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(54) Titre : COMPOSITION NUMERIQUE D'UNE IMAGE MOSAIQUE
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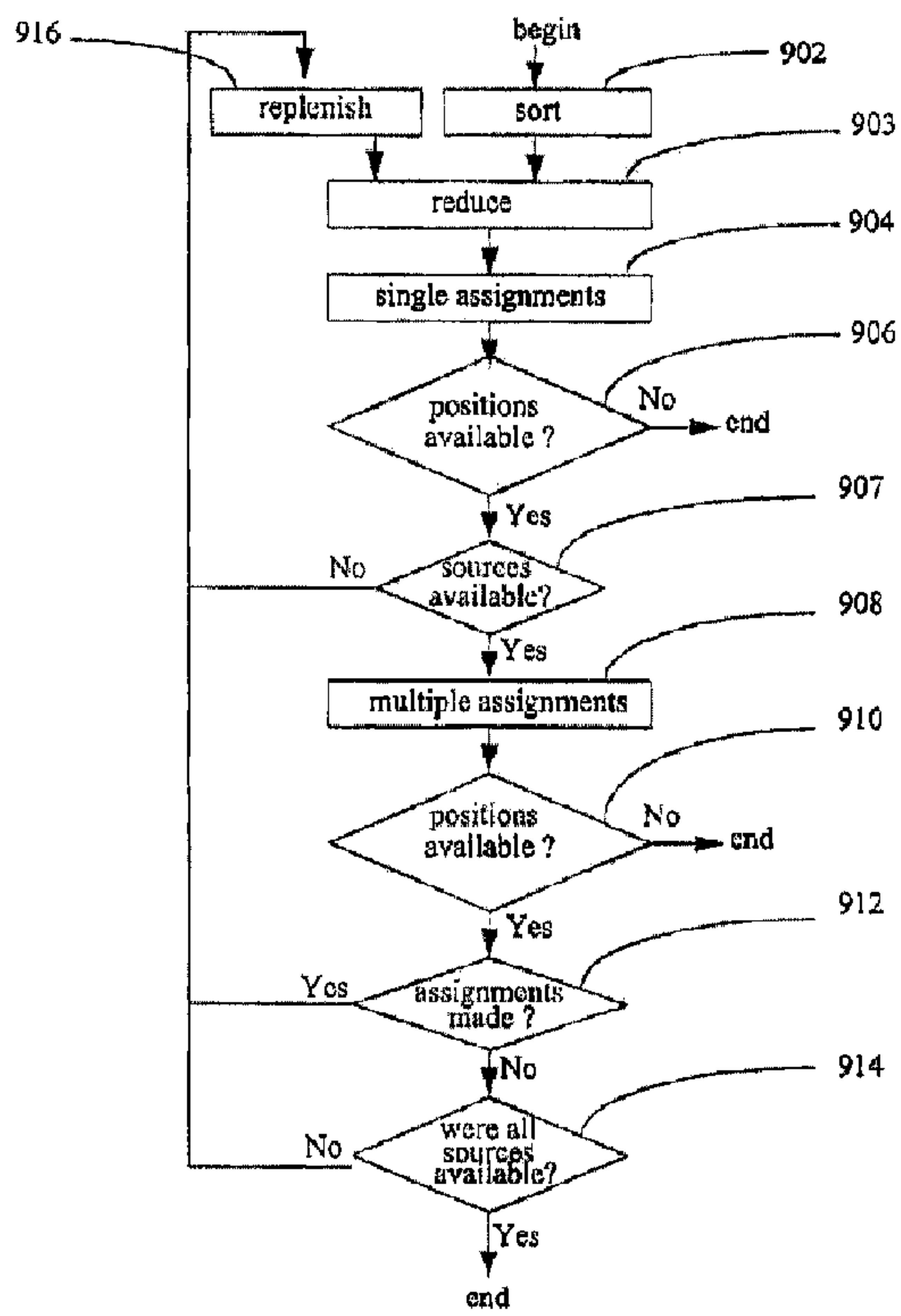


(57) Abrégé/Abstract:
A mosaic image resembling a target image is composed of images from a data base. The target image is divided into regions of a specified size and shape, and the individual images from the data base are compared to each region to find the best matching tile. The comparison is performed by calculating a figure of visual difference between each tile and each region. The data base of tile images is created from raw source images using digital image processing, whereby multiple instances of each individual raw source image are produced. The tile images are organized by subject matter, and tile matching is performed such that all required subject matters are represented in the final mosaic. The digital image processing involves the adjustment of colour, brightness and contrast of tile images, as well as cropping. An image description index locates each image in the final mosaic.

Title: Digital composition of a mosaic image

[1] Inventor: Aryan Saèd

References:

[2] US Patent 6137498, October 24 2000, Silvers, 345/629

[3] US Patent Application Publication 2003/0001858 A1, January 2 2003, Jack, 345/582

Abstract

[4] A mosaic image resembling a target image is composed of images from a data base. The target image is divided into regions of a specified size and shape, and the individual images from the data base are compared to each region to find the best matching tile. The comparison is performed by calculating a figure of visual difference between each tile and each region. The data base of tile images is created from raw source images using digital image processing, whereby multiple instances of each individual raw source image are produced. The tile images are organized by subject matter, and tile matching is performed such that all required subject matters are represented in the final mosaic. The digital image processing involves the adjustment of colour, brightness and contrast of tile images, as well as cropping. An image description index locates each image in the final mosaic.

Background - Field of Invention

[5] The present invention relates generally to the computerized composition of images from a plurality of source images. More specifically, the composed image resembles a target image, whereby the target image and the source images are photographic images or frames from motion video. The composition of an image from a plurality of other images is a well known method to create artistically pleasing effects.

Background - Discussion of Prior Art

[6] Mosaic images are increasingly popular in the field of graphic design and graphic art. Whereas traditionally mosaic images were manually composed, such collages are now generally composed using digital search and matching techniques in specialised computer software. With such software it is possible to create mosaics containing hundreds and even thousands of images by automatically placing images from thousands of raw source images in a digital image library in a mosaic. These library images are typically digital still pictures (photographs) or digital snapshots from motion video.

[7] The art of manual composition of a mosaic image precedes the art of digital composition. In either case, the artist composes a collage of images that, when seen from a distance, resembles a different image. That different image, the target image, is often a portrait of a person. The more source images are available to the artist, the more choice the artist has to find a suitable match for a region in order to achieve optimum visual effect.

[8] U.S. patent 6137498 to Silvers describes a computerized method to compare regions of a digital target image with digital images from a data base. Specifically the method describes how for each tile of a target image, the best matching image in a specified data base of source images is found.

