block, according to mode 6 – horizontal-down-mode intra prediction – may be performed according to the pseudo code, where pred[y][x] denotes the predicted pixel value, y denotes the row index and x denotes the column index:

```
// Horizontal Down
// pU array holds upper neighbors
// pL array holds left neighbors
BLOCK_SIZE = N;
bound = BLOCK_SIZE-1;
zHD = 2*y-x;
if ( ((zHD&0x1) == 0) && (zHD>=0) && zHD<=2*bound )
  pred[y][x] = (pL[y-(x>>1)-1] + pL[y-(x>>1)] +1) >> 1;
else if ( ((zHD&0x1) == 1) && (zHD>0) && zHD<2*bound)
  pred[y][x] = (pL[y-(x>>1)-2] + 2*pL[y-(x>>1)-1] + pL[y-(x>>1)] +2) >> 2;
else if (zHD == -1)
```

```
  pred[y][x] = (pL[0] + 2*pU[-1] + pU[0] +2) >> 2;
else
  pred[y][x] = (pU[x-(y<<1)-1] + 2*pU[x-(y<<1)-2] + pU[x-(y<<1)-3] +2) >> 2;
// end pseudo code.
```

In some embodiments of the present invention, prediction, for an N x N block, according to mode 7 – vertical-left-mode intra prediction – may be performed according to the pseudo code, where pred[y][x] denotes the predicted pixel value, y denotes the row index and x denotes the column index:

```
// Vertical Left
// pU array holds upper neighbors
// pL array holds left neighbors
BLOCK_SIZE = N;
bound = BLOCK_SIZE-1;
if ((y&0x1) == 0)   //even
  pred[y][x] = (pU[x+(y>>1)] + pU[x+(y>>1)+1] +1) >> 1;
else   //odd
  pred[y][x] = (pU[x+(y>>1)] + 2*pU[x+(y>>1)+1] + pU[x+(y>>1)+2] +2) >> 2;
// end pseudo code.
```

In some embodiments of the present invention, prediction \, for an N x N block, according to mode 8 – horizontal-up-mode intra prediction – may be performed according to the pseudo code, where pred[y][x] denotes the predicted pixel value, y denotes the row index and x denotes the column index:

```
// Horizontal Up
// pU array holds upper neighbors
// pL array holds left neighbors
BLOCK_SIZE = N;
bound = BLOCK_SIZE-1;
 zHU = x+2*y;
  if ( ((zHU&0x1) == 0) && zHU<=2*(bound-1) )
    pred[y][x] = (pL[y+(x>>1)] + pL[y+(x>>1)+1]+1) >> 1;
```

```
else if ( ((zHU&0x1) ==1) && zHU<2*(bound-1))
  pred[y][x] = (pL[y+(x>>1)] + 2*pL[y+(x>>1)+1] + pL[y+(x>>1)+2] +2)  >>2;
else if (zHU>2*bound-1)
  pred[y][x]  = pL[bound];
else          // (zHU==2*bound-1) 29 for MB, 13 for 8x8 block, 5 for 4x4 block
  pred[y][x]  = (pL[bound-1] + 3*pL[bound] +2) >> 2;
// end pseudo code.
```

The above-listed pseudo code is provided for illustration and not for limitation, and there is no intention to exclude alternative implementations and extensions of the above-described prediction formulae.

In some embodiments of the present invention, in DC prediction (mode 2), and other prediction modes, the neighboring upper and left macroblock pixel values may be weighted according to their distance to the block that is being predicted. For example, when predicting the pixel values in the exemplary block **316** in Figure 9, the pixel values in the left neighboring macroblock may be given more weight than the pixel values in the upper neighboring macroblocks. In some embodiments of the present invention, the distance may be defined as the number of macroblocks plus one between the block being predicted and the neighboring upper macroblock and the number of macroblocks plus one between the block being predicted and the neighboring left macroblock In alternative embodiments of the present invention, the distance may be defined as the number of macroblocks between the block being predicted and the neighboring upper/left macroblock in the order of a zig-zag scan. In some embodiments of the present invention, a weight assigned to the neighboring upper block pixel values may be the ratio of the distance between the block being predicted and the neighboring left macroblock and the sum of the distances between the block being predicted and both the neighboring left and upper macroblocks. In some embodiments of the present invention, a weight assigned to the neighboring left block pixel values may be the ratio of the distance between the block being predicted and the neighboring upper macroblock and the sum of the distances between the block being predicted and both the neighboring left and upper macroblocks.

Some embodiments of the present invention may comprise mode prediction. To reduce the bits used to signal the intra modes, in H.264/AVC the intra prediction mode for a block may be predicted from the modes of the upper neighboring block and the left neighboring block according to Min(intraMxMPredModeA, intraMxMPredModeB), where intraMxMPredModeA denotes the mode of the left neighbor block and intraMxMPredModeB denotes the mode of the upper neighbor block. A rate-distortion optimized (RDO) decision may be made at an encoder when determining the intra modes. In the RDO decision step, a rate calculation may be made to calculate the rate used by sending intra modes.

According to some embodiments of the present invention, for blocks in a first plurality of blocks encoded first using reconstructed pixels from neighboring macroblocks, the modes of the closest available blocks that are also within the first plurality of blocks or neighboring macroblocks may be used during mode prediction and during rate-distortion optimization. An available block may refer to a block for which an intra-prediction mode has been determined.

These embodiments may be understood in relation to an example shown in Figure 10. Figure 10 depicts an exemplary macroblock **330**. The blocks **331-346** of the macroblock **330** may be partitioned, for example, according to a checker-board pattern, into two pluralities of blocks: a first plurality **332**, **334**, **335**, **337**, **340**, **342**, **343**, **345** and a second plurality **331**, **333**, **336**, **338**, **339**, **341**, **344**, **346**. For this example, all of the blocks within the first plurality of blocks may be processed, in a zig-zag order **332**, **335**, **334**, **337**, **340**, **343**, **342**, **345**, before the blocks within the second plurality of blocks.

According to some embodiments of the present invention, during mode prediction, block **337** may use, for its upper mode, the mode of block **332** since block **333** has not been processed, and block **332** is the nearest available block, for the zig-zag processing order of this example, above the block **337** for which mode prediction is being performed. In some embodiments of the present invention, the nearest block may be determined based on the Euclidean distance between the blocks. For its left mode, block **337** may use the mode of block **335** since block **336** has not been processed, and block **335** is the nearest available block, for the zig-zag processing order of this example, to the left of the block **337** for which mode prediction is being performed. In these embodiments of the present invention, mode prediction may use a block above, but not directly above, the block for which the mode prediction is being performed. In these embodiments of the present invention, mode prediction may use a block to the left of, but not directly to the left of, the block for which the mode prediction is being performed.

For further illustration, according to some embodiments of the present invention in which an intra-prediction mode is predicted from a block above and a block to the left of the block for which the mode prediction is being performed, mode prediction for block **335** in Figure 10 may use, for its left mode, the mode of block **348** in the neighboring available macroblock and, for its upper mode, the mode of block **347** in the neighboring available macroblock. In alternative embodiments of the present invention, the mode of block **351** in the neighboring available macroblock may be used for the upper mode.

For further illustration, according to some embodiments of the present invention in which an intra-prediction mode is predicted from a block above and a block to the left of the block for which the mode prediction is being performed, mode prediction for block **334** in Figure 10 may use, for its left mode, the mode of available block **332** and, for its upper mode, the mode of block **349** in the neighboring available macroblock. In alternative embodiments of the present invention, the mode of block **350** in the neighboring available macroblock may be used for the left mode.

In alternative embodiments, mode prediction may use the modes of other available blocks located directionally relative to the block for which the mode is being predicted. For example, an intra-prediction mode for a block may be predicted from the mode of a lower block and a right block.

In alternative embodiments, the modes of blocks in previously encoded neighboring macroblocks may be used in mode prediction. These embodiments may be understood in relation to an example shown in Figure 10. According to these embodiments of the present invention, during mode prediction, block **337** may use, for its upper mode, the mode of block **350** from the previously encoded, upper neighboring macroblock, and for its mode, the mode of block **348** from the previously encoded, left neighboring macroblock.

In some embodiments of the present invention, both of the above-described methods of mode prediction may be available. An encoder may signal, in the bitstream, the mode-prediction method used for a plurality of blocks. In some embodiments of the present invention, the signaling may occur with meta-data which may include a picture parameter set, a sequence parameter set or other parameter set. In some embodiments of the present invention, the signaling may occur at the macroblock level. In alternative embodiments of the present invention, the signaling may occur at the slice level.

In some embodiments of the present invention, for blocks in a plurality of blocks processed subsequent to a first plurality of blocks, the modes of the closest available blocks that are in the current or preceding plurality of blocks or neighboring macroblocks may be used during mode prediction and rate-distortion optimization. In alternative embodiments of the present invention, for blocks in a plurality of blocks processed subsequent to a first plurality of blocks, only the modes of the closest available blocks that are in the current plurality of blocks or neighboring macroblocks may be used during mode prediction and rate-distortion optimization. In some embodiments of the present invention, blocks in different pluralities of blocks may use different methods for intra prediction. For these blocks, only the modes of the closest available blocks that are in the current or neighboring macroblocks and that use the same method for intra prediction may be used during mode prediction and rate-distortion optimization. In some embodiments of the present invention, the different method for intra-prediction may be signaled with a flag. In some embodiments of the present invention, the different methods for intra-prediction may be signaled with multiple flags.

For blocks in a set of blocks reconstructed subsequent to the first set of blocks reconstructed, in addition to previously reconstructed upper and/or left neighboring blocks, previously reconstructed right and bottom neighboring blocks may be available for intra prediction. These additional reconstructed blocks may be used to improve the intra prediction and, therefore, improve the coding efficiency due to the high correlation between blocks.

In some embodiments of the present invention, a previously reconstructed non-neighboring block may be used in intra prediction. In some of these embodiments, the contribution of a previously reconstructed signal value to the prediction value may be weighted by the distance of the reconstructed block to the current block.

In some embodiments of the present invention, the equations related to the previously described nine prediction mode directions, which may be referred to as standard-defined prediction-mode directions associated with standard-defined prediction modes, may be modified to use previously encoded blocks to the right of and/or below a current block for intra prediction. An exemplary modification of the prediction formulas for the exemplary partition shown in Figure 4 may be illustrated for intra 4x4 prediction and may be understood in relation to Figure 11 and Table 1.

Figure 11 shows an exemplary 4x4 block **360** of sixteen pixels **361-376**, where a pixel in column x and row y is denoted $p(x,y)$. If the block **360** is one 4x4 block in a 16x16 macroblock partitioned in a checker-board pattern according to Figure 4, and the block **360** is in the second plurality of blocks encoded, previously reconstructed pixels **381-396** are available above (**381-384**), below (**385-388**), to the right (**389-392**) and to the left (**393-396**) of the macroblock **360**. The values of the corner pixels **397-400** may not be available. In some embodiments, these unavailable corner pixel values may be interpolated from the neighboring, available pixel values. In some embodiments, the pixel values may be interpolated according to:

$$X = (A + I + 1) >> 1$$
$$E = (D + II + 1) >> 1$$
$$X2 = (L + AA + 1) >> 1\ ,$$
$$X3 = (DD + LL + 1) >> 1$$

where the pixel values are as indicated in Figure 11. Table 1 shows both the original prediction equations and the modified, also considered extended, prediction equations. In some embodiments, if a pixel value required for an intra-prediction mode is not available, then the mode may not be used. Note that for some prediction modes, no modification of the original prediction formula is made.

Table 1. Prediction Formulas – Original and Modified

ORIGINAL FORMULAS	MODIFIED FORMULAS
Intra_4x4_DC **(Mode 2)** $p(0,0) = p(1,0) = P(2,0) = P(3,0) =$ $p(0,1) = p(1,1) = P(2,1) = P(3,1) =$ $p(0,2) = p(1,2) = P(2,2) = P(3,2) =$ $p(0,3) = p(1,3) = P(2,3) = P(3,3) =$ $(A+B+C+D+I+J+K+L+(1<<2)) >> 3$ If all neighbors are available.	**Intra_4x4_DC_modified** **(Mode 2 - modified)** $p(0,0) = p(1,0) = P(2,0) = P(3,0) =$ $p(0,1) = p(1,1) = P(2,1) = P(3,1) =$ $p(0,2) = p(1,2) = P(2,2) = P(3,2) =$ $p(0,3) = p(1,3) = P(2,3) = P(3,3) =$ $(A+AA+B+BB+C+CC+D+DD+$ $I+II+J+JJ+K+KK+L+LL+(1<<3)) >> 4$ If all neighbors are available.
Intra_4x4_Diagonal_Down_Left **(Mode 3)** $p(0,0) = (A+C+2*B+2) >> 2$ $p(1,0) = p(0,1) = (B+D+2*C+2) >> 2$ $p(2,0) = p(1,1) = p(0,2) = (C+E+2*D+2) >> 1$ $p(3,0) = p(2,1) = p(1,2) = p(0,3) = (D+F+2*E+2) >> 2$ $p(3,1) = p(2,2) = p(1,3) = (E+G+2*F+2) >> 2$ $p(3,2) = p(2,3) = (F+H+2*G) >> 2$ $p(3,3) = (G+3*H+2) >> 2$	**Intra_4x4_Diagonal_Down_Left_modified** **(Mode 3 - modified)** $p(0,0) = (A+C+2*B+2) >> 2$ $p(1,0) = p(0,1) = (B+D+2*C+2) >> 2$ $p(2,0) = p(1,1) = p(0,2) = (C+E+2*D+2) >> 1$ $p(3,0) = p(2,1) = p(1,2) = p(0,3) = (D+2*E+II+2) >> 2$ $p(3,1) = p(2,2) = p(1,3) = (E+2*II+JJ+2) >> 2$ $p(3,2) = p(2,3) = (II+2*JJ+KK) >> 2$ $p(3,3) = (JJ+2*KK+LL+2) >> 2$
Intra_4x4_Vertical_Left **(Mode 7)**	**Intra_4x4_Vertical_Left _modified** **(Mode 7 - modified)**

$p(0,0)=(A+B+1)>>1$ $p(1,0)=p(0,2)=(B+C+1)>>1$ $p(2,0)=p(1,2)=(C+D+1)>>1$ $p(3,0)=p(2,2)=(D+E+1)>>1$ $p(3,2)=(E+F+1)>>1$ $p(0,1)=(A+2*B+C+2)>>2$ $p(1,1)=p(0,3)=(B+2*C+D+2)>>2$ $p(2,1)=p(1,3)=(C+2*D+E+2)>>2$ $p(3,1)=p(2,3)=(D+2*E+F+2)>>2$ $p(3,3)=(E+2*F+G+2)>>2$	$p(0,0)=(A+B+1)>>1$ $p(1,0)=p(0,2)=(B+C+1)>>1$ $p(2,0)=p(1,2)=(C+D+1)>>1$ $p(3,0)=p(2,2)=(D+E+1)>>1$ $p(3,2)=(E+2*II+JJ+2)>>2$ $p(0,1)=(A+2*B+C+2)>>2$ $p(1,1)=p(0,3)=(B+2*C+D+2)>>2$ $p(2,1)=p(1,3)=(C+2*D+E+2)>>2$ $p(3,1)=p(2,3)=(D+2*E+II+2)>>2$ $p(3,3)=(II+2*JJ+KK+2)>>2$
Intra_4x4_Horizontal_Up (Mode 8) $p(0,0)=(I+J+1)>>1$ $p(1,0)=(I+2*J+K+2)>>2$ $p(2,0)=p(0,1)=(J+K+1)>>1$ $p(3,0)=p(1,1)=(J+2*K+L+2)>>2$ $p(2,1)=p(0,2)=(K+L+1)>>1$ $p(3,1)=p(1,2)=(K+3*L+2)>>2$ $p(0,3)=p(1,3)=p(2,2)=p(2,3)=p(3,2)=p(3,3)=L$	**Intra_4x4_Horizontal_Up_modified (Mode 8 - modified)** $p(0,0)=(I+J+1)>>1$ $p(1,0)=(I+2*J+K+2)>>2$ $p(2,0)=p(0,1)=(J+K+1)>>1$ $p(3,0)=p(1,1)=(J+2*K+L+2)>>2$ $p(2,1)=p(0,2)=(K+L+1)>>1$ $p(3,1)=p(1,2)=(K+2*L+X2+2)>>2$ $p(2,2)=p(0,3)=(L+X2+1)>>1$ $p(1,3)=p(3,2)=(L+2*X2+AA+2)>>2$ $p(2,3)=(X2+2*AA+BB+2)>>2$ $p(3,3)=(AA+2*BB+CC+2)>>2$

In some embodiments of the present invention, nine directional intra-prediction modes opposite in direction to the nine intra-prediction mode directions previously described may be defined. These opposite-direction modes may be described in relation to Figure 12. Pixel values in a current block may be predicted from pixel values in reconstructed blocks above, to the left of, below and/or to the right of the current block. In Figure 12, the direction of the arrow depicting the mode indicates the prediction direction for each mode.

In Figure 12, the center point **422** does not represent a direction so this point may be associated with DC prediction modes, which may be referred to as “mode 2” and “mode 11.” In some embodiments of the present invention, “mode 2” predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned}&p(0,0)=p(1,0)=P(2,0)=P(3,0)=\\&p(0,1)=p(1,1)=P(2,1)=P(3,1)=\\&p(0,2)=p(1,2)=P(2,2)=P(3,2)=\\&p(0,3)=p(1,3)=P(2,3)=P(3,3)=\\&(A+B+C+D+I+J+K+L+(1<<2))>>3\end{aligned},$$

and "mode 11" predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned}&p(0,0)=p(1,0)=P(2,0)=P(3,0)=\\&p(0,1)=p(1,1)=P(2,1)=P(3,1)=\\&p(0,2)=p(1,2)=P(2,2)=P(3,2)=\\&p(0,3)=p(1,3)=P(2,3)=P(3,3)=\\&(AA+BB+CC+DD+II+JJ+KK+LL+(1<<2))>>3\end{aligned},$$

where the pixel locations and values may be as shown in Figure 11. In alternative embodiments, "mode 2" and "mode 11" predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned}&p(0,0)=p(1,0)=P(2,0)=P(3,0)=\\&p(0,1)=p(1,1)=P(2,1)=P(3,1)=\\&p(0,2)=p(1,2)=P(2,2)=P(3,2)=\\&p(0,3)=p(1,3)=P(2,3)=P(3,3)=\\&(A+AA+B+BB+C+CC+D+DD+\\&I+II+J+JJ+K+KK+L+LL+(1<<3))>>4\end{aligned}.$$

A vertical arrow **420** extending in the downward direction from the center point **422** may represent a first vertical prediction mode, which may be referred to as "mode 0," and a vertical arrow **429** extending in the upward direction from the center point **422** may represent a second vertical prediction mode, which may be referred to as "mode 9." In some embodiments of the present invention, "mode 0" predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned}&p(0,0)=p(0,1)=P(0,2)=P(0,3)=A\\&p(1,0)=p(1,1)=P(1,2)=P(0,3)=B\\&p(2,0)=p(2,1)=P(2,2)=P(2,3)=C\\&p(3,0)=p(3,1)=P(3,2)=P(3,3)=D\end{aligned},$$

and "mode 9" predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned}&p(0,0)=p(0,1)=P(0,2)=P(0,3)=AA\\&p(1,0)=p(1,1)=P(1,2)=P(0,3)=BB\\&p(2,0)=p(2,1)=P(2,2)=P(2,3)=CC\\&p(3,0)=p(3,1)=P(3,2)=P(3,3)=DD\end{aligned},$$

where the pixel locations and values may be as shown in Figure 11.

A horizontal arrow **421** extending to the right from the center point **422** may represent a first horizontal prediction mode, which may be referred to as "mode 1." A horizontal arrow **430** extending to the left from the center point **422** may represent a second horizontal prediction mode, which may be referred to as "mode 10." In some embodiments of the present invention, "mode 1" predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned} &p(0,0)=p(1,0)=P(2,0)=P(3,0)=I\\ &p(0,1)=p(1,1)=P(2,1)=P(3,1)=J\\ &p(0,2)=p(1,2)=P(2,2)=P(3,2)=K\\ &p(0,3)=p(1,3)=P(2,3)=P(3,3)=L \end{aligned},$$

and "mode 10" predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned} &p(0,0)=p(1,0)=P(2,0)=P(3,0)=II\\ &p(0,1)=p(1,1)=P(2,1)=P(3,1)=JJ\\ &p(0,2)=p(1,2)=P(2,2)=P(3,2)=KK\\ &p(0,3)=p(1,3)=P(2,3)=P(3,3)=LL \end{aligned},$$

where the pixel locations and values may be as shown in Figure 11.

