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Newman

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(54) **COMPRESSION AND DECODING OF SINGLE SENSOR COLOR IMAGE DATA**

(71) Applicant: **GoPro, Inc.**, San Mateo, CA (US)

(72) Inventor: **David A. Newman**, San Diego, CA (US)

(73) Assignee: **GoPro, Inc.**, San Mateo, CA (US)

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(63) Continuation of application No. 14/222,549, filed on Mar. 21, 2014, now Pat. No. 8,879,861, which is a continuation of application No. 14/108,240, filed on Dec. 16, 2013, now Pat. No. 8,718,390, which is a continuation of application No. 13/968,423, filed on Aug. 15, 2013, now Pat. No. 8,644,629, which is a continuation of application No. 13/683,965, filed on Nov. 21, 2012, now Pat. No. 8,538,143, which is a continuation of application No. 13/196,175, filed on Aug. 2, 2011, now Pat. No. 8,345,969, which is a continuation of application No. 11/689,975, filed on Mar. 22, 2007, now Pat. No. 8,014,597.

(60) Provisional application No. 60/784,866, filed on Mar. 22, 2006.

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G06F 3/0484	(2013.01)

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CPC ***H04N 5/23293*** (2013.01); ***H04N 1/648*** (2013.01); ***H04N 9/045*** (2013.01); ***G06K 9/36*** (2013.01); ***G06T 9/00*** (2013.01); ***H04N 19/117*** (2014.11); ***H04N 19/136*** (2014.11); ***H04N 19/186*** (2014.11); ***H04N 19/44*** (2014.11); ***G06F 3/0484*** (2013.01)

(58) **Field of Classification Search**

USPC 382/166, 167, 233, 240, 260; 348/266, 348/267, 273, 280

See application file for complete search history.

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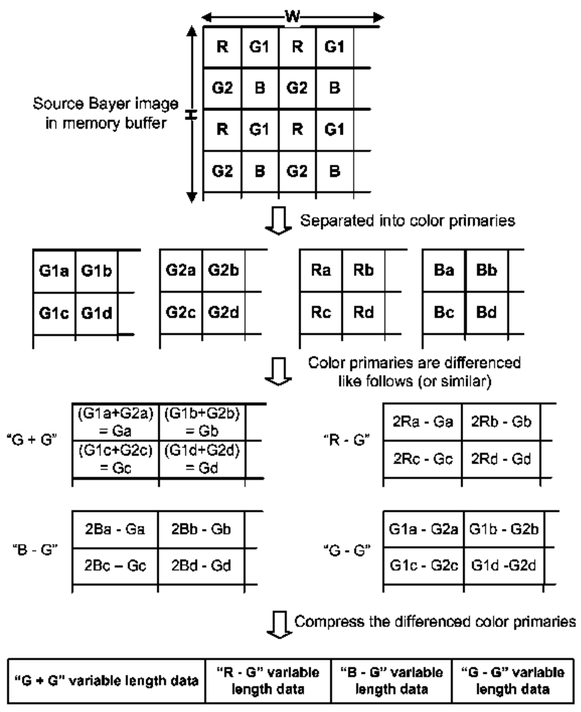
Primary Examiner — Phuoc Tran

(74) *Attorney, Agent, or Firm* — Fenwick & West LLP

(57) **ABSTRACT**

A method is described to greatly improve the efficiency of and reduce the complexity of image compression when using single-sensor color imagers for video acquisition. The method in addition allows for this new image compression type to be compatible with existing video processing tools, improving the workflow for film and television production.