[9] A limitation of the method described in patent 6137498 lies in the required number of source images. To obtain an optically and artistically pleasing end result, a data base containing thousands or ten thousands of individual images is required. A large data base is desirable since it would ensure to some degree that images covering a broad visual range are provided. A broad visual range would entail, for instance, images ranging from very dark to very light, and images ranging from having a dark area against a light background to images having a light area against a dark background. Image data bases containing large number of images are available publicly, and the larger the data base, the better the final outcome. It is beneficial to invent a method for composing pleasing mosaic images from smaller data bases. Smaller sized private data bases consist for instance of private photographs, and using the prior art, such a data base may yield a less than pleasing mosaic due to the limitations imposed by the size of the data base and the resulting limited visual range of the source images. For instance, the smaller data base may not contain sufficient dark images, or dark images with lighter areas. As a result, an image that is considered the best match for a particular region in the mosaic in comparison to all other images, may actually turn out not to produce a visually pleasing match.

[10] A second limitation lies in the matching method. The described method is tailored for large image data bases. For each tile of the target image, the described matching method finds the best source image in the data base. Hence, the method cannot guarantee the insertion of specific or all source images of the data base. Not only is this a result of the matching method itself, it is also a side effect of the underlying desire to use large data bases. Clearly, if a data base contains thousands of images, as desired, a mosaic composed of hundreds of tiles can impossibly contain all the images in that data base. In some prior art an effort is made to guarantee the insertion of a small number of tile images (in relation to the total number of tile images in the mosaic), but not all tile images. It is hence beneficial to invent a matching method that enables the placement of select or all source images of a data base, resulting in a mosaic that better represents the images in a data base. For instance, if a mosaic is to be composed using a data base of photographs taken at a private event, and if all participants at the event were pottered in one or more photographs in the data base, it is beneficial if all participants are represented in the mosaic.

[11] A third limitation lies in the cropping method. The set of source images is generated from a set of raw source images by cropping each raw source image to a square or rectangle of specified size. In prior art the purpose of cropping is to produce source images of a desired shape regardless the shape of the underlying raw source image. For instance, this allows an entire data base consisting of digital photographs with a variety of aspect ratios (square, 3:4 and 9:16 rectangles) to be used for mosaic tiles of any aspect ratio. For simplicity and to enable automation, each crop is performed from centre to ensure that the centered subject matter of a tile (an object, a person etc.) appears in the crop and is not cut out.

[12] When the data base is of limited size, it is beneficial to produce multiple different crops based on a given aspect ratio, and to let a matching method determine which crop is best suitable to be applied to a source image for a given region in the final mosaic.

[13] US Patent Application Publication 2003/0001858 A1, to Jack, describes a method for creating a mosaic image whereby tile images represent single pixels of the traget image. The publication further describes the enhancement of the target image itself and modification of the colour of the selected tile image for a particular tile region based on the colour of the underlying pixie in the target image. The publication further describes the automatic creation of tile images using pattern recognition techniques. Each occurrence of a pattern (e.g. a person's face) in a raw source image leads to the creation of a tile image based on the identified pattern. For instance,

a photograph of two people leads to the creation of two tile images from that photograph, each tile image covering the area of the photograph in which a set pattern (a person's face) has been found.

Brief Description of Drawings

[14] The invention will now be described in greater detail having reference to the attached drawings, wherein:
Figure 1 describes the general concept of the invention;
Figure 2A illustrates the application of cropping boundaries and centered crops;
Figure 2B illustrates the application of scattered crops;
Figure 3A describes the calculation of centered crop frames;
Figure 3B illustrates several centered crop frames;
Figures 4A, 4B, 4C, 4D, and 4E illustrate several scattered and mixed crop frames;
Figure 5 illustrates the application of contrast and brightness adjustment.

[15] Figure 6A illustrates the range of allowable contrast and brightness adjustments based on a limiting rectangle;
Figure 6B illustrates the range of allowable contrast and brightness adjustments based on a limiting polygon;
Figure 7 illustrates the relationship between subject matters, source images, renditions, candidate renditions and individual tile regions of a target image;
Figure 8 illustrates a possible preferred candidate for each tile region;
Figure 9 illustrates the case whereby there is one raw source image per subject matter, and only one rendition per raw source image.

[16] Figure 10 describes the flow of operations for the search stage of the present invention;
Figure 11, is a sample disparity matrix representing figures of visual difference;
Figure 12 illustrates the removal of rows and columns based on tile region assignments;
Figure 13 illustrates the composition of sub-matrices for a multiple source image and tile region assignment;
Figure 14 illustrates the replenishment of available source images as part of the iteration steps.

Summary of the Invention

[17] A method for generating a mosaic image with an appearance that approximates a target
image by utilizing a plurality of tile images and a computer, comprising the steps of loading the target image into the computer, dividing the target image into a plurality of tile regions, each tile region representing a distinct locus of the target image, and

for each tile region: dividing the tile region into distinct sub-regions; to produce a measurement of visual similarity, said comparing step including comparing each sub-region of the tile region with a corresponding portion of each source image to produce the measurement of visual similarity; selecting the tile region with the highest measurement of visual similarity to be represented by the tile image and positioning the selected source image in the mosaic at a locus corresponding to the locus of the tile region.

[18] A method for generating a plurality of tile images from a single raw source image by appling digital image processing to said raw source image.

Description of the Invention

[19] In the following, Adobe PhotoShop is photo editing software by Adobe Systems Incorporated. Adobe and Photoshop are either registered trademarks or trademarks of Adobe Systems Incorporated in the United States and/or other countries.

[20] Referring to **FIGURE 1,** in the prior art of the generation of a digital mosaic image, a black and white image is a target image **101** in the composition of a color mosaic **103**. The mosaic is composed of square shaped tile images, one of which is tile image 105, that are arranged in a regular grid **102.** The appearance of the mosaic resembles that of the target image.

[21] The grid divides the target image into corresponding tile regions, one of which is tile region **106**. For each individual tile region, tile images from a data base **104** of tile images are compared to the tile region, to produce a figure of visual difference. The tile image with the lowest figure of visual difference is selected to represent the tile region and it is positioned at the corresponding location in the mosaic.

[22] The process of generating a mosaic hence consists of a search phase, whereby for each tile region best suited tile image is found, and a composition phase whereby a mosaic image is rendered through the placement of the best suited tile image in the corresponding location.

[23] If a mosaic is composed of M-by-N tiles (M tiles in vertical direction, N tiles in horizontal direction), and if each tile is sized m-by-n pixels (m pixels in vertical direction, n pixels in horizontal direction), then at the time of composition, the final mosaic is sized M times m pixels by N times n pixels. Image resizing can be employed to change the size of the mosaic after composition, however a blurring of the tile edges in the mosaic could be an undesirable side effect. It is therefore better to consider the size (number of pixels horizontally and vertically) of the mosaic when determining the number of tiles and the size of each tile in the mosaic.

[24] In a further refinement, tile region **106** is divided into sub-regions **108**, and tile image **105** is divided into corresponding sub-regions. A tile region **107** is an enlarged version of tile region **106**. The colour based comparison for visual similarity often includes the computation of the average mean square error of the red, green and blue (RGB) channels between pixels or sub-regions of the tile region and pixels or sub-regions of the tile image under consideration. If the comparison is based on greyvalue only, the measure for visual similarity is instead based on the computation of the average mean square error of the greyvalue between pixels or sub-regions. For computational simplicity the calculation step of squaring the error value can be replaced by taking the absolute value of the error value, and averaging can be simplified to summing. Also a weighting of the different colour channels in the error calculation is possible, although equal weighting is most common.