An arrow **423** extending from the center point **422** diagonally downward to the left at approximately a 45 degree angle from horizontal may represent a diagonal down-left (DDL) prediction mode, also referred to as "mode 3," and an arrow **432** extending from the center point **422** in a direction 180 degrees opposite may represent a diagonal up-right (DUR) prediction mode, which may be referred to as "mode 12" or a DDL 2 mode. In some embodiments of the present invention, "mode 3" predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned} &p(0,0)=(A+C+2*B+2)>>2\\ &p(1,0)=p(0,1)=(B+D+2*C+2)>>2\\ &p(2,0)=p(1,1)=p(0,2)=(C+E+2*D+2)>>1\\ &p(3,0)=p(2,1)=p(1,2)=p(0,3)=(D+2*E+II+2)>>2,\\ &p(3,1)=p(2,2)=p(1,3)=(E+2*II+JJ+2)>>2\\ &p(3,2)=p(2,3)=(II+2*JJ+KK)>>2\\ &p(3,3)=(JJ+2*KK+LL+2)>>2 \end{aligned}$$

where the pixel locations and values may be as shown in Figure 11. In some embodiments of the present invention, "mode 12" predicted values may be predicted, for 4x4 intra prediction, by rotating the block data and the neighboring data by 90 degrees clockwise and using the "mode 4" prediction equations:

$$
\begin{aligned}
&p(0,0)=p(1,1)=p(2,2)=p(3,3)=(I+2*X+A+2)>>2\\
&p(1,0)=p(2,1)=p(3,2)=(X+2*A+B+2)>>2\\
&p(2,0)=p(3,1)=(A+2*B+C+2)>>2\\
&p(3,0)=(B+2*C+D+2)>>2\\
&p(0,1)=p(1,2)=p(2,3)=(J+2*I+X+2)>>2\\
&p(0,2)=p(1,3)=(K+2*J+I+2)>>2\\
&p(0,3)=(L+2*K+J+2)>>2
\end{aligned},
$$

where the pixel locations and values may be as shown in Figure 11.

Figure 13A and Figure 13B illustrate this process. As depicted in Figure 13A, a 4x4 block **450** of sixteen pixels **451-466** may be predicted in the diagonal up-right direction **479** from the reconstructed pixel values to the left **470-473** and below **475-478** and an interpolated corner pixel value **474**. Figure 13B depicts the pixels of Figure 13A after a 90 degree clockwise rotation. A 4x4 block **480** of sixteen pixels **481-496** may be predicted in the diagonal down-right direction **509** from the reconstructed pixels to the left **505-508** and above **501-504** and an interpolated corner pixel **500** using the "mode 4" prediction equations. These predicted pixel values **481-496** may be mapped back to the proper pixels by a 90 degree counter-clockwise rotation. In some embodiments of the present invention, the "mode 12" predicted values may be predicted through rotation and using the "mode 4" prediction equations. In alternative embodiments, the "mode 12" predicted values may be directly predicted, for 4x4 intra prediction, according to:

$$
\begin{aligned}
&p(0,3)=p(1,2)=p(2,1)=p(3,0)=(AA+2*X2+L+2)>>2\\
&p(0,2)=p(1,1)=p(2,0)=(X2+2*L+K+2)>>2\\
&p(1,0)=p(0,1)=(L+2*K+J+2)>>2\\
&p(0,0)=(K+2*J+I+2)>>2\\
&p(3,1)=p(1,3)=p(2,2)=(BB+2*AA+X2+2)>>2\\
&p(2,3)=p(3,2)=(CC+2*BB+AA+2)>>2\\
&p(3,3)=(DD+2*CC+BB+2)>>2
\end{aligned},
$$

where the pixel values and locations are shown in Figure 13A.

An arrow **424** extending from the center point **422** diagonally downward to the right at approximately a 45 degree angle from horizontal may represent a diagonal down-right (DDR) prediction mode, also referred to as "mode 4," and an arrow **433** extending from the center point **422** in a direction 180 degrees opposite may represent a diagonal up-left (DUL) prediction mode, which may be referred to as "mode 13" or a DDR 2 mode. In some embodiments of the present invention, "mode 4" predicted values may be predicted, for 4x4 intra prediction, according to:

$$
\begin{aligned}
&p(0,0)=p(1,1)=p(2,2)=p(3,3)=(I+2*X+A+2)>>2\\
&p(1,0)=p(2,1)=p(3,2)=(X+2*A+B+2)>>2\\
&p(2,0)=p(3,1)=(A+2*B+C+2)>>2\\
&p(3,0)=(B+2*C+D+2)>>2\\
&p(0,1)=p(1,2)=p(2,3)=(J+2*I+X+2)>>2\\
&p(0,2)=p(1,3)=(K+2*J+I+2)>>2\\
&p(0,3)=(L+2*K+J+2)>>2
\end{aligned},
$$

where the pixel locations and values may be as shown in Figure 11. In some embodiments of the present invention, "mode 13" predicted values may be predicted, for 4x4 intra prediction, by rotating the block data and the neighboring data by 180 degrees and using the "mode 4" prediction equations.

Figure 14A and Figure 14B illustrate this process. As depicted in Figure 14A, a 4x4 block **520** of sixteen pixels **521-536** may be predicted in the diagonal up-left direction **549** from the reconstructed pixel values to the right **545-548** and below **540-543** and an interpolated corner pixel value **544**. Figure 14B depicts the pixels of Figure 14A after a 180 degree rotation. A 4x4 block **550** of sixteen pixels **551-566** may be predicted in the diagonal down-right direction **579** from the reconstructed pixels to the left **575-578** and above **571-574** and an interpolated corner pixel **570** using the "mode 4" prediction equations. These predicted pixel values **551-566** may be mapped back to the proper pixels by a 180 degree rotation. In some embodiments of the present invention, the "mode 13" predicted values may be predicted through rotation and using the "mode 4" prediction equations. In alternative embodiments, the "mode 13" predicted values may be directly predicted, for 4x4 intra prediction, according to:

$$
\begin{aligned}
&p(3,3)=p(2,2)=p(1,1)=p(0,0)=(LL+2*X3+DD+2)>>2\\
&p(2,3)=p(0,1)=p(1,2)=(X3+2*DD+CC+2)>>2\\
&p(1,3)=p(0,2)=(DD+2*CC+BB+2)>>2\\
&p(0,3)=(CC+2*BB+AA+2)>>2\\
&p(3,2)=p(2,1)=p(1,0)=(KK+2*LL+X3+2)>>2\\
&p(3,1)=p(2,0)=(JJ+2*KK+LL+2)>>2\\
&p(3,0)=(II+2*JJ+KK+2)>>2
\end{aligned},
$$

where the pixel values and locations are shown in Figure 14A.

An arrow **425** extending from the center point 422 diagonally downward to the right at approximately a 67.5 degree angle from horizontal may represent a vertical right (VR) prediction mode, which may be referred to as "mode 5," and an arrow **434** extending from the center point **422** in a direction 180 degrees opposite may represent vertical right 2 prediction mode, which may be referred to as "mode 14" or a VR 2 mode. In some embodiments of the present invention, "mode 5" predicted values may be predicted, for 4x4 intra prediction, according to:

$$
\begin{aligned}
&p(0,0)=p(1,2)=(X+A+1)>>1\\
&p(1,0)=p(2,2)=(A+B+1)>>1\\
&p(2,0)=p(3,2)=(B+C+1)>>1\\
&p(3,0)=(C+D+1)>>1\\
&p(0,1)=p(1,3)=(I+2*X+A+2)>>2\,,\\
&p(1,1)=p(2,3)=(X+2*A+B+2)>>2\\
&p(2,1)=p(3,3)=(A+2*B+C+2)>>2\\
&p(3,1)=(B+2*C+D+2)>>2\\
&p(0,2)=(X+2*I+J+2)>>2\\
&p(0,3)=(I+2*J+K+2)>>2
\end{aligned}
$$

where the pixel locations and values may be as shown in Figure 11. In some embodiments of the present invention, "mode 14" predicted values may be predicted, for 4x4 intra prediction, by rotating the block data and the neighboring data by 180 degrees and using the "mode 5" prediction equations.

Figure 15A and Figure 15B illustrate this process. As depicted in Figure 15A, a 4x4 block **590** of sixteen pixels **591-606** may be predicted in the vertical right 2 direction **619** from the reconstructed pixel values to the right **615-618** and below **610-613** and an interpolated corner pixel value **614**. Figure 15B depicts the pixels of Figure 15A after a 180 degree rotation. A 4x4 block **620** of sixteen pixels **621-636** may be predicted in the vertical right direction **649** from the reconstructed pixels to the left **645-648** and above **641-644** and an interpolated corner pixel **640** using the "mode 5" prediction equations. These predicted pixel values **621-636** may be mapped back to the proper pixels by a 180 degree rotation. In some embodiments of the present invention, the "mode 14" predicted values may be predicted through rotation and using the "mode 5" prediction equations. In alternative embodiments, the "mode 14" predicted values may be directly predicted, for 4x4 intra prediction, according to:

$$p(3,3)=p(2,1)=(X3+DD+1)>>1$$
$$p(2,3)=p(1,1)=(DD+CC+1)>>1$$
$$p(1,3)=p(0,1)=(CC+BB+1)>>1$$
$$p(0,3)=(BB+AA+1)>>1$$
$$p(3,2)=p(2,0)=(LL+2*X3+DD+2)>>2,$$
$$p(2,2)=p(1,0)=(X3+2*DD+CC+2)>>2$$
$$p(1,2)=p(0,0)=(DD+2*CC+BB+2)>>2$$
$$p(3,1)=(X3+2*LL+KK+2)>>2$$
$$p(3,0)=(LL+2*KK+JJ+2)>>2$$

where the pixel values and locations are shown in Figure 15A.

An arrow **426** extending from the center point diagonally downward to the right at approximately a 22.5 degree angle from horizontal may represent a horizontal down (HD) prediction mode, which may be referred to as "mode 6," and an arrow **435** extending from the center point **422** in a direction 180 degrees opposite may represent a horizontal down 2 prediction mode, which may be referred to as "mode 15" or an HD 2 mode. In some embodiments of the present invention, "mode 6" predicted values may be predicted, for 4x4 intra prediction, according to:

$$p(0,0)=p(2,1)=(X+I+1)>>1$$
$$p(1,0)=p(3,1)=(I+2*X+A+2)>>2$$
$$p(2,0)=(X+2*A+B+2)>>2$$
$$p(3,0)=(A+2*B+C+2)>>2$$
$$p(0,1)=p(2,2)=(I+J+1)>>1,$$
$$p(1,1)=p(3,2)=(X+2*I+J+2)>>2$$
$$p(0,2)=p(2,3)=(J+K+1)>>1$$
$$p(1,2)=p(3,3)=(I+2*J+K+2)>>2$$
$$p(0,3)=(K+L+1)>>1$$
$$p(1,3)=(J+2*K+L+2)>>2$$

where the pixel locations and values may be as shown in Figure 11. In some embodiments of the present invention, "mode 15" predicted values may be predicted, for 4x4 intra prediction, by rotating the block data and the neighboring data by 180 degrees and using the "mode 6" prediction equations.

Figure 16A and Figure 16B illustrate this process. As depicted in Figure 16A, a 4x4 block **660** of sixteen pixels **561-676** may be predicted in the horizontal down 2 direction **689** from the reconstructed pixel values to the right **685-688** and below **680-683** and an interpolated corner pixel value **684**. Figure 16B depicts the pixels of Figure 16A after a 180 degree rotation. A 4x4 block **690** of sixteen pixels **691-706** may be predicted in the horizontal down direction **719** from the reconstructed pixels to the left **715-718** and above **711-714** and an interpolated corner pixel **710** using the "mode 6" prediction equations. These predicted pixel values **691-706** may be mapped back to the proper pixels by a 180 degree rotation. In some embodiments of the present invention, the "mode 15" predicted values may be predicted through rotation and using the "mode 6" prediction equations. In alternative embodiments, the "mode 15" predicted values may be directly predicted, for 4x4 intra prediction, according to:

$$\begin{aligned}
&p(3,3)=p(1,2)=(X3+LL+1)>>1\\
&p(2,3)=p(0,2)=(LL+2*X3+DD+2)>>2\\
&p(1,3)=(X3+2*DD+CC+2)>>2\\
&p(0,3)=(DD+2*CC+BB+2)>>2\\
&p(3,2)=p(1,1)=(LL+KK+1)>>1\\
&p(2,2)=p(0,1)=(X3+2*LL+KK+2)>>2\\
&p(3,1)=p(1,0)=(KK+JJ+1)>>1\\
&p(2,1)=p(0,0)=(LL+2*KK+JJ+2)>>2\\
&p(3,0)=(JJ+II+1)>>1\\
&p(2,0)=(KK+2*JJ+II+2)>>2
\end{aligned},$$

where the pixel values and locations are shown in Figure 16A.

An arrow **427** extending from the center point **422** diagonally downward to the left at approximately a 67.5 degree angle from horizontal may represent a vertical left (VL) prediction mode, which may be referred to as "mode 7," and an arrow **436** extending from the center point **422** in a direction 180 degrees opposite may represent a vertical left 2 prediction mode, which may be referred to as "mode 16" or a VL 2 mode. In some embodiments of the present invention, "mode 7" predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned}
&p(0,0)=(A+B+1)>>1\\
&p(1,0)=p(0,2)=(B+C+1)>>1\\
&p(2,0)=p(1,2)=(C+D+1)>>1\\
&p(3,0)=p(2,2)=(D+E+1)>>1\\
&p(3,2)=(E+2*II+JJ+2)>>2\\
&p(0,1)=(A+2*B+C+2)>>2\\
&p(1,1)=p(0,3)=(B+2*C+D+2)>>2\\
&p(2,1)=p(1,3)=(C+2*D+E+2)>>2\\
&p(3,1)=p(2,3)=(D+2*E+II+2)>>2\\
&p(3,3)=(II+2*JJ+KK+2)>>2
\end{aligned},$$

where the pixel locations and values may be as shown in Figure 11. In some embodiments of the present invention, "mode 16" predicted values may be predicted, for 4x4 intra prediction, by rotating the block data and the neighboring data by 90 degrees clockwise and using the "mode 6" prediction equations.

Figure 17A and Figure 17B illustrate this process. As depicted in Figure 17A, a 4x4 block **730** of sixteen pixels **731-746** may be predicted in the vertical left 2 direction **758** from the reconstructed pixel values to the left **750-752** and below **754-757** and an interpolated corner pixel value **753**. Figure 17B depicts the pixels of Figure 17A after a 90 degree clockwise rotation. A 4x4 block **760** of sixteen pixels **761-776** may be predicted in the horizontal down direction **798** from the reconstructed pixels to the left **794-797** and above **791-793** and an interpolated corner pixel **790** using the "mode 6" prediction equations. These predicted pixel values **761-776** may be mapped back to the proper pixels by a 90 degree clockwise rotation. In some embodiments of the present invention, the "mode 16" predicted values may be predicted through rotation and using the "mode 6" prediction equations. In alternative embodiments, the "mode 16" predicted values may be directly predicted, for 4x4 intra prediction, according to:

$$
\begin{aligned}
&p(0,3)=p(1,1)=(X2+AA+1)>>1\\
&p(0,2)=p(1,0)=(AA+2*X2+L+2)>>2\\
&p(0,1)=(X2+2*L+K+2)>>2\\
&p(0,0)=(L+2*K+J+2)>>2\\
&p(1,3)=p(2,1)=(AA+BB+1)>>1\\
&p(1,2)=p(2,0)=(X2+2*AA+BB+2)>>2\\
&p(2,3)=p(3,1)=(BB+CC+1)>>1\\
&p(2,2)=p(3,0)=(AA+2*BB+CC+2)>>2\\
&p(3,3)=(CC+DD+1)>>1\\
&p(3,2)=(BB+2*CC+DD+2)>>2
\end{aligned}
$$

where the pixel values and locations are shown in Figure 17A.

An arrow **428** extending from the center point diagonally upward to the right at approximately a 22.5 degree angle from horizontal may represent a horizontal up (HU) prediction mode, also referred to as "mode 8," and an arrow **437** extending from the center point **422** in a direction 180 degrees opposite may represent a horizontal up 2 prediction mode, which may be referred to as "mode 17" or an HU 2 mode. In some embodiments of the present invention, "mode 8" predicted values may be predicted, for 4x4 intra prediction, according to:

$$\begin{aligned}
&p(0,0)=(I+J+1)>>1\\
&p(1,0)=(I+2*J+K+2)>>2\\
&p(2,0)=p(0,1)=(J+K+1)>>1\\
&p(3,0)=p(1,1)=(J+2*K+L+2)>>2\\
&p(2,1)=p(0,2)=(K+L+1)>>1\\
&p(3,1)=p(1,2)=(K+2*L+X2+2)>>2\\
&p(2,2)=p(0,3)=(L+X2+1)>>1\\
&p(1,3)=p(3,2)=(L+2*X2+AA+2)>>2\\
&p(2,3)=(X2+2*AA+BB+2)>>2\\
&p(3,3)=(AA+2*BB+CC+2)>>2
\end{aligned},$$

where the pixel locations and values may be as shown in Figure 11. In some embodiments of the present invention, "mode 17" predicted values may be predicted, for 4x4 intra prediction, by flipping the block data and the neighboring data across the right-side boundary and using the "mode 6" prediction equations.

Figure 18A and Figure 18B illustrate this process. As depicted in Figure 18A, a 4x4 block **810** of sixteen pixels **811-826** may be predicted in the horizontal up 2 direction **838** from the reconstructed pixel values to the right **834-837** and above **830-832** and an interpolated corner pixel value **833**. Figure 18B depicts the pixels of Figure 18A after a flip across the right-side boundary. A 4x4 block **840** of sixteen pixels **841-856** may be predicted in the horizontal down direction **868** from the reconstructed pixels to the left **864-867** and above **861-863** and an interpolated corner pixel **860** using the "mode 6" prediction equations. These predicted pixel values **841-856** may be mapped back to the proper pixels by an inverse flip across the left-side boundary. In some embodiments of the present invention, the "mode 17" predicted values may be predicted through flipping and using the "mode 6" prediction equations. In alternative embodiments, the "mode 17" predicted values may be directly predicted, for 4x4 intra prediction, according to:

$$\begin{aligned}
&p(3,0)=p(1,1)=(E+II+1)>>1\\
&p(2,0)=p(0,1)=(II+2*E+D+2)>>2\\
&p(1,0)=(E+2*D+C+2)>>2\\
&p(0,0)=(D+2*C+B+2)>>2\\
&p(3,1)=p(1,2)=(II+JJ+1)>>1\\
&p(2,1)=p(0,2)=(E+2*II+JJ+2)>>2\\
&p(3,2)=p(1,3)=(JJ+KK+1)>>1\\
&p(2,2)=p(0,3)=(II+2*JJ+KK+2)>>2\\
&p(3,3)=(KK+LL+1)>>1\\
&p(2,3)=(JJ+2*KK+LL+2)>>2
\end{aligned},$$

where the pixel values and locations are shown in Figure 18A.

An advantage of intra prediction using an opposite-direction mode may be understood in relation to Figure 19. Figure 19 depicts an exemplary block **900** of sixteen pixels **901-916**. When the block **900** is in a set of blocks reconstructed subsequent to the reconstruction of all blocks within a first set of blocks in a macroblock partitioned according to a checker-board pattern, reconstructed pixel values (for example, **931-938**) in neighboring blocks other than the left-neighboring block and the above neighboring-block may be available to use for intra prediction in addition to pixels **925-928** within the left-neighboring block and pixels **921-924** within the above-neighboring block. For images with luminance content, for example, that as illustrated in Figure 19 by white pixels **901-907**, **909**, **910**, **913**, **931**, **921-928**, **935**, **940-942** and gray pixels **908**, **911**, **912**, **914-916**, **932-934**, **936-938**, **943**, **950-957** the pixel values of the gray pixels **908**, **911**, **912**, **914-916**, **932-934** within the block **900** may be better predicted from the reconstructed pixel values in the right-neighboring block and the below-neighboring block. Thus, the use of the opposite-direction prediction modes may increase the compression efficiency due to the higher correlation between the pixel values being predicted and the reconstructed pixel values used in the prediction.

In general, with increased number of prediction modes to select from, encoding efficiency may be increased due to better pixel value prediction. However, with more prediction modes, there may be increased signaling requirements. In some embodiments of the present invention, an encoder may balance the number of modes with the increased overhead associated with additional prediction modes.

In some embodiments of the present invention, a pixel value in a block in a set of blocks reconstructed subsequent to the first set of blocks reconstructed may be predicted according to a prediction mode, wherein the prediction mode is one of the standard-defined prediction modes.