18 Claims, 9 Drawing Sheets



Bayer compression with an example of color differencing

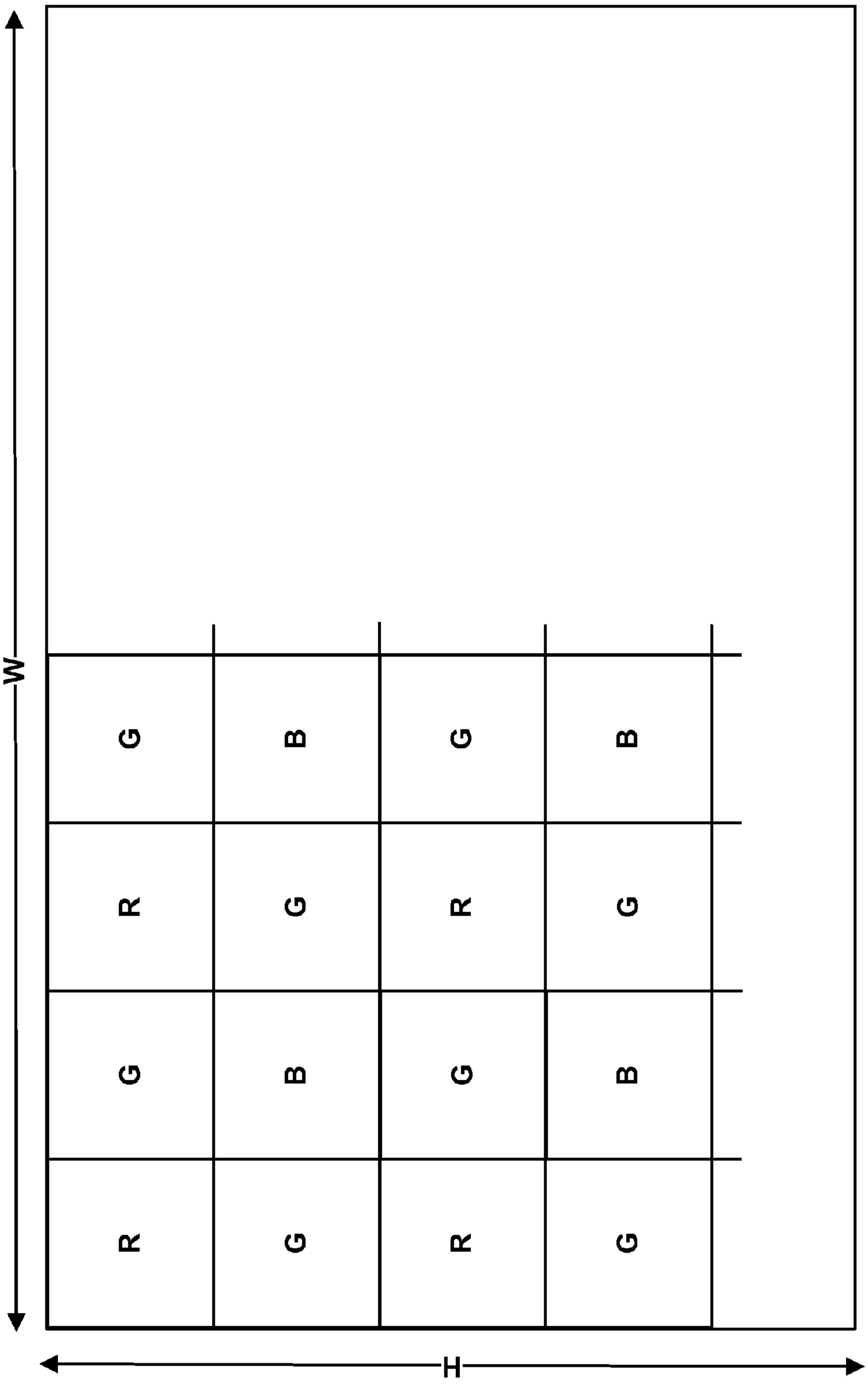


FIG. 1: Typical Bayer sensor

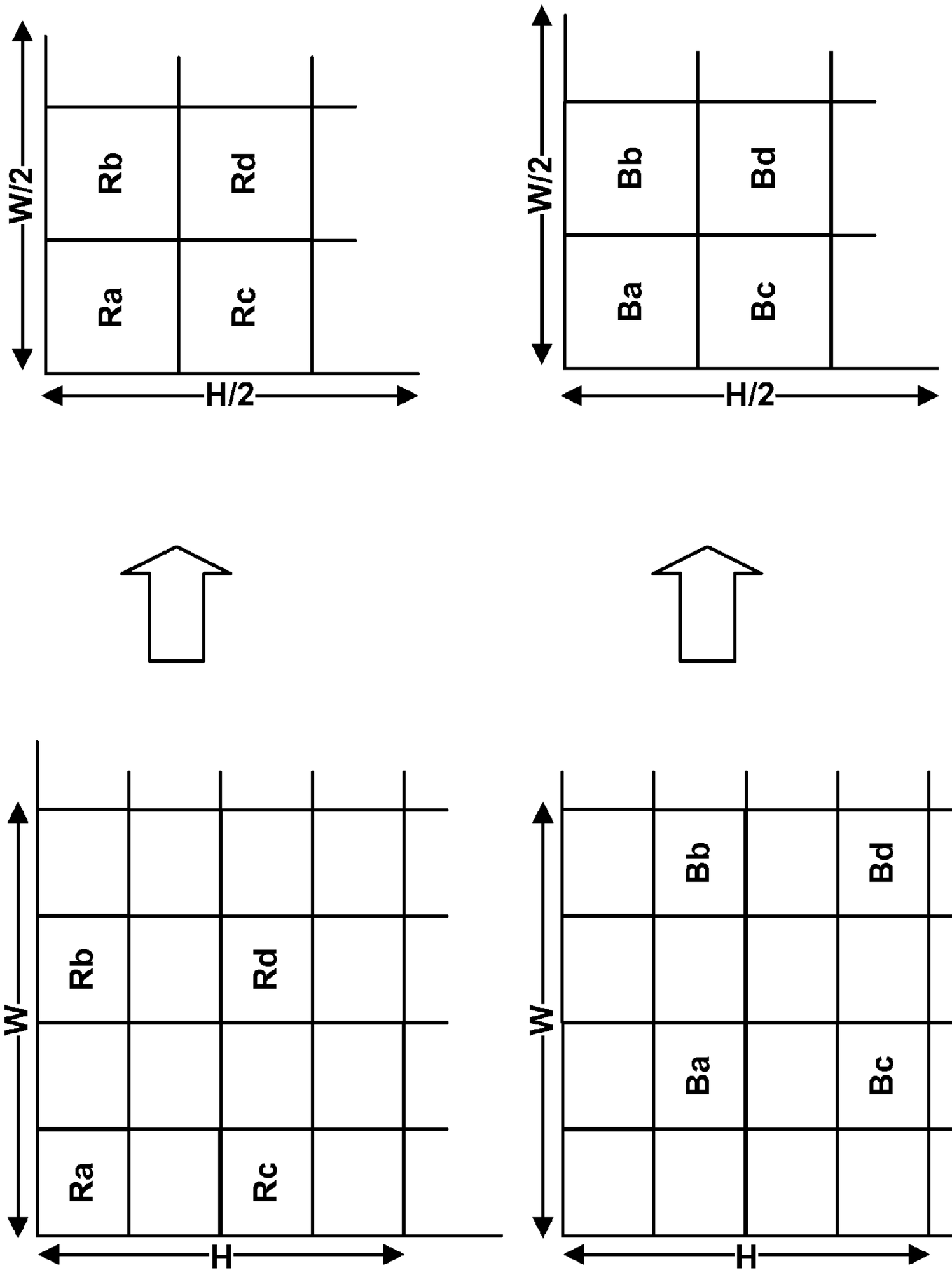


FIG. 2: Fast extraction of color primaries

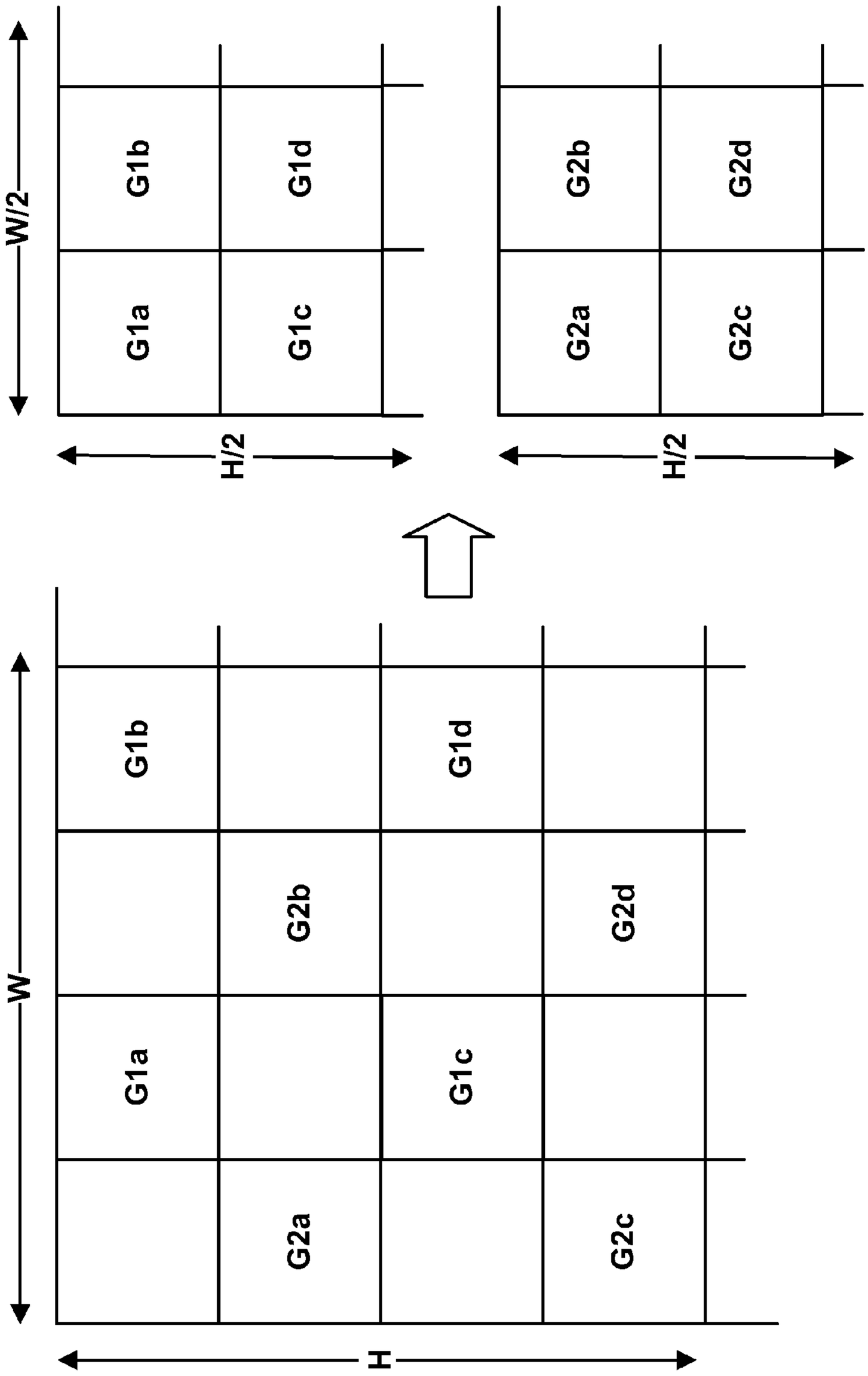