[25] When no sub-regions are employed, the comparison is based on the red, green and blue average values of the entire tile region and the red, green and blue average values of the entire tile image.

[26] Often the sub-regions correspond to the individual pixels of the tile and of the region. For instance, a tile sized at 16-by-16 pixels is compared to a region sized at 16-by-16 pixels. Consequently, the tile region and tile image are compared based on 16-by-16 sub-regions, each sub-region covering precisely one pixel. The tile size and region size at time of comparison are in general independent from the tile size at time of composition, and this can be used to advantage by reducing the computational effort during composition. This involves calculating the figure of visual difference using low resolution version of the tiles (e.g. 16-by16 pixels), while composing the mosaic with a higher resolution version of the tiles (e.g. 256-by-256 pixels). Hence, it is beneficial to produce a low resolution version (smaller sized version) of each tile in the data base in preparation for the search phase of the mosaic generation process, and it is beneficial to produce a version of each tile in the data base with the desired higher resolution (larger size) in preparation for the composition phase of the mosaic generation process.

[27] These large and small sizes are in general independent from the size and cropping of the underlying source image. Image resampling is used to convert a target image, a tile region or a tile image from one size to another, and it often involves image processing operations such as anti-aliasing filtering and bilinear or bicubic interpolation. For instance, a raw source image obtained by scanning a photograph, might be sized 300-by-400 pixels, whereas it is cropped and resized to a 256-by-256 square tile image for the composition phase.

[28] All tile regions in a mosaic are commonly of a same shape and size, and hence all raw source images are cropped and resized to the same shape and size.

[29] A colour mosaic based on a colour target image employs colour tile images. A mosaic composition may produce a black and white composition even if colour tiles are employed. In this case during the search phase greyvalue matching is accomplished by comparing regions of a black and white target image with a black and white converted version of each colour tile, but

during composition the actual coloured tile is used. Then, viewing the mosaic in detail reveals the colour of the tiles, and viewing the mosaic from a distance reveals a black and white mosaic image resembling the target image. As is well known in the art, black and white images are easily produced from colour images. As a result, colour tiles can be used to compose a mosaic resembling a black and white target image. Alternatively, black and white tiles can be used to compose a mosaic resembling a black and white target image.

[30] In colour mosaics with colour tiles, colour dithering can be employed to approximate colour regions of the target image by available colours in the tile images.

[31] After the composition phase, a further step of blending the target image with the mosaic increases the visual similarity between the mosaic and the target. This blending involves overlaying the final mosaic with a version of the target image itself that has a high degree of transparency, thus forcefully enhancing the similarity with the target image. (*)

[32] As discussed, in prior art tile images are obtained from raw source images by cropping the raw source image, from centre, to a rectangle or square, and resizing the dimensions as necessary. The purpose of cropping is thus to ensure that tiles of the desired shape are available for comparison and composition, regardless the shape of the raw source images. Cropping is performed from centre, since commonly this would ensure that the centered subject matter of a tile (an object, a person etc.) appears in the crop. Typically the largest possible crop is produced, considering the size of the raw source image and the shape difference between the tile image and the raw source image. Notably, for each raw source image only one cropped version is produced.

[33] When the raw source image data base is of limited size, it is beneficial to produce multiple, different, crops corresponding to the desired shape but with varying visual effect. This is illustrated in **Figure 2**. **Fig. 2A** depicts a rectangular landscape oriented raw source image **601**, with a group of kayakers as subject matter.

[34] The figure further depicts an outer cropping boundary **605** as a white frame overlaying the image, and it further depicts an inner cropping boundary **606**. These two bondaries can be set automatically by a cropping tool (not depicted) based on parameters common to all raw source images under consideration, as set by an operator. These parameters would entail the shape of the boundaries, the amount of area coverage by the outer boundary (e.g. as a percentage of the source image size), the amount of area coverage by the inner boundary, and a requirement that both boundaries should be centered with regard to the raw source image. Better results may be obtained when the operator selects the inner and outer boundary for each individual raw source image, while considering the subject matter of the image and the visual effect of cropping. This will be explained in more detail further below.

[35] **Fig 2A** also depicts cropped tile images obtained from raw source image **601**. Cropped tile image **602** corresponds to outer boundary **605**. Cropped tile image **604** corresponds to inner boundary **606**. Cropped image **603** is an intermediate cropped tile image. It encloses the inner boundary entirely, and it remains within the outer boundary. In this particular example, the intermediate cropped tile image is centered with the inner boundary. In addition to centered crops, also scattered crops may be obtained. As illustrated in **Fig 2B**, scatter-cropped tile images **611**, **612**, **613** and **614** are not concentric and are not centered with the inner boundary, but they enclose the inner boundary **606** and do not exceed outer boundary **605**.

[36] Cropped tile images **602, 603, 604, 611, 612 613,** and **614** are entered into a tile image data base, also called a tile library (not depicted), and are associated with source image **601** from the raw source image data base. This data base is also called a source library (not depicted). The association serves the purpose of reporting whether and where raw source image **601** is represented in the mosaic, by noting whether and where either crop appears in the mosaic, as explained in more detail further below.

[37] The benefit of multiple croppings becomes apparent when considering the dark and light areas in the various crops of this example. For instance, the depicted sky, kayaks and water in image **602** produce three horizontal layers: a light layer (the sky), a dark layer (the trees) and a layer with intermediate brightness (the water with the kayaks). Image **604**, produced form the same source image, has a different combination of horizontal layers: dark (the trees), intermediate (the kayakers) and again dark (the kayaks).

[38] Thus, a single source image can produce multiple tile images with completely different visual effects, and it is now clear how cropping is not only used to obtain a single tile image of the desired size.

[39] The lighter and darker regions of the various tiles are matched with lighter and darker subregions of the target image. Hence, the more variation in lighter and darker regions exist across the tile images in the tile library, the better the final composition can be when during the matching process the brightness in these regions are taken into consideration. The same holds for colour tiles, whereby not only the brightness of the regions is considered, but also the colour. Whereas for instance one crop produces a light blue layer (the sky), a dark green layer (the trees) and a greyish blue layer (the water with the kayaks), a different crop may have a different combination of horizontal layers.

[40] It is now clear how cropping is not only used to obtain a tile image of the desired size, but also to produce multiple tile images with completely different visual effects. It is further important to note that the inner boundary ensures that a desired subject matter of the raw source image is represented in all of the multiple tile images that are based on the specified inner boundary. Furthermore, in order to obtain tile images based on multiple subject matters, it is possible to repeat the production of multiple tile images based on multiple inner boundaries. For instance, one set of tile images is based on an inner boundary that covers one person's face in a photograph, and another set of tile images is based on an inner boundary that covers another person's face in the same photograph. Clearly, the benefit of creating multiple crops is that there are multiple tile images for each of the two faces. As a result, during the search phase of the mosaic generation process, depending on the particular tile region, the best tile image for either face can be selected when considering either face as a potential subject for that tile region.