In alternative embodiments of the present invention, a pixel value in a block in a set of blocks reconstructed subsequent to the first set of blocks reconstructed may be predicted according to a prediction mode, wherein the prediction mode is one of the above-defined opposite-direction modes.

In still alternative embodiments of the present invention, a pixel value in a block in a set of blocks reconstructed subsequent to the first set of blocks reconstructed may be predicted by weighted interpolation of the values predicted by two modes that are of 180 degrees different in prediction direction. In some embodiments, a pixel value may be predicted according to:

$$p(y,x) = w_{p1}(y,x) * p1(y,x) + (1 - w_{p1}(y,x))\, p2(y,x),$$

where $p(y,x)$ may denote the predicted pixel value at location (y,x), $p1$ and $p2$ may denote two prediction modes with opposite prediction directions and $w_{p1}(y,x)$ may denote a weight associated with prediction mode $p1$ at location (y,x). In some embodiments of the present invention, the weights may be approximately proportional to the distance to the prediction neighbors. Table 2 shows exemplary weights for 4x4 intra prediction. In some embodiments of the present invention, the weights may be stored for each prediction-mode direction. In alternative embodiments of the present invention, weights for a subset of prediction-mode directions may be stored, and weights for an un-stored prediction-mode direction may be generated by a transformation, for example, a rotation or flipping, of an appropriate stored weighting table.

Table 2. Exemplary Weights for Opposite-Direction-Mode Interpolation

Weighted Interpolated Modes	**Weights**
Mode 0 and Mode 9 $\begin{bmatrix} w_m(0,0) & w_m(1,0) & w_m(2,0) & w_m(3,0) \\ w_m(0,1) & w_m(1,1) & w_m(2,1) & w_m(3,1) \\ w_m(0,2) & w_m(1,2) & w_m(2,2) & w_m(3,2) \\ w_m(0,3) & w_m(1,3) & w_m(2,3) & w_m(3,3) \end{bmatrix}$ $p(y,x) = w_0(y,x)\,p_0(y,x) + w_9(y,x)\,p_9(y,x)$ $w_0(y,x) = 1 - w_9(y,x)$	Mode 0 $w_0(y,x)$: $\begin{bmatrix} \frac{4}{5} & \frac{4}{5} & \frac{4}{5} & \frac{4}{5} \\ \frac{3}{5} & \frac{3}{5} & \frac{3}{5} & \frac{3}{5} \\ \frac{2}{5} & \frac{2}{5} & \frac{2}{5} & \frac{2}{5} \\ \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} \end{bmatrix}$ Mode 9 $w_9(y,x)$: $\begin{bmatrix} \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} \\ \frac{2}{5} & \frac{2}{5} & \frac{2}{5} & \frac{2}{5} \\ \frac{3}{5} & \frac{3}{5} & \frac{3}{5} & \frac{3}{5} \\ \frac{4}{5} & \frac{4}{5} & \frac{4}{5} & \frac{4}{5} \end{bmatrix}$
Mode 1 and Mode 10 $\begin{bmatrix} w_m(0,0) & w_m(1,0) & w_m(2,0) & w_m(3,0) \\ w_m(0,1) & w_m(1,1) & w_m(2,1) & w_m(3,1) \\ w_m(0,2) & w_m(1,2) & w_m(2,2) & w_m(3,2) \\ w_m(0,3) & w_m(1,3) & w_m(2,3) & w_m(3,3) \end{bmatrix}$ $p(y,x) = w_1(y,x)\,p_1(y,x) + w_{10}(y,x)\,p_{10}(y,x)$ $w_1(y,x) = 1 - w_{10}(y,x)$	Mode 1 $w_1(y,x)$: $\begin{bmatrix} \frac{4}{5} & \frac{3}{5} & \frac{2}{5} & \frac{1}{5} \\ \frac{4}{5} & \frac{3}{5} & \frac{2}{5} & \frac{1}{5} \\ \frac{4}{5} & \frac{3}{5} & \frac{2}{5} & \frac{1}{5} \\ \frac{4}{5} & \frac{3}{5} & \frac{2}{5} & \frac{1}{5} \end{bmatrix}$ Mode 10 $w_{10}(y,x)$: $\begin{bmatrix} \frac{1}{5} & \frac{2}{5} & \frac{3}{5} & \frac{4}{5} \\ \frac{1}{5} & \frac{2}{5} & \frac{3}{5} & \frac{4}{5} \\ \frac{1}{5} & \frac{2}{5} & \frac{3}{5} & \frac{4}{5} \\ \frac{1}{5} & \frac{2}{5} & \frac{3}{5} & \frac{4}{5} \end{bmatrix}$
Mode 3 and Mode 12	Mode 3 $w_3(y,x)$ Mode 12 $w_{12}(y,x)$

$\begin{bmatrix} w_m(0,0) & w_m(1,0) & w_m(2,0) & w_m(3,0) \\ w_m(0,1) & w_m(1,1) & w_m(2,1) & w_m(3,1) \\ w_m(0,2) & w_m(1,2) & w_m(2,2) & w_m(3,2) \\ w_m(0,3) & w_m(1,3) & w_m(2,3) & w_m(3,3) \end{bmatrix}$ $p(y,x)=w_3(y,x)p_3(y,x)+w_{12}(y,x)p_{12}(y,x)$ $w_3(y,x)=1-w_{12}(y,x)$	$\begin{bmatrix} \frac{4}{8} & \frac{5}{8} & \frac{6}{8} & \frac{7}{8} \\ \frac{3}{8} & \frac{4}{8} & \frac{5}{8} & \frac{6}{8} \\ \frac{2}{8} & \frac{3}{8} & \frac{4}{8} & \frac{5}{8} \\ \frac{1}{8} & \frac{2}{8} & \frac{3}{8} & \frac{4}{8} \end{bmatrix}$ $\begin{bmatrix} \frac{4}{8} & \frac{3}{8} & \frac{2}{8} & \frac{1}{8} \\ \frac{5}{8} & \frac{4}{8} & \frac{3}{8} & \frac{2}{8} \\ \frac{6}{8} & \frac{5}{8} & \frac{4}{8} & \frac{3}{8} \\ \frac{7}{8} & \frac{6}{8} & \frac{5}{8} & \frac{4}{8} \end{bmatrix}$
Mode 4 and Mode 13 $\begin{bmatrix} w_m(0,0) & w_m(1,0) & w_m(2,0) & w_m(3,0) \\ w_m(0,1) & w_m(1,1) & w_m(2,1) & w_m(3,1) \\ w_m(0,2) & w_m(1,2) & w_m(2,2) & w_m(3,2) \\ w_m(0,3) & w_m(1,3) & w_m(2,3) & w_m(3,3) \end{bmatrix}$ $p(y,x)=w_4(y,x)p_4(y,x)+w_{13}(y,x)p_{13}(y,x)$ $w_4(y,x)=1-w_{13}(y,x)$	Mode 4 Mode 13 $w_4(y,x)$ $w_{13}(y,x)$ $\begin{bmatrix} \frac{7}{8} & \frac{6}{8} & \frac{5}{8} & \frac{4}{8} \\ \frac{6}{8} & \frac{5}{8} & \frac{4}{8} & \frac{3}{8} \\ \frac{5}{8} & \frac{4}{8} & \frac{3}{8} & \frac{2}{8} \\ \frac{4}{8} & \frac{3}{8} & \frac{2}{8} & \frac{1}{8} \end{bmatrix}$ $\begin{bmatrix} \frac{1}{8} & \frac{2}{8} & \frac{3}{8} & \frac{4}{8} \\ \frac{2}{8} & \frac{3}{8} & \frac{4}{8} & \frac{5}{8} \\ \frac{3}{8} & \frac{4}{8} & \frac{5}{8} & \frac{6}{8} \\ \frac{4}{8} & \frac{5}{8} & \frac{6}{8} & \frac{7}{8} \end{bmatrix}$
Mode 5 and Mode14 $\begin{bmatrix} w_m(0,0) & w_m(1,0) & w_m(2,0) & w_m(3,0) \\ w_m(0,1) & w_m(1,1) & w_m(2,1) & w_m(3,1) \\ w_m(0,2) & w_m(1,2) & w_m(2,2) & w_m(3,2) \\ w_m(0,3) & w_m(1,3) & w_m(2,3) & w_m(3,3) \end{bmatrix}$ $p(y,x)=w_5(y,x)p_5(y,x)+w_{14}(y,x)p_{14}(y,x)$ $w_5(y,x)=1-w_{14}(y,x)$	Mode 5 Mode 14 $w_5(y,x)$ $w_{14}(y,x)$ $\begin{bmatrix} \frac{10}{12} & \frac{9}{12} & \frac{8}{12} & \frac{7}{12} \\ \frac{8}{12} & \frac{7}{12} & \frac{6}{12} & \frac{5}{12} \\ \frac{6}{12} & \frac{5}{12} & \frac{4}{12} & \frac{3}{12} \\ \frac{4}{12} & \frac{3}{12} & \frac{2}{12} & \frac{1}{12} \end{bmatrix}$ $\begin{bmatrix} \frac{2}{12} & \frac{3}{12} & \frac{4}{12} & \frac{5}{12} \\ \frac{4}{12} & \frac{5}{12} & \frac{6}{12} & \frac{7}{12} \\ \frac{6}{12} & \frac{7}{12} & \frac{8}{12} & \frac{9}{12} \\ \frac{8}{12} & \frac{9}{12} & \frac{10}{12} & \frac{11}{12} \end{bmatrix}$
Mode 6 and Mode 15 $\begin{bmatrix} w_m(0,0) & w_m(1,0) & w_m(2,0) & w_m(3,0) \\ w_m(0,1) & w_m(1,1) & w_m(2,1) & w_m(3,1) \\ w_m(0,2) & w_m(1,2) & w_m(2,2) & w_m(3,2) \\ w_m(0,3) & w_m(1,3) & w_m(2,3) & w_m(3,3) \end{bmatrix}$ $p(y,x)=w_6(y,x)p_6(y,x)+w_{15}(y,x)p_{15}(y,x)$ $w_6(y,x)=1-w_{15}(y,x)$	Mode 6 Mode 15 $w_6(y,x)$ $w_{15}(y,x)$ $\begin{bmatrix} \frac{10}{12} & \frac{8}{12} & \frac{6}{12} & \frac{4}{12} \\ \frac{9}{12} & \frac{7}{12} & \frac{5}{12} & \frac{3}{12} \\ \frac{8}{12} & \frac{6}{12} & \frac{4}{12} & \frac{2}{12} \\ \frac{7}{12} & \frac{5}{12} & \frac{3}{12} & \frac{1}{12} \end{bmatrix}$ $\begin{bmatrix} \frac{2}{12} & \frac{4}{12} & \frac{6}{12} & \frac{8}{12} \\ \frac{3}{12} & \frac{5}{12} & \frac{7}{12} & \frac{9}{12} \\ \frac{4}{12} & \frac{6}{12} & \frac{8}{12} & \frac{10}{12} \\ \frac{5}{12} & \frac{7}{12} & \frac{9}{12} & \frac{11}{12} \end{bmatrix}$

Mode 7 and Mode 16	Mode 7 $w_7(y,x)$	Mode 16 $w_{16}(y,x)$
$\begin{bmatrix} w_m(0,0) & w_m(1,0) & w_m(2,0) & w_m(3,0) \\ w_m(0,1) & w_m(1,1) & w_m(2,1) & w_m(3,1) \\ w_m(0,2) & w_m(1,2) & w_m(2,2) & w_m(3,2) \\ w_m(0,3) & w_m(1,3) & w_m(2,3) & w_m(3,3) \end{bmatrix}$ $p(y,x)=w_7(y,x)p_7(y,x)+w_{16}(y,x)p_{16}(y,x)$ $w_7(y,x)=1-w_{16}(y,x)$	$\begin{bmatrix} \frac{7}{12} & \frac{8}{12} & \frac{9}{12} & \frac{10}{12} \\ \frac{5}{12} & \frac{6}{12} & \frac{7}{12} & \frac{8}{12} \\ \frac{3}{12} & \frac{4}{12} & \frac{5}{12} & \frac{6}{12} \\ \frac{1}{12} & \frac{2}{12} & \frac{3}{12} & \frac{4}{12} \end{bmatrix}$	$\begin{bmatrix} \frac{5}{12} & \frac{4}{12} & \frac{3}{12} & \frac{2}{12} \\ \frac{7}{12} & \frac{6}{12} & \frac{5}{12} & \frac{4}{12} \\ \frac{9}{12} & \frac{8}{12} & \frac{7}{12} & \frac{6}{12} \\ \frac{11}{12} & \frac{10}{12} & \frac{9}{12} & \frac{8}{12} \end{bmatrix}$
Mode 8 and Mode 17	Mode 8 $w_8(y,x)$	Mode 17 $w_{17}(y,x)$
$\begin{bmatrix} w_m(0,0) & w_m(1,0) & w_m(2,0) & w_m(3,0) \\ w_m(0,1) & w_m(1,1) & w_m(2,1) & w_m(3,1) \\ w_m(0,2) & w_m(1,2) & w_m(2,2) & w_m(3,2) \\ w_m(0,3) & w_m(1,3) & w_m(2,3) & w_m(3,3) \end{bmatrix}$ $p(y,x)=w_8(y,x)p_8(y,x)+w_{17}(y,x)p_{17}(y,x)$ $w_8(y,x)=1-w_{17}(y,x)$	$\begin{bmatrix} \frac{7}{12} & \frac{5}{12} & \frac{3}{12} & \frac{1}{12} \\ \frac{8}{12} & \frac{6}{12} & \frac{4}{12} & \frac{2}{12} \\ \frac{9}{12} & \frac{7}{12} & \frac{5}{12} & \frac{3}{12} \\ \frac{10}{12} & \frac{8}{12} & \frac{6}{12} & \frac{4}{12} \end{bmatrix}$	$\begin{bmatrix} \frac{5}{12} & \frac{7}{12} & \frac{9}{12} & \frac{11}{12} \\ \frac{4}{12} & \frac{6}{12} & \frac{8}{12} & \frac{10}{12} \\ \frac{3}{12} & \frac{5}{12} & \frac{7}{12} & \frac{9}{12} \\ \frac{2}{12} & \frac{4}{12} & \frac{6}{12} & \frac{8}{12} \end{bmatrix}$

In some embodiments of the present invention, an encoder may perform RDO mode selection between the modified previously existing nine modes (mode 0 – mode 8), the nine opposite directional modes (mode 9 – mode 17) and the weighted interpolated modes.

In some embodiments, to save the overhead of mode signaling, nine modes may be used and weighted interpolated modes may be used when available.

In alternative embodiments of the present invention, the modified previously existing nine modes (mode 0 – mode 8) and the nine opposite directional modes (mode 9 – mode 17) may be used. One additional bit, also referred to as a flag, may be used to signal whether the mode is one of the previously existing nine modes or one of the opposite directional modes. In some embodiments of the present invention, the bit value, also referred to as the flag value, may not be signaled for every block. In these embodiments, the flag value may be predicted from the flag values of neighboring blocks within the currently processed plurality of blocks in the macroblock partition. In other embodiments, the flag value may be predicted from the flag values of neighboring blocks in pluralities of blocks that also use a flag value to signal alternative intra-prediction modes. By way of illustration, a first plurality of blocks within a macroblock may not use a flag value to signal alternative intra-prediction modes, while a second plurality of blocks within a macroblock may use a flag value to signal alternative intra-prediction modes. In alternative embodiments, the flag value may be predicted from the nearest block that uses a flag value. In yet alternative embodiments, the flag value may be predicted from the nearest block, in the horizontal direction, that uses a flag value and the nearest block, in the vertical direction, that uses a flag value. In still alternative embodiments, the flag value may be predicted using the nearest block in a neighboring macroblock that uses a flag value. In further alternative embodiments, the flag value may be predicted using the nearest block that uses a flag value in the macroblock that is the left neighbor of the current macroblock. In other embodiments, the flag value may be predicted using the nearest block in the macroblock that uses a flag value in the macroblock that is the upper neighbor of the current macroblock. In some embodiments of the present invention, the flag value may be predicted from the same blocks used for mode prediction. In some embodiments of the present invention, an encoder may signal whether or not a predicted flag value is correct or not. In some embodiments of the present invention, a decoder may decode information from a received bitstream as to whether or not a predicted flag value is correct or not.

In yet alternative embodiments of the present invention, the modified previously existing nine modes (mode 0 – mode 8) and the weighted interpolated modes may be used. An additional bit, also referred to as a flag, may be used to signal whether the mode is one of the modified previously existing nine modes or one of the weighted interpolated modes. In some embodiments of the present invention, the bit value, also referred to as the flag value, may not be signaled for every block. In these embodiments, the flag value may be predicted from the flag values of neighboring blocks within the currently processed plurality of blocks in the macroblock partition. In other embodiments, the flag value may be predicted from the flag values of neighboring blocks in pluralities of blocks that also use a flag value to signal alternative intra-prediction modes. By way of illustration, a first plurality of blocks within a macroblock may not use a flag value to signal alternative intra-prediction modes, while a second plurality of blocks within a macroblock may use a flag value to signal alternative intra-prediction modes. In alternative embodiments, the flag value may be predicted from the nearest block that uses a flag value. In yet alternative embodiments, the flag value may be predicted from the nearest block, in the horizontal direction, that uses a flag value and the nearest block, in the vertical direction, that uses a flag value. In still alternative embodiments, the flag value may be predicted using the nearest block in a neighboring macroblock that uses a flag value. In further alternative embodiments, the flag value may be predicted using the nearest block that uses a flag value in the macroblock that is the left neighbor of the current macroblock. In other embodiments, the flag value may be predicted using the nearest block in the macroblock that uses a flag value in the macroblock that is the upper neighbor of the current macroblock. In some embodiments of the present invention, the flag value may be predicted from the same blocks used for mode prediction. In some embodiments of the present invention, an encoder may signal whether or not a predicted flag value is correct or not. In some embodiments of the present invention, a decoder may decode information from a received bitstream as to whether or not a predicted flag value is correct or not.

In yet alternative embodiments of the present invention, the opposite directional modes (mode 9 – mode 17) and the weighted interpolated modes may be used. An additional bit, also referred to as a flag, may be used to signal whether the mode is one of the modified previously existing nine modes or one of the weighted interpolated modes. In some embodiments of the present invention, the bit value, also referred to as the flag value, may not be signaled for every block. In these embodiments, the bit value may be predicted from the bit values of neighboring blocks within the currently processed plurality of blocks in the macroblock partition. In other embodiments, the flag value may be predicted from the flag values of neighboring blocks in pluralities of blocks that also use a flag value to signal alternative intra-prediction modes. By way of illustration, a first plurality of blocks within a macroblock may not use a flag value to signal alternative intra-prediction modes, while a second plurality of blocks within a macroblock may use a flag value to signal alternative intra-prediction modes. In alternative embodiments, the flag value may be predicted from the nearest block that uses a flag value. In yet alternative embodiments, the flag value may be predicted from the nearest block, in the horizontal direction, that uses a flag value and the nearest block, in the vertical direction, that uses a flag value. In still alternative embodiments, the flag value may be predicted using the nearest block in a neighboring macroblock that uses a flag value. In further alternative embodiments, the flag value may be predicted using the nearest block that uses a flag value in the macroblock that is the left neighbor of the current macroblock. In other embodiments, the flag value may be predicted using the nearest block in the macroblock that uses a flag value in the macroblock that is the upper neighbor of the current macroblock. In some embodiments of the present invention, the flag value may be predicted from the same blocks used for mode prediction. In some embodiments of the present invention, an encoder may signal whether or not a predicted flag value is correct or not. In some embodiments of the present invention, a decoder may decode information from a received bitstream as to whether or not a predicted flag value is correct or not.

In yet alternative embodiments of the present invention, pixel values may be predicted using weighted interpolation of any two independent intra modes.

In some embodiments of the present invention a mode may be numbered between "0" and "8." In these embodiments, the mode prediction of the first set of intra blocks will not be affected by the mode numbering. Table 3 shows exemplary syntax for intra 4x4 prediction. The italicized text is a new addition, to the existing H.264/AVC syntax, in accordance with embodiments of the present invention.

