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**Chuang et al.**

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(54) **METHOD AND APPARATUS FOR ASSIGNING MOTION VECTOR PREDICTOR TO SUB-BLOCK WITHOUT PERFORMING ASSOCIATED ITERATION OF SUB-BLOCK MOTION VECTOR PREDICTOR DETERMINATION FLOW**

(58) **Field of Classification Search**  
CPC ..... H04N 19/593  
(Continued)

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(71) Applicant: **MEDIATEK INC.**, Hsin-Chu (TW)

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(72) Inventors: **Shun-Hsiang Chuang**, Taipei (TW);  
**Chih-Ming Wang**, Hsinchu County (TW);  
**Yung-Chang Chang**, New Taipei (TW)

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(73) Assignee: **MEDIATEK INC.**, Hsin-Chu (TW)

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“International Search Report” dated Oct. 20, 2015 for International application No. PCT/CN2015/084190, International filing date: Jul. 16, 2015.

*Primary Examiner* — Richard Torrente  
(74) *Attorney, Agent, or Firm* — Winston Hsu

(21) Appl. No.: **14/753,004**

(22) Filed: **Jun. 28, 2015**

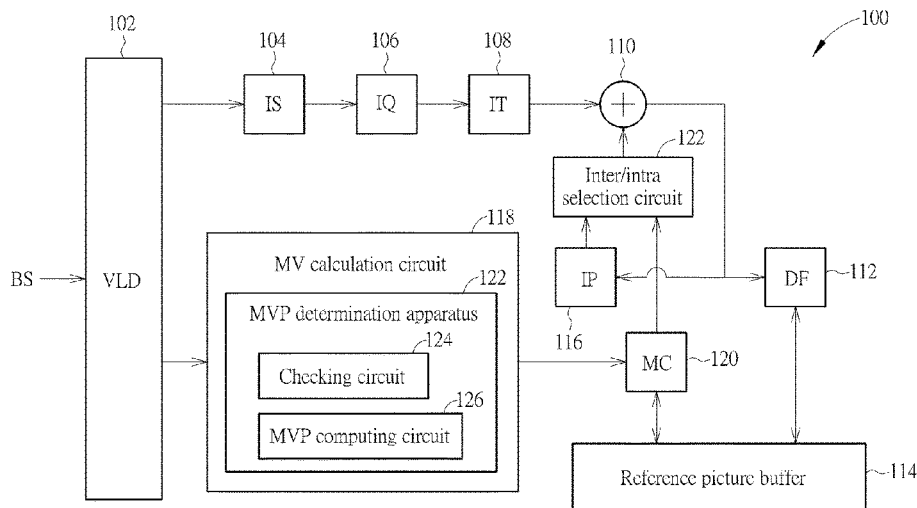
(57) **ABSTRACT**

(65) **Prior Publication Data**  
US 2016/0021387 A1 Jan. 21, 2016

A motion vector predictor determination method includes: checking if motion vector data of at least one first neighbor unit adjacent to a block and motion vector data of at least one second neighbor unit adjacent to the block are identical to each other; and when a checking result indicates that the motion vector data of the at least one first neighbor unit is identical to the motion vector data of the at least one second neighbor unit, assigning a motion vector predictor determined for a first sub-block within the block to a second sub-block within the block. The motion vector data of the at least one first neighbor unit is involved in determining the motion vector predictor of the first sub-block, and the motion vector data of the at least one second neighbor unit is not involved in determining the motion vector predictor of the first sub-block.

**Related U.S. Application Data**  
(60) Provisional application No. 62/026,084, filed on Jul. 18, 2014.  
(51) **Int. Cl.**  
**H04N 7/12** (2006.01)  
**H04N 19/593** (2014.01)  
(Continued)  
(52) **U.S. Cl.**  
CPC ..... **H04N 19/593** (2014.11); **H04N 19/119** (2014.11); **H04N 19/176** (2014.11); **H04N 19/52** (2014.11)

**10 Claims, 20 Drawing Sheets**



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*H04N 19/52* (2014.01)

*H04N 19/176* (2014.01)

*H04N 19/119* (2014.01)

(58) **Field of Classification Search**

USPC ..... 375/240.16

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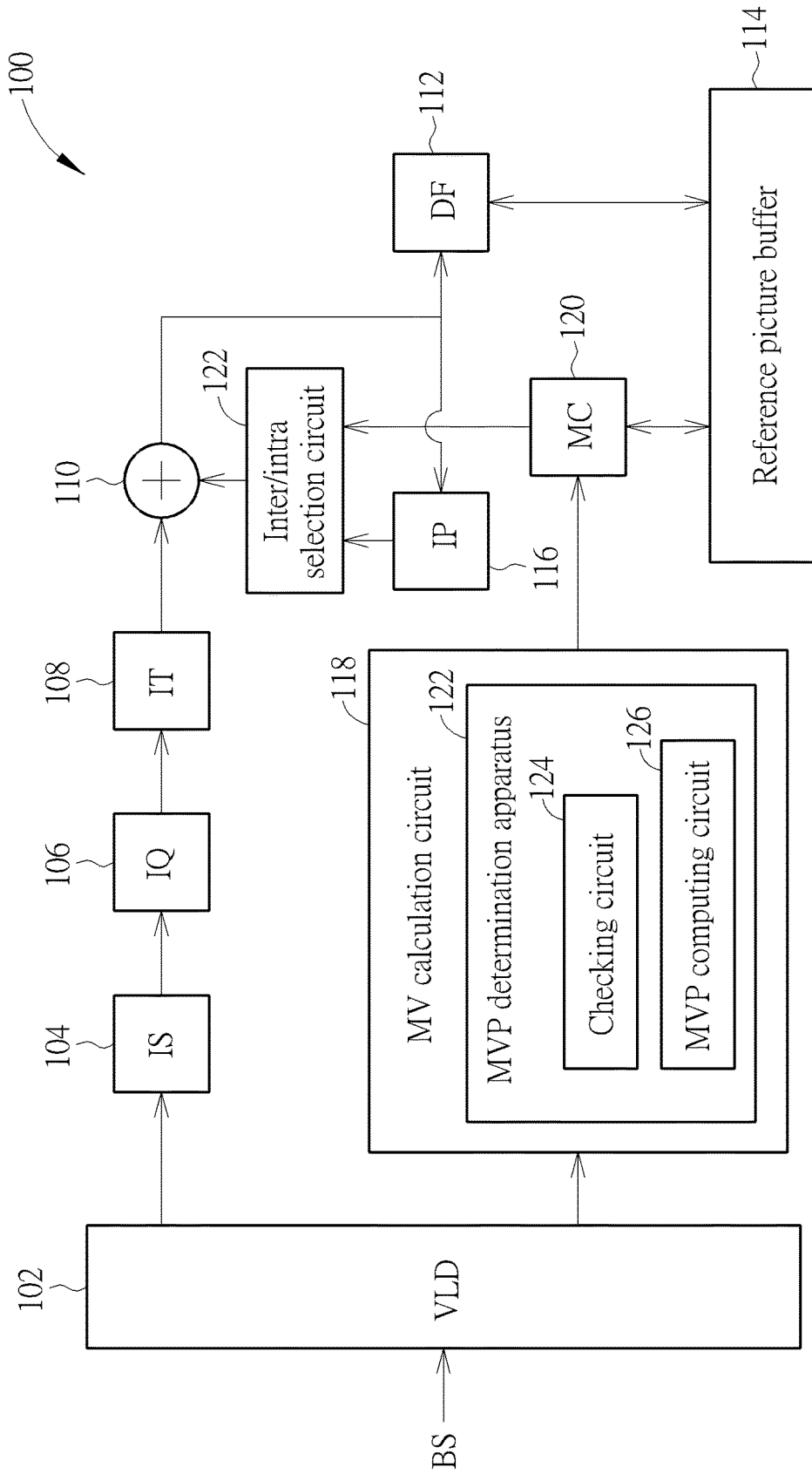


FIG. 1

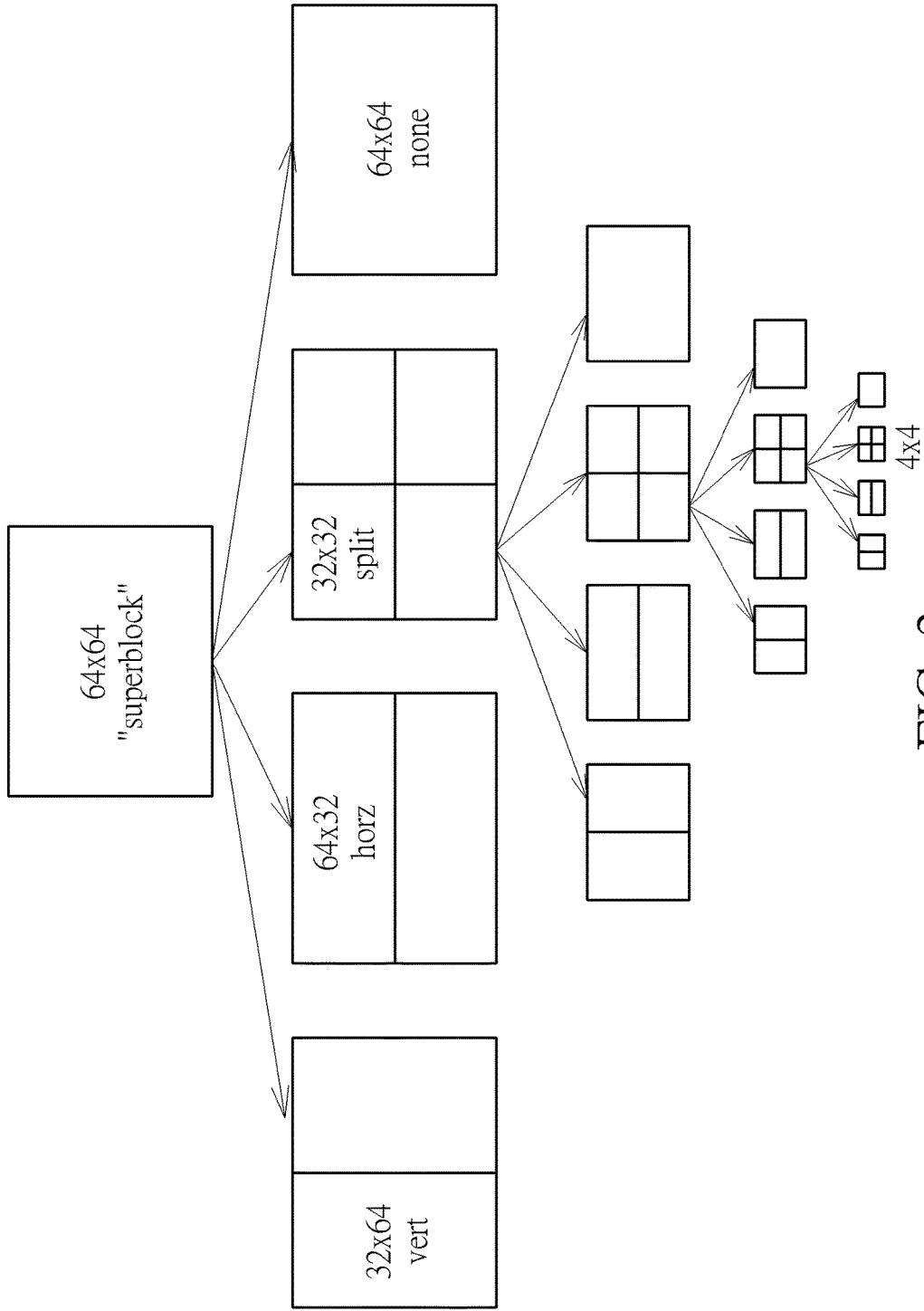


FIG. 2

$nb_{a7}$	$nb_{a5}$	$nb_{a3}$
$nb_{a6}$	$nb_{a2}$	$nb_{a0}$
$nb_{a4}$	$nb_{a1}$	$mi_a$

$nb_{b7}$	$nb_{b5}$	$nb_{b3}$
$nb_{b6}$	$nb_{b2}$	$nb_{b0}$
$nb_{b4}$	$nb_{b1}$	$mi_b$