[41] Multiple tile images with a given aspect ratio r are obtained from a single raw source image by centered and scattered cropping according to the following. The coordinates of a point in an image are expressed in terms of a pair of pixel values (x, y), whereby the first value corresponds to the x-coordinate (the horizontal coordinate) and whereby the second value corresponds to the y-coordinate (the vertical coordinate). The corresponding origin is located in the top left corner of the image. Positive valued x-chlorinated correspond to points to the right of the origin, and positive valued y-coordinates correspond to points below the origin. The size $m \times n$ (m-by-n) of a rectangular frame (a landscape, portrait or square frame) is expressed in terms of the number of pixels m (the x-size) along the horizontal side (the x-side) and in terms

of the number of pixels n (the y-size) along the vertical side (the y-side). The aspect ratio r of the frame is $r = m/n$. The steps are now as follows:

1. Obtain the raw source image from the source library.

2. Define an inner boundary frame with aspect ratio r while considering the subject matter of the raw source image. Note the centre $C_i = (x_i, y_i)$ and the size $m_i \times n_i$ of the inner boundary frame.

3. Define an outer boundary with aspect ratio r while considering the subject matter of the raw source image. Note the centre $C_o = (x_o, y_o)$ and the size $m_o \times n_o$ of the outer boundary frame.

4. Define N frame sizes $m_k \times n_k$ (with $k = 1 \ldots N$) based on N linearly spaced x-sizes m_k starting at $m_1 = m_i$ and ending at $m_N = m_o$. The y-sizes are calculated with $n_k = r \cdot m_k$.

5. Define N centered frames with centres C_k (with $k = 1 \ldots N$) based on N linearly spaced y-coordinates starting at y_i and ending at y_o each paired with the corresponding linearly spaced x-coordinates starting at x_i and ending at x_o. As a result, the inner most centered frame ($k = 1$) corresponds to the inner boundary frame, and has centre $C_1 = C_i$ and size $m_1 \times n_1 = m_i \times n_i$. The outer most centered frame ($k = N$) corresponds to the outer boundary frame, and has centre $C_N = C_i$ and size $m_N \times n_N = m_o \times n_o$.

6. A scattered frame with centre $S_{k,q}$ has size $m_k \times n_k$ (as defined above) and has a corner q in common with a corner of the inner boundary as follows: a first frame has its bottom left corner ($q = 1$) in common with the bottom left corner of the inner boundary, a second frame has its bottom right corner ($q = 2$) in common with the bottom right corner of the inner boundary, a third frame its top right corner ($q = 3$) in common with the top right corner of the inner boundary, and a fourth frame its top left corner ($q = 4$) in common with the top left corner of the inner boundary. These frames are fully defined given the coordinates of a specified corner, the aspect ratio and the size. There are hence four scattered frames for each size $m_k \times n_k$. Define scattered frames for $k = 2 \ldots N-1$, thus yielding a total of $4 \cdot (N-2)$ scattered frames.

7. Calculate the centres $S_{k,q}$ of each of the above $4 \cdot (N-2)$ scattered frames. This is easily accomplished using basic geometry, considering that the size and one corner of the frame is known.

8. Optionally, move the centres of the scattered frames slightly towards the centre of the inner boundary, following steps further below, to yield new centres $S'_{k,q}$.

9. Reject those scattered crops of which the frame falls outside the outer boundary, in part or in whole.

10. A plurality of crop selection frames with rectangular or square shape are thus defined by centres C_k or $S_{k,q}$ (or $S'_{k,q}$), and by their sizes $m_k \times n_k$ They are stored in the tile library, in association with the underlying raw source image. The frames of the crops may be displayed as rectangular frames with thin lines overlaying the raw source image. At this point the crops may be rendered to yield high and low resolution tile images, and the resulting tile images may be presented to the operator for final approval, or the rendering may be performed at a later time, after having defined such frames for all source images first. In either case, when rendering is complete, the resulting high and low resolution tile images are entered in the tile library.

[42] The above steps are repeated for each desired subject matter (eg each individual face) in the raw source image. This involves re-selecting, for each subject matter, the inner and outer boundary according to the desired composition of the resulting tile images.

[43] An automated method for the optional step of moving the centres of the scattered frames slightly towards the centre of the inner boundary is as follows, whereby the new centres $S'_{k,q}$ are based on the scattered centres $S_{k,q}$:

1. Define mixing coefficients M_k for $k = 2 \ldots N-1$ as follows: if N is even define $K = N/2$ linearly spaced values $v_1, v_2 \ldots v_K$ starting at zero and ending at a maximum mixing value M_{Max}. Then $M_2 = v_2$, $M_3 = v_3$ and so on until $M_K = v_K$ (inclusive), $M_{K+1} = v_K$ (v_K is repeated), and $M_{K+2} = v_{K-1}$, $M_{K+3} = v_{K-2}$ and so on until $M_{N-1} = v_2$ (inclusive). Note that v_1 is discarded. If N is odd define $K = (N+1)/2$ linearly spaced values $v_1, v_2 \ldots v_K$ starting at zero and ending at a maximum mixing value M_{Max}. Then $M_2 = v_2$, $M_3 = v_3$ and so on until $M_K = v_K$ (inclusive), and $M_K = v_{K-1}$, $M_{K+1} = v_{K-1}$ and so on until $M_{N-1} = v_2$ (inclusive). Note that v_1 is discarded. The range for the maximum mixing value is $0 \le M_{Max} \le 1$ and a generally suitable value is $M_{Max} = 0.7$.

2. For each corner $q = 1 \ldots 4$ calculate a new scattered centre $S'_{k,q} = M_k \cdot S_{k,q} + (1 - M_k) \cdot C_k$. (It should be clear that the scalar multiplications are applied to the x and y coordinates separately.) The new centre is hence a weighted average of the scattered and the centered centre. The mixing coefficients ensure that when the size of the frame is close to the size of the inner boundary, the centre is located close to the centre of the inner boundary. As well, the mixing coefficients ensure that when the size of the frame is close to the size of the outer boundary, the centre is located close to the centre of the outer boundary. As a result, the subject matter within the inner boundary will be better centered within the scattered frame.

[44] The above centered and scattered cropping is executed for each raw source image in the source library. Parameter N is set by the operator. The choice for the selected value is in part

dictated by a trade off between the variety and visual range of the generated tiles versus the computational load of generating the crops and involving them in the comparison with tile regions. A suitable value for N ranges from 5 to 10.