FIG. 3: Green pixel extraction into two planes

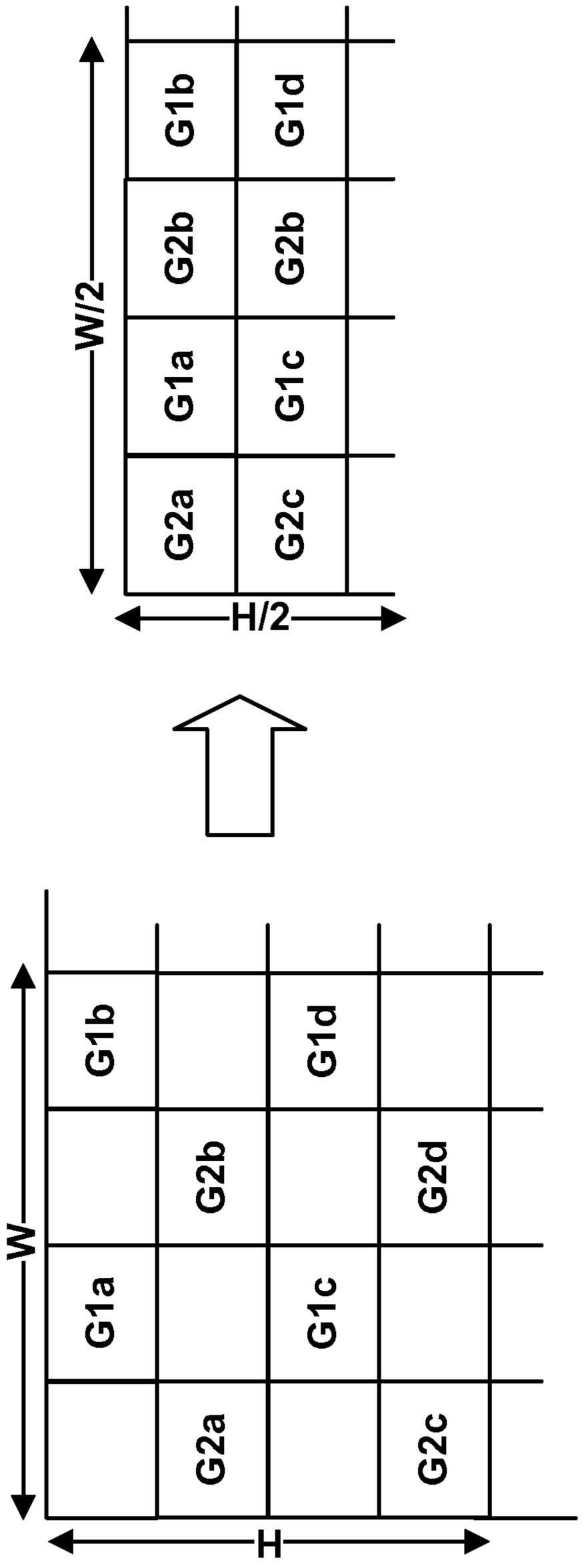


FIG. 4A: Alternative green pixel extraction into a single plane, although some uncorrelated elements

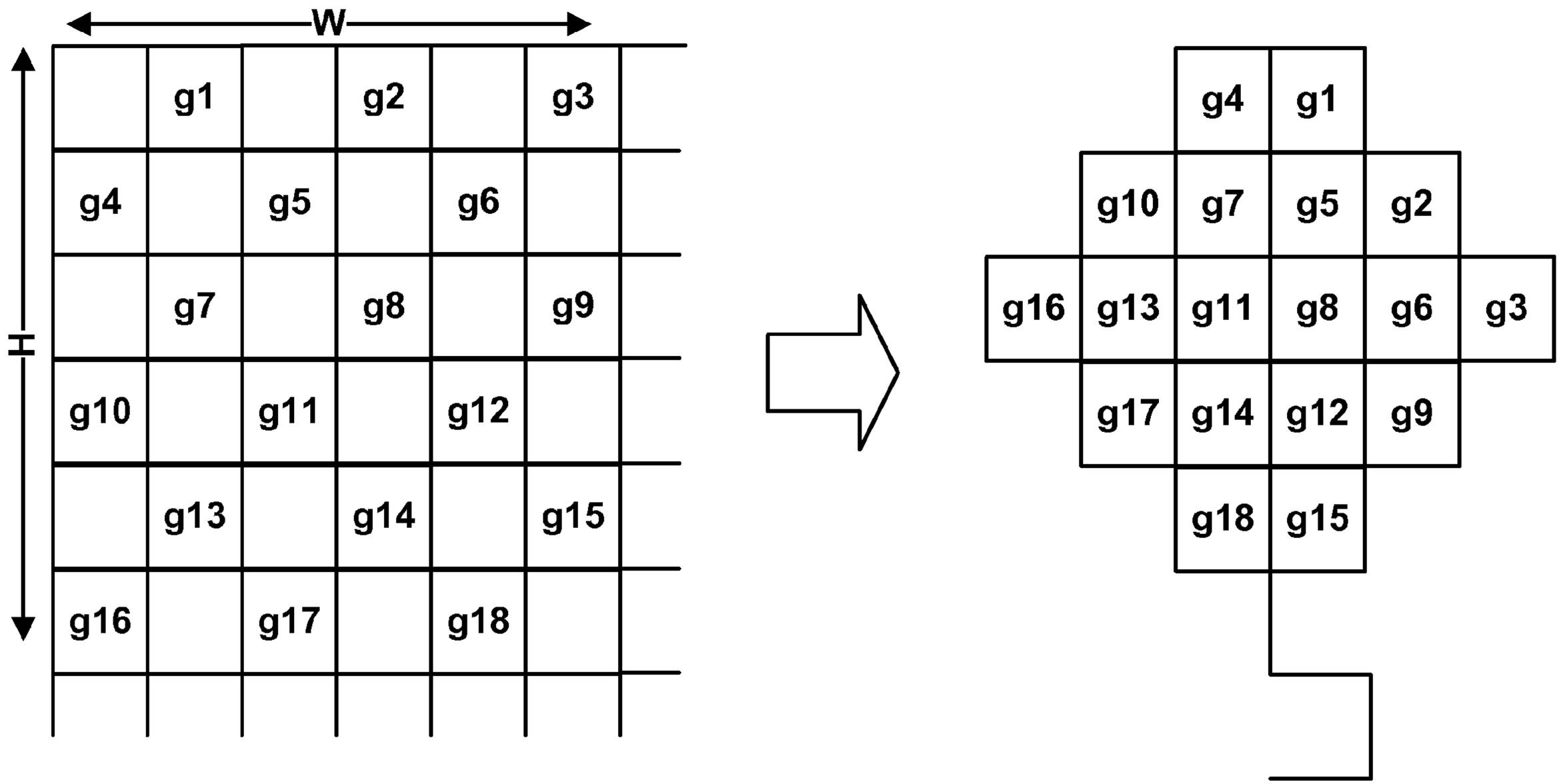
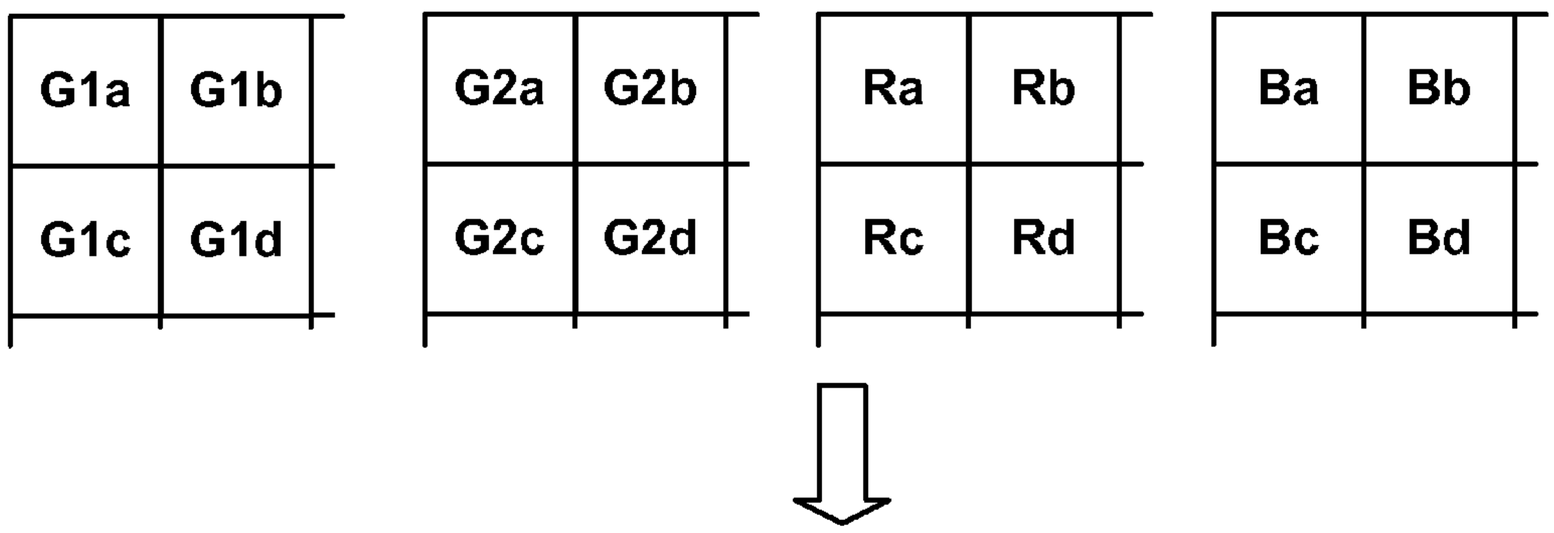