FIG. 3

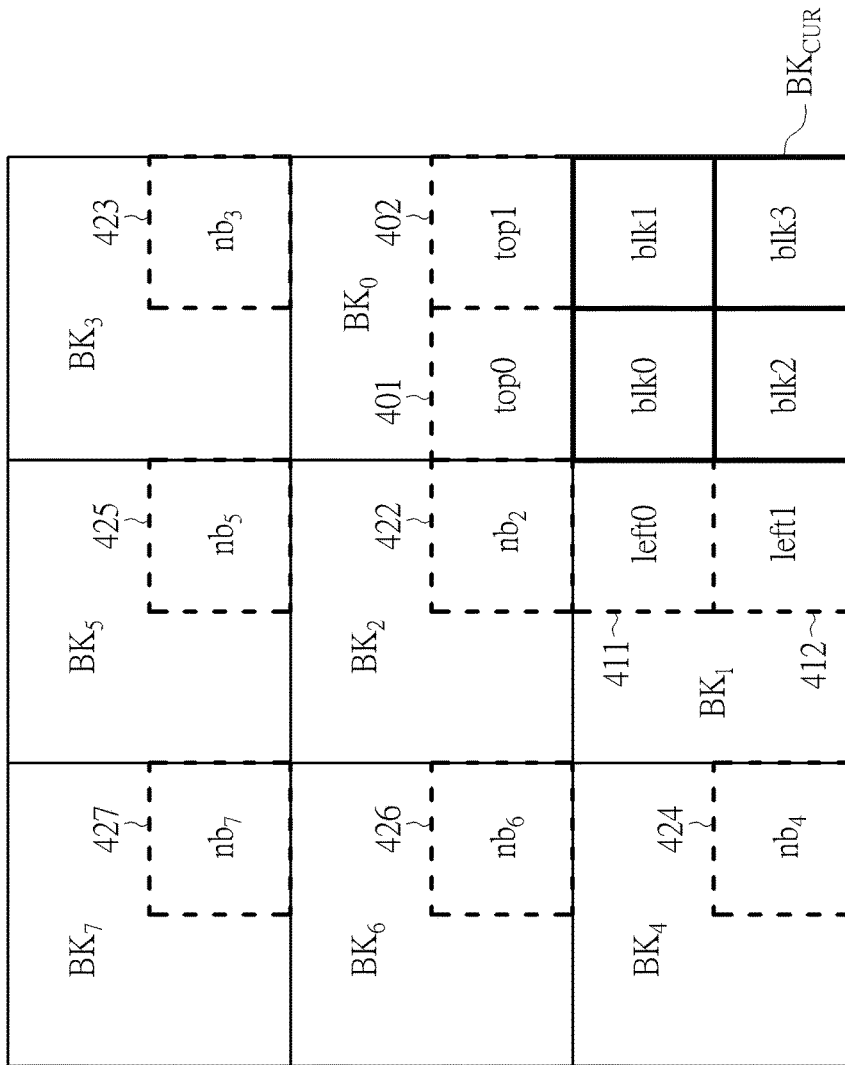


FIG. 4

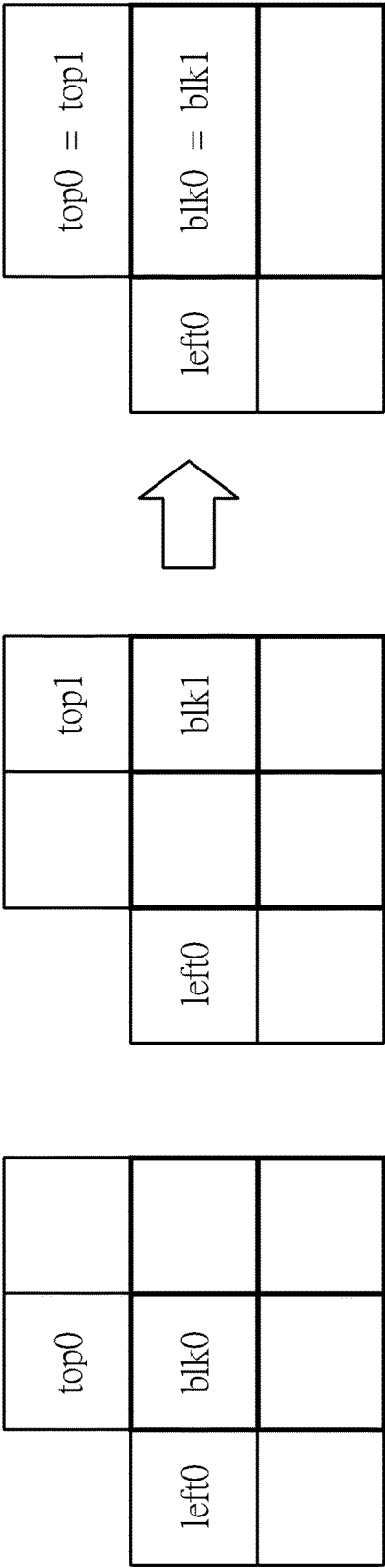


FIG. 5

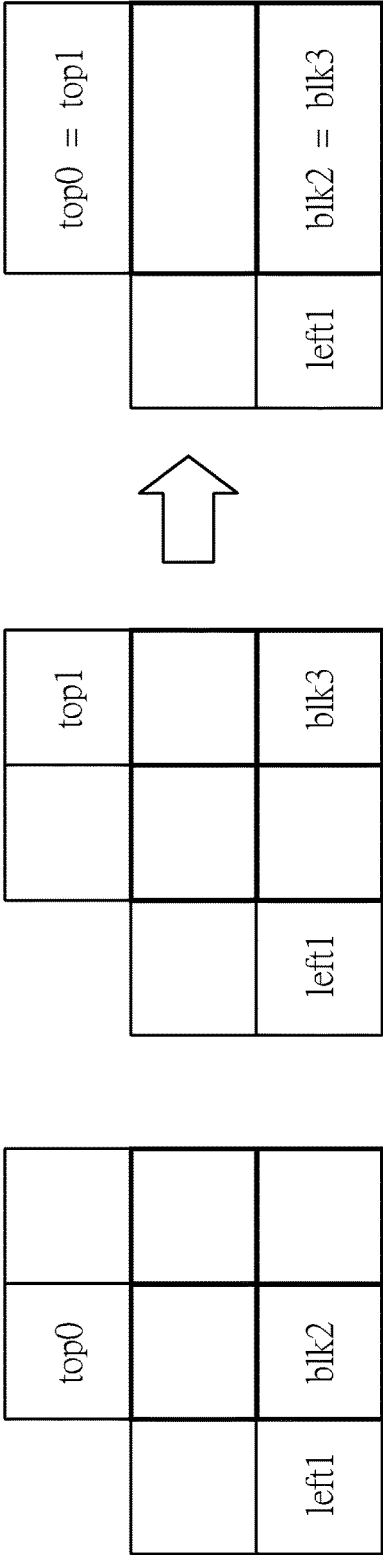


FIG. 6



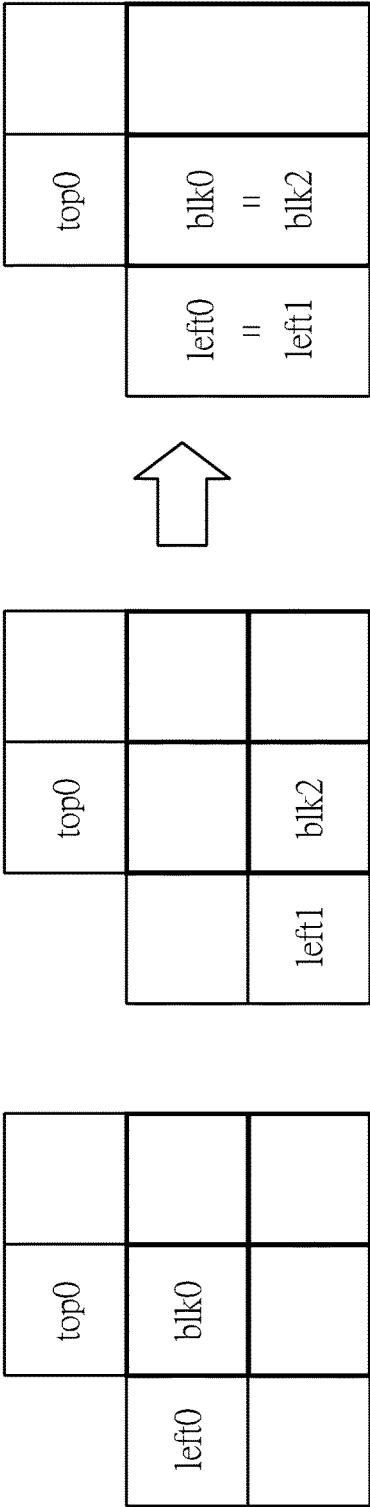


FIG. 7

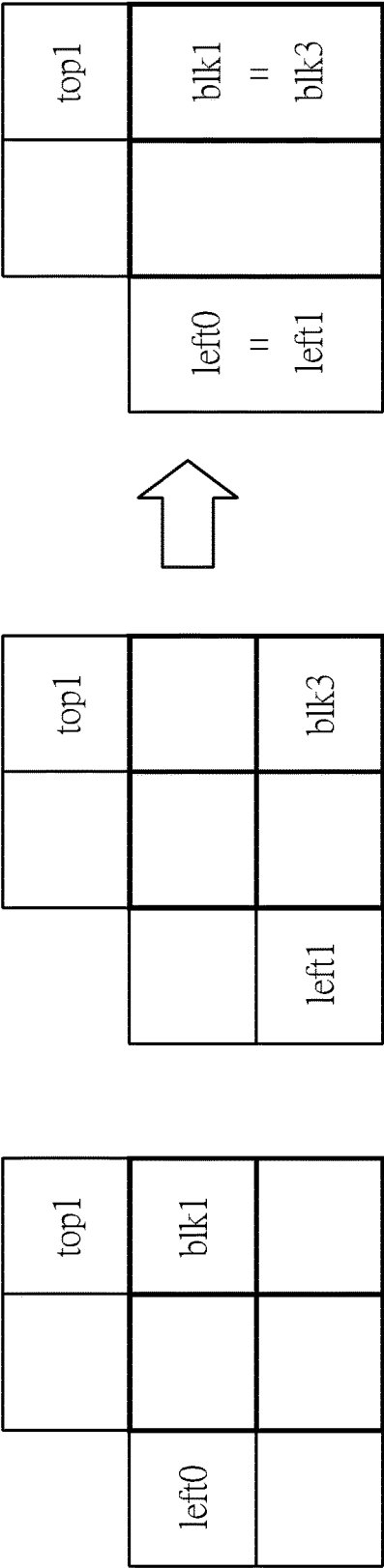


FIG. 8

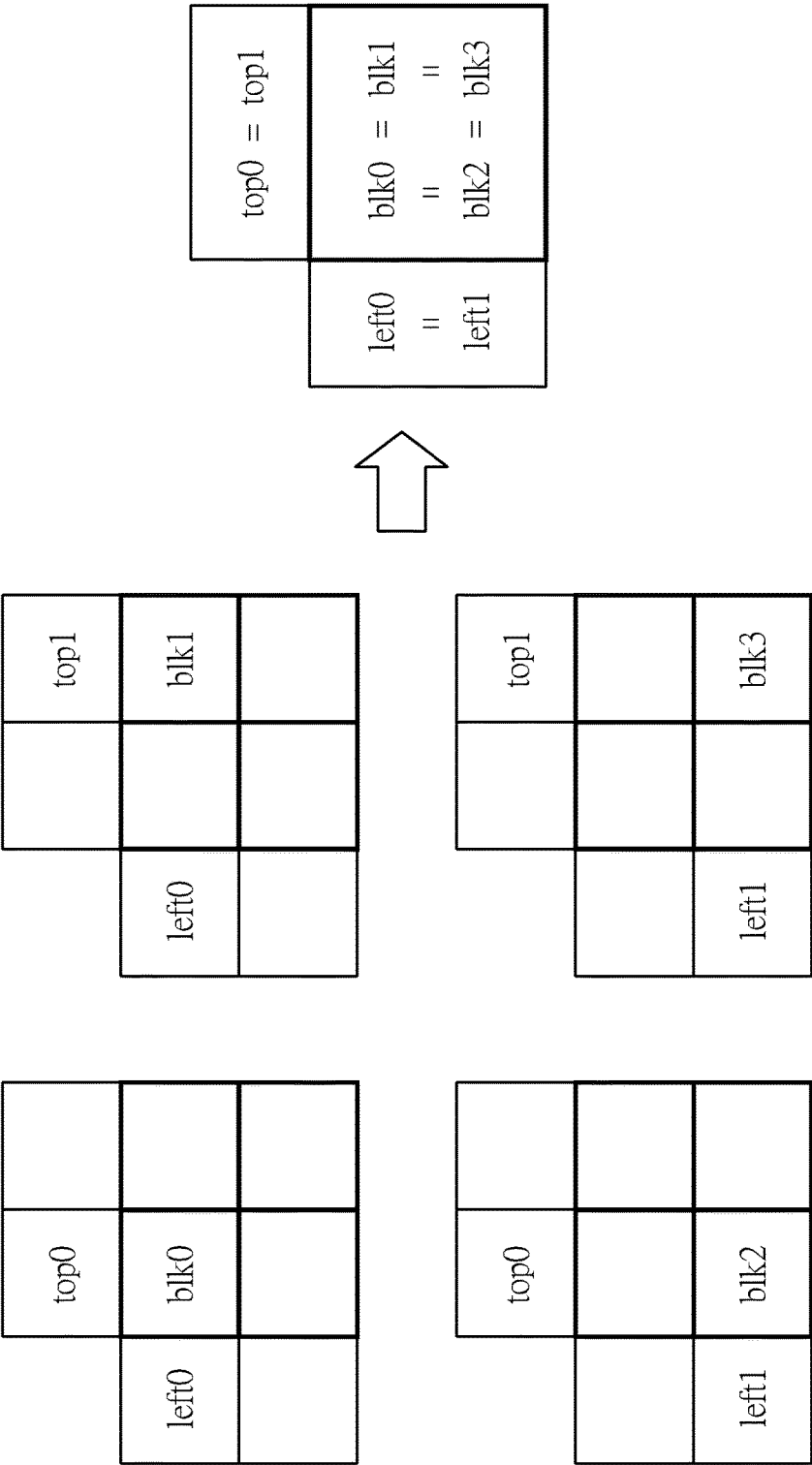


FIG. 9

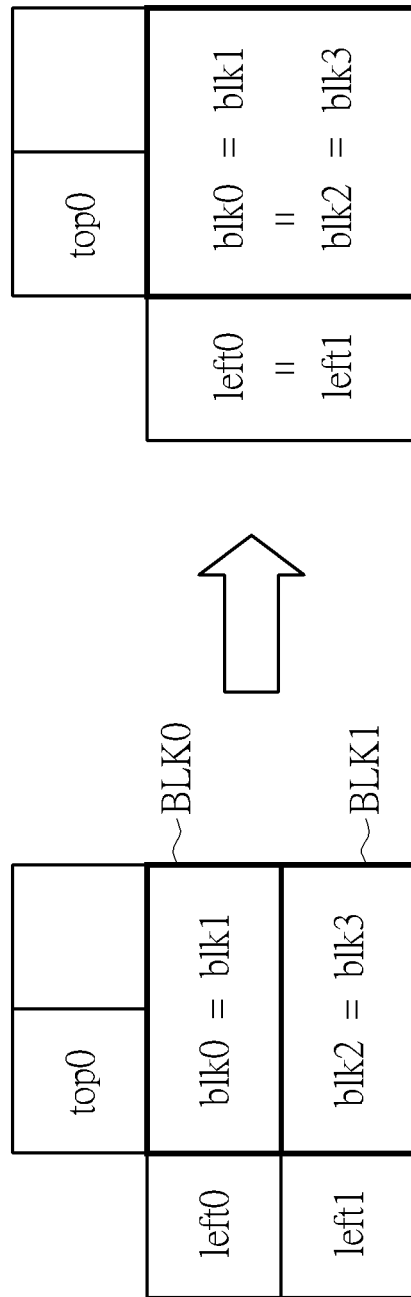


FIG. 10

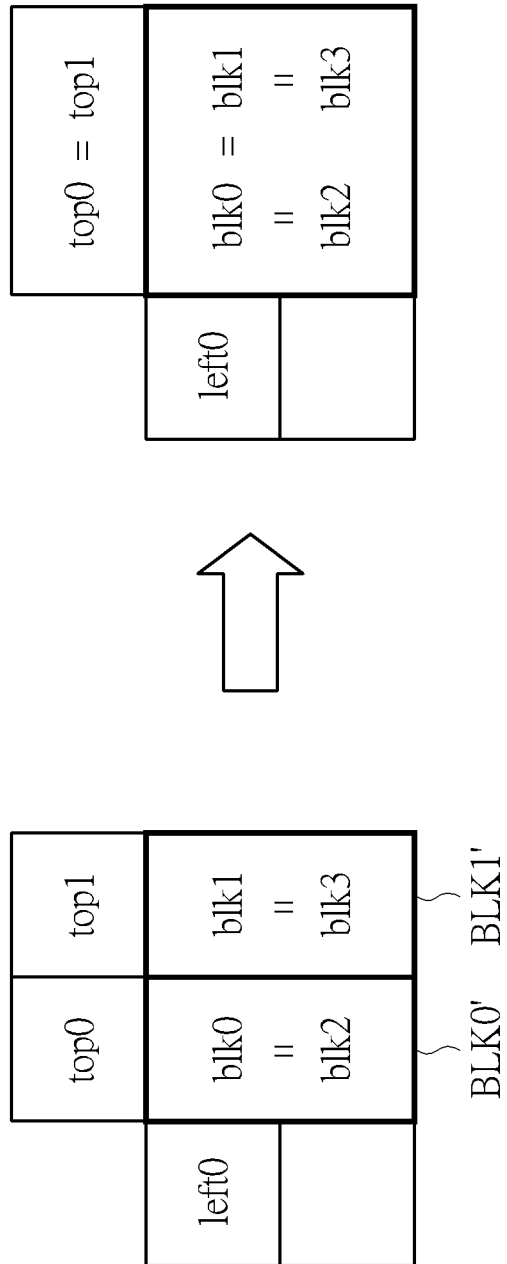
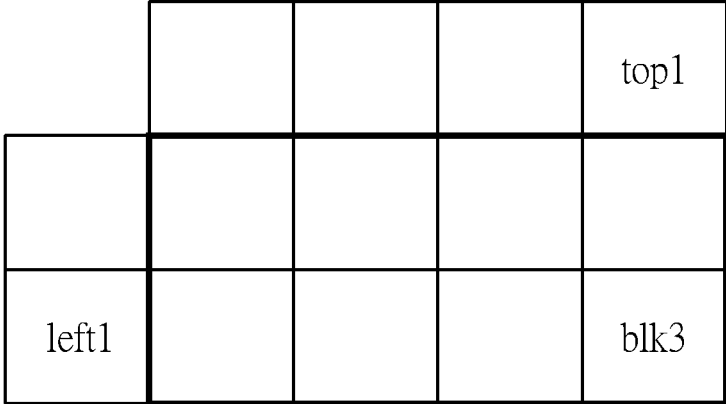
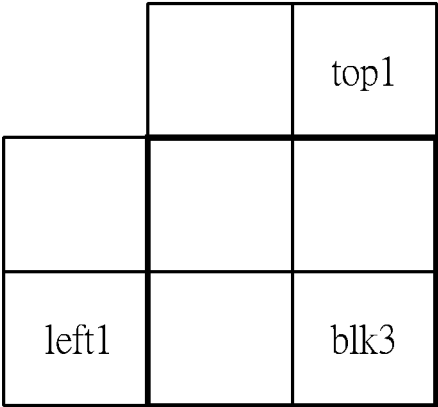


FIG. 11



MI unit size = 16x8

(A)



MI unit size = 8x8

(B)