Table 3. Example syntax table for parallel intra 4x4 prediction

	C	Descriptor
mb_pred(mb_type)		
....		
if(MbPartPredMode(mb_type, 0) == Intra_4x4) {		
MB_has_weighted_intra_block_flag	2	u(1) | ae(v)
for(luma4x4BlkIdx=0; luma4x4BlkIdx<16; luma4x4BlkIdx++) {		
If (!MB_has_weighted_intra_block_flag || !weighted_intra_possible(luma4x4BlkIdx)) {		
prev_intra4x4_pred_mode_flag[luma4x4BlkIdx]	2	u(1) | ae(v)
if(!prev_intra4x4_pred_mode_flag[luma4x4BlkIdx])		
rem_intra4x4_pred_mode[luma4x4BlkIdx]	2	u(3) | ae(v)
} else {		
intra4x4_pred_weighted_flag[*luma4x4BlkIdx* ***]***	2	u(1) | ae(v)
prev_intra4x4_pred_mode_flag[luma4x4BlkIdx]	2	u(1) | ae(v)
if(!prev_intra4x4_pred_mode_flag[luma4x4BlkIdx])		
rem_intra4x4_pred_mode[luma4x4BlkIdx]	2	u(3) | ae(v)
}		
}		

The flag "MB_has_weighted_intra_block_flag" may specify whether any block in the Macroblock uses the weighted intra prediction mode. If "MB_has_weighted_intra_block_flag" is equal to 0, then no block in the Macroblock uses weighted intra prediction mode. If the flag "MB_has_weighted_intra_block_flag" is equal to 1, then the Macroblock contains at least one block that uses weighted intra prediction mode.

The flag "intra4x4_pred_weighted_flag" may specify whether an intra4x4 prediction mode is the weighted intra-prediction mode. This flag may only be present when

"MB_has_weighted_intra_block_flag" is equal to 1 and the 4x4 block is in a position it which it is possible to have the weighted intra prediction mode. Blocks that can possibly have the weighted intra prediction mode may be blocks in the second set of blocks except block 15 which does not have right and bottom neighbors. If the flag "intra4x4_pred_weighted_flag" is equal to 0, then the intra-prediction mode of the block may be the original intra prediction mode which is predicted from upper and left neighbors. If the flag "intra4x4_pred_weighted_flag" is equal to 1, then the intra prediction mode of the block may be the weighted intra-prediction mode, which predicts the block values using a weighted combination between a prediction from the upper and left neighbors and a prediction from the bottom and right neighbors. In some embodiments of the present invention, the flag value may not be signaled for every block. In these embodiments, the flag value may be predicted from the flag values of neighboring blocks within the currently processed plurality of blocks in the macroblock partition. In other embodiments, the flag value may be predicted from the flag values of neighboring blocks in pluralities of blocks that also use a flag value to signal alternative intra-prediction modes. By way of illustration, a first plurality of blocks within a macroblock may not use a flag value to signal alternative intra-prediction modes, while a second plurality of blocks within a macroblock may use a flag value to signal alternative intra-prediction modes. In alternative embodiments, the flag value may be predicted from the nearest block that uses a flag value. In yet alternative embodiments, the flag value may be predicted from the nearest block, in the horizontal direction, that uses a flag value and the nearest block, in the vertical direction, that uses a flag value. In still alternative embodiments, the flag value may be predicted using the nearest block in a neighboring macroblock that uses a flag value. In further alternative embodiments, the flag value may be predicted using the nearest block that uses a flag value in the macroblock that is the left neighbor of the current macroblock. In other embodiments, the flag value may be predicted using the nearest block in the macroblock that uses a flag value in the macroblock that is the upper neighbor of the current macroblock. In some embodiments of the present invention, the flag value may be predicted from the same blocks used for mode prediction. In some embodiments of the present invention, an encoder may signal whether or not a predicted flag value is correct or not. In some embodiments of the present invention, a decoder may decode information from a received bitstream as to whether or not a predicted flag value is correct or not.

In some embodiments of the present invention, the intra-prediction mode, Intra4x4PredMode[luma4x4BlkIdx], for a block may be derived according to the following pseudo code:

```
predIntra4x4PredMode = Min( intraMxMPredModeA, intraMxMPredModeB )
if( prev_intra4x4_pred_mode_flag[ luma4x4BlkIdx ] )
    Intra4x4PredMode[ luma4x4BlkIdx ] = predIntra4x4PredMode
else
  if( rem_intra4x4_pred_mode[ luma4x4BlkIdx ] < predIntra4x4PredMode )
     Intra4x4PredMode[ luma4x4BlkIdx ] = rem_intra4x4_pred_mode[ luma4x4BlkIdx ]
  else
     Intra4x4PredMode[ luma4x4BlkIdx ] = rem_intra4x4_pred_mode[ luma4x4BlkIdx ]
+ 1.
```

Where in the pseudo code, intraMxMPredModeA and Intra MxMPredModeB are the prediction modes of a first and a second neighboring block, for which the intra-prediction mode is available, and prev_intra4x4_pred_mode_flag[luma4x4BlkIdx] and rem_intra4x4_pred_mode[luma4x4BlkIdx] specify the Intra_4x4 prediction of the 4x4 luma block with index luma4x4BlkIdx=0,...,15.

An available intra-prediction mode may refer to the intra-prediction mode for a block for which an intra-prediction mode has been determined. An available block may refer to a block for which an intra-prediction mode has been determined.

In some embodiments of the present invention, residual data of the first set of blocks and the second set of blocks may be signaled as specified in H.264/AVC and other video standards. In alternative embodiments of the present invention, the residual data may be signaled in block-coding order. For example, in some embodiments, the residuals of the first set of blocks may be sent in the bitstream first, and the residuals of the second set of blocks may be subsequently sent in the bitstream. In some of these embodiments, the decoder may start reconstructing the first set of blocks immediately after entropy decoding the residual data. Some embodiments of the present invention may comprise a bit flag "parallelResidualSignaling" which may specify whether the residual data of the first set of blocks and the second set of intra 4x4 block are sent separately. The flag "If the flag "parallelResidualSignaling" is equal to 0, then the residual data of the Macroblock may be sent as one Macroblock as specified in H.264/AVC. If the flag "parallelResidualSignaling" is equal to 1, then the residual data of the first set of intra 4x4 blocks in a Macroblock may be sent first, and the residual data of the second set of parallel intra 4x4 blocks may be sent subsequently. Table 4 lists exemplary syntax comprising the flag "parallelResidualSignaling." The flag bit "parallelResidualSignaling" may be sent in the sequence parameter set in some embodiments of the present invention. In alternative embodiments, the flag bit "parallelResidualSignaling" may be sent in the picture parameter set.

Table 4. Example syntax table for parallel intra 4x4 prediction residual signaling

residual( ) {	C	Descriptor
....		
if(MbPartPredMode(mb_type, 0) == Intra_4x4 && parallelResidualSignaling) {		
for(4x4 block in 1st set of blocks) {		
residual_block()		
}		
for(4x4 block in 2nd set of blocks) {		
residual_block()		
}		
}		
......		

In some embodiments of the present invention, the prediction modes for a plurality of blocks may be signaled interleaved with the block residuals. In alternative embodiments, the prediction modes may be signaled for all of the blocks within the plurality of blocks prior to the signaling of the residuals for the blocks within the plurality of blocks.

In some embodiments of the present invention, an encoder may determine a macroblock partition and signal the partition choice in a bitstream. In alternative embodiments, an encoder may use a default partition.

In some embodiments of the present invention, a decoder may decode, from a bitstream, information identifying a macroblock partition. In alternative embodiments, a partition may be determined at a decoder to be a default partition.

Referring to FIG. 20, an exemplary encoder 1200 in some embodiments of the present invention is described for purposes of illustration. It is to be understood that any video encoder may be used. The input video 1210 is provided to a buffer suitable to reorder frames, or portions thereof, as necessary 1220. A combiner 1230 modifies a portion of the suitable reordered frame in a manner suitable for a transform and quantization process 1240. The transform and quantization process 1240 provides a signal to an entropy coder 1250.

The entropy coder 1250 provides a signal to an output buffer 1260 for the output bit stream 1270. An encoder controller 1280 that receives the input video 1210 provides control signals to all the modules of the encoder 1200.

The transform and quantization process 1240 also provides its output to an inverse transform and quantization 1300 so that the corresponding decoder can be simulated. A picture-type decision process 1310 is interconnected with the frame ordering buffer 1220. The picture-type decision process 1310 is also interconnected to a macro-block-type decision 1320. In this manner, control over the frame ordering buffer 1220 may be achieved. In addition, control over the type of macro-block may be achieved.

The inverse transform and quantization 1300 provides a signal to a combiner 1330, which in combination with the macro-block type decision 1320, provides a signal to an intra coding prediction module 1340 and a deblocking filter 1350. The deblocking filter 1350 is interconnected to a reference picture buffer 1360. The reference picture buffer 1360 provides a signal to a motion estimation process 1370 and a motion compensation process 1380. The motion estimation 1370 provides a signal to the motion compensation 1380 and to the entropy coder 1250. A selector 1390 selects between the output of the motion compensation 1380 and the output of the intra-coded prediction 1340 for the combiner 1230. In this manner, the combiner 1230 receives information related to whether the macro-block is intra coded 1340 or motion-compensation coded 1380.

The decision made by the selector 1390 relates to the macro-block type decision 1320. For example, if the macro-block type decision 1320 decides that the macro-block should be intra-coded, then the selector should select a form of intra-prediction. For example, if the macro-block type decision 1320 decides that the macro-block should be motion compensated, then the selector should select a form of motion compensation. The decisions made by the macro-block type decision 1320, the picture-type decision 1310, the selector 1390, and the selection among one or more intra-prediction techniques 1340, are all included within the bit-stream by the entropy coding 1250. In addition, the combiner 1330 may receive an input from the selector 1390 to provide information about the selection made.

Any suitable decoder may be used. An exemplary video decoder 1400 for an input bit stream 1410 includes an input buffer 1420. The input buffer 1420 provides a signal to an entropy decoder 1430. The entropy decoder 1430 provides a signal to an inverse transform and quantization process 1440. The inverse transform and quantization process 1440 provides a signal to a combiner 1450. The combiner 1450 provides a signal to a deblocking filter 1460 and an intra-prediction module 1470. The deblocking filter 1460 provides a signal to a reference picture buffer 1480. The reference picture buffer 1480 provides a signal to a motion compensator 1490.

The entropy decoder 1430 provides a signal to the motion compensation 1490 and the deblocking filter 1460. The entropy decoder 1430 also provides a signal to a decoder controller 1500. The decoder controller is interconnected with the other modules of the decoder 1400. The motion compensator 1490 provides a signal to a switch 1510. The intra-prediction module 1470 provides a signal to the switch 1510. The switch 1510 selectively provides a signal to the combiner 1450. The deblocking filter 1460 provides an output picture 1520.

Referring to FIG. 22, different frames, or portions thereof, of video are typically encoded using different techniques. One such technique includes the use of picture types generally referred to as I-frames, P-frames, and B-frames. I-frames do not require other video frames to decode. P-frames may use data from a previously transmitted frame to decode. B-frames may use two or more previously transmitted frames to decode. The encoding of the video may likewise be based upon one or more different sized blocks of pixels from within the frame. Also, the encoding of the video may likewise be based upon motion estimation, slices, spatial prediction of blocks, or otherwise between one or more frames. Therefore, in general there is decoder prediction information transmitted with the video bitstream which indicates the type of encoding of the frames, the type of prediction of the frames, the direction(s) of the predictions, which frames are used, motion estimation information between the frames, frame size information, block sizing information within the frame, spatial prediction information, and/or other suitable parameters. Accordingly, the decoder 1400 decodes the frames of the video based upon the prediction information provided with the bit-stream by the encoder 1200.

Some embodiments of the present invention may comprise a computer program product comprising a computer-readable storage medium having instructions stored thereon/in which may be used to program a computing system to perform any of the features and methods described herein. Exemplary computer-readable storage media may include, but are not limited to, flash memory devices, disk storage media, for example, floppy disks, optical disks, magneto-optical disks, Digital Versatile Discs (DVDs), Compact Discs (CDs), micro-drives and other disk storage media, Read-Only Memory (ROMs), Programmable Read-Only Memory (PROMs), Erasable Programmable Read-Only Memory (EPROMS), Electrically

Erasable Programmable Read-Only Memory (EEPROMs), Random-Access Memory (RAMS), Video Random-Access Memory (VRAMs), Dynamic Random-Access Memory (DRAMs) and any type of media or device suitable for storing instructions and/or data.

The terms and expressions which have been employed in the foregoing specification are used therein as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding equivalence of the features shown and described or portions thereof, it being recognized that the scope of the invention is defined and limited only by the claims which follow.

CLAIMS

1. A method for intra prediction of a macroblock, said method comprising:

a) in a video device, predicting a pixel value, in a first block of a macroblock, using a reconstructed pixel value from a second block of said macroblock;

b) wherein said second block is located, relative to said first block, in a direction selected from the group consisting of to the right of and below;

c) wherein said second block is in a first plurality of blocks in a partition of said macroblock and said first block is in a second plurality of blocks in said partition; and

d) wherein said first plurality of blocks are predicted using reconstructed pixel values from only one or more neighboring macroblocks to said macroblock.

2. A method as described in claim 1, wherein said video device is a device selected from the group consisting of a video encoder, a video decoder and a video transcoder.

3. A method as described in claim 1 further comprising determining said partition.

4. A method as described in claim 1, wherein said first plurality of blocks and said second plurality of blocks form a checker-board pattern relative to each other.

5. A method as described in claim 1, wherein each block in said second plurality of blocks has a neighboring block in said first plurality of blocks.

6. A method as described in claim 1, wherein said first block and said second block are neighboring blocks in said macroblock.

7. A method as described in claim 1, wherein said pixel value is associated with a signal selected from the group consisting of a luminance signal, a chrominance signal and a disparity signal.

8. A computer program product, stored on a computer-readable medium, comprising a computer program processable by a computing system for causing said computing system to execute a method comprising:

a) predicting a pixel value, in a first block of a macroblock, using a reconstructed pixel from a second block of said macroblock;

b) wherein said second block is located, relative to said first block, in a direction selected from the group consisting of to the right of and below;

c) wherein said second block is in a first plurality of blocks in a partition of said macroblock and said first block is in a second plurality of blocks in said partition; and

d) wherein said first plurality of blocks are predicted using reconstructed pixel values from only one or more neighboring macroblocks to said macroblock.

9. A computer program product as described in claim 8, wherein said method further comprises determining said partition.

10. A computer program product as described in claim 8, wherein said first plurality of blocks and said second plurality of blocks form a checker-board pattern relative to each other.

11. A computer program product as described in claim 8, wherein each block in said second plurality of blocks has a neighboring block in said first plurality of blocks.

12. A computer program product as described in claim 8, wherein said first block and said second block are neighboring blocks in said macroblock.

13. A computer program product as described in claim 8, wherein said pixel value is associated with a signal selected from the group consisting of a luminance signal, a chrominance signal and a disparity signal.

14. A method for intra prediction of a macroblock, said method comprising:

a) in a video device, predicting a pixel value, in a first block of a macroblock, based on a weighted average of a first value predicted according to a first-direction intra-prediction mode and a second value predicted according to a second-direction intra-prediction mode;

b) wherein said first-direction intra-prediction mode and said second-direction intra-prediction mode are associated with opposite prediction directions;

c) wherein said first value is determined from a first plurality of reconstructed pixel values in a second block of said macroblock;

d) wherein said second block is in a first plurality of blocks in a partition of said macroblock and said first block is in a second plurality of blocks in said partition of said macroblock; and

e) wherein said first plurality of blocks are predicted using reconstructed pixel values from only one or more neighboring macroblocks to said macroblock.

15. A method as described in claim 14, wherein said video device is a device selected from the group consisting of a video encoder, a video decoder and a video transcoder.

16. A method as described in claim 14, wherein said pixel value is associated with a signal selected from the group consisting of a luminance signal, a chrominance signal and a disparity signal.

17. A method as described in claim 14, wherein said weighted average comprises a first weight, wherein said first weight is based on the distance of said first pixel from said second block.

18. A method as described in claim 14 further comprising determining said partition.

19. A method as described in claim 14, wherein said first plurality of blocks and said second plurality of blocks form a checker-board pattern relative to each other.

20. A method as described in claim 14, wherein each block in said second plurality of blocks has a neighboring block in said first plurality of blocks.

21. A method as described in claim 14, wherein said first block and said second block are neighboring blocks in said macroblock.

22. A method as described in claim 14, wherein said second block is located, relative to said first block, in a direction selected from the group consisting of to the right of and below.

23. A computer program product, stored on a computer-readable medium, comprising a computer program processable by a computing system for causing said computing system to execute a method comprising:

a) predicting a pixel value, in a first block of a macroblock, based on a weighted average of a first value predicted according to a first-direction intra-prediction mode and a second value predicted according to a second-direction intra-prediction mode, wherein said first-direction intra-prediction mode and said second-direction intra-prediction mode are associated with opposite prediction directions;

b) wherein said first-direction intra-prediction mode and said second-direction intra-prediction mode are associated with opposite prediction directions;

c) wherein said first value is determined from a first plurality of reconstructed pixel values in a second block of said macroblock;

d) wherein said second block is in a first plurality of blocks in a partition of said macroblock and said first block is in a second plurality of blocks in said partition of said macroblock; and

e) wherein said first plurality of blocks are predicted using reconstructed pixel values from only one or more neighboring macroblocks to said macroblock.

24. A computer program product as described in claim 23, wherein said pixel value is associated with a signal selected from the group consisting of a luminance signal, a chrominance signal and a disparity signal.

25. A computer program product as described in claim 23, wherein said weighted average comprises a first weight, wherein said first weight is based on the distance of said first pixel from said second block.

26. A computer program product as described in claim 23 further comprising determining said partition.

27. A computer program product as described in claim 23, wherein said first plurality of blocks and said second plurality of blocks form a checker-board pattern relative to each other.

28. A computer program product as described in claim 23, wherein each block in said second plurality of blocks has a neighboring block in said first plurality of blocks.

29. A computer program product as described in claim 23, wherein said first block and said second block are neighboring blocks in said macroblock.

30. A computer program product as described in claim 23, wherein said second block is located, relative to said first block, in a direction selected from the group consisting of to the right of and below.