[45] Manual definition of an inner boundary through selection by an operator is easily accomplished with a Graphical User Interface (GUI) that displays the image and allows the user to overlay a thin-line rectangle (a selection frame with a predetermined aspect ratio) by click-and-dragging the computer mouse over the image, akin to selecting a crop area in photo editing software. The same is repeated for the outer boundary, while the selection frame of the inner boundary remains visible as an aid. The aspect ratio of the selection frame equals the desired aspect ratio of the tile images.

[46] The following is an example of the application of the above steps. A software programme loads a landscape oriented raw source image from a source library and presents the image on a computer screen to an operator. The image size is 500×700 pixels. The operator studies the image and draws a rectangular inner boundary frame with aspect ratio $r = 3/4$ tightly around the subject matter using the GUI. The resulting centre of the inner boundary is $C_i = (260, 300)$ and the size is $m_i \times n_i = 100 \times 133$. In a similar manner the operator then draws a suitable outer boundary frame, of which the resulting centre is $C_o = (200, 350)$ and the size is $m_o \times n_o = 300 \times 400$. With a setting of $N = 6$ the centres of the six centered frames are $C_1 = (260, 300)$, $C_2 = (248, 310)$, $C_3 = (236, 320)$, $C_4 = (224, 330)$, $C_5 = (212, 340)$, and $C_6 = (200, 350)$. The associated sizes are $m_1 \times n_1 = 100 \times 133$, $m_2 \times n_2 = 140 \times 187$, $m_3 \times n_3 = 180 \times 240$, $m_4 \times n_4 = 220 \times 293$, $m_5 \times n_5 = 260 \times 347$, and $m_6 \times n_6 = 300 \times 400$. Rounding has been applied as necessary. With $M_{Max} = 0.7$ the mixing coefficients are $M_2 = 0.35$, $M_3 = 0.7$, $M_4 = 0.7$, and $M_5 = 0.35$. They are based on the three linearly spaced values $v_1 = 0$ (not used), $v_2 = 0.35$ and $v_3 = 0.7$. For $k = 2$ the scattered centres are as follows. The bottom left corner ($q = 1$) of the inner boundary frame is located at $(210, 234)$ and all scattered frames for $k = 2$ are of size $m_2 \times n_2 = 140 \times 187$. Using basic geometry calculations the centre is found to be $S_{2,1} = (280, 328)$. The mixed centre is $S'_{2,1} = (259, 316)$ which is obtained by mixing $S_{2,1}$ with a factor $M_2 = 0.35$ and $C_2 = (248, 310)$ with a factor $1 - M_2 = 0.65$. Other scattered centres are $S_{2,2} = (240, 328)$, $S_{2,3} = (240, 274)$ and $S_{2,4} = (280, 274)$. Other mixed centres are $S'_{2,2} = (245, 316)$, $S'_{2,3} = (245, 297)$ and $S'_{2,4} = (259, 297)$. For $k = 3$ only one mixed frame with centre $S'_{3,2} = (240, 328)$ and size $m_3 \times n_3 = 180 \times 240$ falls within the outer boundary. For $k = 4$ only one mixed frame with centre $S'_{4,2} = (207, 366)$ and size $m_4 \times n_4 = 220 \times 293$ falls within the outer boundary. And finally, for $k = 5$ only one mixed frame with centre $S'_{5,2} = (201, 364)$ and size $m_5 \times n_5 = 260 \times 347$ falls within the outer boundary.

[47] As mentioned earlier, manual definition may be replaced by an automated definition. Such automation may use image recognition techniques to identify the location and size of the subject matter (e.g. by locating the eyes, nose and mouth of a person's face), which determines the location and size of the inner boundary. The outer boundary could be set such to cover the largest possible raw source image area considering the desired shape of the tiles, and centring it as much as possible around the inner boundary without cropping outside the raw image. Typically, if more than one subject matter is present in the raw source image, the outer boundary is selected around the desired subject matter such to avoid too much presence of the other subject matters in the resulting tiles of the desired subject matter.

[48] An illustration of the centre crop selection frames is provided in **Figure 3**. In **Fig. 3A** an inner boundary **414** and an outer boundary **415** are deposited in relation to an outline **410** of a raw source image (not depicted). A line **411** connects a centre **412** of the outer boundary with a centre **413** of the inner boundary. A centre **417** of a crop frame **416** is located on the line as a result of the underlying mathematics. **Fig. 3B** depicts a crop frame **401** based on the outer boundary and a crop frame **402** based on the inner boundary. A further 4 crop frames **403** are depicted as well.

[49] An illustration of the scatter crop selection frames is provided in **Figure 4**. In **Fig 4A**. a scatter crop frame **422** shares a bottom right corner **421** with inner boundary **414**. In **Fig 4B**. a scatter crop frame **424** shares a bottom left corner **425** with inner boundary **414**. Since it lies partially outside outer boundary **415** it would be rejected. In **Fig 4C**. a scatter crop frame **423** is a version of **422**, and its centre has been moved slightly towards the centre of **414**. In **Fig. 4D** a new inner boundary **430** is depicted to better illustrate various scatter crops of equal size. Crops **431** and **432** in **Fig. 4D**, and crops **433** and **434** in **Fig. 4E** are of the same size and they correspond to the four corners of **430**, with the optional step of slightly moving their centres towards the centre of **430** applied. **Fig. 4F** shows a further two crops **435** and **436** that are of a smaller size than **434**. These crops are based on the top left and bottom right corners of **430**. Two further crops of the same size (not shown) can be generated as well, corresponding to the top right and bottom left corners of **430**.

[50] A person skilled in the art can now compose a software subroutine that automatically generates a plurality of crops from a single raw source image, whereby the crops entirely enclose the inner boundary and whereby they do not exceed the outer boundary.

[51] The above cropping techniques apply digital image processing techniques to alter the composition of an image, whereby the composition of an image is mainly determined by the relative positioning of objects and persons with respect to each other and with respect to the frame (the edges) of an image. Other digital image processing techniques may also be employed to alter the composition, for instance image warping, rotation and mirroring.

[52] Whereas the above mainly modifies the composition, digital image processing techniques are now presented that alter the brightness and contrast of a raw source image. Other adjustments are possible as well such as those that alter the colour, edging and texture of areas in an image. Whereas in the preferred approach it is desired to maintain resemblance between the obtained rendered tile image and the underlying raw source image, it is also possible to apply extreme changes, such as colour remapping, for artistic effect.

[53] The objective of applying digital image processing is to generate a plurality of renditions from a raw source image, thus improving the resemblance of the final mosaic that uses tile images from a raw source image library of limited size.