FIG. 12

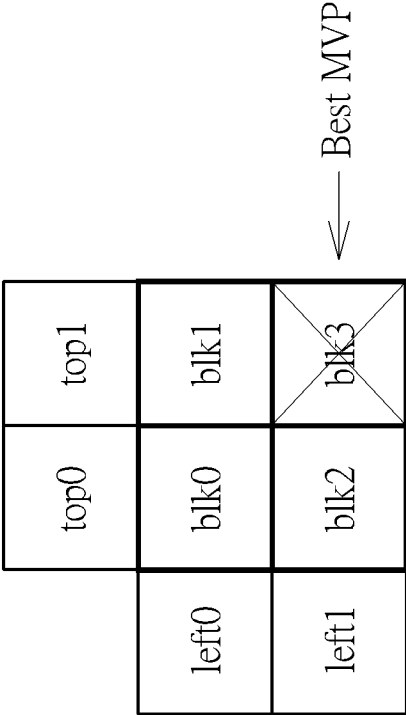


FIG. 13

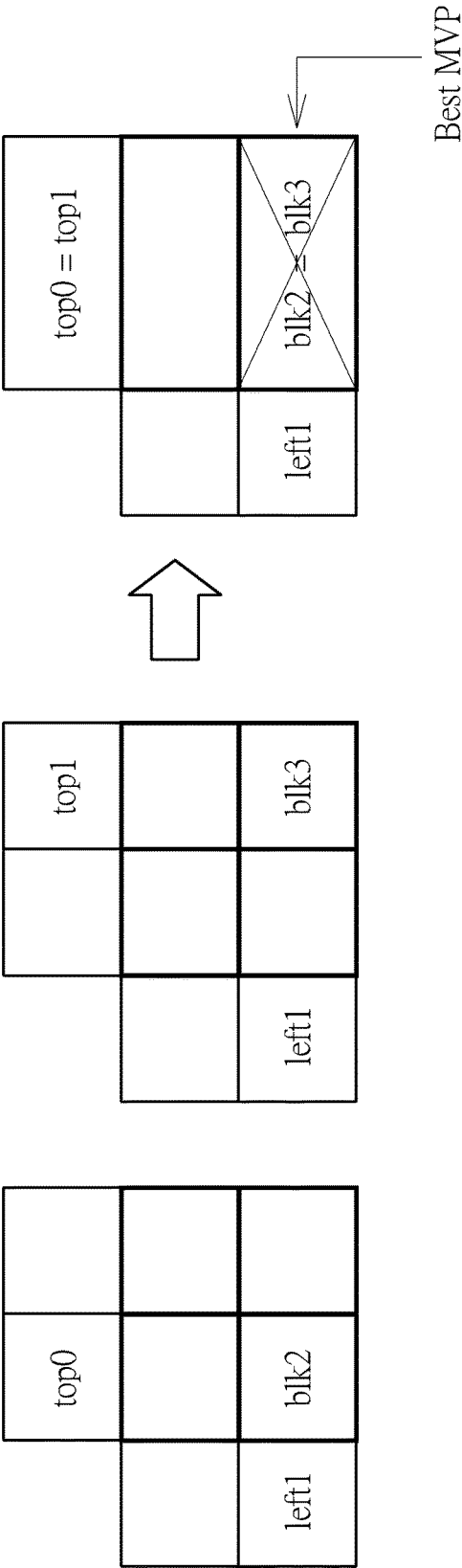


FIG. 14



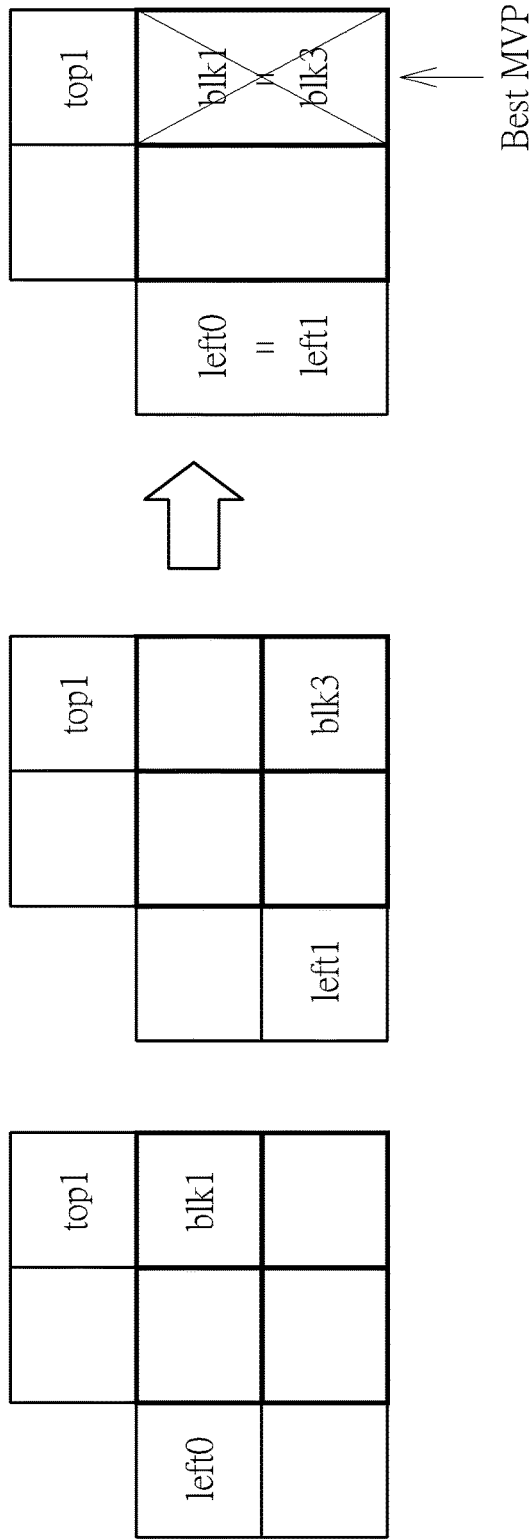


FIG. 15

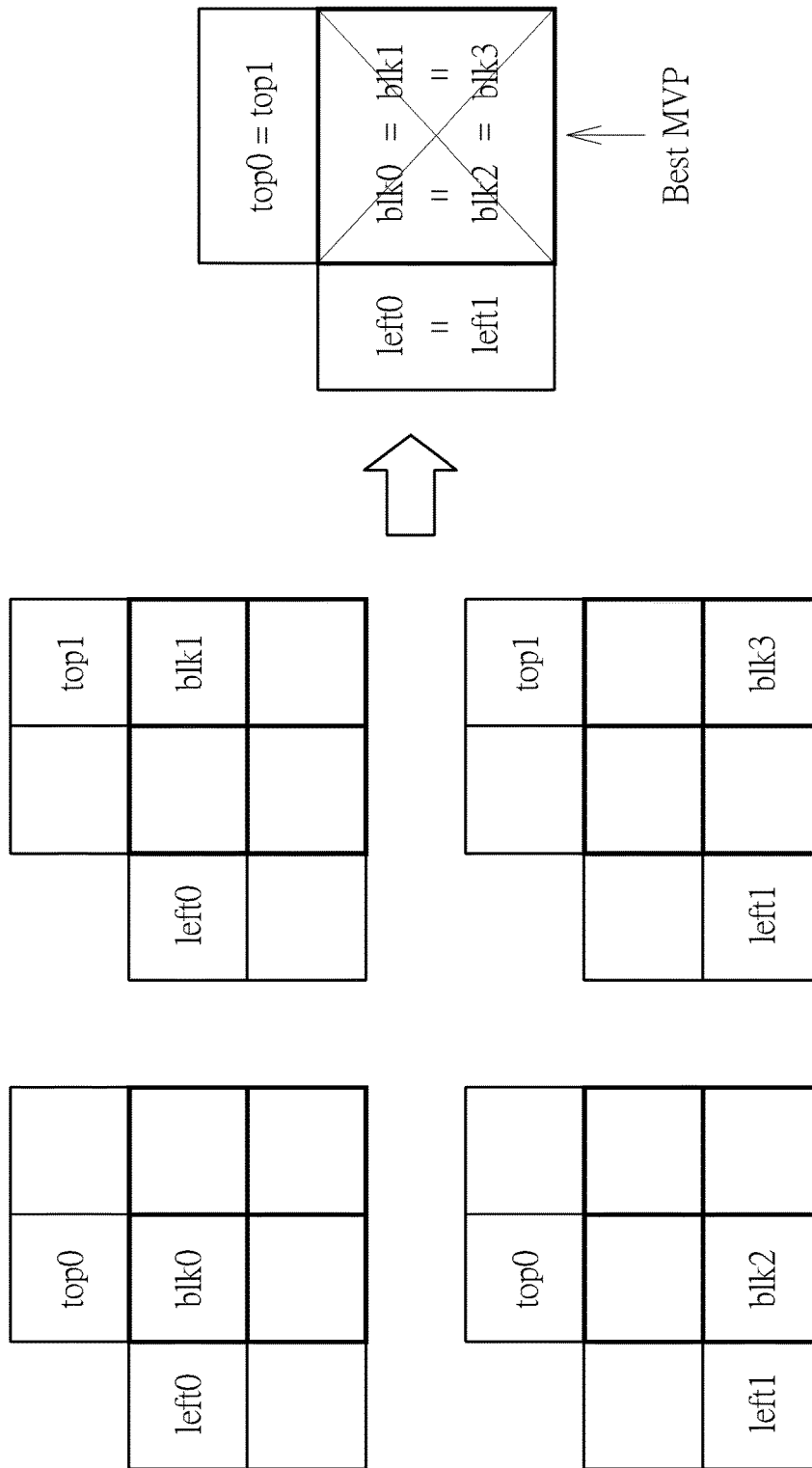


FIG. 16

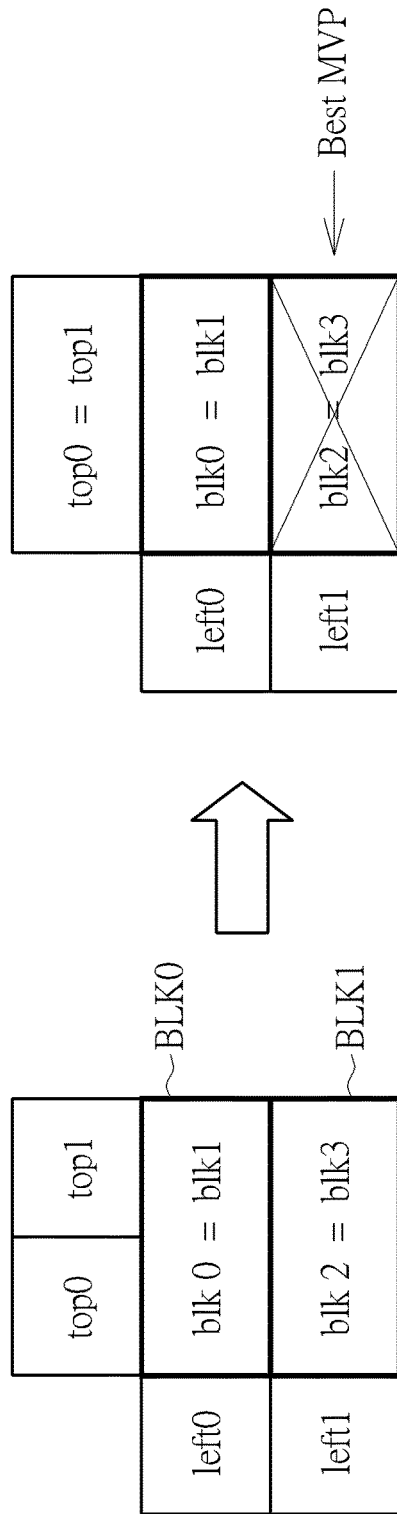


FIG. 17

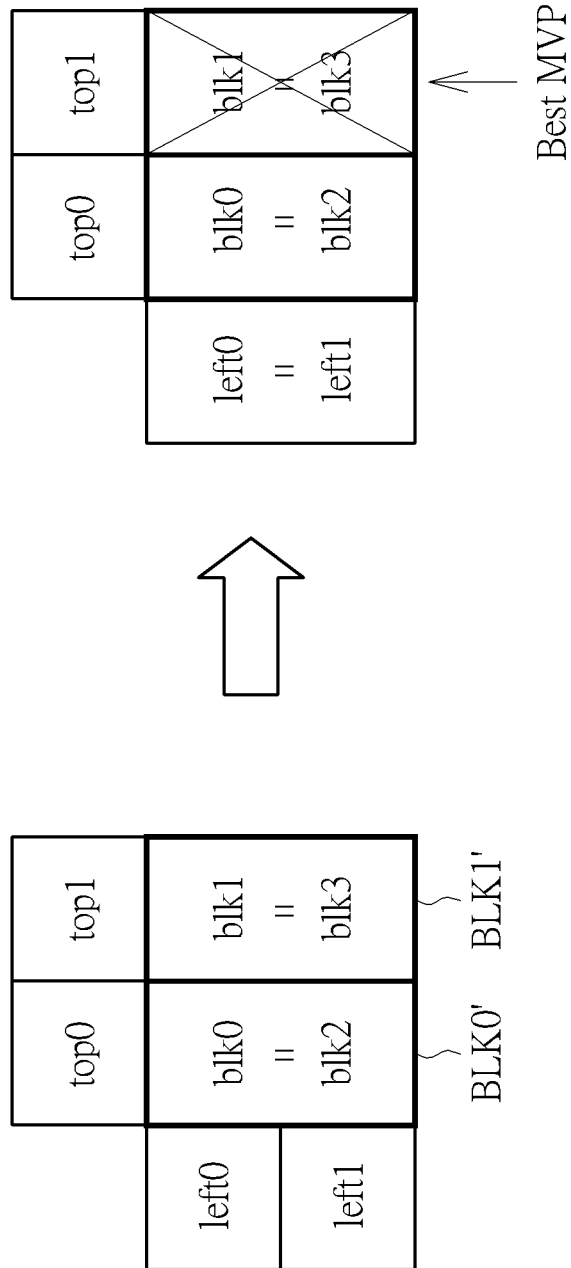


FIG. 18

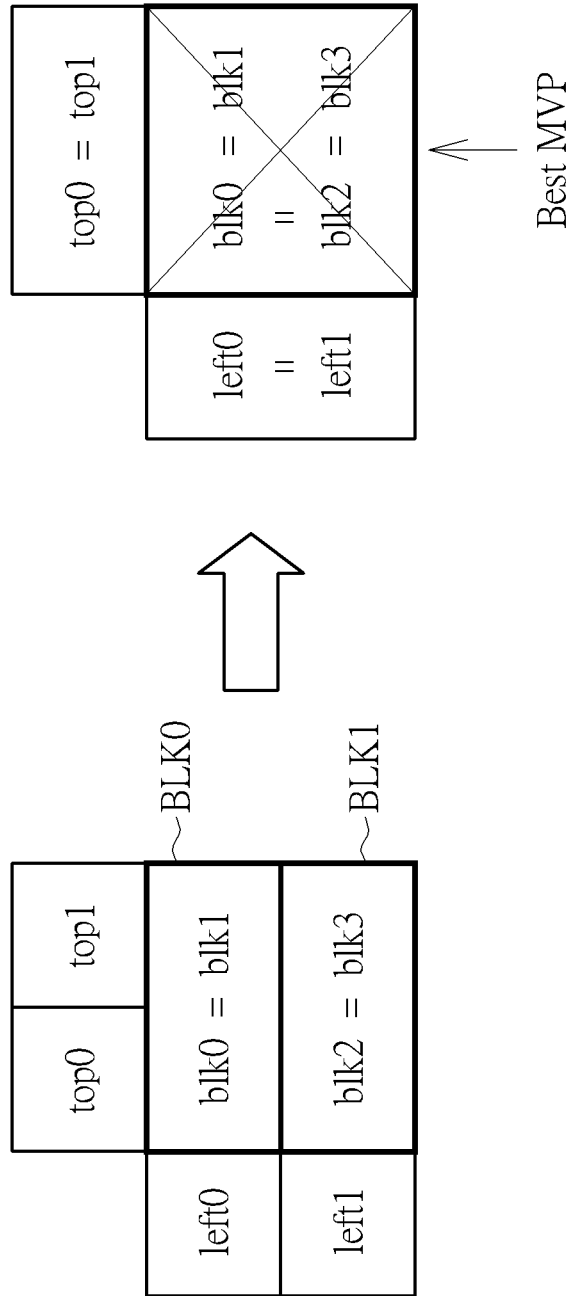


FIG. 19

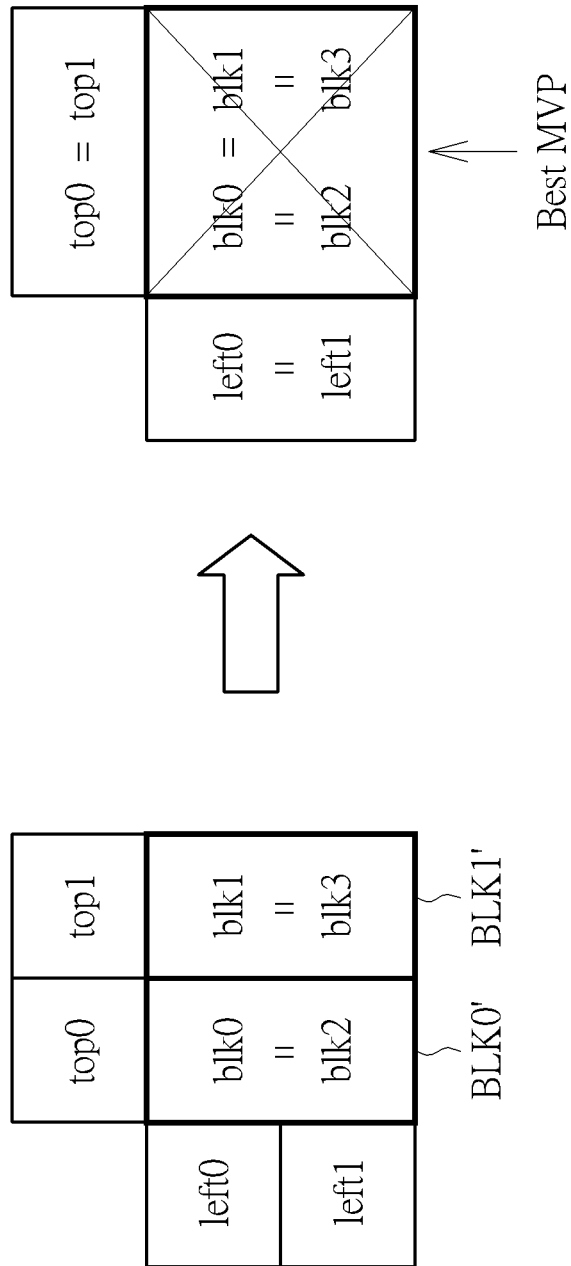


FIG. 20

**METHOD AND APPARATUS FOR  
ASSIGNING MOTION VECTOR PREDICTOR  
TO SUB-BLOCK WITHOUT PERFORMING  
ASSOCIATED ITERATION OF SUB-BLOCK  
MOTION VECTOR PREDICTOR  
DETERMINATION FLOW**

CROSS REFERENCE TO RELATED  
APPLICATIONS

This application claims the benefit of U.S. provisional application No. 62/026,084, filed on Jul. 18, 2014 and incorporated herein by reference.

BACKGROUND

The disclosed embodiments of the present invention relate to video frame processing, and more particularly, to a method and apparatus for assigning a motion vector predictor to a sub-block within a block (e.g., a 4×4 sub-block, a 8×4 sub-block or a 4×8 sub-block within an 8×8 block) without performing an associated iteration of a sub-block motion vector predictor determination flow.

The conventional video coding standards generally adopt a block based coding technique to exploit spatial and temporal redundancy. For example, the basic approach is to divide the whole source frame into a plurality of blocks, perform prediction on each block, transform residues of each block using discrete cosine transform, and perform quantization and entropy encoding. Besides, a reconstructed frame is generated in a coding loop to provide reference pixel data used for coding following blocks. For certain video coding standards, in-loop filter(s) may be used for enhancing the image quality of the reconstructed frame.

Motion vectors are used by motion compensation to reconstruct the inter-frames. With regard to a video decoder, a motion vector (MV) of a current block may be derived from a motion vector predictor (MVP) and a motion vector difference (MVD). For example, the computation of the motion vector may be expressed using the following equation:

$$MV = MVP + MVD,$$

where the MVP of the current block may be determined from motion vector data of neighbor reconstructed blocks, and the MVD may be decoded from a bitstream by a variable length decoder (VLD).