FIG. 1
Prior Art

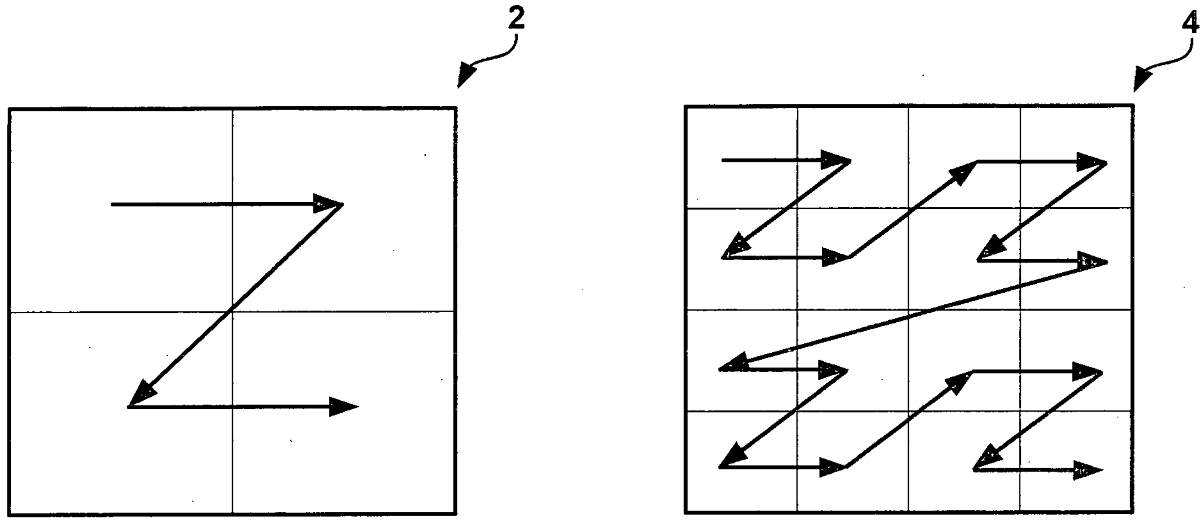


FIG. 2
Prior Art

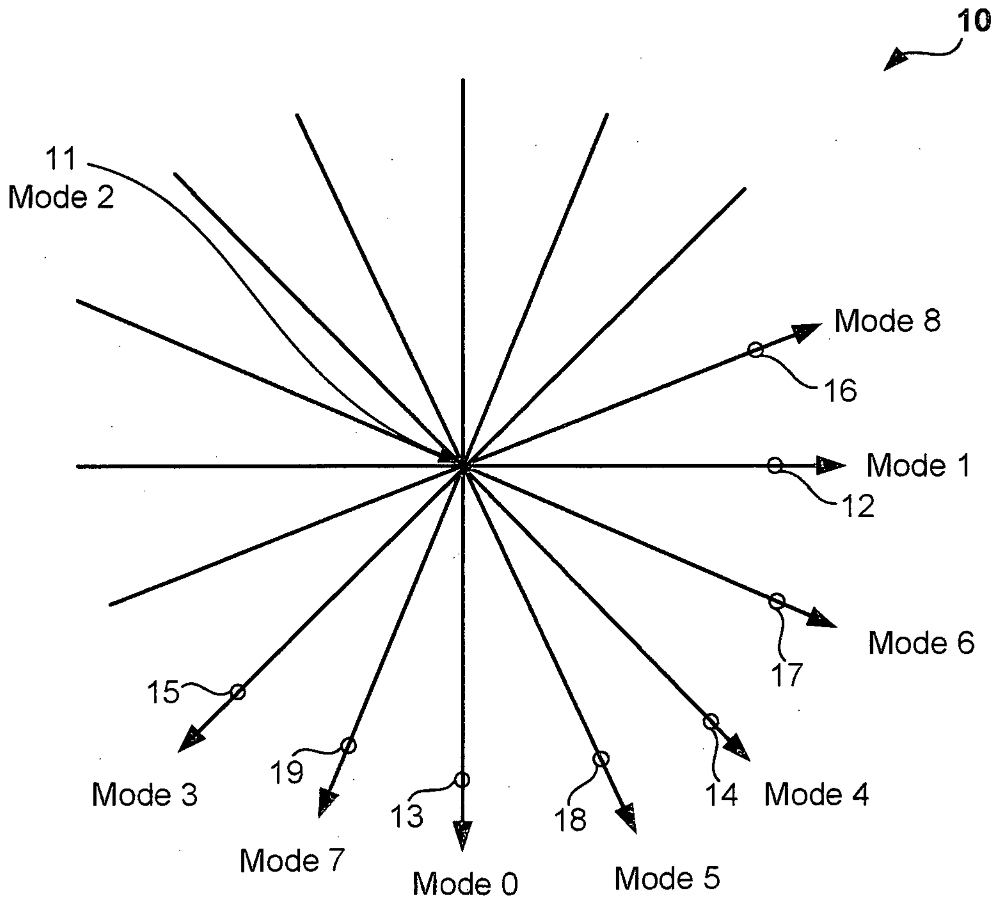


FIG. 3A

Prior Art

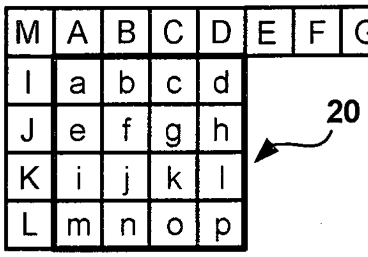


FIG. 3B

Prior Art

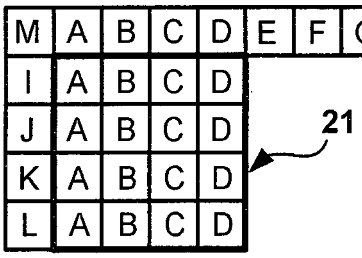


FIG. 3C

Prior Art

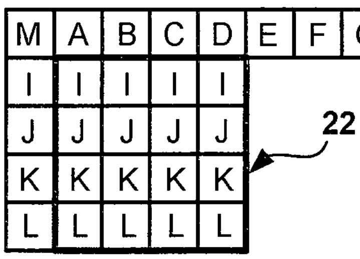


FIG. 3D

Prior Art

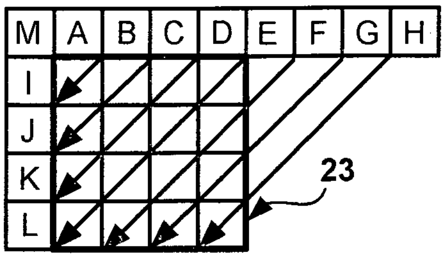


FIG. 3E

Prior Art

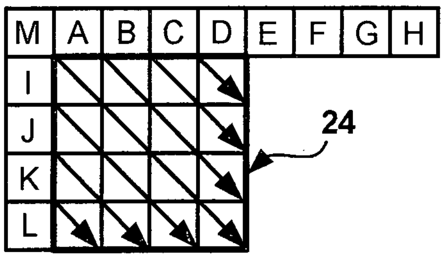


FIG. 3F

Prior Art

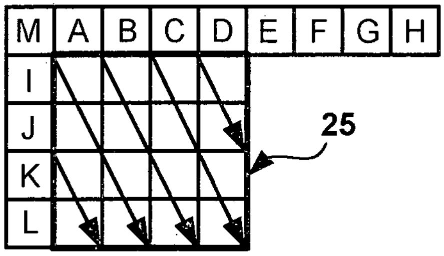


FIG. 3G
Prior Art

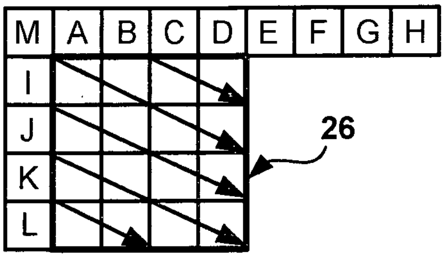


FIG. 3H
Prior Art

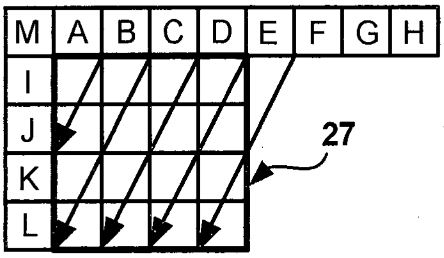


FIG. 3I
Prior Art

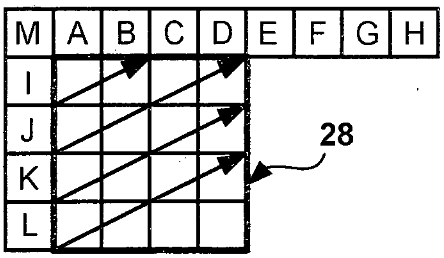


FIG. 4

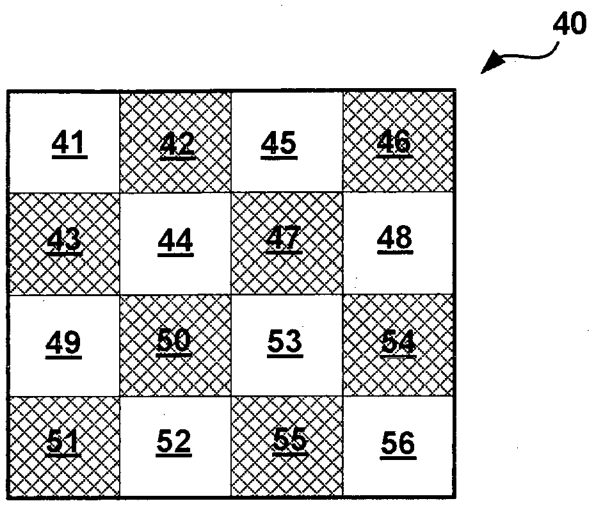

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FIG. 5A

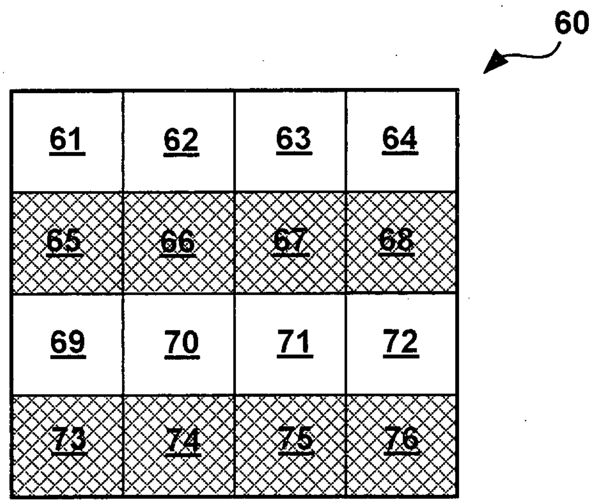
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FIG. 5B

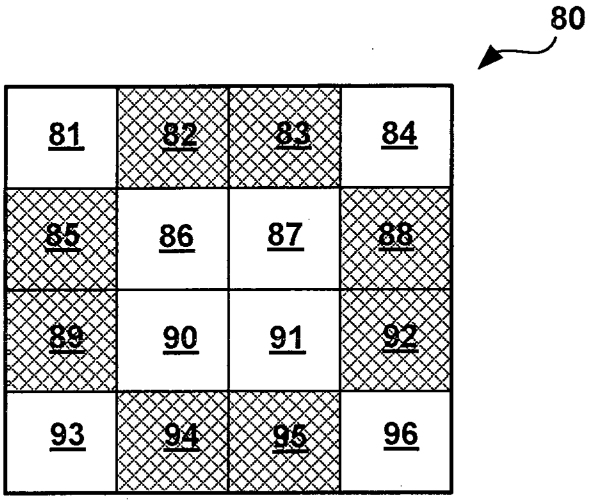
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FIG. 5C

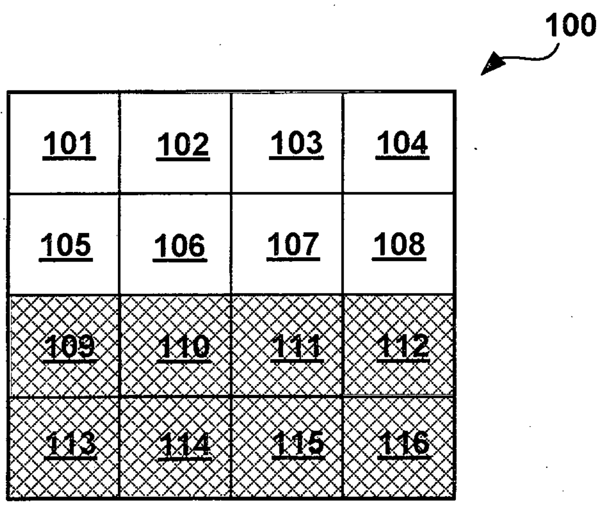
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FIG. 5D

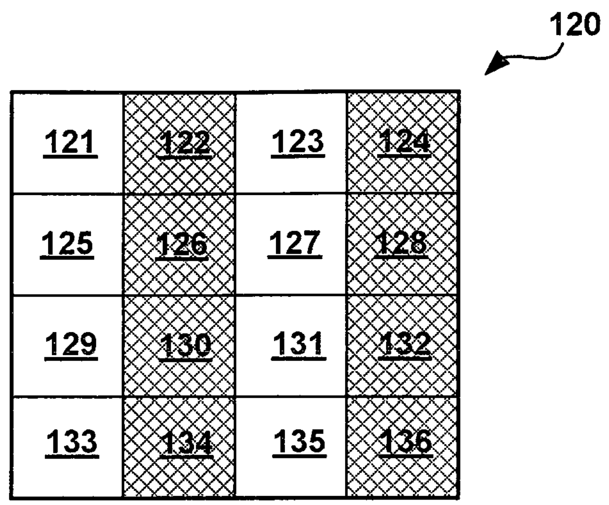
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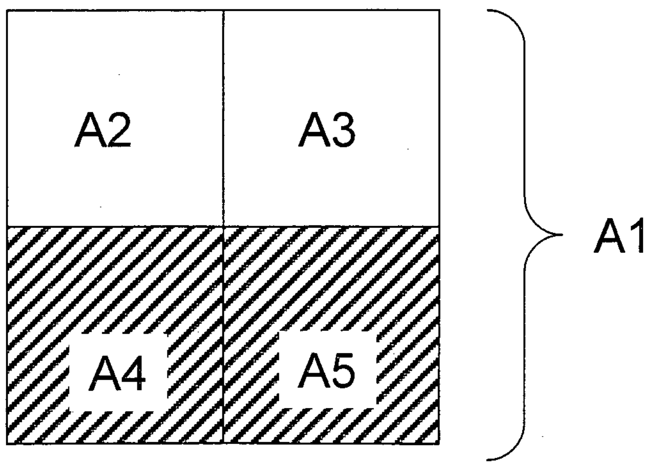
FIG. 5E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A3
A4
A5
A1

FIG. 6A

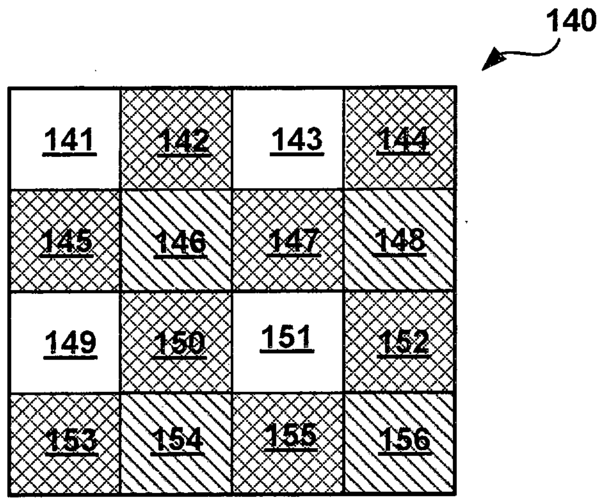
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FIG. 6B

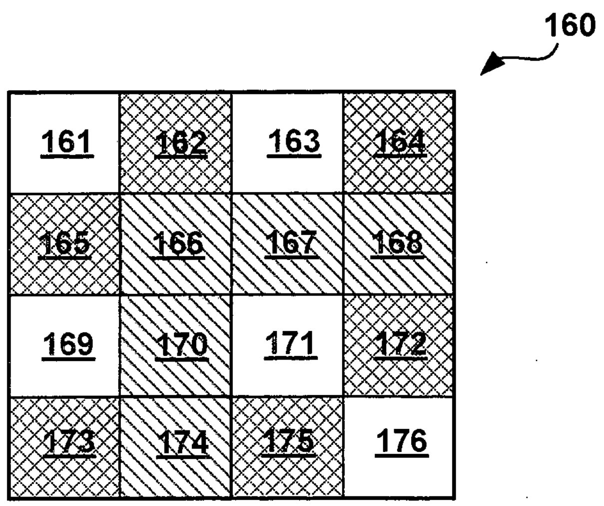
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FIG. 7A

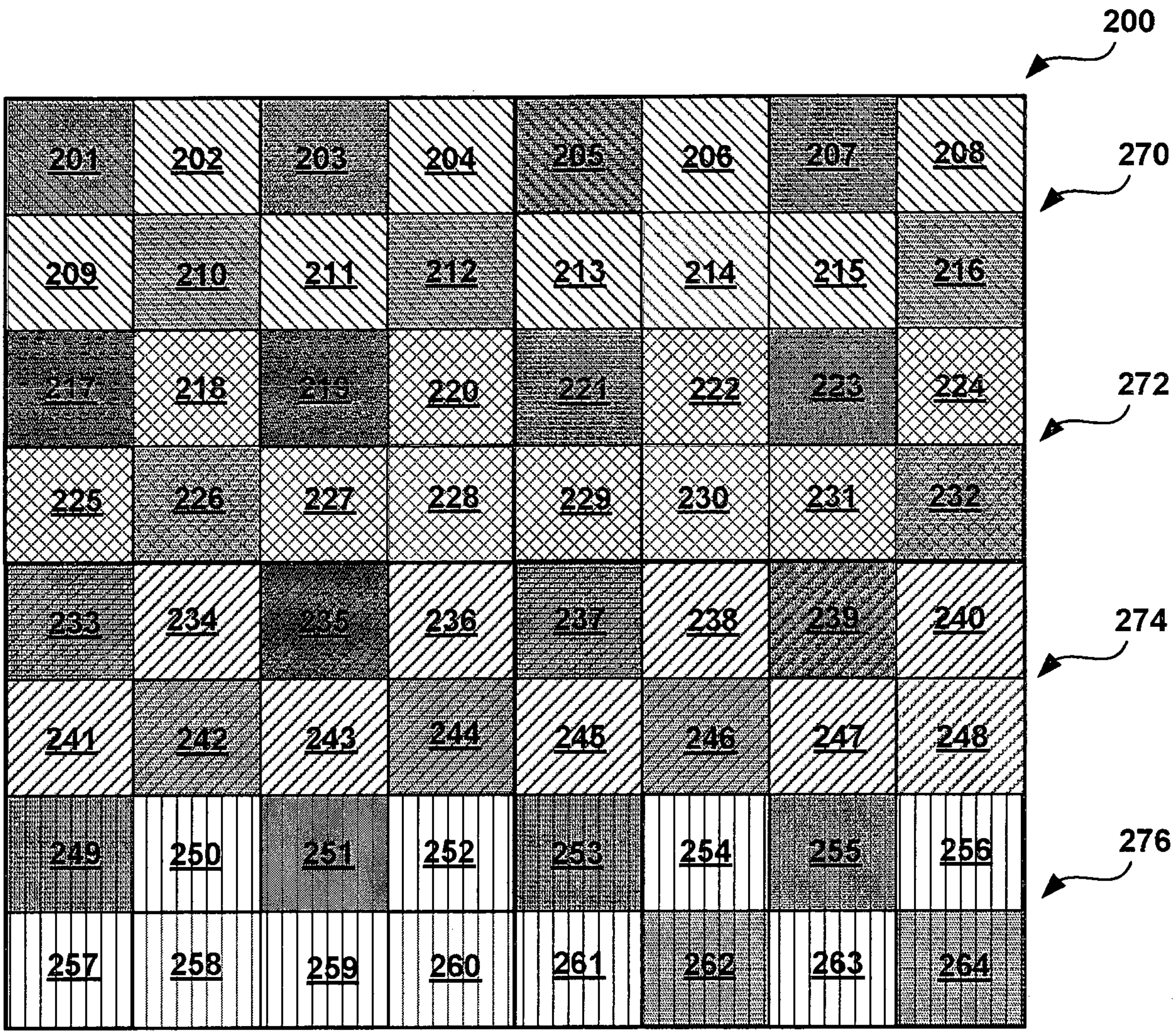
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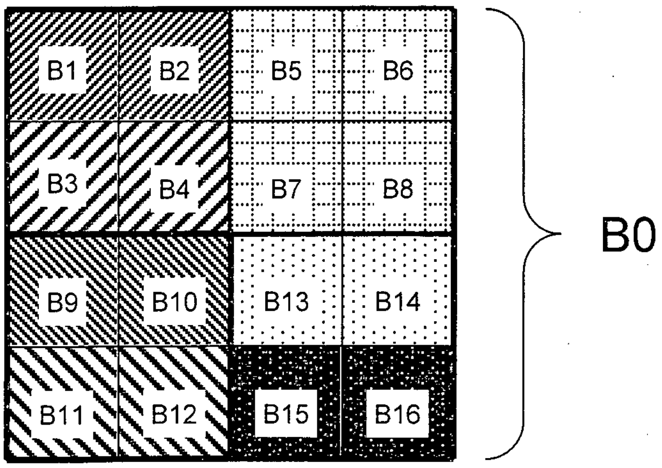
FIG. 7B


B1
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B14
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B15
B16
B0