FIG. 4B: Alternative green pixel extraction into a single plane with high correlation elements but less convenient shape



(G1a + G2a) = Ga	(G1b + G2b) = Gb
(G1c + G2c) = Gc	(G1d + G2d) = Gd

FIG. 5A: New summed green plane

2Ra - Ga	2Rb - Gb
2Rc – Gc	2Rd - Gd

FIG. 5B: Red minus the summed Green pane

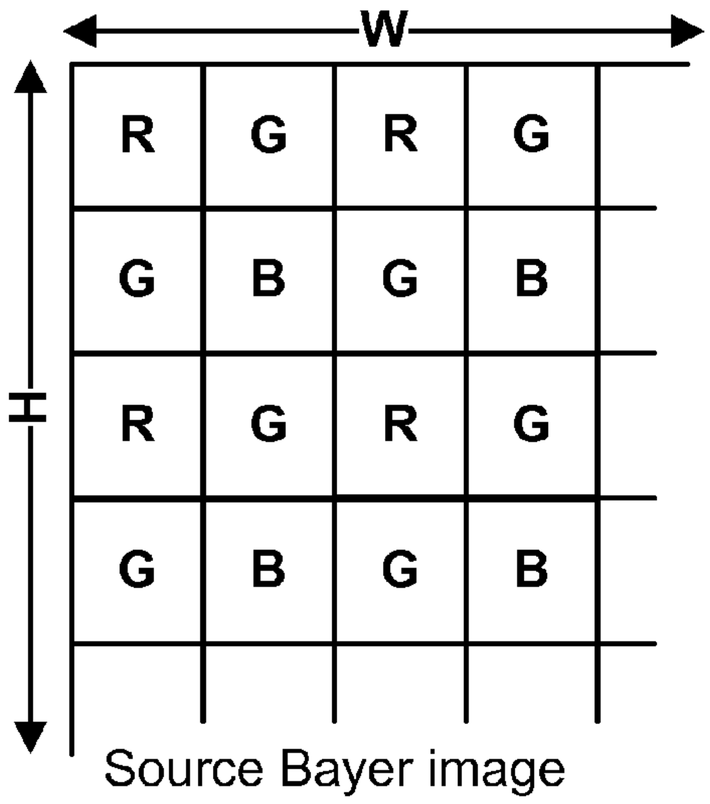
2Ba - Ga	2Bb - Gb
2Bc -Gc	2Bd - Gd

FIG. 5C: Blue minus the summed Green plane

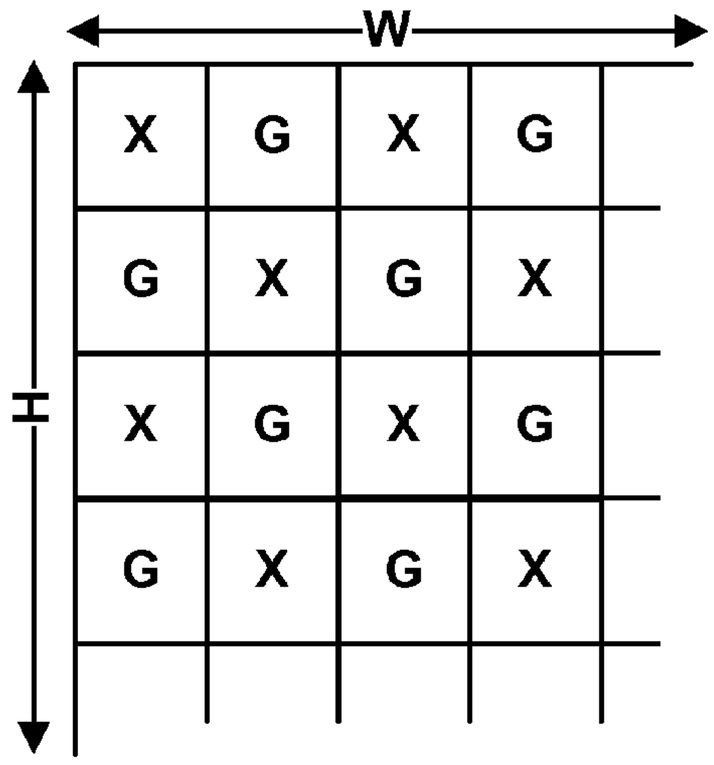
G1a – G2a	G1b – G2b
G1c – G2c	G1d – G2d

FIG. 5D: Green difference plane

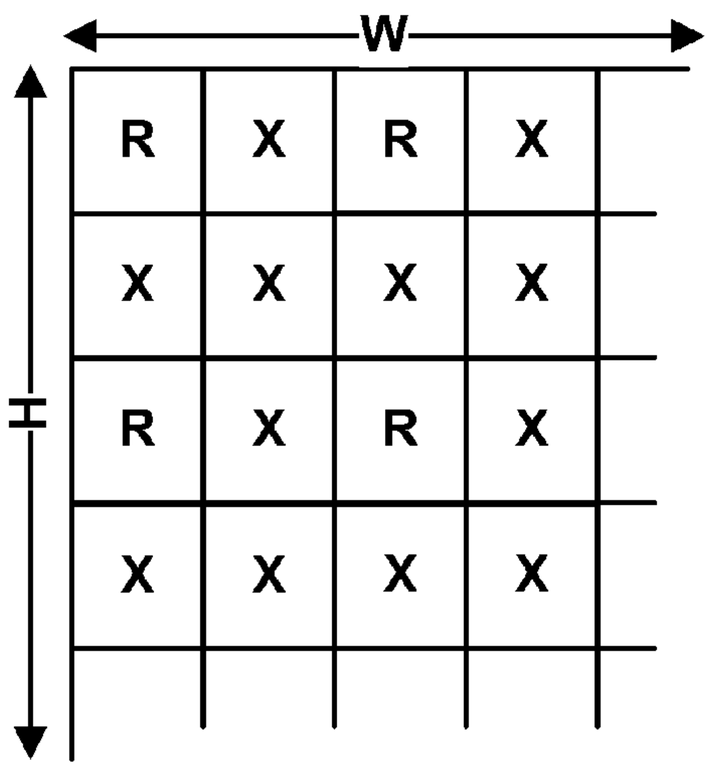
FIG. 5: Calculation of color difference planes