The performance of the motion vector computation depends on the computation of the motion vector predictor. Consider a case where a small-sized block is further subdivided into a plurality of sub-blocks, it may require extra time to find a motion vector predictor for each of the sub-blocks within the same block. This may induce considerable timing overhead if an inter-frame is composed of a large number of sub-blocks. Thus, there is a need for an innovative design which is capable of effectively improving the speed of the MVP determination.

SUMMARY

In accordance with exemplary embodiments of the present invention, a method and apparatus for assigning a motion vector predictor to a sub-block within a block (e.g., a 4×4 sub-block, a 8×4 sub-block or a 4×8 sub-block within an 8×8 block) without performing an associated iteration of a sub-block motion vector predictor determination flow are proposed to solve the above-mentioned problem.

According to a first aspect of the present invention, an exemplary motion vector predictor determination method is disclosed. The exemplary motion vector predictor determination method includes: checking if motion vector data of at least one first neighbor unit adjacent to a block and motion vector data of at least one second neighbor unit adjacent to the block are identical to each other; and when a checking result indicates that the motion vector data of the at least one first neighbor unit is identical to the motion vector data of the at least one second neighbor unit, assigning a motion vector predictor determined for a first sub-block within the block to a second sub-block within the block. The motion vector data of the at least one first neighbor unit is involved in determining the motion vector predictor of the first sub-block, and the motion vector data of the at least one second neighbor unit is not involved in determining the motion vector predictor of the first sub-block.

According to a second aspect of the present invention, an exemplary motion vector predictor determination method is disclosed. The exemplary motion vector predictor determination method includes: determining a motion vector predictor of a block according to motion vector data of neighbor units associated with the block; and assigning the motion vector predictor determined for the block to a first sub-block within the block.

According to a third aspect of the present invention, an exemplary motion vector predictor determination apparatus is disclosed. The exemplary motion vector predictor determination apparatus includes a checking circuit and a motion vector predictor computing circuit. The checking circuit is arranged to check if motion vector data of at least one first neighbor unit adjacent to a block and motion vector data of at least one second neighbor unit adjacent to the block are identical to each other. The motion vector predictor computing circuit is arranged to assign a motion vector predictor determined for a first sub-block within the block to a second sub-block within the block when the checking circuit determines that the motion vector data of the at least one first neighbor unit is identical to the motion vector data of the at least one second neighbor unit, wherein the motion vector data of the at least one first neighbor unit is involved in determining the motion vector predictor of the first sub-block, and the motion vector data of the at least one second neighbor unit is not involved in determining the motion vector predictor of the first sub-block.

According to a fourth aspect of the present invention, an exemplary motion vector predictor determination apparatus is disclosed. The exemplary motion vector predictor determination apparatus includes a motion vector predictor computing circuit. The motion vector predictor computing circuit is arranged to determine a motion vector predictor of a block according to motion vector data of neighbor units associated with the block, and assign the motion vector predictor determined for the block to a first sub-block within the block.

These and other objectives of the present invention will no doubt become obvious to those of ordinary skill in the art after reading the following detailed description of the preferred embodiment that is illustrated in the various figures and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a video decoder according to an embodiment of the present invention.

FIG. 2 is a diagram illustrating recursive partitioning of a superblock into various sizes of mode information units.

3

FIG. 3 is a diagram illustrating an example of two VP9 MI units with the same size and same reference frame.

FIG. 4 is a diagram illustrating an 8×8 block sub-divided into four 4×4 sub-blocks according to an embodiment of the present invention.

FIG. 5 is a diagram illustrating a first case where the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 6 is a diagram illustrating a second case where the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 7 is a diagram illustrating a third case where the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 8 is a diagram illustrating a fourth case where the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 9 is a diagram illustrating a fifth case where the condition of the first lemma is satisfied for all 4×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 10 is a diagram illustrating a case where the condition of the first lemma is satisfied for two 8×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 11 is a diagram illustrating a case where the condition of the first lemma is satisfied for two 4×8 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 12 is a diagram illustrating the best MVP determination performed for blocks with different MI unit sizes not smaller than 8×8.

FIG. 13 is diagram illustrating a case where the second lemma is employed when the MI unit size is smaller than 8×8 according to embodiments of the present invention.

FIG. 14 is a diagram illustrating a case where the second lemma is employed and the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 15 is a diagram illustrating another case where the second lemma is employed and the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 16 is a diagram illustrating a case where the second lemma is employed and the condition of the first lemma is satisfied for all 4×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

FIG. 17 is a diagram illustrating a case where the second lemma is employed and the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 8×4 sub-block according to an embodiment of the present invention.

FIG. 18 is a diagram illustrating a case where the second lemma is employed and the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 4×8 sub-block according to an embodiment of the present invention.

FIG. 19 is a diagram illustrating a case where the second lemma is employed, the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 8×4 block and the condition of the first lemma is satisfied for two 8×4 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

4

FIG. 20 is a diagram illustrating a case where the second lemma is employed, the condition of the first lemma is satisfied for two 4×4 sub-blocks within the same 4×8 block and the condition of the first lemma is satisfied for two 4×8 sub-blocks within the same 8×8 block according to an embodiment of the present invention.

#### DETAILED DESCRIPTION

Certain terms are used throughout the description and following claims to refer to particular components. As one skilled in the art will appreciate, manufacturers may refer to a component by different names. This document does not intend to distinguish between components that differ in name but not function. In the following description and in the claims, the terms “include” and “comprise” are used in an open-ended fashion, and thus should be interpreted to mean “include, but not limited to . . .”. Also, the term “couple” is intended to mean either an indirect or direct electrical connection. Accordingly, if one device is coupled to another device, that connection may be through a direct electrical connection, or through an indirect electrical connection via other devices and connections.

FIG. 1 is a diagram of a video decoder according to an embodiment of the present invention. The video decoder **100** may be part of an electronic device, such as a personal computer (e.g., a laptop computer or a desktop computer), a mobile phone, a tablet, or a wearable device. The video decoder **100** is arranged for decoding a bitstream BS to generate a video sequence composed of a plurality of consecutive decoded pictures (i.e., reconstructed pictures). At least a portion (i.e., part or all) of the video decoder **100** may be implemented in an integrated circuit (IC). To put it simply, any electronic device or electronic system using the proposed video decoder **100** falls within the scope of the present invention.

As shown in FIG. 1, the video decoder **100** includes an entropy decoder (e.g., a variable-length decoder (VLD) **102**), an inverse scan circuit (denoted as “IS”) **104**, an inverse quantization circuit (denoted as “IQ”) **106**, an inverse transform circuit (denoted as “IT”) **108**, a reconstruct circuit **110**, at least one in-loop filter (e.g., a deblocking filter (DF) **112**), a reference picture buffer **114**, an intra prediction circuit (denoted as “IP”) **116**, a motion vector (MV) calculation circuit **118**, a motion compensation circuit (denoted as “MC”) **120**, and an intra/inter selection circuit **122**. The reference picture buffer **114** may be an external storage device such as an off-chip dynamic random access memory (DRAM). In this embodiment, the MV calculation circuit **118** includes a motion vector predictor (MVP) determination apparatus **122** with an improved speed for the MVP determination. The MVP determination apparatus **122** may include a checking circuit **124** and an MVP computing circuit **126**. Further details of the proposed MVP determination apparatus **122** will be described later.

By way of example, but not limitation, the video decoder **100** may be used to decode the incoming bitstream BS generated using a VP9 coding standard that is an open and royalty-free video coding standard being developed by Google®. However, this is for illustrative purposes only, and is not meant to be a limitation of the present invention. Any video decoder using the proposed video decoder structure, particularly the proposed MVP determination apparatus **122**, falls within the scope of the present invention.

The VLD **102** is arranged to apply entropy decoding to the incoming bitstream BS for generating intra/inter mode information (e.g., motion vector differences of inter prediction)



and residues. The residues are transmitted to the reconstruct circuit **110** through being inverse scanned (which is performed at the inverse scan circuit **104**), inverse quantized (which is performed at the inverse quantization circuit **106**), and inverse transformed (which is performed at the inverse transform circuit **108**).

The inter/intra selection circuit **122** is used to decide a prediction mode of a current block to be decoded. For example, when the prediction mode of the current block is decided to be inter prediction, predicted pixels/samples generated from the motion compensation circuit **120** are output to the following decoding stage, such as a reconstruct circuit **110**. For another example, when the prediction mode of the current block is decided to be intra prediction, predicted pixels/samples generated from the intra prediction circuit **116** are output to the following decoding stage, such as the reconstruct circuit **110**.

The reconstruct circuit **110** is arranged to combine a residue output of the inverse transform circuit **108** and a predicted pixel output of one of intra prediction circuit **116** and motion compensation circuit **120** to thereby generate reconstructed pixels/samples of each block of a picture (i.e., a reconstructed/decoded picture). The de-blocking filter **112** is arranged to apply de-blocking filtering to the reconstructed picture generated from the reconstruct circuit **110**, and then generate a de-blocked picture as a reference picture. The de-blocked reference picture is stored into the reference picture buffer **114**, and may be referenced by the motion compensation circuit **118** to generate predicted pixels/samples.

VP9 divides one picture into 64×64-sized blocks that are called superblocks. Superblocks of the picture are processed in raster order: left to right, top to bottom. In addition, VP9 supports quad-tree based encoding. Hence, recursive partitioning may be employed to split each superblock into one or more partitions (e.g., smaller-sized blocks) for further processing. FIG. 2 is a diagram illustrating recursive partitioning of one superblock into various sizes of mode information (MI) units. For example, one superblock with the block size of 64×64 may be split into one or more coding units (or called MI units), where the partitions supported by VP9 coding standard may include square partitions, such as a 64×64-sized block, a 32×32-sized block, a 16×16-sized block, a 8×8-sized block, a 4×4-sized block, and may further include non-square partitions, such as a 64×32-sized block, a 32×64-sized block, 32×16-sized block, a 16×32-sized block, . . . , a 4×8-sized block, a 8×4-sized block. Hence, the coding unit (MI unit) sizes may include 64×64, 32×32, 16×16, 8×8, 64×32, 32×64, 32×16, 16×32, . . . , 8×8, 4×8, 8×4, 4×4. Although “4×4” is the smallest partition, lots of information is stored at “8×8” granularity only. This causes blocks smaller than “8×8” to be handled as sort of a special case.

For any MI unit size, VP9 will perform a best MVP determination flow to find one best MVP. In a case where an MI unit size is not smaller than 8×8, the best MVP is directly referenced to determine an MV of a block with the MI unit size. In another case where an MI unit size is smaller than 8×8, an additional sub-block MVP determination flow will be performed to find one sub-block MVP for each sub-block within one 8×8 block, where the best MVP and the sub-block MVP of a sub-block with the MI unit size may be involved in determining an MV of the sub-block. For example, when the MI unit size is 4×4, one 8×8 block is composed of four square sub-blocks (i.e., 4×4 sub-blocks). Hence, 4 iterations of the sub-block MVP determination flow are required by a conventional design to determine

sub-block MVPs of the four 4×4 sub-blocks, respectively. For another example, when the MI unit size is 4×8, one 8×8 block is composed of two non-square sub-blocks (i.e., 4×8 sub-blocks). Hence, 2 iterations of the sub-block MVP determination flow are required by the conventional design to determine sub-block MVPs of the two 4×8 sub-blocks, respectively. For yet another example, when the MI unit size is 8×4, one 8×8 block is composed of two non-square sub-blocks (i.e., 8×4 sub-blocks). Hence, 2 iterations of the sub-block MVP determination flow are required by the conventional design to determine sub-block MVPs of the two 8×4 sub-blocks, respectively. With regard to the conventional design, the numbers of iterations for finding MVPs in different MI unit sizes are listed in the following table.

TABLE 1

MI Unit Size	Best MVP	Sub-block MVP	Total
MI ≥ 8 × 8	1	0	1
MI = 4 × 8	1	2	3
MI = 8 × 4	1	2	3
MI = 4 × 4	1	4	5

For MI unit size <8×8, VP9 requires extra time to find the sub-block MVPs compared to the condition of MI ≥8×8. This might induce considerable timing overhead if an inter-frame is composed of a large number of MI units smaller than 8×8. The present invention therefore proposes using the MVP determination apparatus **122** to efficiently reduce the number of iterations of the sub-block MVP determination flow.

In a first exemplary implementation, the MVP determination apparatus **122** may be configured to reduce the number of iterations of the sub-block MVP determination flow according to a first lemma. In accordance with the first lemma, given two MI units  $mi_a$ ,  $mi_b$  with the same size and the same reference frame, where the MI units  $mi_a$ ,  $mi_b$  have  $n$  neighbor motion vector data  $nb_{ai}$ ,  $nb_{bi}$  and  $m$  MVPs  $mvp_{aj}$ ,  $mvp_{bj}$ , respectively,  $mvp_{aj}=mvp_{bj}$  if  $nb_{ai}=nb_{bi}$ . Note that  $0 \leq i < n$ ,  $0 \leq j < m$ , where  $n$  and  $m$  depend on the specification in each decoding format. For example,  $n=8$  and  $m=2$  for VP9. FIG. 3 is a diagram illustrating an example of two VP9 MI units  $mi_a$  and  $mi_b$  with the same size and the same reference frame. The MI unit  $mi_a$  has 8 neighbor motion vector data  $nb_{a0}$ - $nb_{a7}$ , and the MI unit  $mi_b$  also has 8 neighbor motion vector data  $nb_{b0}$ - $nb_{b7}$ . The MVP result depends on the input MI unit and the neighbors of the MI unit. If the sizes of the MI units  $mi_a$ ,  $mi_b$  are identical, the reference frames of the MI units  $mi_a$ ,  $mi_b$  are identical (i.e., the neighbor motion vector data  $nb_{a0}$ - $nb_{a7}$  and  $nb_{b0}$ - $nb_{b7}$  are possessed by blocks in the same reference frame), and the neighbor motion vector data of the MI units  $mi_a$ ,  $mi_b$  are identical (i.e.,  $nb_{ai}=nb_{bi}$ ), then the MVP of the MI unit  $mi_a$  must be the same as that of the MI unit  $mi_b$ .