FIG. 8

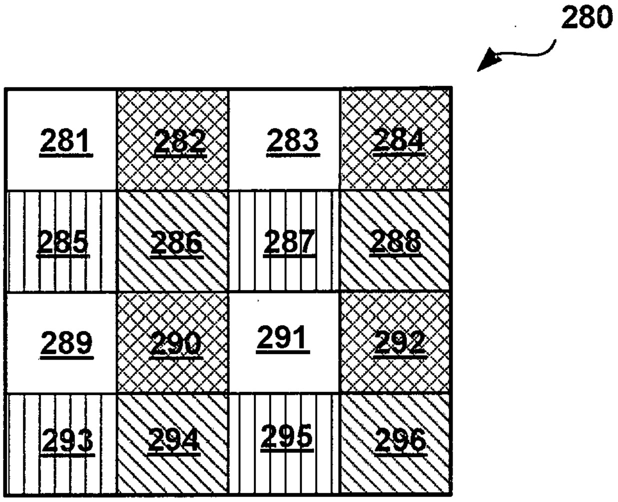
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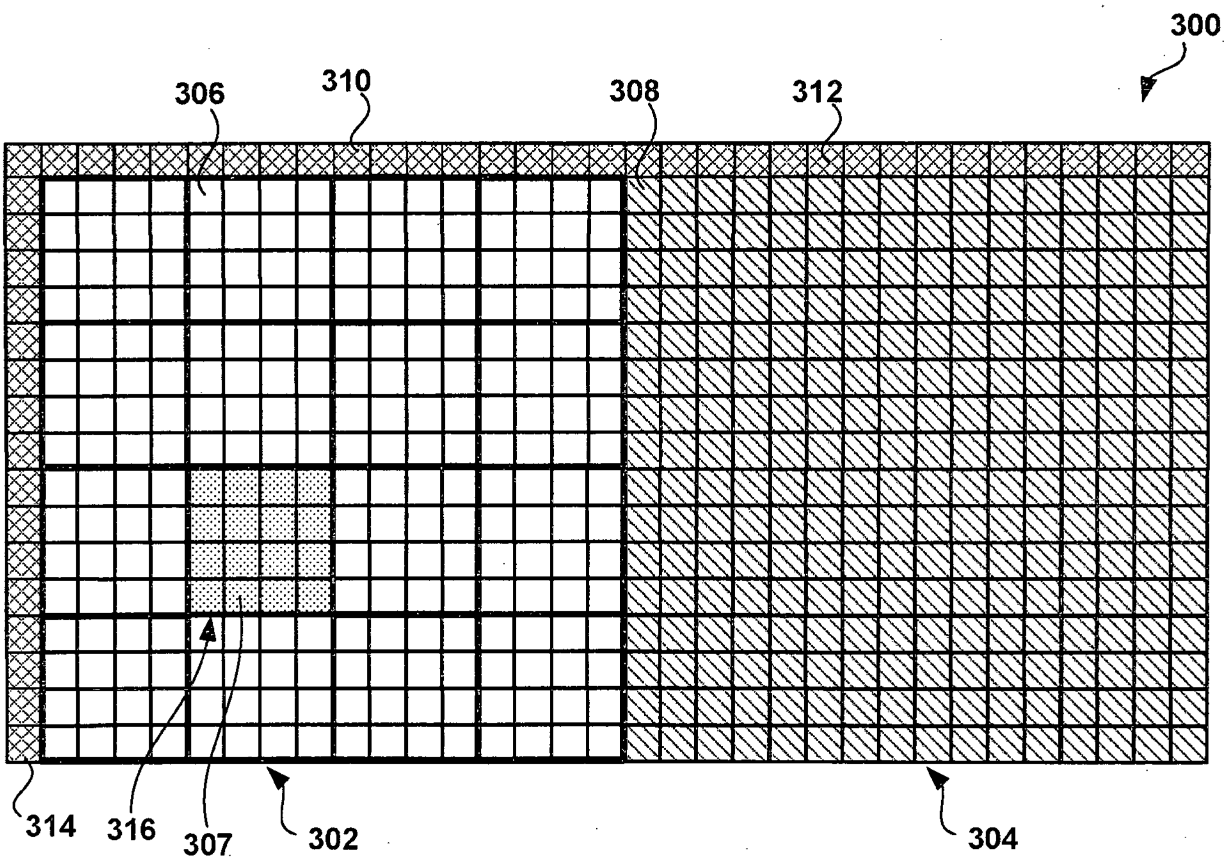
FIG. 9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304

FIG. 10

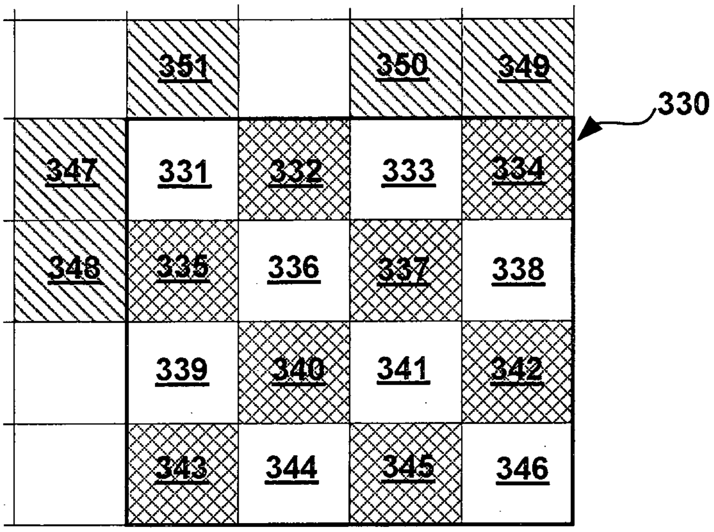
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FIG. 11

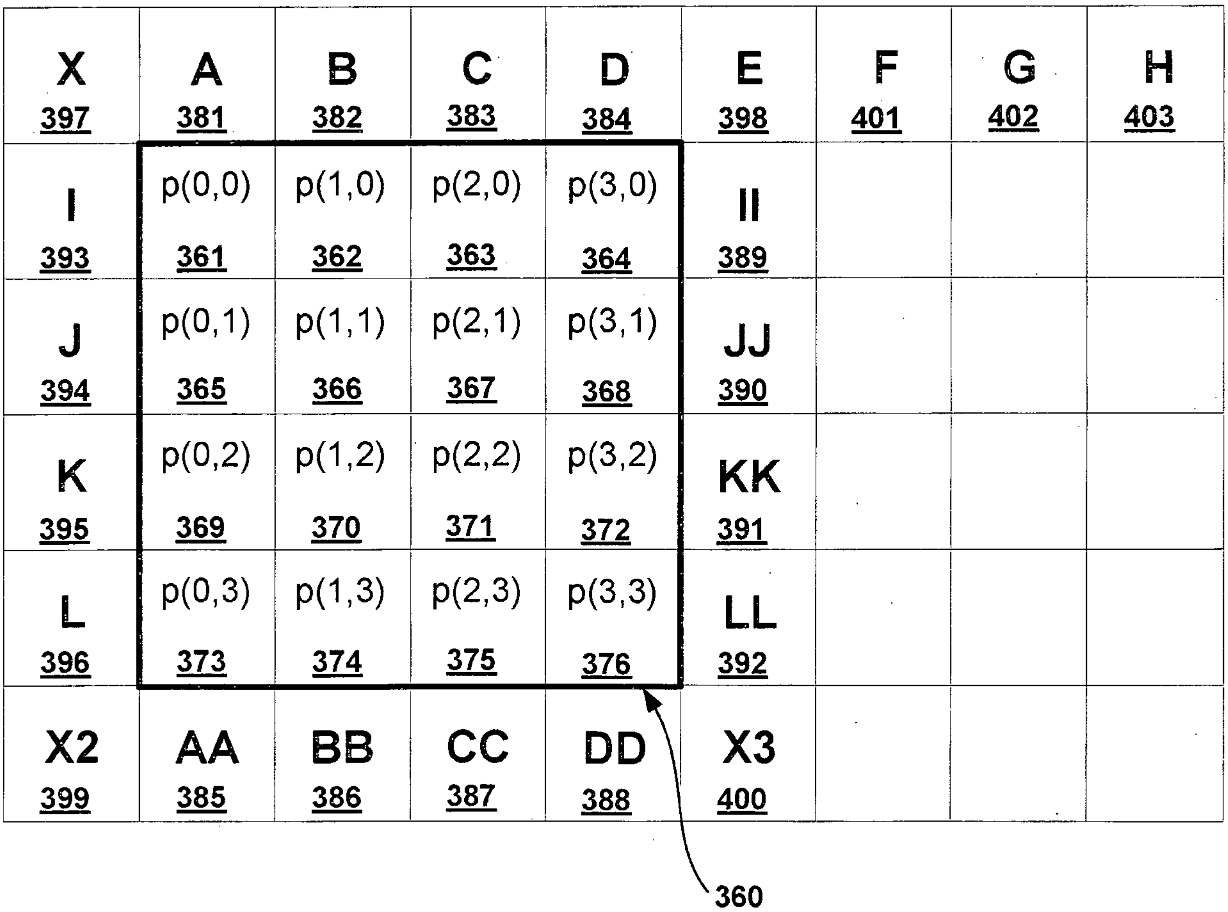
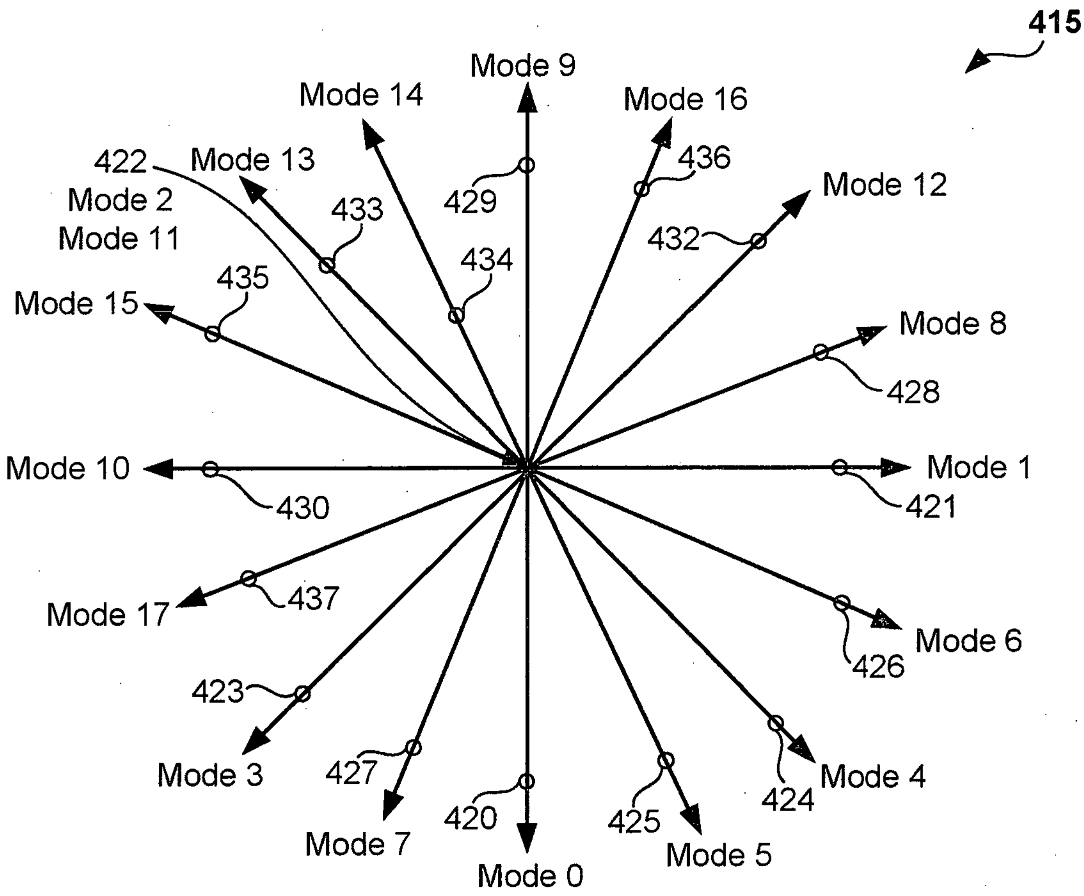

X 397
A 381
B 382
C 383
D 384
E 398
F 401
G 402
H 403
I 393
p(0,0) 361
p(1,0) 362
p(2,0) 363
p(3,0) 364
II 389
J 394
p(0,1) 365
p(1,1) 366
p(2,1) 367
p(3,1) 368
JJ 390
K 395
p(0,2) 369
p(1,2) 370
p(2,2) 371
p(3,2) 372
KK 391
L 396
p(0,3) 373
p(1,3) 374
p(2,3) 375
p(3,3) 376
LL 392
X2 399
AA 385
BB 386
CC 387
DD 388
X3 400
360

FIG. 12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Mode 9
Mode 14
Mode 16
Mode 13
Mode 12
422
Mode 2
Mode 11
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432
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435
Mode 15
Mode 8
428
Mode 10
430
Mode 1
421
Mode 17
437
Mode 6
426
423
Mode 3
427
Mode 4
424
420
425
Mode 7
Mode 5
Mode 0