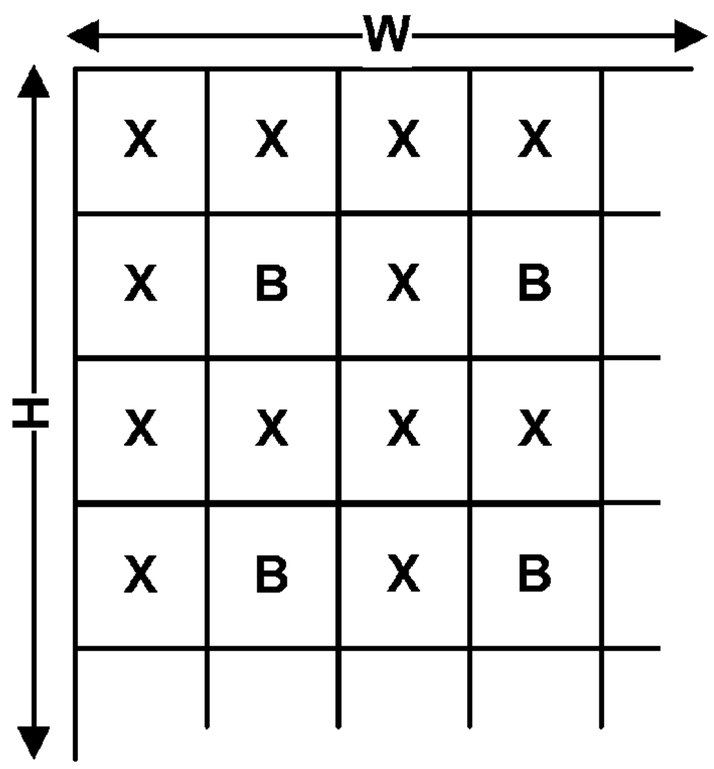
Source Bayer image



"X" locations interpolated for a full resoulution green plane.



"X" locations interpolated for a full resolution red plane.



"X" locations interpolated for a full resolution blue plane.

Note: the demosaicing algorithms for calculating the values at the "X" locations are many. Any de-mosaic/de-bayering technique can be used, although with varying quality.