In accordance with the first lemma, the MVP determination apparatus **122** may speed up the iterations of the sub-block determination flow by early termination or may directly skip one or more iterations of the sub-block determination flow, depending upon the actual design considerations. In the first exemplary implementation employing the first lemma, the checking circuit **124** is arranged to check if motion vector data of at least one first neighbor unit (e.g., 4×4 unit) adjacent to a block (e.g., 8×8 MI unit) and motion vector data of at least one second neighbor unit (e.g., 4×4 unit) adjacent to the block (e.g., 8×8 MI unit) are identical to each other; and the motion vector predictor computing circuit **126** is arranged to assign a motion vector predictor

determined for a first sub-block within the block to a second sub-block within the block when the checking circuit 124 determines that the motion vector data of the at least one first neighbor unit is identical to the motion vector data of the at least one second neighbor unit, where the motion vector data of the at least one first neighbor unit is involved in determining the motion vector predictor of the first sub-block, and the motion vector data of the at least one second neighbor unit is not involved in determining the motion vector predictor of the first sub-block.

FIG. 4 is a diagram illustrating an 8x8 block sub-divided into four 4x4 sub-blocks according to an embodiment of the present invention. Since each of the sub-blocks blk0-blk3 within the same 8x8 block BK<sub>CUR</sub> has a size smaller than 8x8, a sub-block MVP determination flow will be performed. As shown in FIG. 4, there are neighbor 8x8 blocks BK<sub>0</sub>-BK<sub>7</sub> (which are reconstructed blocks). Since the minimum size of the sub-block is 4x4, the neighbor motion vector data is stored in a 4x4 neighbor unit. With regard to the 4x4 sub-block blk0, the associated sub-block MVP may be determined on the basis of the motion vector data top0 of the neighbor unit 401 in the neighbor block BK<sub>0</sub>, the motion vector data left0 of the neighbor unit 411 in the neighbor block BK<sub>1</sub>, the motion vector data nb<sub>2</sub> of the neighbor unit 422 in the neighbor block BK<sub>2</sub>, the motion vector data nb<sub>3</sub> of the neighbor unit 423 in the neighbor block BK<sub>3</sub>, the motion vector data nb<sub>4</sub> of the neighbor unit 424 in the neighbor block BK<sub>4</sub>, the motion vector data nb<sub>5</sub> of the neighbor unit 425 in the neighbor block BK<sub>5</sub>, the motion vector data nb<sub>6</sub> of the neighbor unit 426 in the neighbor block BK<sub>6</sub>, and the motion vector data nb<sub>7</sub> of the neighbor unit 427 in the neighbor block BK<sub>7</sub>. It should be noted that the neighbor units 401 and 411 are adjacent to the 8x8 block BK<sub>CUR</sub>, where among the neighbor units of the 8x8 block BK<sub>CUR</sub>, the neighbor unit 401 is closest to the sub-block blk0 in the vertical direction, and the neighbor unit 411 is closest to the sub-block blk0 in the horizontal direction.

With regard to the 4x4 sub-block blk1, the associated sub-block MVP may be determined on the basis of the motion vector data top1 of the neighbor unit 402 in the neighbor block BK<sub>0</sub>, the motion vector data left0 of the neighbor unit 411 in the neighbor block BK<sub>1</sub>, the motion vector data nb<sub>2</sub> of the neighbor unit 422 in the neighbor block BK<sub>2</sub>, the motion vector data nb<sub>3</sub> of the neighbor unit 423 in the neighbor block BK<sub>3</sub>, the motion vector data nb<sub>4</sub> of the neighbor unit 424 in the neighbor block BK<sub>4</sub>, the motion vector data nb<sub>5</sub> of the neighbor unit 425 in the neighbor block BK<sub>5</sub>, the motion vector data nb<sub>6</sub> of the neighbor unit 426 in the neighbor block BK<sub>6</sub>, and the motion vector data nb<sub>7</sub> of the neighbor unit 427 in the neighbor block BK<sub>7</sub>. It should be noted that the neighbor units 402 and 411 are adjacent to the 8x8 block BK<sub>CUR</sub>, where among the neighbor units of the 8x8 block BK<sub>CUR</sub>, the neighbor unit 402 is closest to the sub-block blk1 in the vertical direction, and the neighbor unit 411 is closest to the sub-block blk1 in the horizontal direction.

With regard to the 4x4 sub-block blk2, the associated sub-block MVP may be determined on the basis of the motion vector data top0 of the neighbor unit 401 in the neighbor block BK<sub>0</sub>, the motion vector data left1 of the neighbor unit 412 in the neighbor block BK<sub>1</sub>, the motion vector data nb<sub>2</sub> of the neighbor unit 422 in the neighbor block BK<sub>2</sub>, the motion vector data nb<sub>3</sub> of the neighbor unit 423 in the neighbor block BK<sub>3</sub>, the motion vector data nb<sub>4</sub> of the neighbor unit 424 in the neighbor block BK<sub>4</sub>, the motion vector data nb<sub>5</sub> of the neighbor unit 425 in the neighbor block BK<sub>5</sub>, the motion vector data nb<sub>6</sub> of the

neighbor unit 426 in the neighbor block BK<sub>6</sub>, and the motion vector data nb<sub>7</sub> of the neighbor unit 427 in the neighbor block BK<sub>7</sub>. It should be noted that the neighbor units 401 and 412 are adjacent to the 8x8 block BK<sub>CUR</sub>, where among the neighbor units of the 8x8 block BK<sub>CUR</sub>, the neighbor unit 401 is closest to the sub-block blk2 in the vertical direction, and the neighbor unit 412 is closest to the sub-block blk2 in the horizontal direction.

With regard to the 4x4 sub-block blk3, the associated sub-block MVP may be determined on the basis of the motion vector data top1 of the neighbor unit 402 in the neighbor block BK<sub>0</sub>, the motion vector data left1 of the neighbor unit 412 in the neighbor block BK<sub>1</sub>, the motion vector data nb<sub>2</sub> of the neighbor unit 422 in the neighbor block BK<sub>2</sub>, the motion vector data nb<sub>3</sub> of the neighbor unit 423 in the neighbor block BK<sub>3</sub>, the motion vector data nb<sub>4</sub> of the neighbor unit 424 in the neighbor block BK<sub>4</sub>, the motion vector data nb<sub>5</sub> of the neighbor unit 425 in the neighbor block BK<sub>5</sub>, the motion vector data nb<sub>6</sub> of the neighbor unit 426 in the neighbor block BK<sub>6</sub>, and the motion vector data nb<sub>7</sub> of the neighbor unit 427 in the neighbor block BK<sub>7</sub>. It should be noted that the neighbor units 402 and 412 are adjacent to the 8x8 block BK<sub>CUR</sub>, where among the neighbor units of the 8x8 block BK<sub>CUR</sub>, the neighbor unit 402 is closest to the sub-block blk2 in the vertical direction, and the neighbor unit 412 is closest to the sub-block blk2 in the horizontal direction.

As can be seen from FIG. 4, the sub-block MVP determination for each of the sub-blocks blk0-blk3 refers to the same motion vector data nb<sub>2</sub>-nb<sub>7</sub>. Hence, the checking circuit 124 may simply check the motion vector data top0 of the neighbor unit 401, the motion vector data top1 of the neighbor unit 402, the motion vector data left0 of the neighbor unit 411, and the motion vector data left1 of the neighbor unit 412, where the neighbor units 401 and 402 are on the same side (i.e., top side) of the block BK<sub>CUR</sub>, and the neighbor units 411 and 412 are on the same side (i.e., left side) of the block BK<sub>CUR</sub>. The MVP computing circuit 126 may refer to a checking result generated from the checking circuit 124 to determine whether the condition of the first lemma is satisfied for certain sub-blocks within the same block BK<sub>CUR</sub>. If the condition of the first lemma is satisfied for certain sub-blocks within the same block BK<sub>CUR</sub>, one iteration of the sub-block MVP determination flow may be actually performed by the MVP computing circuit 126 to compute a sub-block MVP for one sub-block, and then the sub-block MVP determine for the sub-block may be directly assigned to other sub-block(s).

FIG. 5 is a diagram illustrating a first case where the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 8x8 block according to an embodiment of the present invention. As mentioned above, the motion vector data top0 and the motion vector data left0 may be involved in determining the sub-block MVP of the sub-block blk0, and the motion vector data top1 and the same motion vector data left0 may be involved in determining the sub-block MVP of the sub-block blk1. It should be noted that the motion vector data top1 may not be involved in determining the sub-block MVP of the sub-block blk0, and the motion vector data top0 may not be involved in determining the sub-block MVP of the sub-block blk1. However, when the checking circuit 124 determines that the motion vector data top0 and the motion vector data top1 are identical to each other, the condition of the first lemma for the sub-blocks blk0 and blk1 is satisfied, which means that the sub-block MVP of the sub-block blk1 should be the same as the sub-block MVP of the sub-block blk0.

In one exemplary design, the MVP computing circuit 126 may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk0, and then assign the sub-block MVP determined for the sub-block blk0 to the sub-block blk1. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk1 can be skipped or early terminated to reduce the computation load as well as the computation time.

In another exemplary design, the MVP computing circuit 126 may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk1, and then assign the sub-block MVP determined for the sub-block blk1 to the sub-block blk0. Hence, another iteration of the sub-block MVP determination flow to compute the motion vector predictor of the sub-block blk0 can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 6 is a diagram illustrating a second case where the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 8x8 block according to an embodiment of the present invention. As mentioned above, the motion vector data top0 and the motion vector data left1 may be involved in determining the sub-block MVP of the sub-block blk2, and the motion vector data top1 and the same motion vector data left1 may be involved in determining the sub-block MVP of the sub-block blk3. It should be noted that the motion vector data top1 may not be involved in determining the sub-block MVP of the sub-block blk2, and the motion vector data top1 may not be involved in determining the sub-block MVP of the sub-block blk2. However, when the checking circuit 124 determines that the motion vector data top0 and the motion vector data top1 are identical to each other, the condition of the first lemma for the sub-blocks blk2 and blk3 is satisfied, which means that the sub-block MVP of the sub-block blk3 should be the same as the sub-block MVP of the sub-block blk2.

In one exemplary design, the MVP computing circuit 126 may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk2, and then assign the sub-block MVP determined for the sub-block blk2 to the sub-block blk3. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk3 can be skipped or early terminated to reduce the computation load as well as the computation time.

In another exemplary design, the MVP computing circuit 126 may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk3, and then assign the sub-block MVP determined for the sub-block blk3 to the sub-block blk2. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk2 can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 7 is a diagram illustrating a third case where the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 8x8 block according to an embodiment of the present invention. As mentioned above, the motion vector data top0 and the motion vector data left0 may be involved in determining the sub-block MVP of the sub-block blk0, and the motion vector data left1 and the same motion vector data top0 may be involved in determining the sub-block MVP of the sub-block blk2. It should be noted that the motion vector data left1 may not be involved in determining the sub-block MVP of the sub-block blk0, and the motion vector data left0 may not be involved in

determining the sub-block MVP of the sub-block blk2. However, when the checking circuit 124 determines that the motion vector data left0 and the motion vector data left1 are identical to each other, the condition of the first lemma for the sub-blocks blk0 and blk2 is satisfied, which means that the sub-block MVP of the sub-block blk2 should be the same as the sub-block MVP of the sub-block blk0.

In one exemplary design, the MVP computing circuit 126 may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk0, and then assign the sub-block MVP determined for the sub-block blk0 to the sub-block blk2. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk2 can be skipped or early terminated to reduce the computation load as well as the computation time.

In another exemplary design, the MVP computing circuit 126 may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk2, and then assign the sub-block MVP determined for the sub-block blk2 to the sub-block blk0. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk0 can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 8 is a diagram illustrating a fourth case where the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 8x8 block according to an embodiment of the present invention. As mentioned above, the motion vector data top1 and the motion vector data left0 may be involved in determining the sub-block MVP of the sub-block blk1, and the motion vector data left1 and the same motion vector data top1 may be involved in determining the sub-block MVP of the sub-block blk3. It should be noted that the motion vector data left1 may not be involved in determining the sub-block MVP of the sub-block blk1, and the motion vector data left0 may not be involved in determining the sub-block MVP of the sub-block blk3. However, when the checking circuit 124 determines that the motion vector data left0 and the motion vector data left1 are identical to each other, the condition of the first lemma for the sub-blocks blk1 and blk3 is satisfied, which means that the sub-block MVP of the sub-block blk3 should be the same as the sub-block MVP of the sub-block blk1.