FIG. 13A

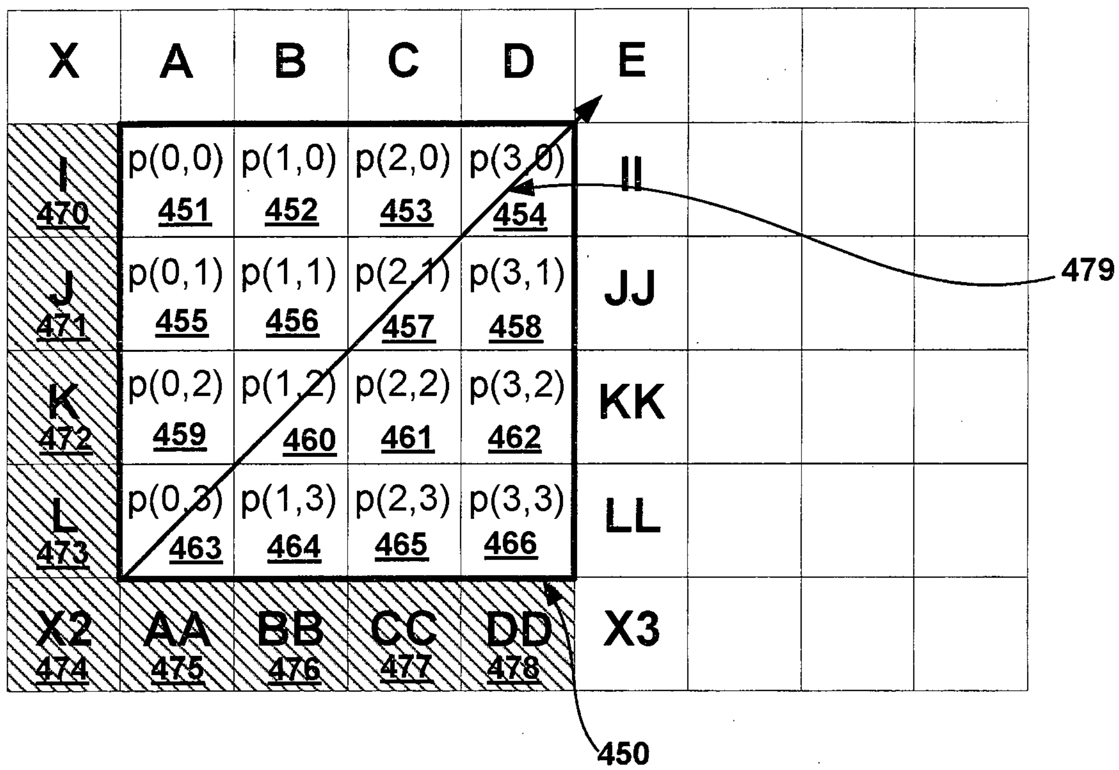


FIG. 13B

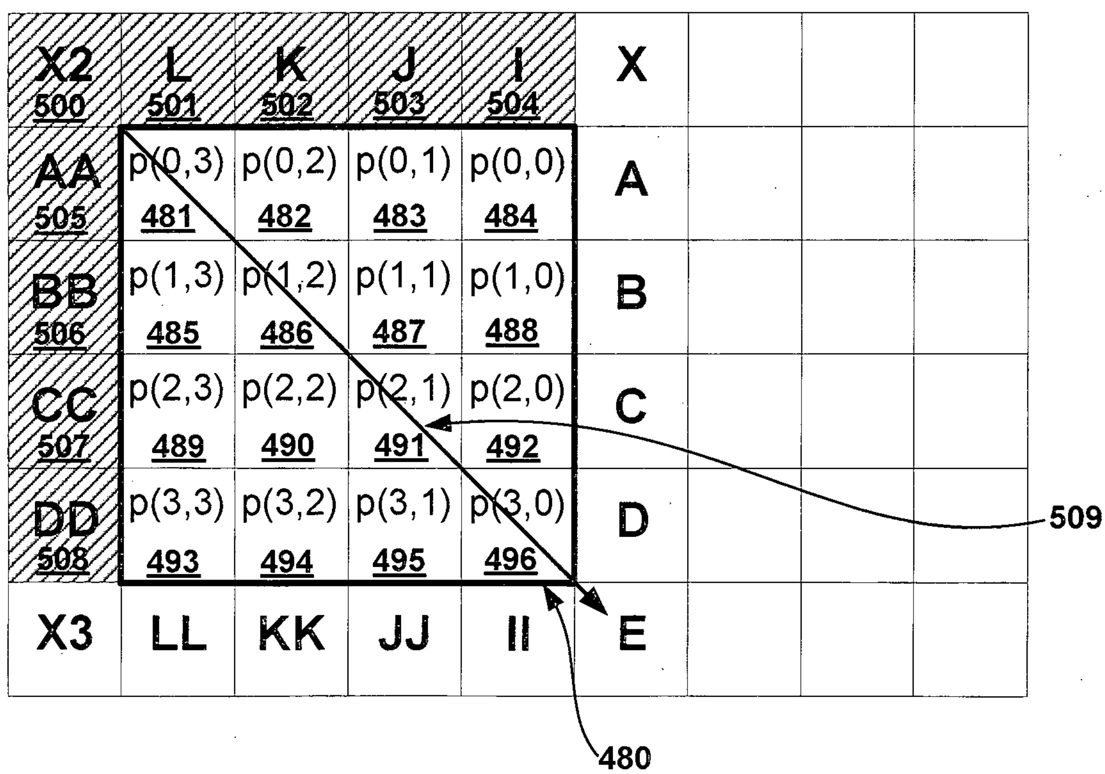


FIG. 14A

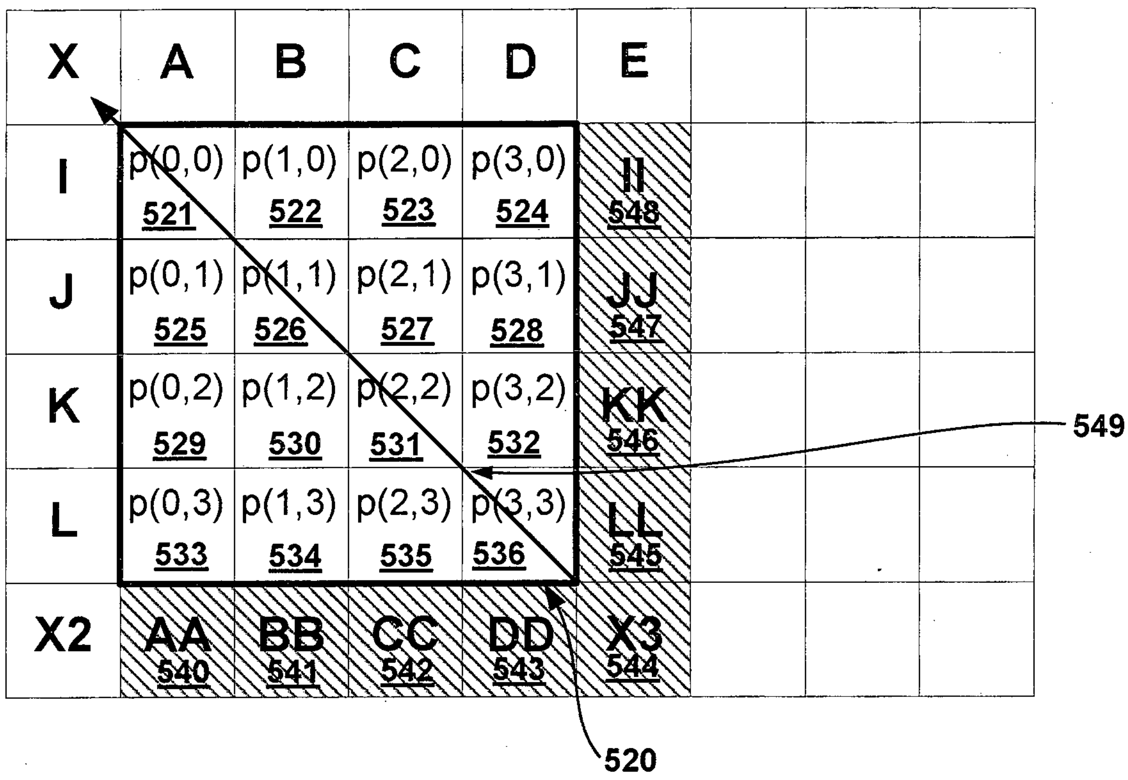


FIG. 14B

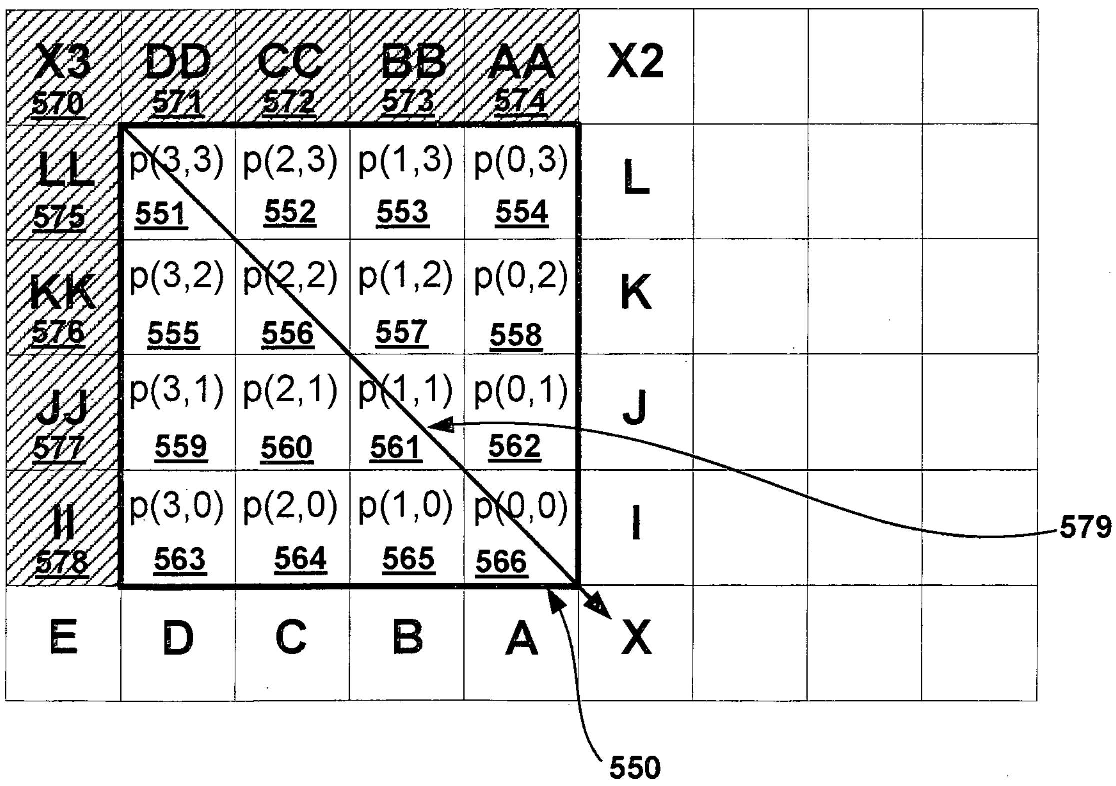


FIG. 15A

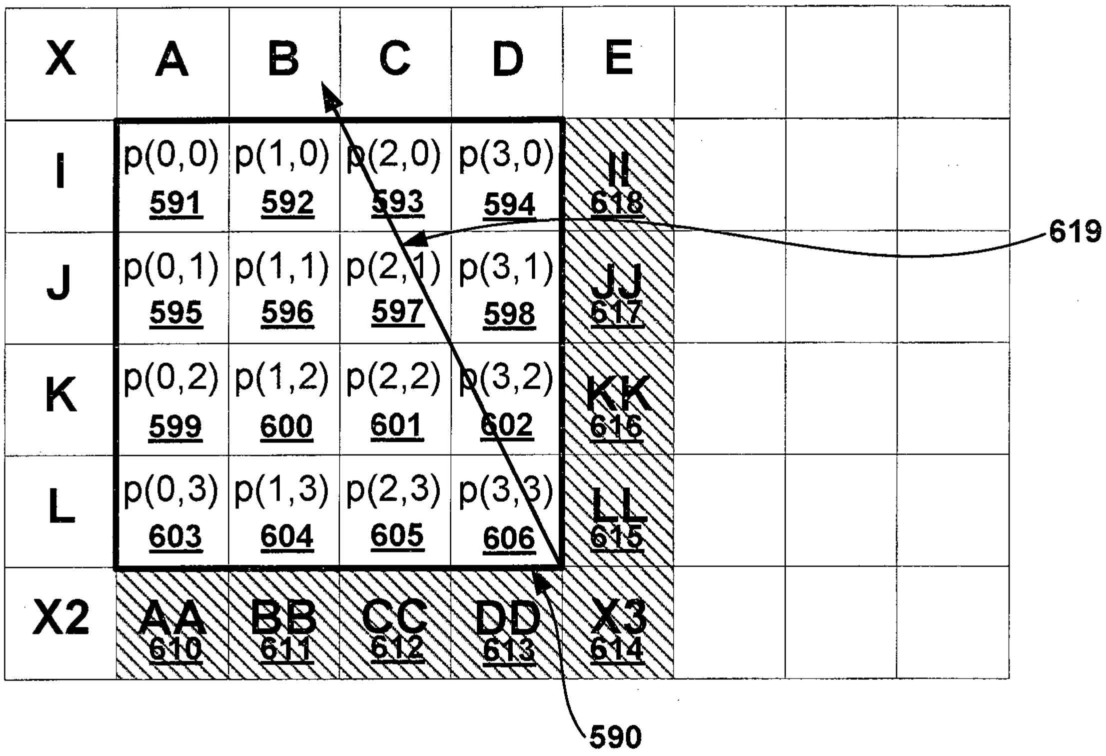


FIG. 15B

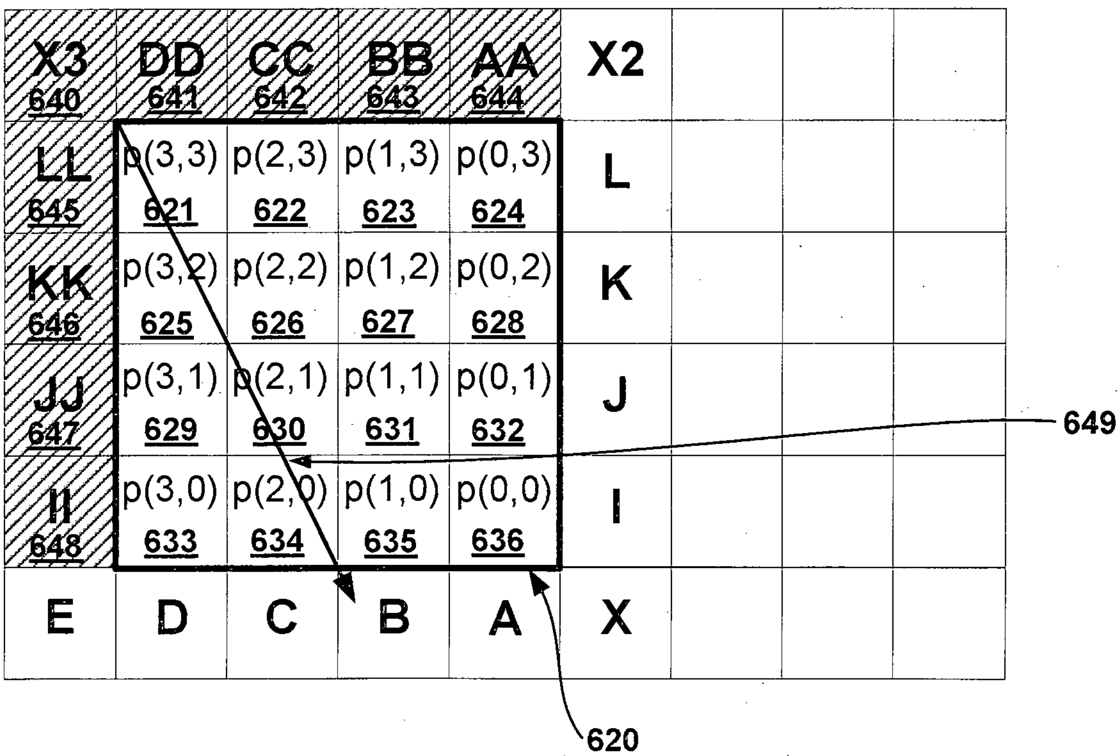


FIG. 16A

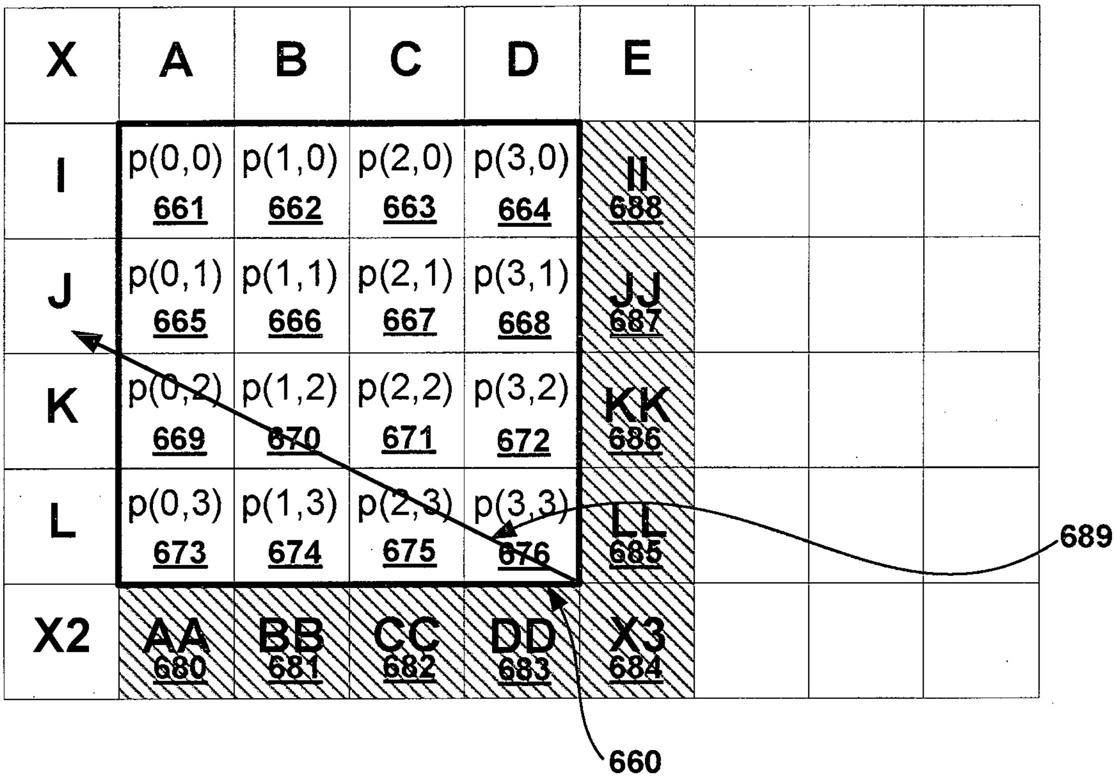


FIG. 16B

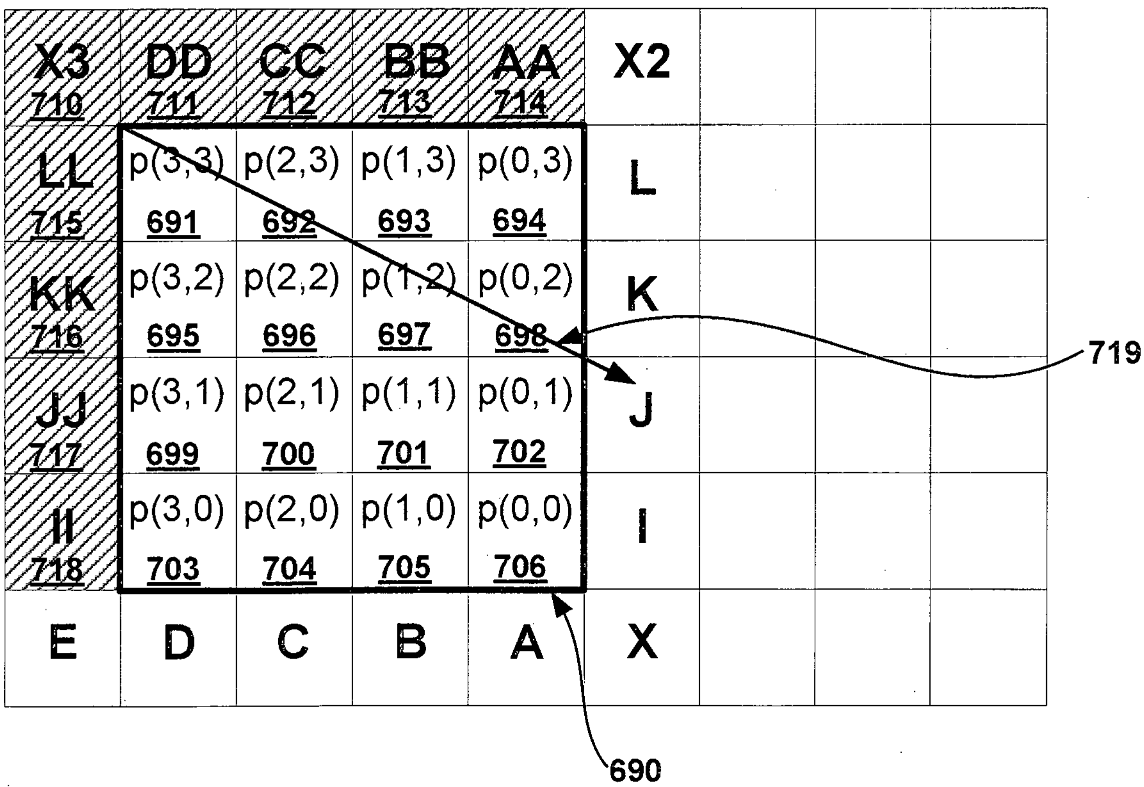


FIG. 17A

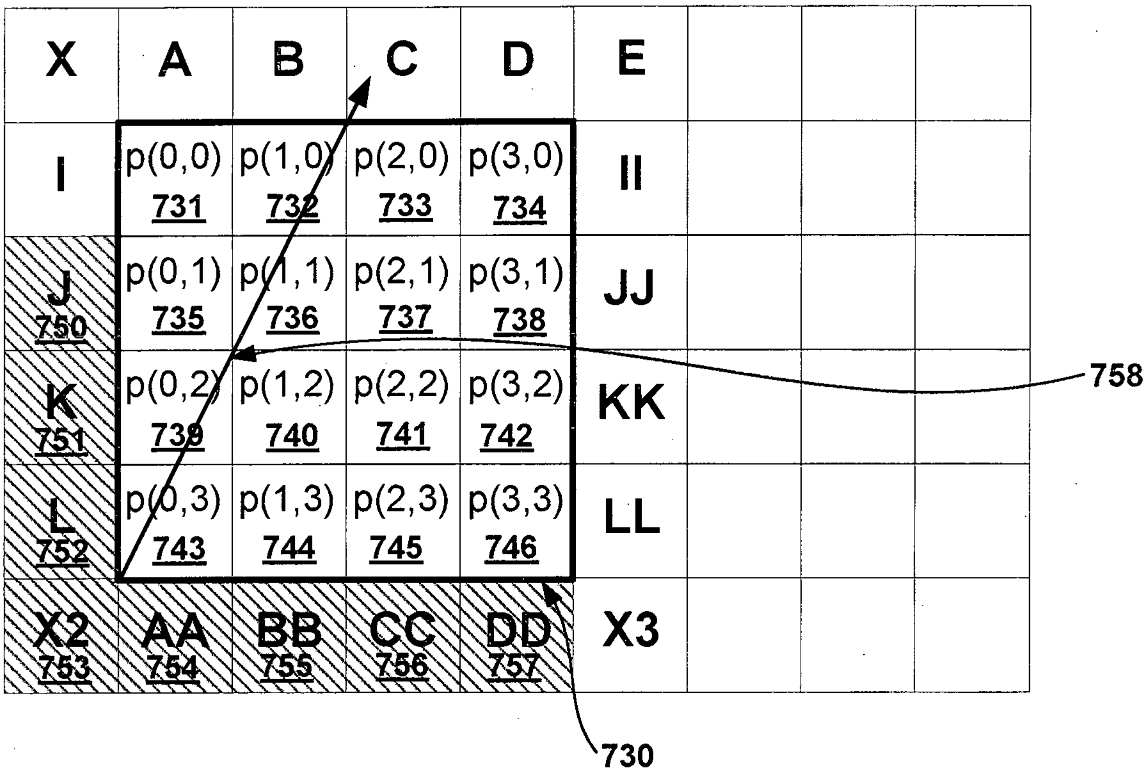


FIG. 17B

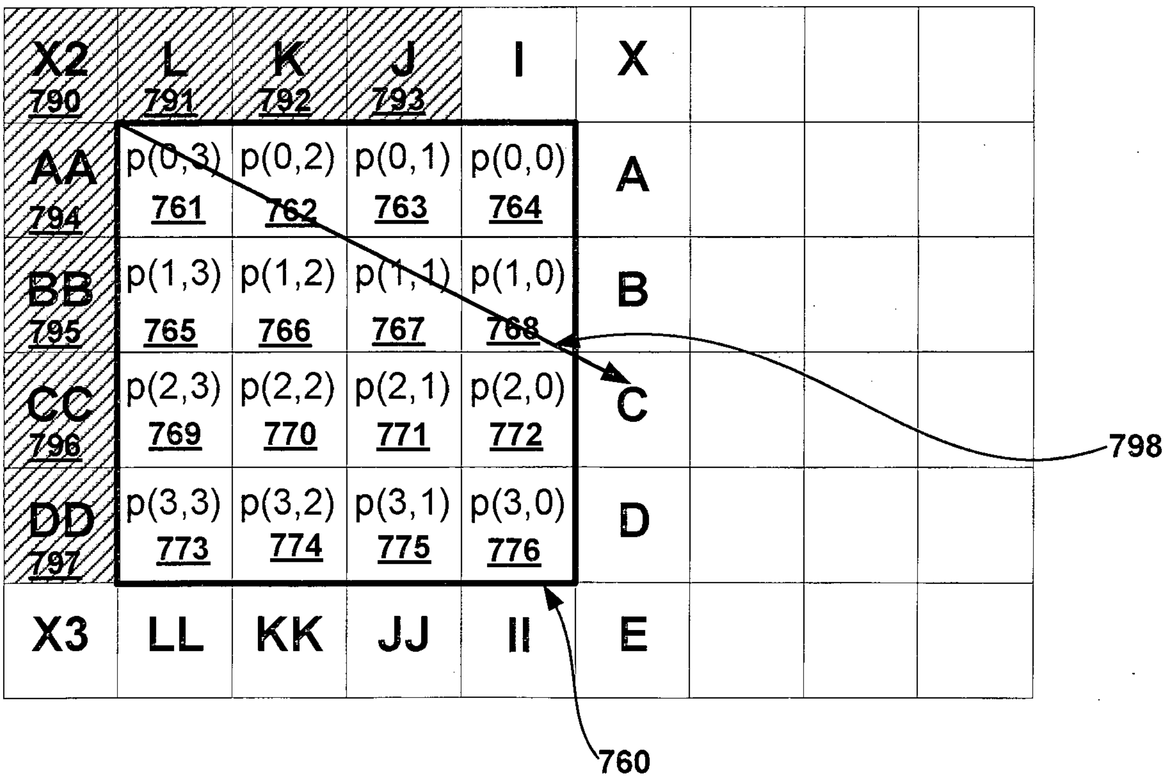


FIG. 18A

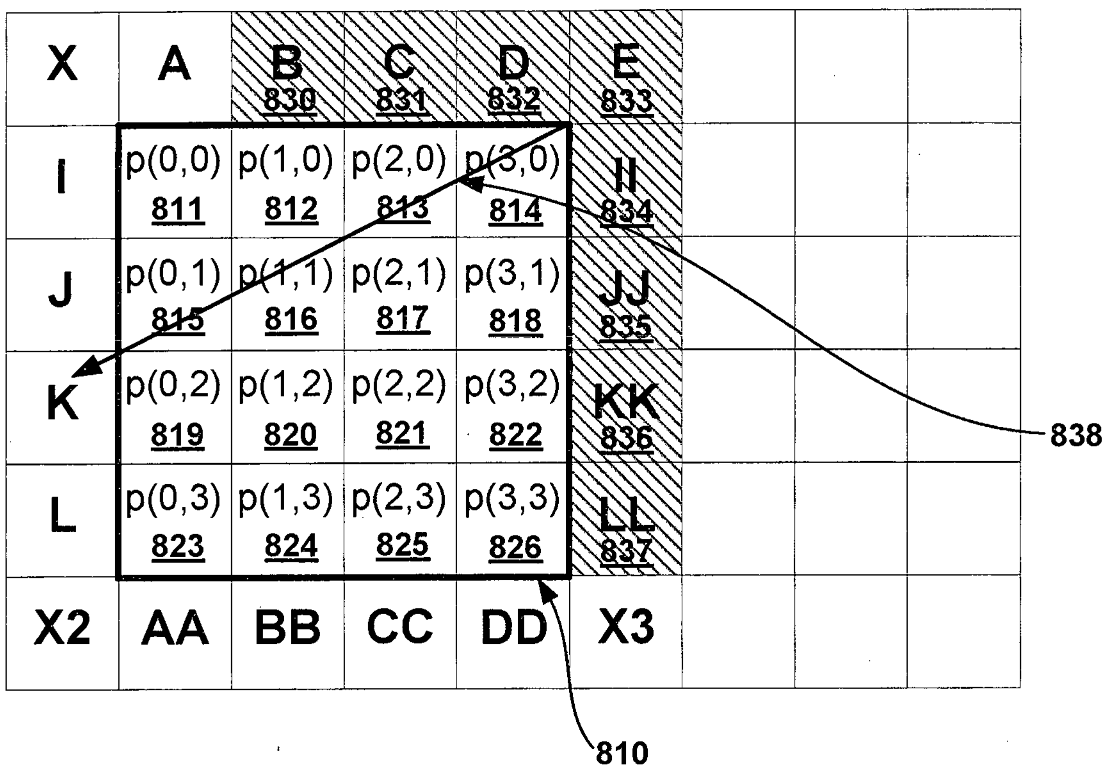


FIG. 18B

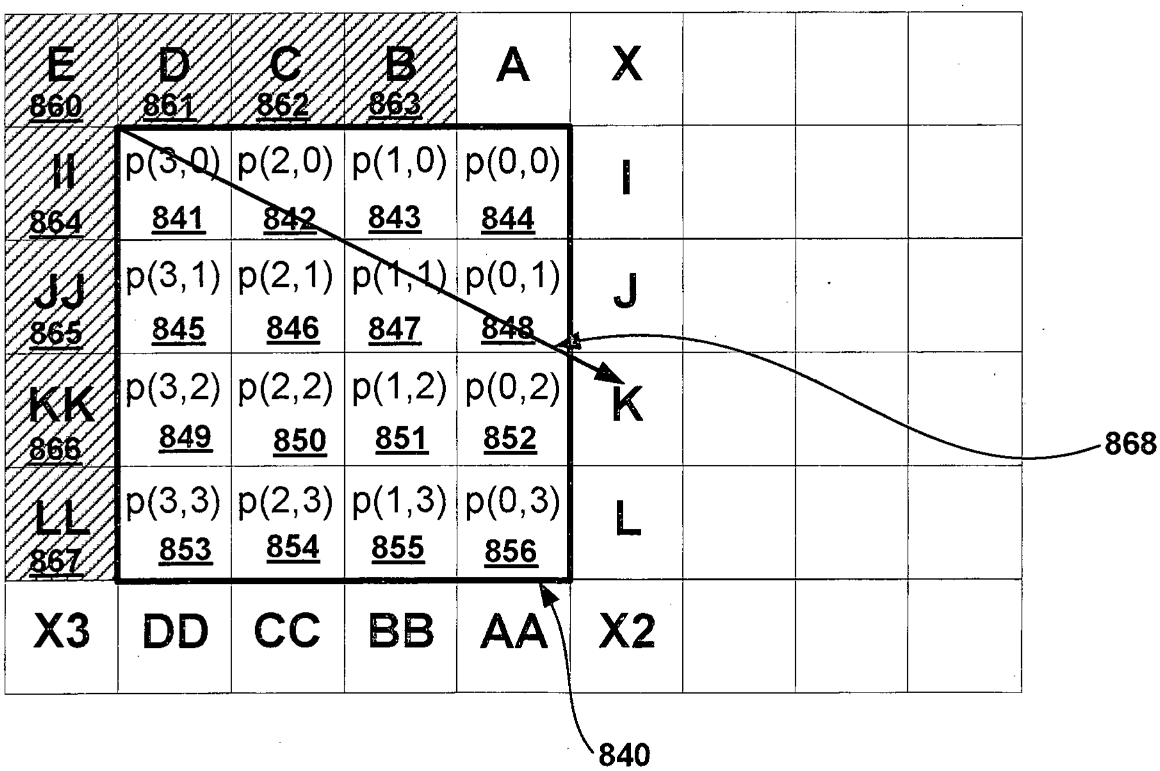
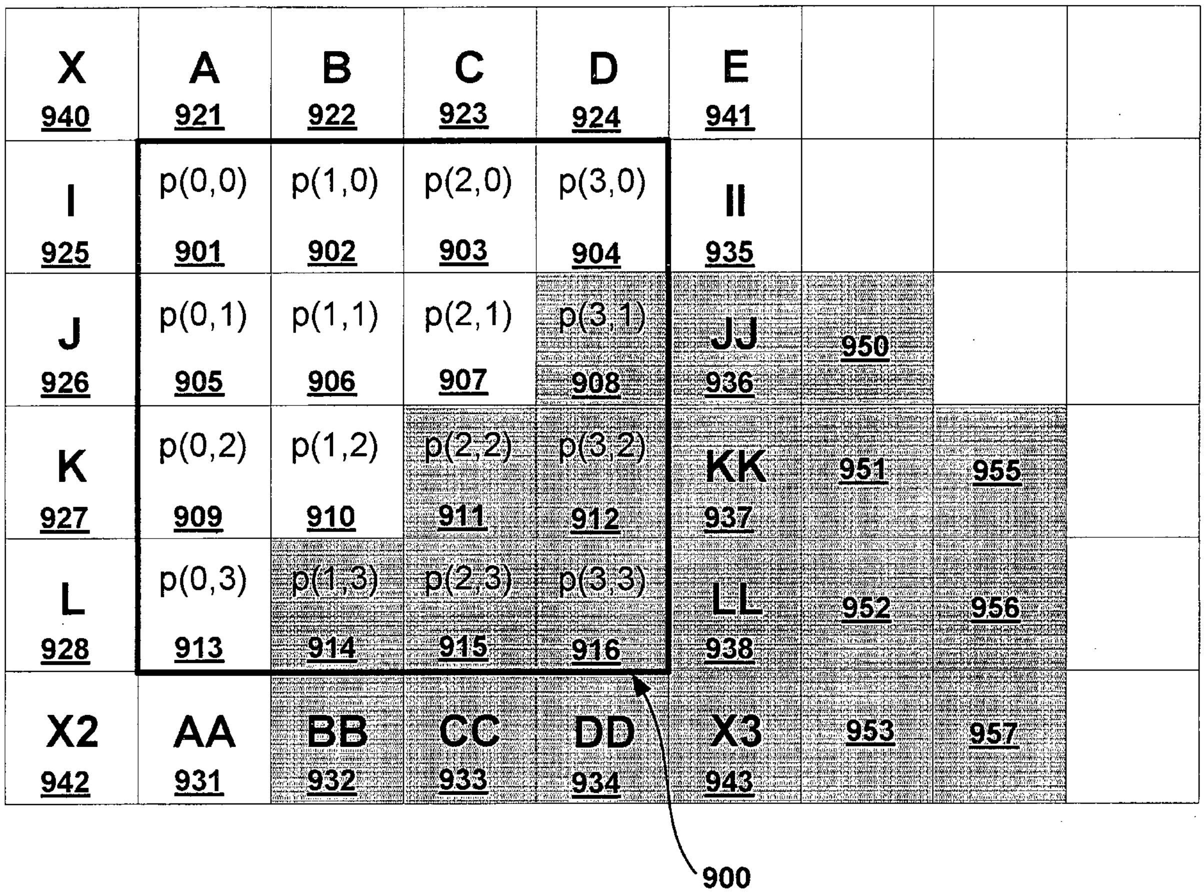


FIG. 19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B 922
C 923
D 924
E 941
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p(1,0) 902
p(2,0) 903
p(3,0) 904
II 935
J 926
p(0,1) 905
p(1,1) 906
p(2,1) 907
p(3,1) 908
JJ 936
950
K 927
p(0,2) 909
p(1,2) 910
p(2,2) 911
p(3,2) 912
KK 937
951
955
L 928
p(0,3) 913
p(1,3) 914
p(2,3) 915
p(3,3) 916
LL 938
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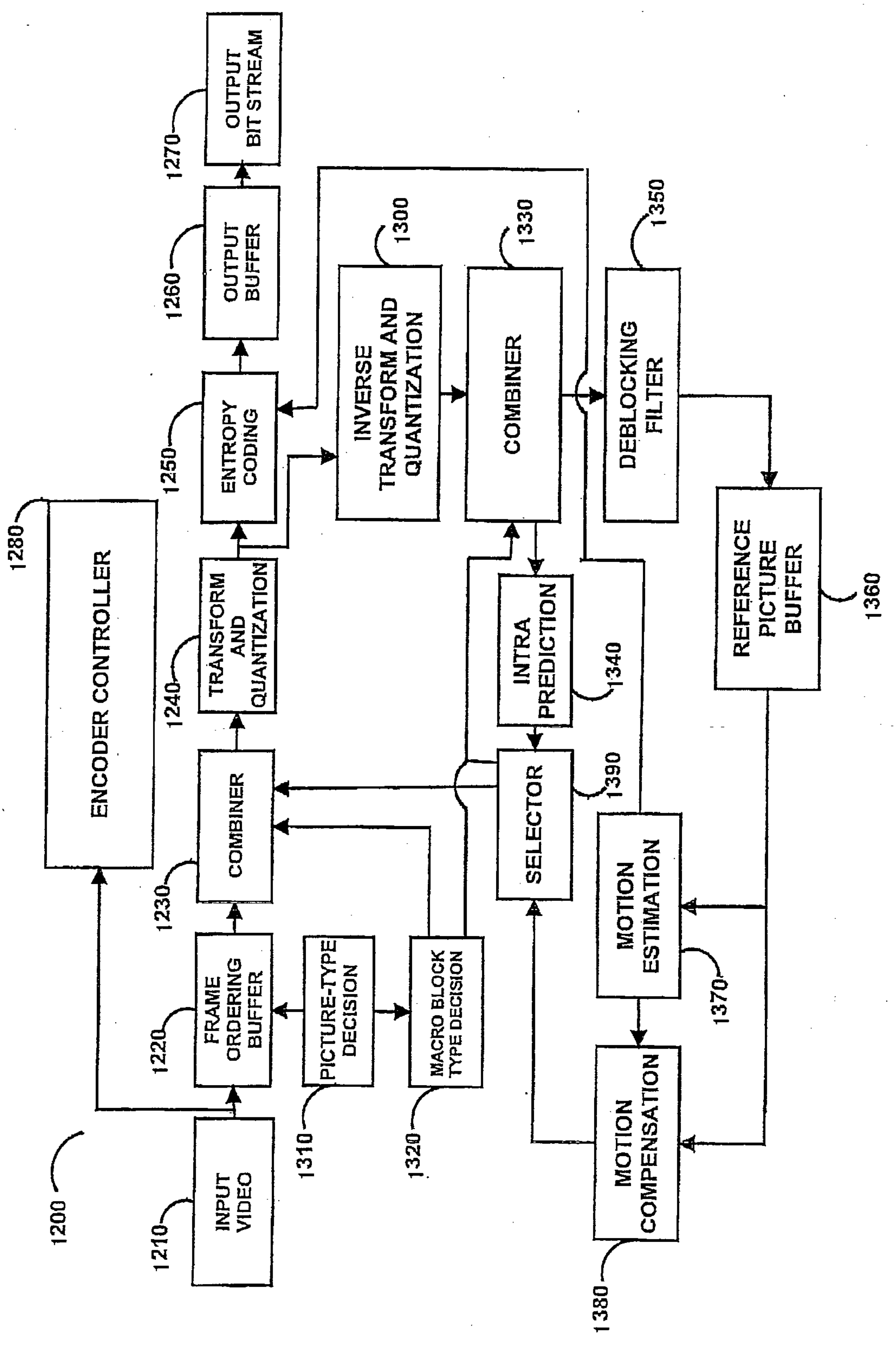
956
X2 942
AA 931
BB 932
CC 933
DD 934
X3 943
953
957
900

FIG. 20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INPUT VIDEO
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FRAME ORDERING BUFFER
1220
PICTURE-TYPE DECISION
1310
MACRO BLOCK TYPE DECISION
1320
COMBINER
1230
TRANSFORM AND QUANTIZATION
1240
ENTROPY CODING
1250
OUTPUT BUFFER
1260
OUTPUT BIT STREAM
1270
ENCODER CONTROLLER
1280
INVERSE TRANSFORM AND QUANTIZATION
1300
COMBINER
1330
INTRA PREDICTION
1340
DEBLOCKING FILTER
1350
REFERENCE PICTURE BUFFER
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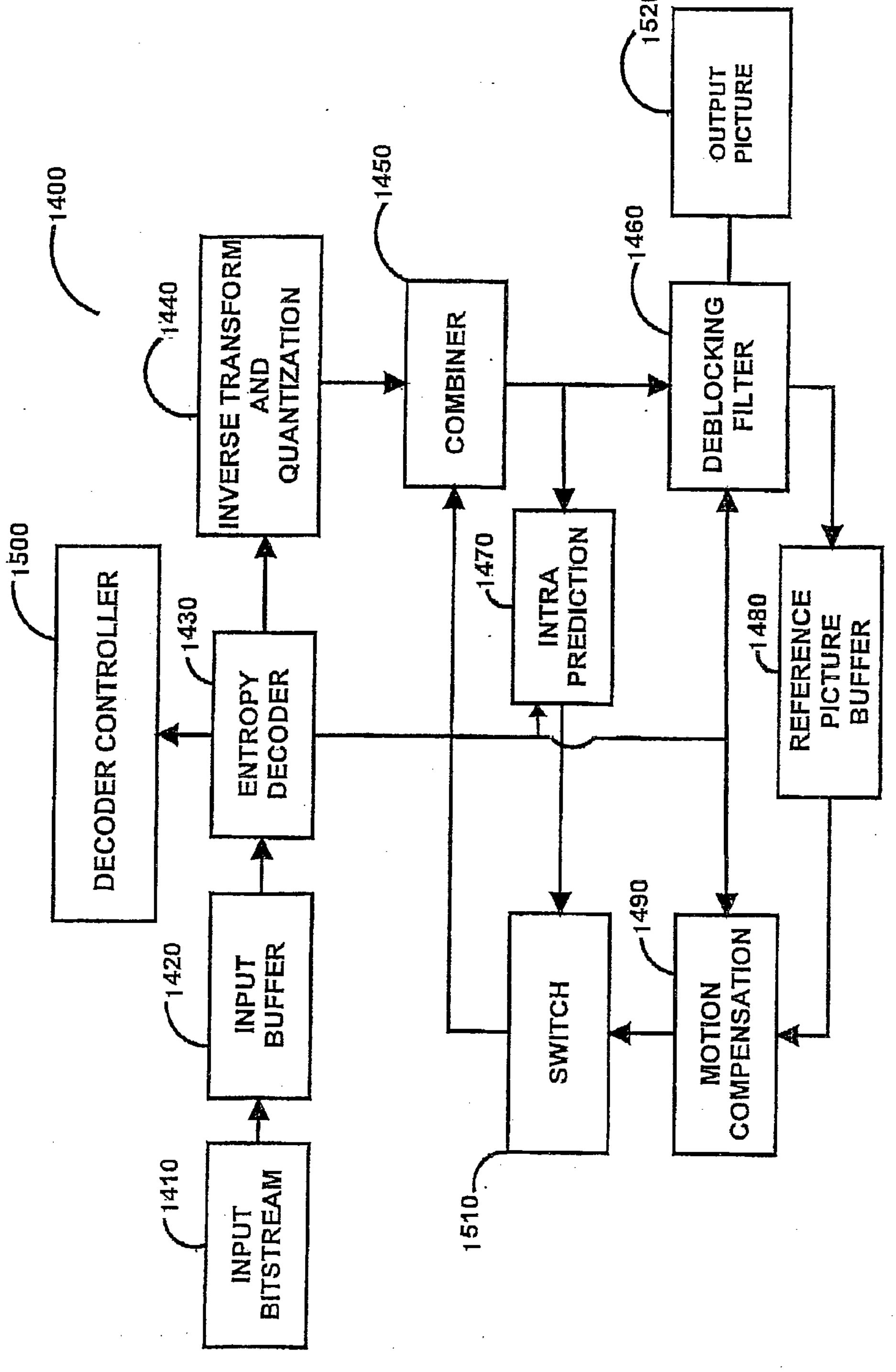
MOTION ESTIMATION
1370
MOTION COMPENSATION
1380
SELECTOR
1390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INPUT BITSTREAM
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INPUT BUFFER