FIG. 6: De-bayer Interpolation

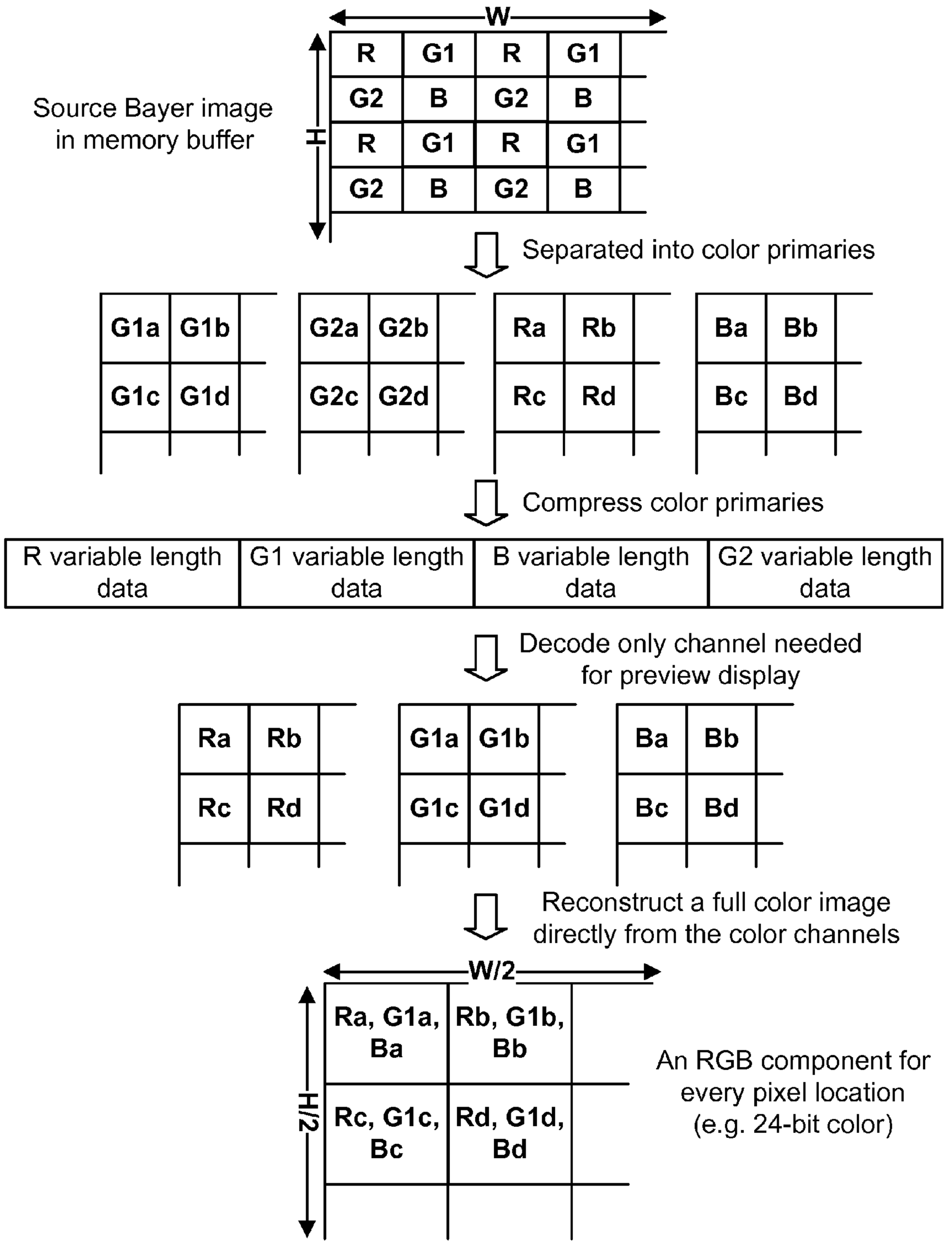


FIG. 7: Bayer compression with faster decode to an RGB display

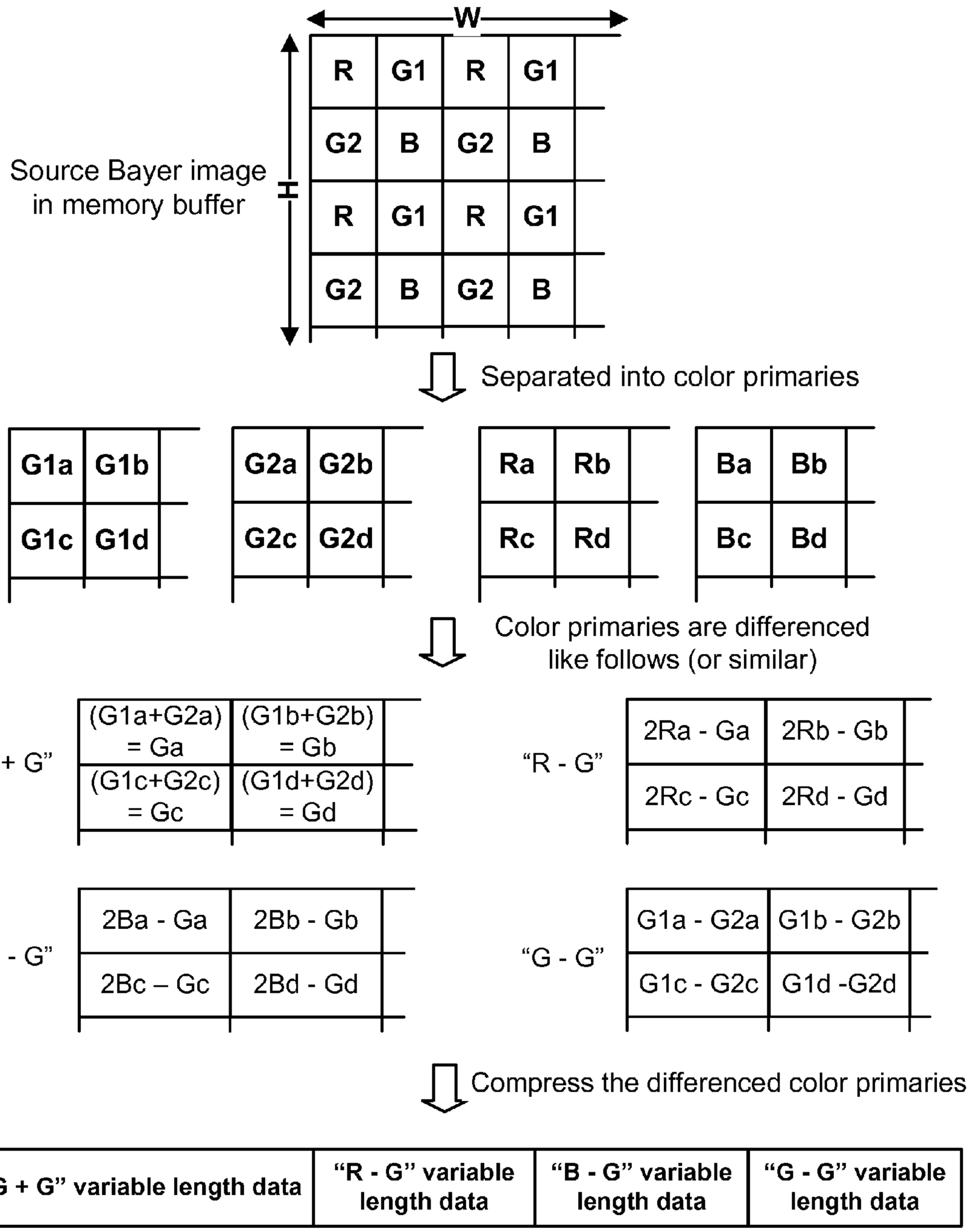


FIG. 8: Bayer compression with an example of color differencing

COMPRESSION AND DECODING OF SINGLE SENSOR COLOR IMAGE DATA

RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/222,549, filed Mar. 21, 2014, now issued as U.S. Pat. No. 8,879,861, which is a continuation of U.S. patent application Ser. No. 14/108,240, filed Dec. 16, 2013, now issued as U.S. Pat. No. 8,718,390, which is a continuation of U.S. patent application Ser. No. 13/968,423, filed Aug. 15, 2013, now issued as U.S. Pat. No. 8,644,629, which is a continuation of U.S. patent application Ser. No. 13/683,965, filed Nov. 21, 2012, now issued as U.S. Pat. No. 8,538,143, which is a continuation of U.S. patent application Ser. No. 13/196,175, filed Aug. 2, 2011, now issued as U.S. Pat. No. 8,345,969, which is a continuation of U.S. patent application Ser. No. 11/689,975, filed Mar. 22, 2007, now issued as U.S. Pat. No. 8,014,597, which claims the benefit under 35 U.S.C. §119(e) of Provisional Patent Application Ser. No. 60/784,866, entitled "Efficient Storage and Editing of High Resolution Single Sensor Color Video Data," filed Mar. 22, 2006. This application relates to U.S. patent application Ser. No. 10/779,335, entitled "System and Method for Encoding and Decoding Selectively Retrievable Representations of Video Content," filed Feb. 12, 2004. All of the foregoing applications are incorporated herein in their entirety by reference for all purposes.

FIELD OF THE ART

This present invention relates to compression and retrieval of video content gathered from a single-sensor imager.

BACKGROUND

Professional video cameras typically have three sensors to collect light, each filtered for red, green, and blue channels. Digital still photography typically does not employ a three-sensor design; digital still photography instead uses a single sensor design with individual pixels filtered for red, green, and blue (or other color primaries such as magenta, cyan and yellow.) This single-sensor color design is sometimes called a Bayer sensor, which is common in nearly all digital still cameras, both professional and consumer models. As the spatial resolution of video increases, there are numerous benefits in switching to the single-sensor Bayer design—as observed in some very high-end digital cinema cameras used for movie acquisition. Yet traditionally there are post-production workflow issues that arise when applying Bayer sensors to video applications.

Notably, image data collected from Bayer-pattern imagers (also known as RAW images) is neither YUV nor RGB, the most common color orientation expected by traditional post-production tools. This is true for both still cameras and emerging digital cinema cameras. This characteristic demands that existing industry tools either be "upgraded" so they are compatible with RAW images, or that new utilities be written that convert RAW images into traditional planar color spaces compatible with existing industry tools. The most common workflow employed by the industry today is to arithmetically convert RAW images into planar RGB images before common operations are performed, such as applying a saturation matrix or white balance, which is then followed by compressing or encoding the result into a smaller file size.

In order to extract full spatial and color information from a RAW image, a highly compute-intensive operation known as a "demosaic filter" must first be applied to each RAW image. The demosaic operation interpolates missing color primaries at each pixel location, as Bayer sensors only natively provide one primary color value per pixel location. These operations are generally performed by special algorithms residing inside the camera. In this situation the RAW image is never presented to the user, but instead the "developed" YUV or RGB image is presented to the user from the camera after internal processing, sometimes in the form of a compressed JPEG (or other compressed format) image. In the case of RAW modes on digital still cameras, some camera processing is delayed and performed outside the camera (most notably the compute-intensive demosaic processing). In this case the unprocessed RAW image is presented to the user from the camera, but prior to traditional YUV or RGB processing the demosaic (also known as de-Bayer) filter still must first be applied to the RAW image, but is done so outside the camera, yet the processing order described remains the same. The "developed" output of the de-Bayer filter operation is a planar image, usually RGB, but may also be other color primaries instead. A filter to correct color and contrast (compensating for sensor characteristics) is then applied to the planar image. Typically the planar image color space is further converted to a more compressible form such as YUV (common for DV, JPEG, or MPEG compression). The YUV image is compressed for delivery or storage, whether inside the camera or performed as a second step outside the camera.

In the RAW mode, some digital still cameras allow preprocessed sensor data to be written to the file along with metadata describing the cameras settings. A still-camera RAW mode does not achieve the workflow benefits described here, as it does not allow easy or fast previews, and the images can only be displayed by tools designed to understand the RAW format from Bayer-pattern imagers.

SUMMARY

Exemplary embodiments of the invention that are shown in the drawings are summarized below. These and other embodiments are more fully described in the detailed description section. It is to be understood, however, that there is no intention to limit the invention to the forms described in this Summary of the Invention or in the detailed description. One skilled in the art can recognize that there are numerous modifications, equivalents and alternative constructions that fall within the spirit and scope of the invention as expressed in the claims.

Embodiments of the invention describe systems and methods for effecting RAW Bayer compression using a camera by itself or an external device that performs the Bayer compression. In both cases this compressed stream is stored to a disk or memory system for later review and editing. During the review and editing stages, embodiments of the invention enable the new compressed video type to operate seamlessly within existing post production tools, without modification to those tools.

BRIEF DESCRIPTION OF THE DRAWINGS

Various objects and advantages plus a more complete understanding of the invention are apparent and more readily appreciated by reference to the following detailed description and to the appended claims when taken in conjunction with the accompanying drawings wherein:

FIG. **1** shows the primary color layout for a typical "Bayer" image sensor which consists of twice as many green cells/

pixels as red or blue cells. These pixels or cells are most commonly arranged in a 2×2 pixel grid as shown here.