In one exemplary design, the MVP computing circuit 126 may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk1, and then assign the sub-block MVP determined for the sub-block blk1 to the sub-block blk3. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk3 can be skipped or early terminated to reduce the computation load as well as the computation time.

In another exemplary design, the MVP computing circuit 126 may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk3, and then assign the sub-block MVP determined for the sub-block blk3 to the sub-block blk1. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the sub-block blk1 can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 9 is a diagram illustrating a fifth case where the condition of the first lemma is satisfied for all 4x4 sub-blocks within the same 8x8 block according to an embodiment of the present invention. When the checking circuit 124 determines that the motion vector data top0 and the

motion vector data **top1** are identical to each other and the motion vector data **left0** and the motion vector data **left1** are identical to each other, the condition of the first lemma for all sub-blocks **blk0-blk3** is satisfied, which means that the sub-block MVPs of all sub-blocks **blk0-blk3** should be the same. In one exemplary design, the MVP computing circuit **126** may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of a selected sub-block (e.g., **blk0**) among the sub-blocks **blk0-blk3**, and then assign the sub-block MVP determined for the selected sub-block (e.g., **blk0**) to each of the rest of the sub-blocks **blk0-blk3**. Hence, other iterations of the sub-block MVP determination flow to compute the sub-block MVPs of the rest of the sub-block **blk0-blk3** can be skipped or early terminated to reduce the computation load as well as the computation time.

When the MI unit size is  $8 \times 4$ , one  $8 \times 8$  block is composed of two  $8 \times 4$  sub-blocks. Similarly, the checking circuit **124** may check the motion vector data of neighbor units (which are  $4 \times 4$  units), and the MVP computing circuit **126** may refer to a checking result generated from the checking circuit **124** to determine whether the condition of the first lemma is satisfied for two  $8 \times 4$  sub-blocks within the same  $8 \times 8$  block. If the condition of the first lemma is satisfied for two  $8 \times 4$  sub-blocks within the same  $8 \times 8$  block, one iteration of the sub-block MVP determination flow is actually performed by the MVP computing circuit **126** to compute a sub-block MVP for one  $8 \times 4$  sub-block, and the sub-block MVP determined for one  $8 \times 4$  sub-block is assigned to the other  $8 \times 4$  sub-block.

FIG. 10 is a diagram illustrating a case where the condition of the first lemma is satisfied for two  $8 \times 4$  sub-blocks within the same  $8 \times 8$  block according to an embodiment of the present invention. Each of the  $8 \times 4$  sub-blocks may be regarded as having two  $4 \times 4$  sub-blocks. For example, the  $8 \times 4$  sub-block **BLK0** is composed of two  $4 \times 4$  sub-blocks **blk0** and **blk1**, and the  $8 \times 4$  sub-block **BLK1** is composed of two  $4 \times 4$  sub-blocks **blk2** and **blk3**. In addition, the sub-block MVP of the  $8 \times 4$  sub-block **BLK0** may be set by the sub-block MVP determined for the  $4 \times 4$  sub-block **blk0**, and the sub-block MVP of the  $8 \times 4$  sub-block **BLK1** may be set by the sub-block MVP determined for the  $4 \times 4$  sub-block **blk2**. Since the  $4 \times 4$  sub-blocks **blk0** and **blk1** are within the same  $8 \times 4$  sub-block **BLK0**, the sub-block MVP determined for the  $4 \times 4$  sub-block **blk0** (i.e., the sub-block MVP of the  $8 \times 4$  sub-block **BLK0**) may also be used by the  $4 \times 4$  sub-block **blk1**. Similarly, since the  $4 \times 4$  sub-blocks **blk2** and **blk3** are within the same  $8 \times 4$  sub-block **BLK1**, the sub-block MVP determined for the  $4 \times 4$  sub-block **blk2** (i.e., the sub-block MVP of the  $8 \times 4$  sub-block **BLK1**) may also be used by the  $4 \times 4$  sub-block **blk3**.

As mentioned above, the motion vector data **top0** and the motion vector data **left0** may be involved in determining the sub-block MVP of the sub-block **blk0**, and the motion vector data **left1** and the same motion vector data **top0** may be involved in determining the sub-block MVP of the sub-block **blk2**. Hence, the motion vector data **top0** and the motion vector data **left0** may be involved in determining the sub-block MVP of the  $8 \times 4$  sub-block **BLK0**, and the motion vector data **left1** and the same motion vector data **top0** may be involved in determining the sub-block MVP of the  $8 \times 4$  sub-block **BLK1**. When the checking circuit **124** determines that the motion vector data **left0** and the motion vector data **left1** are identical to each other, the condition of the first lemma for the  $8 \times 4$  sub-blocks **BLK0** and **BLK1** is satisfied,

which means that the sub-block MVP of the  $8 \times 4$  sub-block **BLK0** should be the same as the sub-block MVP of the  $8 \times 4$  sub-block **BLK1**.

In one exemplary design, the MVP computing circuit **126** may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the  $8 \times 4$  sub-block **BLK0**, and then assign the sub-block MVP determined for the  $8 \times 4$  sub-block **BLK0** to the  $8 \times 4$  sub-block **BLK1**. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the  $8 \times 4$  sub-block **BLK1** can be skipped or early terminated to reduce the computation load as well as the computation time.

In another exemplary design, the MVP computing circuit **126** may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the  $8 \times 4$  sub-block **BLK1**, and then assign the sub-block MVP determined for the  $8 \times 4$  sub-block **BLK1** to the  $8 \times 4$  sub-block **BLK0**. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the  $8 \times 4$  sub-block **BLK0** can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 11 is a diagram illustrating a case where the condition of the first lemma is satisfied for two  $4 \times 8$  sub-blocks within the same  $8 \times 8$  block according to an embodiment of the present invention. Each of the  $4 \times 8$  sub-blocks may be regarded as having two  $4 \times 4$  sub-blocks. For example, the  $4 \times 8$  sub-block **BLK0'** is composed of two  $4 \times 4$  sub-blocks **blk0** and **blk2**, and the  $4 \times 8$  sub-block **BLK1'** is composed of two  $4 \times 4$  sub-blocks **blk1** and **blk3**. In addition, the sub-block MVP of the  $4 \times 8$  sub-block **BLK0'** may be set by the sub-block MVP determined for the  $4 \times 4$  sub-block **blk0**, and the sub-block MVP of the  $4 \times 8$  sub-block **BLK1'** may be set by the sub-block MVP determined for the  $4 \times 4$  sub-block **blk1**. Since the  $4 \times 4$  sub-blocks **blk0** and **blk2** are within the same  $4 \times 8$  sub-block **BLK0'**, the sub-block MVP determined for the  $4 \times 4$  sub-block **blk0** (i.e., the sub-block MVP of the  $8 \times 4$  sub-block **BLK0'**) may also be used by the  $4 \times 4$  sub-block **blk2**. Similarly, since the  $4 \times 4$  sub-blocks **blk1** and **blk3** are within the same  $4 \times 8$  sub-block **BLK1'**, the sub-block MVP determined for the  $4 \times 4$  sub-block **blk1** (i.e., the sub-block MVP of the  $4 \times 8$  sub-block **BLK1'**) may also be used by the  $4 \times 4$  sub-block **blk3**.

As mentioned above, the motion vector data **top0** and the motion vector data **left0** may be involved in determining the sub-block MVP of the sub-block **blk0**, and the motion vector data **top1** and the same motion vector data **left0** may be involved in determining the sub-block MVP of the sub-block **blk1**. In other words, the motion vector data **top0** and the motion vector data **left0** may be involved in determining the sub-block MVP of the  $4 \times 8$  sub-block **BLK0'**, and the motion vector data **top1** and the same motion vector data **left0** may be involved in determining the sub-block MVP of the  $4 \times 8$  sub-block **BLK1'**. When the checking circuit **124** determines that the motion vector data **top0** and the motion vector data **top1** are identical to each other, the condition of the first lemma for the  $4 \times 8$  sub-blocks **BLK0'** and **BLK1'** is satisfied, which means that the sub-block MVP of the  $4 \times 8$  sub-block **BLK0'** should be the same as the sub-block MVP of the  $4 \times 8$  sub-block **BLK1'**.

In one exemplary design, the MVP computing circuit **126** may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the  $4 \times 8$  sub-block **BLK0'**, and then assign the sub-block MVP determined for the  $4 \times 8$  sub-block **BLK0'** to the  $4 \times 8$  sub-block **BLK1'**. Hence, another iteration of the sub-block

MVP determination flow to compute the sub-block MVP of the 4x8 sub-block BLK1' can be skipped or early terminated to reduce the computation load as well as the computation time.

In another exemplary design, the MVP computing circuit 126 may perform one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the 4x8 sub-block BLK1', and then assign the sub-block MVP determined for the 4x8 sub-block BLK1' to the 4x8 sub-block BLK0'. Hence, another iteration of the sub-block MVP determination flow to compute the sub-block MVP of the 4x8 sub-block BLK0' can be skipped or early terminated to reduce the computation load as well as the computation time.

With regard to the aforementioned first exemplary implementation that employs the first lemma to efficiently improve the speed of the MVP determination, the numbers of iterations of sub-block MVP determination flow under different MI unit sizes and different cases are listed in the following table.

TABLE 2

MI Unit Size	Conventional design	Proposed Design	Proposed Design	Proposed Design
		(Case 1: top0 = top1 & left0 = left1)	(Case 2: left0 = top1)	(Case 3: top0 = top1 & left0 = left1)
MI = 4 x 8	2	1	2	1
MI = 8 x 4	2	2	1	1
MI = 4 x 4	4	2	2	1

In a second exemplary implementation, the MVP determination apparatus 122 may be configured to reduce the number of iterations of the sub-block MVP determination flow according to a second lemma. In accordance with the second lemma, given one VP9 MI unit mi with an MI unit size < 8x8, the best MVPs of the MI unit mi are  $mvp_{besti}$  and the sub-block MVPs of the MI unit mi are  $mvp_{blkji}$ , the sub-block MVP  $mvp_{blk3i}$  must be equivalent to the best MVP  $mvp_{besti}$ . Note that  $0 \leq i < 2$  and  $0 \leq j < 4$  for VP9.

When the MI unit size is not smaller than 8x8, a best MVP is determined for a block, where the best MVP is used to calculate an MV for the block with the MI unit size  $\geq 8 \times 8$ . When the MI unit size is smaller than 8x8, a best MVP is determined for each sub-block, and then at least one iteration of the sub-block MVP determination flow is performed to determine one sub-block MVP for each sub-block, where the best MVP and the sub-block MVP of each sub-block with the MI unit size < 8x8 are used to calculate an MV for each sub-block. Since the minimum size of a sub-block is 4x4, the neighbors are stored in 4x4 units. However, the minimum MI unit size for the best MVP determination is 8x8. FIG. 12 is a diagram illustrating the best MVP determination performed for blocks with different MI unit sizes not smaller than 8x8. As shown in sub-diagram (A) of FIG. 12, the MI unit size is 16x8. The best MVP determination takes the 4x4 sub-block blk3 as a base, and refers to motion vector data of 4x4 neighbor units, including the motion vector data top1 of one top 4x4 neighbor unit (which is adjacent to the 16x8 block and closest to the 4x4 sub-block blk3 in the vertical direction) and the motion vector data left1 of one left 4x4 neighbor unit (which is adjacent to the 16x8 block and closest to the 4x4 sub-block blk3 in the horizontal direction). As shown in sub-diagram (B) of FIG. 12, the MI unit size is 8x8. Similarly, the best MVP determination takes the 4x4

sub-block blk3 as a base, and refers to motion vector data of 4x4 neighbor units, including the motion vector data top1 of one top 4x4 neighbor unit (which is adjacent to the 8x8 block and closest to the 4x4 sub-block blk3 in the vertical direction) and the motion vector data left1 of one left 4x4 neighbor unit (which is adjacent to the 8x8 block and closest to the 4x4 sub-block blk3 in the horizontal direction).

However, when the MI unit size is smaller than 8x8, the best MVPs for all sub-blocks within the same 8x8 block are the same. Specifically, the best MVP determined for an 8x8 block (which has the minimum MI unit size for the best MVP determination) can be used as the best MVP for each of the sub-blocks (e.g., four 4x4 sub-blocks, or two 4x8 sub-blocks, or two 8x4 sub-blocks) within the same 8x8 block. It should be noted that the best MVP of one 8x8 block (e.g., BK<sub>CUR</sub> shown in FIG. 4) may be determined on the basis of the motion vector data top1 of the neighbor unit 402 in the neighbor block BK<sub>0</sub>, the motion vector data left1 of the neighbor unit 412 in the neighbor block BK<sub>1</sub>, the motion vector data nb<sub>2</sub> of the neighbor unit 422 in the neighbor block BK<sub>2</sub>, the motion vector data nb<sub>3</sub> of the neighbor unit 423 in the neighbor block BK<sub>3</sub>, the motion vector data nb<sub>4</sub> of the neighbor unit 424 in the neighbor block BK<sub>4</sub>, the motion vector data nb<sub>5</sub> of the neighbor unit 425 in the neighbor block BK<sub>5</sub>, the motion vector data nb<sub>6</sub> of the neighbor unit 426 in the neighbor block BK<sub>6</sub>, and the motion vector data nb<sub>7</sub> of the neighbor unit 427 in the neighbor block BK<sub>7</sub>. Hence, the best MVP determined for one 8x8 block is the same as the sub-block MVP determined for the 4x4 sub-block blk3 within this 8x8 block. With regard to the second exemplary implementation employing the second lemma, the MVP determination apparatus 122 may assign the best MVP determined for one 8x8 block to one 4x4 sub-block (e.g., blk3) within the 8x8 block.