1420
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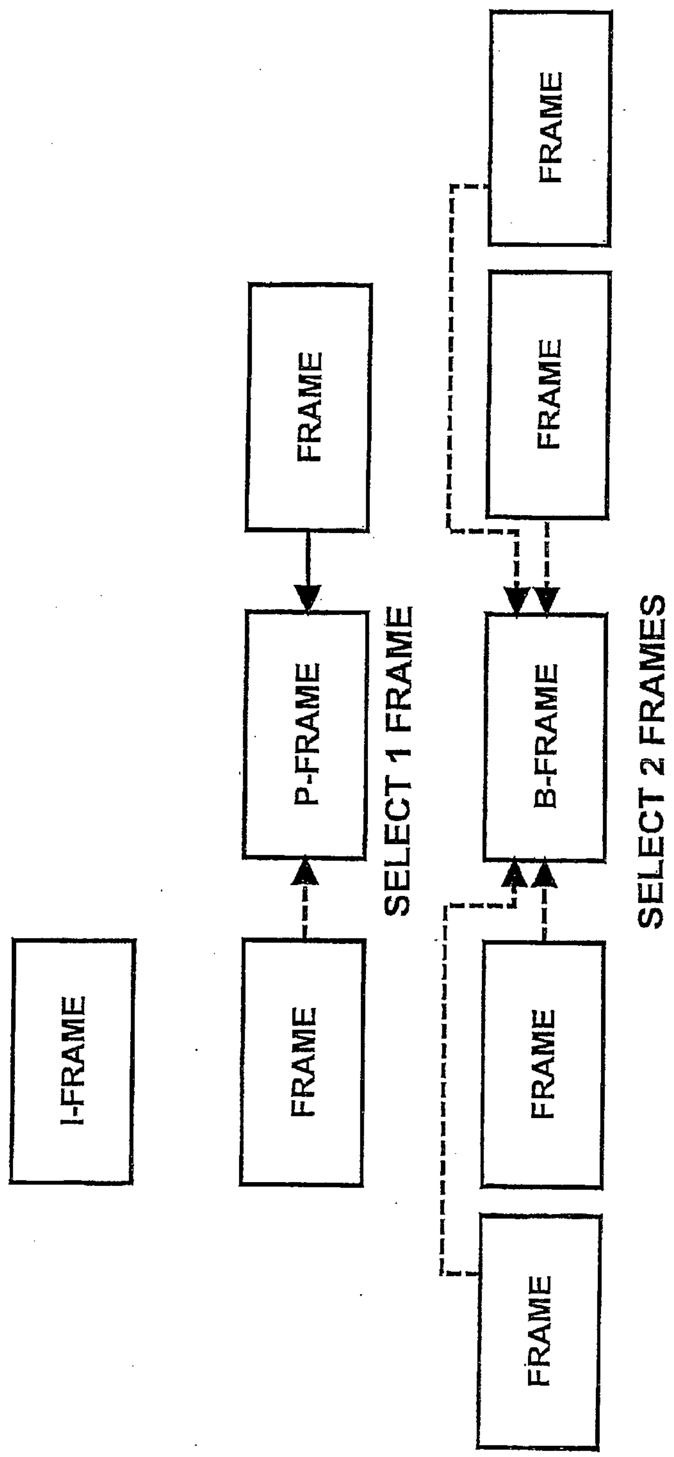
1430
DECODER CONTROLLER
1500
INVERSE TRANSFORM AND QUANTIZATION
1440
COMBINER
1450
INTRA PREDICTION
1470
SWITCH
1510
DEBLOCKING FILTER
1460
MOTION COMPENSATION
1490
REFERENCE PICTURE BUFFER
1480
OUTPUT PICTURE
1520

FIG. 21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FRAME
P-FRAME
FRAME
SELECT 1 FRAME
FRAME
FRAME
B-FRAME
FRAME
FRAME
SELECT 2 FRAMES

FIG. 22

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/059465

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H04N7/32(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. H04N7/24-7/68

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2011
Registered utility model specifications of Japan 1996-2011
Published registered utility model applications of Japan 1994-2011

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2008/012918 A1 (KABUSHIKI KAISHA TOSHIBA) 2008.01.31, Fig.7A, Fig.7D, Fig.19A, Fig.20A, Fig.15A, [0112]-[0113], Fig.22 & US 2009/0310677 A1 & EP 2056606 A1	1-13 14-30
Y	WO 2008/084817 A1 (KABUSHIKI KAISHA TOSHIBA) 2008.07.17, [0246]-[0252] & US 2010/0118943 A1 & EP 2136564 A1	14-30
A	JP 2009-177352 A (CANON KABUSHIKI KAISHA) 2009.08.06, Fig. 6 (Family: None)	1-30

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

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"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05.07.2011	19.07.2011

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Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan

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Daigoro BANDO
Telephone No. +81-3-3581-1101 Ext. 3541

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/059465

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2006-246431 A (MATSUSHITA ELECTRIC INDUSTRIAL CO LTD) 2006.09.14, whole document & US 2006/0176962 A1 & CN 1819657 A	1-30