FIG. **2** shows the separation of the red and blue channel color primaries into independent half-resolution channels.

FIG. **3** shows the separation of the green primary into two highly correlated channels.

FIG. **4**A shows an alternative separation of the green primary into one channel with reduced correlation, but still effective.

FIG. **4**B shows an alternative separation of green into a single channel that is highly correlated, but with an image shape that would require more advanced processing during compression.

FIG. **5***a* shows an implementation of green color summation, according to one embodiment.

FIG. **5***b* shows an implementation of red-green color differencing, according to one embodiment.

FIG. **5***c* shows an implementation of blue-green color differencing, according to one embodiment.

FIG. **5***d* shows an implementation of green color differencing, according to one embodiment.

FIG. **6** shows the pixels that are derived through de-Bayer filtering.

FIG. **7** shows an overview of Bayer compression for preview presentation.

FIG. **8** shows an overview of Bayer compression using color differencing.

DETAILED DESCRIPTION

The invention allows for video images from Bayer-style cameras to be processed in high resolution far more efficiently than the current state of the art. The interleaved color components within a Bayer sensor are typically arranged in 2×2 pixel squares over the entire image with red and green on the top pair, and green and blue on the bottom of each 2×2 pixel array. This pattern of interleaved red, green and blue pixels is problematic for compression as a single image because the spatially adjacent pixels are much less correlated and therefore less compressible than a plane of monochrome data. Compression operates most effectively when adjacent pixels have a high likelihood of being similar, yet in a Bayer image the adjacent pixels are filtered for different color primaries, so pixel magnitudes will vary greatly. Attempting direct compression of a Bayer image using common techniques such as DCT or wavelet compression will either result in little or no reduction of data size, or a significant amount of image distortion. This invention allows higher compression without introducing visually-damaging distortion of the image, using existing compression technologies like DCT and wavelet.

A single high definition Bayer frame of 1920×1080 interleaved red, green, and blue pixels can be separated into four planes of quarter-resolution images, each consisting 960×540 pixels of either the red component, blue component, or one of the two green components. If red is the upper left pixel of the frame, a correlated red plane is fetched by reading every second pixel on every other scan-line. The same technique can be applied for all colors so that each plane contains the signal for one color primary. For the most common RGGB Bayer pattern imager, there are two green planes for each red and blue plane. It is possible to encode each of the planes using common compression techniques (DCT, Wavelet, etc.) such that significant data reduction is achieved without significant quality impacts. However, more compression may be obtained by differencing the channels in the following manner:

G=green plane**1**+green plane**2**

R−G=2×red plane−G

B−G=2×blue plane−G

D=green plane**1**−green plane**2** (D for difference between the green planes)

These modified image planes are encoded (e.g., compressed) just as they would if they were separate planes of R, G and B, or Y, U and V components. Other planar differencing algorithms could be used to decrease the size of the compressed data output yielding a similar result. Reordering the data into planes of the color primaries is not compute intensive, and the operation is reversible. No data is added or lost as it is with de-Bayer processing.

De-Bayer filtering (or demosaicing) is the process of interpolating the missing color components at every pixel location. As acquired, the Bayer sensor only collects one of the three color primaries at every pixel site—the two other primaries are predicted via a range of different algorithms that typically take substantial compute time for high quality results. In the above 1920×1080 encoding example, the compressed video image produced will be smaller in data size yet higher in visual quality than results from existing techniques used in today's video cameras. If a Bayer image is to be compressed in a format like MPEG or HOV, then de-Bayering (a.k.a. demosaicing) will expand the single plane of 1920×1080 pixel data into three 1920×1080 planes, one for each color primary. This increases the size of the data by 3×, and does not benefit the compression (much larger compressed files result), and potentially introduces visual artifacts depending on the choice of de-Bayer filter applied (no de-Bayer algorithm is ideal). Although disadvantages (larger file sizes and visual impairments) are clearly evident in this example, this is the standard approach used in single-sensor video cameras. By encoding four quarter-resolution planes versus three full-resolution planes, the computational load is greatly reduced, allowing for simpler implementations and longer camera battery life. The size of the compressed data is reduced significantly, allowing for longer record times or alternatively reduced storage requirements for the captured video.

Although advantages for encoding four quarter-resolution planes are evident, the resulting compressed image would not be playable using typical hardware or software tools, as no viewing or editing tools anticipate four quarter-resolution planes instead of three full-resolution planes. A modification to the decompression algorithm will solve this problem. By way of example, a traditional three-plane 1920×1080 encoding would present a full-resolution 1920×1080 image upon decode. The codec, which is a combination of the compressor and the decompressor, is just a black box to the viewer or editing tool. Codecs normally are intended to precisely reproduce their input(s). In this invention, the decoder will change its default behavior depending on how it is being used, and modify its output as needed by the application. For fast preview/playback the decoder will reconstruct the image at quarter resolution of the source (in this example 960×540), and to do this it only needs to decode Channel G, R-G and B-G to provide a standard RGB image to the requesting tool. As this is just for preview, the reconstructed RGB planes require no de-Bayer step to produce a good quality video output. Further, decoding of three quarter-resolution channels is significantly faster than decoding three full-resolution channels, resulting in reduced costs of the player and editing system. The decreased resolution is of minor or no issue for preview applications within post-production for film or television, and is in fact an advantage in many situations, yet this would not be suitable for a live event where high-quality full-resolution

decoding is needed immediately (for live projects more traditional camera processing is better suited). Fortunately most video productions undergo a shot selection process and editing stage, which is one area where this invention is well-suited.

By way of example, a fast decode mode may perform the following method outlined in the following paragraphs. During the fast decode mode, only the necessary planes are decompressed. If the unmodified red, green**1**, green**2**, and blue planes were encoded, only one of the two green channels needs to be presented for preview. This selection of decoding three of the four channels offers additional performance. When color differencing is applied, the RGB planes would be reconstructed as follows:

Red plane=(R−G+G) divide **2**

Green plane=G divide **2**

Blue plane=(B−G+G) divide **2**

The fourth channel of the two differenced green channels in not required for a preview playback. The resulting three color primary channels can be presented to the playback/editing application as a standard quarter-resolution image, even though those channels were originally derived from a larger Bayer image. The slight spatial offset of each color plane, such as red pixels being sampled from a slightly different location than the blue or green pixels, does not present an issue for fast preview/playback. The image quality is high. The three color channels are typically interleaved in a RGBRGBRGB . . . format for display. Each pixel now has the needed three primary colors for display. As an optional step, if the application can only support full resolution (versus quarter resolution), then using a simple bi-linear interpolation or pixel duplication may be performed by the decoder on the quarter-resolution image to quickly convert it to a full-resolution RGB image. This operation is significantly faster than performing a high-quality demosaic filter in real time. For higher quality full-resolution presentation, the decoder performs de-Bayer filtering so the post-production tools can manipulate a traditional full-resolution image. DeBayer filtering is slow because it is highly compute intensive, and certain embodiments of the invention allow transfer of the processing from the camera to the post-production stage at which point the processing is typically performed on powerful computer workstations and is more suited to high-quality de-Bayer processing. Workflow also gains efficiency through this change, For example, a film or television production will on average record 20 times the length of source footage as compared with the length of the edited product. In this example, a two-hour movie will likely have 40 hours of source footage. The compute-expensive de-Bayer processing is now only needed on 5% on the acquired video because it is performed at the end of the workflow instead of at the beginning In addition, the review process to select this 5% of the video is now easier and faster because the data size and computational load are much smaller. This compares to more traditional handling of Bayer-format source data on which de-mosaic processing must be performed on 100% of the data before it is even viewable.