FIG. 13 is diagram illustrating a case where the second lemma is employed when the MI unit size is smaller than 8x8 according to embodiments of the present invention. In this example, the MI unit size is 4x4, and the sub-block MVP of the 4x4 sub-block blk3 within an 8x8 block can be directly set by the best MVP determined for the 8x8 block. Hence, an iteration of the sub-block MVP determination flow to compute the sub-block MVP of the 4x4 sub-block blk3 can be skipped or early terminated to reduce the computation load as well as the computation time.

With regard to the second exemplary implementation that employs the second lemma to efficiently improve the speed of the MVP determination, the numbers of iterations of sub-block MVP determination flow under different MI unit sizes are listed in the following table.

TABLE 3

MI Unit Size	Conventional design	Proposed Design
MI = 4 x 8	2	2
MI = 8 x 4	2	2
MI = 4 x 4	4	3

It should be noted that the first lemma and the second lemma can be exploited simultaneously to reduce the number of iterations of sub-block MVP determination flow in a more efficient manner. This also falls within the scope of the present invention.

FIG. 14 is a diagram illustrating a case where the second lemma is employed and the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 8x8 block according to an embodiment of the present invention. When

15

the checking circuit 124 determines that the motion vector data top0 and the motion vector data top1 are identical to each other, the condition of the first lemma for the 4x4 sub-blocks blk2 and blk3 is satisfied, which means that the sub-block MVP of the sub-block blk2 should be the same as the sub-block MVP of the sub-block blk3. Further, when the second lemma is employed, the best MVP of an 8x8 block should be the same as the sub-block MVP of the 4x4 sub-block blk3 within the 8x8 block. Hence, two iterations of the sub-block MVP determination flow to compute the sub-block MVPs of the 4x4 sub-blocks blk2 and blk3 can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 15 is a diagram illustrating another case where the second lemma is employed and the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 8x8 block according to an embodiment of the present invention. When the checking circuit 124 determines that the motion vector data left0 and the motion vector data left1 are identical to each other, the condition of the first lemma for the 4x4 sub-blocks blk1 and blk3 is satisfied, which means that the sub-block MVP of the sub-block blk3 should be the same as the sub-block MVP of the sub-block blk1. Further, when the second lemma is employed, the best MVP of an 8x8 block should be the same as the sub-block MVP of the 4x4 sub-block blk3 within the 8x8 block. Hence, two iterations of the sub-block MVP determination flow to compute the sub-block MVPs of the 4x4 sub-blocks blk1 and blk3 can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 16 is a diagram illustrating a case where the second lemma is employed and the condition of the first lemma is satisfied for all 4x4 sub-blocks within the same 8x8 block according to an embodiment of the present invention. When the checking circuit 124 determines that the motion vector data top0 and the motion vector data top1 are identical to each other and the motion vector data left0 and the motion vector data left1 are identical to each other, the condition of the first lemma for all sub-blocks blk0-blk3 is satisfied, which means that the sub-block MVPs of the sub-blocks blk0-blk3 should be the same. Further, when the second lemma is employed, the best MVP of an 8x8 block should be the same as the sub-block MVP of the sub-block blk3 within the 8x8 block. Hence, four iterations of the sub-block MVP determination flow to compute the sub-block MVPs of the 4x4 sub-blocks blk0-blk3 can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 17 is a diagram illustrating a case where the second lemma is employed and the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 8x4 sub-block according to an embodiment of the present invention. In this example, the MI unit size is 8x4. When the checking circuit 124 determines that the motion vector data top0 and the motion vector data top1 are identical to each other, the condition of the first lemma for the 4x4 sub-blocks blk2 and blk3 within the 8x4 sub-block BLK1 is satisfied, which means that the sub-block MVP of the sub-block blk2 should be the same as the sub-block MVP of the sub-block blk3. Further, when the second lemma is employed, the best MVP of an 8x8 block should be the same as the sub-block MVP of the 4x4 sub-block blk3 within the 8x8 block. It should be noted that the sub-block MVP of the 8x4 sub-block BLK1 is set by the sub-block MVP of the 4x4 sub-block blk2 within the 8x4 sub-block BLK1. Hence, one iteration of the sub-block MVP determination flow to compute the sub-

16

block MVP of the 8x4 sub-block BLK1 can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 18 is a diagram illustrating a case where the second lemma is employed and the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 4x8 sub-block according to an embodiment of the present invention. In this example, the MI unit size is 4x8. When the checking circuit 124 determines that the motion vector data left0 and the motion vector data left1 are identical to each other, the condition of the first lemma for the 4x4 sub-blocks blk1 and blk3 within the same 4x8 sub-block BLK1' is satisfied, which means that the sub-block MVP of the sub-block blk1 should be the same as the sub-block MVP of the sub-block blk3. Further, when the second lemma is employed, the best MVP of an 8x8 block should be the same as the sub-block MVP of the 4x4 sub-block blk3 within the 8x8 block. It should be noted that the sub-block MVP of the 4x8 sub-block BLK1' is set by the sub-block MVP of the 4x4 sub-block blk1 within the 4x8 sub-block BLK1'. Hence, one iteration of the sub-block MVP determination flow to compute the sub-block MVP of the 4x8 sub-block BLK1' can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 19 is a diagram illustrating a case where the second lemma is employed, the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 8x4 block and the condition of the first lemma is satisfied for two 8x4 sub-blocks within the same 8x8 block according to an embodiment of the present invention. In this example, the MI unit size is 8x4. When the checking circuit 124 determines that the motion vector data left0 and the motion vector data left1 are identical to each other, the condition of the first lemma for the 8x4 sub-blocks BLK0 and BLK1 is satisfied, which means that the sub-block MVP of the 8x4 sub-block BLK1 (i.e., the sub-block MVP of the 4x4 sub-block blk2) should be the same as the sub-block MVP of the 8x4 sub-block BLK0 (i.e., the sub-block MVP of the 4x4 sub-block blk0). When the checking circuit 124 determines that the motion vector data top0 and the motion vector data top1 are identical to each other, the condition of the first lemma for the 4x4 sub-blocks blk2 and blk3 within the same 8x4 sub-block BLK1 is satisfied, which means that the sub-block MVP of the sub-block blk2 should be the same as the sub-block MVP of the sub-block blk3. Further, when the second lemma is employed, the best MVP of an 8x8 block should be the same as the sub-block MVP of the 4x4 sub-block blk3 within the 8x8 block. Hence, two iterations of the sub-block MVP determination flow to compute the sub-block MVPs of the 8x4 sub-blocks BLK0 and BLK1 can be skipped or early terminated to reduce the computation load as well as the computation time.

FIG. 20 is a diagram illustrating a case where the second lemma is employed, the condition of the first lemma is satisfied for two 4x4 sub-blocks within the same 4x8 block and the condition of the first lemma is satisfied for two 4x8 sub-blocks within the same 8x8 block according to an embodiment of the present invention. In this example, the MI unit size is 4x8. When the checking circuit 124 determines that the motion vector data top0 and the motion vector data top1 are identical to each other, the condition of the first lemma for the 4x8 sub-blocks BLK0' and BLK1' is satisfied, which means that the sub-block MVP of the 4x8 sub-block BLK1' (i.e., the sub-block MVP of the 4x4 sub-block blk1) should be the same as the sub-block MVP of the 4x8 sub-block BLK0' (i.e., the sub-block MVP of the 4x4 sub-block blk0). When the checking circuit 124 determines

that the motion vector data left0 and the motion vector data left1 are identical to each other, the condition of the first lemma for the 4x4 sub-blocks blk1 and blk3 within the same 4x8 sub-block BLK1' is satisfied, which means that the sub-block MVP of the sub-block blk1 should be the same as the sub-block MVP of the sub-block blk3. Further, when the second lemma is employed, the best MVP of an 8x8 block should be the same as the sub-block MVP of the 4x4 sub-block blk3 within the 8x8 block. Hence, two iterations of the sub-block MVP determination flow to compute the sub-block MVPs of the 4x8 sub-blocks BLK0' and BLK1' can be skipped or early terminated to reduce the computation load as well as the computation time.

With regard to a third exemplary implementation that employs both of the first lemma and the second lemma to more efficiently improve the speed of the MVP determination flow under different MI unit sizes and different cases are listed in the following table.

TABLE 4

MI Unit Size	Conventional design	Proposed Design (Case 1: top0 = top1 & left0 ≠ left1)	Proposed Design (Case 2: left0 = left1 & top0 ≠ top1)	Proposed Design (Case 3: top0 = top1 & left0 = left1)
		MI = 4 × 8	2	1
MI = 8 × 4	2	1	1	0
MI = 4 × 4	4	1	1	0

Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention. Accordingly, the above disclosure should be construed as limited only by the metes and bounds of the appended claims.

What is claimed is:

1. A motion vector predictor determination method comprising:

utilizing a checking circuit for checking if motion vector data of at least one first neighbor unit adjacent to a block and motion vector data of at least one second neighbor unit adjacent to the block are identical to each other; and

when a checking result indicates that the motion vector data of the at least one first neighbor unit is identical to the motion vector data of the at least one second neighbor unit, assigning a motion vector predictor determined for a first sub-block within the block to a second sub-block within the block;

wherein the motion vector data of the at least one first neighbor unit is involved in determining the motion vector predictor of the first sub-block, and the motion vector data of the at least one second neighbor unit is not involved in determining the motion vector predictor of the first sub-block;

wherein at least a portion of the at least one first neighbor unit and at least a portion of the at least one second neighbor unit are located at a same row of a frame, at least a portion of the first sub-block and at least a portion of the second sub-block are located at a same row of the frame, at least a portion of the at least one first neighbor unit and at least a portion of the first sub-block are located at a same column of the frame, and at least a portion of the at least one second neighbor

unit and at least a portion of the second sub-block are located at a same column of the frame; or at least a portion of the at least one first neighbor unit and at least a portion of the at least one second neighbor unit are located at a same column of the frame, at least a portion of the first sub-block and at least a portion of the second sub-block are located at a same column of the frame, at least a portion of the at least one first neighbor unit and at least a portion of the first sub-block are located at a same row of the frame, and at least a portion of the at least one second neighbor unit and at least a portion of the second sub-block are located at a same row of the frame.

2. The method of claim 1, wherein one of the at least one first neighbor unit and one of the at least one second neighbor unit are on a same side of the block.

3. The method of claim 2, wherein the same side is a top side of the block.

4. The method of claim 2, wherein the same side is a left side of the block.

5. The method of claim 1, wherein the first sub-block and the second sub-block have a same size.

6. The method of claim 5, wherein the at least one first neighbor unit and the at least one second neighbor unit have a same size; and a size of each of the first sub-block and the second sub-block is equal to a size of each of the at least one first neighbor unit and the at least one second neighbor unit.

7. The method of claim 6, wherein each of the first sub-block, the second sub-block, the at least one first neighbor unit and the at least one second neighbor unit is square.

8. The method of claim 5, wherein the first neighbor unit and the second neighbor unit have a same size; and a size of each of the first sub-block and the second sub-block is larger than a size of each of the at least one first neighbor unit and the at least one second neighbor unit.

9. The method of claim 8, wherein each of the first sub-block and the second sub-block is non-square, and each of the at least one first neighbor unit and the at least one second neighbor unit is square.

10. A motion vector predictor determination apparatus comprising:

a checking circuit, arranged to check if motion vector data of at least one first neighbor unit adjacent to a block and motion vector data of at least one second neighbor unit adjacent to the block are identical to each other; and

a motion vector predictor computing circuit, arranged to assign a motion vector predictor determined for a first sub-block within the block to a second sub-block within the block when the checking circuit determines that the motion vector data of the at least one first neighbor unit is identical to the motion vector data of the at least one second neighbor unit, wherein the motion vector data of the at least one first neighbor unit is involved in determining the motion vector predictor of the first sub-block, and the motion vector data of the at least one second neighbor unit is not involved in determining the motion vector predictor of the first sub-block;

wherein at least a portion of the at least one first neighbor unit and at least a portion of the at least one second neighbor unit are located at a same row of a frame, at least a portion of the first sub-block and at least a portion of the second sub-block are located at a same row of the frame, at least a portion of the at least one first neighbor unit and at least a portion of the first sub-block are located at a same column of the frame, and at least a portion of the at least one second neighbor

unit and at least a portion of the second sub-block are located at a same column of the frame; or at least a portion of the at least one first neighbor unit and at least a portion of the at least one second neighbor unit are located at a same column of the frame, at least a portion of the first sub-block and at least a portion of the second sub-block are located at a same column of the frame, at least a portion of the at least one first neighbor unit and at least a portion of the first sub-block are located at a same row of the frame, and at least a portion of the at least one second neighbor unit and at least a portion of the second sub-block are located at a same row of the frame.

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