[54] In the preferred embodiment, various combinations of contrast and brightness changes are applied to a raw source image, thus creating a plurality of tile images. It is understood that in photo editing typically contrast and brightness changes may be made to an image with the intent to make the contrast and brightness of the image more pleasing. However, often contrast and brightness adjustments may be made within a certain range while keeping the appearance of the image satisfactory. For instance, an image may be slightly and noticeably darkened or lightened while the subject matter is still well lit and recognizable. Also, the contrast of an image may be slightly reduced or increased while the visual details of the subject matter are still well distinguishable and recognizable. Methods for individually adjusting contrast and brightness are well

known in the art. In the following, in terms of contrast and brightness adjustment values, reference is made to contrast and brightness adjustments in Adobe PhotoShop (photo editing software by Adobe Systems Incorporated) in which the contrast adjustment ranges from -100 to +100 and the brightness adjustment ranges from -100 to +100. For the purpose of generating multiple tile images from a single raw source image, it is preferred to embed a software routine for such adjustments within the mosaic generating software. Applying stand alone photo editing software instead is cumbersome, and the reference to Adobe PhotoShop is merely made to refer to contrast and brightness adjustment values. For simplicity of operation, contrast and brightness adjustments within the range of +100 to -100 are made in steps of +/-1.

[55] Examples of contrast and brightness adjustments are provided in **Figure 5**. A cropped tile image **701** with neutral contrast and neutral brightness adjustments is obtained from a raw source image (not depicted) with no adjustments, and contrast and brightness adjustments are made with respect to image **701**. For instance, cropped tile image **702** has neutral contrast and maximum brightness, and cropped tile image **703** has maximum contrast and minimum brightness. These two adjusted and cropped tile images together with all other adjusted tile images in the figure are then made available by adding them to the tile library. Referring to Adobe Photoshop, for the purpose of this illustration, an adjustment of +/-30 (out of +/-100) has been applied for the contrast and brightness adjustments in the above example.

[56] In general, contrast and brightness adjustments within a range of +/-20 provide a suitable level of adjustment, but it is preferred to set the range individually for each raw source image, as some raw source images can tolerate more adjustment than others. The ranges are mostly subjective and depend on the photographic quality and the subject matter of the raw source image. As an aid in judgement, or to automate the judgement, the grey-value or colour histograms of the image may be used.

[57] The following steps determine the upper and lower boundaries for contrast and brightness adjustments of an individual raw source image, based on judgements by an operator:

1. Load the raw source image from the data base and present it to an operator in a first image display

2. Set the contrast adjustment c to neutral: $c = 0$

3. Set the brightness adjustment b to neutral $b = 0$

4. In a second image display present the image with the current contrast and brightness settings applied, and when at any time the contrast or brightness are altered, the image is updated to reflect the changes

5. While keeping $b = 0$ an operator adjusts c to find the highest possible contrast setting whereby the visual appearance remains satisfactory. That setting is noted as c_{max}.

6. While keeping $c = 0$ an operator adjusts b to find the highest possible brightness setting whereby the visual appearance remains satisfactory. That setting is noted as b_{max}.

7. While keeping $b = 0$ an operator adjusts c to find the lowest possible contrast setting whereby the visual appearance remains satisfactory. That setting is noted as c_{min}.

8. While keeping $c = 0$ an operator adjusts b to find the highest possible brightness setting whereby the visual appearance remains satisfactory. That setting is noted as b_{min}.

[58] The extreme settings c_{max} b_{max} c_{min} and b_{min} are thus obtained through adjustments by an operator, who interfaces with an image processing subroutine. These extremes may also be found automatically, for instance by following the above steps, but numerically evaluating the brightness histogram of the image, in replacement of visual evaluation by an operator. Based on these extreme settings, an automatic contrast and brightness selection tool is now able to generate multiple images from an underlying raw source image by selecting contrast and brightness pairs within the extreme settings.

[59] **Figure 6** illustrates a possible outcome of the above steps. A delimiting rectangle **462** is based on the extreme settings and has sides parallel to contrast and brightness axes in a two-dimensional plane. A second rectangle **461** is based on the maximum possible settings of +/-100. All contrast and brightness value pairs within rectangle **462** (with adjustment step size of 1) are deemed suitable. To reduce the amount of adjusted images generated (thus limiting the complexity of the search for suitable tiles in a composition) a larger step size may be elected, for instance 5. An alternative is provided by a limiting polygon **463** which has its corners on the horizontal and vertical axes. This is preferred over rectangle **462**, as it better limits the cases whereby both contrast and brightness are not neutral.

[60] An example shall further illustrate how pairs of adjustment values are obtained based on a limiting polygon with corners on the horizontal and vertical axes. Consider example extremes $c_{max} = 20$, $b_{max} = 25$, $c_{min} = -15$ and $b_{min} = -10$ as found for a particular raw source image by an operator. These values determine the corners of the polygon. On a grid with a contrast resolution of 7 and a brightness resolution of 9, the following points fall within the polygon (the notation is (c, b)): $(0, 0)$, $(0, 9)$, $(0, 18)$, $(7, 0)$, $(7, 9)$, $(14, 0)$, $(0, -9)$, and $(-7, 9)$. An individual tile image is then generated for each of these individual adjustment pairs, and the tile images are added to the tile library while noting the underlying raw source image. Whereas the above example employs a grid resolution of 7 for contrast adjustment values and 9 for brightness adjustment values, it suffices to have both grid resolutions equal. A suitable value for the resolution is 5.

[61] A person skilled in the art can now compose a software subroutine that automatically generates from a single raw source image a plurality of tile images by adjusting the brightness and contrast of the raw source image within preset bounds that are specific to the raw source image.

[62] It is further beneficial to combine cropping with contrast and brightness adjustment to generate multiple tile images from a single raw source image. This is accomplished as follows:

1. Load a raw source image from the source library

2. Find a plurality of suitable crop frames for the raw source image, using the cropping method described above

3. Find a plurality of contrast and brightness adjustment values for the raw source image, using the contrast and brightness adjustment described above

4. For each crop frame, apply each possible pair of contrast and brightness adjustment, and save the cropped and adjusted image as a tile image in the tile library.

[63] It is now clear how an operator determines suitable crop extremes and suitable adjustment extremes, and how an automated process generates a plurality of tile images with varying composition, contrast and brightness based on the operators specific settings for an individual raw source image. The above cropping and adjustments can be generalized to other forms of digital image processing and it may include manual digital photo editing and manual digital graphic as long as the goal is to produce multiple renditions of a single raw source image.

[64] The following highlights some properties of the relationship between raw source images, renditions (tile images from a raw source image) and subject matters, since the present invention distinguishes between them. First, generally there are multiple renditions of a single raw source image, but there may also be only a single rendition of it, meaning that one or more tiles can be generated from a raw source image. Secondly, generally there are multiple raw source images of a particular subject matter, but there may also be only a single raw source image of a particular subject matter, and there may also be a single raw source image containing multiple raw source images. As a result, there is more than one rendition (more than one tile image) associated with a subject matter if there is more than one raw source image associated with that subject matter or if there are multiple renditions of a single raw source image.

[65] In one embodiment of the invention, all renditions are treated as individual tiles in a tile library without consideration of their associated subject matters. Each tile in the library is compared with each tile region to produce a figure of visual difference, and the assignment of a tile image to a tile region is made based on that figure. The lower the figure, the more visually similar the two are and the more preferred the assignment is. Hence a high figure of visual difference implies a low measurement of visual similarity, and a low figure of visual difference implies a high measurement of visual similarity.