By way of a new example, a full-resolution decode mode may perform the method outlined in the following paragraphs. During the full-resolution decode mode, all four quarter-resolution planes are decoded. Any color-plane differencing is reversed so that planes of red, green**1**, green**2** and blue are restored. The resulting planes are interleaved back into the original Bayer layout, and the result of the decode now matches the original source image. A de-Bayer operation is performed to convert the image into a full raster RGB frame and this result is presented to the calling application.

De-Bayer filters are typically non-linear filters designed with flexibility to offer a significant range of characteristics. Because of this, the style of de-Bayer filter may be selectable, either directly by the user or automatically via the type of operation being performed by the editing tools. As an example, the "export" mode from an NLE, when the result is intended to be transferred to film for viewing, would use the highest quality de-Bayer filter, whereas scrubbing the timeline in a nonlinear editor would use a simpler/faster filter).

One skilled in the art will recognize that, because the original video data size is unwieldy, today's post-production world typically scales high-resolution images to approximately one-quarter resolution to select shots for editing. This technique is called "offline" editing. Once an offline edit session is completed, a "conform" process is used to gather only the necessary full-resolution files (e.g., now 5% of the source—although the large full-resolution files have to be archived somewhere) to complete the TV/feature production. Certain embodiments of the invention achieve much the same workflow without the expensive steps of image scaling and conforming, and offer much smaller archival storage requirements. This novel new workflow is further enhanced by allowing full-resolution decodes whenever the editing/user needs, which is not possible in offline editing. Switching between very fast preview-decode and full-resolution de-Bayer output is made automatically in one embodiment. For example, playback and review may use the fast decode mode, while single-frame review and export may be performed at full resolution.

When the de-Bayer operation is not performed in the camera, the choices for post-production image enhancement are greatly improved. For example, the selection of the specific de-Bayer filter can be made after post-production when the edited material is exported to its final presentation format. A lower quality, but more efficient, de-Bayer filter can be used for real-time preview during editing and a higher quality algorithm, which may be computationally slower, can be used for export (e.g., to film or a digital presentation format). Workflow is improved further because preprocessed sensor data is better for adjusting color characteristics such as white balance, contrast and saturation during post-production.

Embodiments of the invention may be used to improve any existing compression algorithm for encoding and decoding. No new compression technologies are required to enable direct Bayer processing. For example, algorithms including DCT, wavelet, or others can be used. The compression can be lossy or lossless. The codec must decode to the format used by the post-production tools, otherwise the tools would need to be updated to be aware of the new format. To maintain compatibility with the widest range of video applications the Bayer codec is wrapped in one or more of the standard media interfaces, such as QuickTime, DirectShow, Video for Windows, etc. These media interfaces allow existing applications to gain support for new media types, without requiring any internal knowledge of the media's structure. By using the standard codec wrapper of these common media interfaces, even RAW data can be presented to an application by developing the image to the format requirements of the calling application. Video cameras that offer codec-less (uncompressed) raw acquisition, and which do not abstract the format through a codec wrapper, require special tools within post-production to convert this data into a more traditional form before review and editing can begin, introducing a cumbersome workflow.

Those skilled in the art can readily recognize that numerous variations and substitutions may be made in the invention, its use and its configuration to achieve substantially the same

results as achieved by the embodiments described herein. Accordingly, there is no intention to limit the invention to the disclosed exemplary forms. Many variations, modifications and alternative constructions fall within the scope and spirit of the disclosed invention as expressed in the claims.

What is claimed is:

1. A method for decoding an encoded image, the method comprising:

storing encoded image data in a non-transitory computer-readable storage medium, the encoded image data representative of an original image at an original resolution, the original image comprising a plurality of image planes, the encoded image data comprising a set of encoded image planes each representative of one or more of the image planes of the original image;

receiving a request for a preview of the original image, the requested preview comprising the original image at a preview resolution less than the original resolution; and

in response to receiving the request for a preview of the original image:

accessing a subset of the set of encoded image planes, the subset comprising less than all of the set of encoded image planes; and

decoding, by a processor, the accessed subset of encoded image planes to produce the original image at the preview resolution.

2. The method of claim **1**, wherein the preview resolution comprises a resolution that is one-quarter the resolution of the original resolution.

3. The method of claim **1**, wherein the set of encoded image planes comprises a first encoded image plane representative of a first color and a second encoded image plane representative of the first color, and wherein the subset of the set of encoded image planes comprises only one of the first encoded image plane and the second encoded image plane.

4. The method of claim **1**, wherein decoding the accessed subset of the set of encoded image planes comprises:

decoding one or more of the accessed subset of the set of encoded image planes to produce a subset of the plurality of original image planes comprising less than all of the plurality of original image planes; and

combining the subset of the plurality of original image planes to produce the original image at the preview resolution.

5. The method of claim **4**, wherein decoding the accessed subset of the set of encoded image planes further comprises:

decoding one of the accessed subset of encoded image planes to produce a preview image plane representative of two original image planes; and

combining the preview image plane and the subset of the plurality of original image planes to produce the original image at the preview resolution.

6. The method of claim **5**, wherein decoding one of the accessed subset of encoded image planes comprises decoding an encoded image plane comprising an average of the two original image planes.

7. The method of claim **6**, wherein the two original image planes are representative of the same color.

8. The method of claim **1**, wherein each pixel of the original image at the preview resolution comprises a red sub-pixel, a blue sub-pixel, and a green sub-pixel.

9. The method of claim **1**, wherein each pixel of the original image at the original resolution comprises a red sub-pixel, a blue sub-pixel, a first green sub-pixel, and a second green sub-pixel.

10. A system for decoding an encoded image, the system comprising:

a non-transitory computer-readable storage medium configured to store encoded image data, the encoded image data representative of an original image at an original resolution, the original image comprising a plurality of image planes, the encoded image data comprising a set of encoded image planes each representative of one or more of the image planes of the original image;

an input configured to receive a request for a preview of the original image, the requested preview comprising the original image at a preview resolution less than the original resolution; and

a decoder configured to, in response to receiving the request for a preview of the original image:

access a subset of the set of encoded image planes, the subset comprising less than all of the set of encoded image planes; and

decode the accessed subset of encoded image planes to produce the original image at the preview resolution.

11. The system of claim **10**, wherein the preview resolution comprises a resolution that is one-quarter the resolution of the original resolution.

12. The system of claim **10**, wherein the set of encoded image planes comprises a first encoded image plane representative of a first color and a second encoded image plane representative of the first color, and wherein the subset of the set of encoded image planes comprises only one of the first encoded image plane and the second encoded image plane.

13. The system of claim **10**, wherein decoding the accessed subset of the set of encoded image planes comprises:

decoding one or more of the accessed subset of the set of encoded image planes to produce a subset of the plurality of original image planes comprising less than all of the plurality of original image planes; and

combining the subset of the plurality of original image planes to produce the original image at the preview resolution.

14. The system of claim **13**, wherein decoding the accessed subset of the set of encoded image planes further comprises:

decoding one of the accessed subset of encoded image planes to produce a preview image plane representative of two original image planes; and

combining the preview image plane and the subset of the plurality of original image planes to produce the original image at the preview resolution.

15. The system of claim **14**, wherein decoding one of the accessed subset of encoded image planes comprises decoding an encoded image plane comprising an average of the two original image planes.

16. The system of claim **15**, wherein the two original image planes are representative of the same color.

17. The system of claim **10**, wherein each pixel of the original image at the preview resolution comprises a red sub-pixel, a blue sub-pixel, and a green sub-pixel.

18. The system of claim **10**, wherein each pixel of the original image at the original resolution comprises a red sub-pixel, a blue sub-pixel, a first green sub-pixel, and a second green sub-pixel.

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