[66] In the preferred embodiment of the invention, the renditions are tiles in a tile library whereby each tile is associated with the underlying subject matter. In a first matching step, all renditions of a selected subject matter are compared with a selected tile region, and the best matching rendition (the rendition with the lowest figure of visual difference) is identified. This is repeated for all subject matters and the selected tile region, thus producing a list of candidate renditions for the selected tile region. Each subject matter produces one candidate, and the production of candidates is repeated for each tile region. In a second matching step, for each tile region one of the candidates is identified as the preferred candidate, again based on the figure of visual difference. As will be explained in more detail below, other factors in addition to the figure alone may play a role in the selection of the preferred candidate.

[67] In order to facilitate the ability to cover multiple subject matters in a single raw source image, it suffices to copy the raw source image within the raw source image data base for each subject matter. For instance, if the raw source image is a digital photograph of two faces, a simple way to ensure that either face is considered a separate subject matter is to enter the photograph twice: once for one face and once for the other, and labelling of either raw source image is done according to the image content.

[68] As is clear from the above explanations, there are multiple tile images associated with a single subject matter. This involves producing multiple renditions of a raw source image. During the composition phase of the mosaic generation, each of the multiple renditions is compared

to an individual tile region, and the best matching rendition is considered the candidate rendition (a candidate tile image). Importantly, during this step the candidate rendition is not yet assigned to the tile region, yet the candidate is a potential tile. This step finds for each subject matter the best matching rendition for a particular tile region. During a second step all candidate renditions for a particular tile region are considered and the best matching candidate tile becomes the preferred candidate tile. Recalling that each candidate rendition is associated with a single subject matter, the assignment of a preferred candidate tile to a tile region is also an assignment of the underlying subject matter to that tile region. For instance, if a darker rendition of a raw source image of a person's face is assigned to a dark tile region, at the same time the name of the person (the subject matter, the label of raw source image) is assigned to that tile region.

[69] In the above digital image processing has been applied to generate multiple renditions in preparation for the search for a tile region dependent candidate rendition, and the cropping and contrats and brightness adjustments are performed without knowledge of the target image or any tile region in particular. Alternatively, renditions may be produced whereby a cropping or a contrast and brightness adjustment is made with consideration of an underlying tile image. Hence, in stead of generating brighter renditions as well as darker renditions for potential use, renditions are made that are tailored for a particular tile region. Hence the step of finding the candidate rendition among all renditions of a particular subject matter may be omitted. Performing contrast and brightness adjustments then involves measuring the contrast and brightness of the tile region and producing an adjusted rendition accordingly, whereby the visual difference between the rendered (adjusted) image and the tile region under consideration is minimized through the adjustment. Performing cropping then involves an iterative cropping process whereby the location and size of the cropping frame are varied until the visual difference between the rendered (cropped) image and the tile region under consideration is minimized.

[70] In the following, an illustration describes how the multiple renditions of a raw source image are considered in the composition phase of the mosaic generation, particularly highlighting the organization of the tile images based on their underlying subject matter. **Figure 7** illustrates the relationship between subject matters, source images, renditions, candidate renditions and individual tile regions of a target image. Shown are subject matters **10**, raw source images **20**, renditions **30** and an array **40** of tile regions. The relationship between tile regions and tile images has been provided in **Figure 1**, and a method to determine candidate renditions will be described further below. In the example, three raw source images A1, A2 and A3 are associated with subject matter A; one raw source image B1 is associated with subject matter B; one raw source image C1 is associated with subject matter C (the images themselves are not shown, only their labels). The subject matters are, for instance, individual persons (not shown). A raw source image could then be a digital photograph of a person, and A B and C would be the names of the three different people (not shown). Through digital image processing, 3 renditions of raw source image A1 are produced: rendition A1.1, A1.2 and A1.3 (the digital image processing could comprise of a combination of cropping with contrast and brightness adjustments). As well, through digital image processing, 2 renditions of raw source image A2 are produced: renditions A2.1 and A2.2. As well, through digital image processing, 4 renditions of raw source image A3 are produced: renditions A3.1 to A3.4. Furthermore, through digital image processing two renditions of raw source image B1 are produced: renditions B1.1 and B1.2. Furthermore, through digital image processing one rendition of raw source image C1 is produced: rendition C1.1. Since there are three subject matters, there are three candidate renditions for each tile region. A sample tile region 45 lists three candidate renditions, one for each of the three subject matters A, B and C. The illustration shows that the rendition of subject matter A that best matches tile region 45 is A1.3; the rendition of subject matter B that best matches tile region **45** is B1.2; and

for subject matter C the only rendition C1.1 is the candidate rendition. Whereas for the purpose of illustration this example is based on 3 subject matters and at most 9 renditions per subject matter (subject matter A), it should be clear that the number of subject matters and renditions are generally only limited by the computing complexity and memory requirements. Typically there are tens to hundreds of subject matters, and each subject matter may have one to hundreds of renditions. Of course, in one extreme it is also possible to render all tile images in the tile library based on only one raw source image.

[71] **Figure 8** illustrates a possible preferred candidate for each tile region, as would be determined during the composition phase. An index **50** provides as an aid to find all instances of subject matters in the final composition. The coordinates in the index relate to numerals **60** which indicate the horizontal tile coordinate, and to literals **61** which indicate the vertical tile coordinate. Clearly, in a composition with hundreds of tile images, the index is a useful aid to spot specific subject matters quickly. The index could be used to locate pictures of specific people in the mosaic.

[72] **Figure 9** illustrates the case whereby there is one raw source image per subject matter, and only one rendition per raw source image. Clearly, the three candidate renditions are the same three across all tile regions, and hence the first matching step (in which the candidate rendition is produced) can be omitted without affecting the final composition.

[73] As appreciated by someone in the art, when the tile image and the target image are represented by Red, Green and Blue (RGB) pixel values, a suitable figure of visual difference would be based on the pixel-by-pixel squared sum RGB difference between the tile image and the tile region under consideration. More precisely, if the RGB pixel values in the tile region under consideration are R_i, G_i and B_i (index $i = 1...N$ covers all pixels in the rectangular or square region, and that region can be consider as an image itself), and if the RGB pixel values in the tile image under consideration are r_i, g_i and b_i, (whereby the tile region and the tile image are of equal size) then a figure of difference based on the summed square with equal weighting of the three colour channels is

[74] $$e = \sum_{i = 1...N} ((R_i - r_i)^2 + (G_i - g_i)^2 + (B_i - b_i)^2)$$

[75] In the case whereby the tile image and tile region are compared based on the grey values V_i and v_i, a suitable figure of difference would be based on grey value difference:

[76] $$e = \sum_{i = 1...N} (V_i - v_i)^2$$

[77] Colour RGB images are easily transformed to a grey value image, and this is useful if the tile matching is performed based on colour tiles but a black and white target image.

[78] A method is now described that selects the preferred candidate for each tile region. The method is best understood in terms of mathematical operations on a matrix D that represents figures of visual difference. Each column of the matrix corresponds to an individual position (a tile region), whereby the positions are numbered $1 \ldots N_P$ uniquely identifying each tile region in the target image, a two-dimensional plane of tile regions. Each row of the matrix corresponds to a source (an individual subject matter), whereby the sources are numbered $1 \ldots N_S$. Hence the size of matrix D is $N_P \times N_S$. The entries in the matrix are figures of visual difference based on the tile region (identified by the row number) and on the candidate image of the subject matter (the subject matter is identified by the column number). A hash table T lists for each subject

matter the label of the rendition that is the candidate rendition, and it hence represents all sources.

[79] Reference is now made to the flow chart in **Figure 10**. The flow begins at operation **902** whereby matrix D is provided. The operation sorts the elements in each individual column of matrix D in ascending order. The result is D_s and an index matrix D_x, whereby D_s contains the sorted elements and D_x contains the original row index of each sorted element as follows: $D_s(r, c) = D(Dx(r, c), c)$ for all rows $r = 1 \ldots N_P$ and for all columns $c = 1 \ldots N_S$. The top row in D_x hence indicates for each source (identified by the column number) the best matching position (identified by the value of the element in the top row). A copy of D_x and D_s are made as well: $D_x' = D_x$ and $D_s' = D_s$.

[80] Operation **903** reduces matrix D to size $N_P \times N_S'$, with $N_S' = N_P$, in the event that there are more subject matters than tile regions. This is accomplished by calculating for each column individually the sum of all elements (across all rows), and by pruning the columns with the highest sum from the matrix, thus removing subject matters from consideration until there are N_S' subject matters left. The column sum is a general indication of the suitability of the candidate rendition of a subject matter considering all tile regions as a potential assignment. An alternative to calculating a sum of the entire column is to consider the minimum element of each row and to prune the matrix by removing the column with the highest minimum in comparison with the minimums of the other columns. Operation **903** identifies the beginning of a new iteration of the flow.

[81] Operation **904** assigns sources to positions based on the top row in D_x while considering only those positions that occur precisely once in the top row. The assignments made are single assignments, and they can be made simultaneously. Furthermore, in D_s and D_x the rows and columns corresponding to the assignments are removed from consideration, reflecting that the assigned sources are no longer available for assignments and that the assigned positions are no longer available for assignments. It is important to note that the top row indicates which tile region is the best tile region for a particular tile image. This is in contrast to the case whereby a search algorithm finds the best tile image for a particular tile region, as is common in prior art.

[82] Condition **906** ends the flow if there are no positions are available any more, otherwise the flow continues with condition **907**.

[83] Condition **907** checks for the availability of sources. If no sources are available, the flow continues with operation **916**, otherwise the flow continues with operation **908**.

[84] Operation **908** assigns sources to positions based on the top row in D_x while considering only those positions that occur more than once in the top row. The assignments made are multiple assignments for a group of sources and positions. Furthermore, in D_s and D_x the rows and columns corresponding to the assignments are removed from consideration, reflecting that the assigned sources are no longer available for assignments and that the assigned positions are no longer available for assignments. Multiple assignments are made by first considering square sub-matrices $\tilde{D}_s$ and $\tilde{D}_x$ of D_s and D_x respectively which are composed and applied as follows:

1. select the position with the least number of multiple occurrences in the top row. The number is by definition greater than one. If more multiple positions share the same mini-

mum number of occurrences, one of them is selected randomly. Define q to be the number of occurrences.

2. $\tilde{D}_x$ is composed of the top q rows of the q columns in D_x which have the selected position in their top row. $\tilde{D}_s$ is defined as the sub-matrix that corresponds to $\tilde{D}_x$.

3. the sub-matrices are searched for a simultaneous assignment of q sources to q positions whereby the sum of the visual differences corresponding to the assignment (as calculated from elements $\tilde{D}_s$) is the minimum possible sum, and whereby for obvious reasons each position only occurs once in the assignment. This is easily accomplished by considering all possible multiple assignments represented by $\tilde{D}_x$ (there are at most q^q such multiple assignments) and by calculating the sum over the q visual differences of the assignment. The multiple assignment is then selected. This step is particularly illustrated in a following example.

[85] This part of the invention provides means to handle the conflicting case in which multiple tile images most prefer a single and same tile region. Clearly, in contrast to the single assignment case from above, an immediate assignment is not possible. The above sub-steps provide the preferred method to make multiple assignments while considering the ranked (sorted) preferences of each tile image. An alternative with less computational effort includes making q random assignments based on the sub-matrix $\tilde{D}_x$.

[86] Since the complexity for the search of a suitable assignment is of the order q^q, it is practical to limit q. A suitable limit is $q = 5$ or $q = 6$, but in general the limit depends on the speed and memory capabilities of the computing equipment. The limit is then found experimentally by increasing a maximum allowable value of q, q_{max}, until the execution time reaches unacceptable duration. In the event that q exceeds the desired maximum q_{max}, sub-matrices according to q_{max} are obtained in replacement of the sub-matrices according to q. This is easily accomplished by reducing $\tilde{D}_s$ and $\tilde{D}_x$ to their top q_{max} rows and left most q_{max} columns. The preferred reduction involves the calculation of the column sums over the top q_{max} rows, and selecting the q_{max} columns with the lowest sum, and again the top q_{max} rows.

[87] Condition **910** ends the flow if there are no positions available any more, otherwise the flow continues with condition **912**.

[88] Condition **912** examines whether during the most recent iteration of the flow any single or multiple assignments have been made. If this is the case, the flow continues with operation **914**, otherwise the flow continues operation **908**.

[89] Condition **914** examines whether during the most recent iteration of the flow all sources as originally present in the potentially reduced matrix D were available. If this was not the case, the flow continues operation **916** otherwise it ends.

[90] Operation **916** checks whether matrix D_s contains at least one column for consideration. If this is the case, the flow immediately continues with operation **903**. Otherwise, all sources in the potentially reduced matrix D are made available again for consideration prior to continuation with operation **903**. This means that for each remaining position the sorted elements and

the sorted indices of all sources are made available in D_s and D_x for reconsideration, using the data in the copies D_s' and D_x'. As a result, D_s and D_x again have N_S' columns. The number of rows remains unchanged, as it reflects the number of unassigned positions.

[91] The involvement of a visual difference threshold (not shown in the flow) provides a further enhancement of the final composition. If thresholding is applied, an assignment is only executed if the underlying visual difference is less than a specified threshold value. This value can be an individual value for each individual tile image. In the preferred embodiment this value is general to all tile images, allowing the use of a single value for a complete mosaic. The desired threshold value is best determined based on experimental experience. A suitable threshold is found by performing mosaic compositions for various threshold values and selecting the composition that delivers the best trade-off between visual similarity of the mosaic with the target image on one hand and a wide distribution of tile images and subject matters present in the mosaic on the other hand. The lower the threshold, generally the better the similarity, and the higher the threshold, generally a higher variety of subject matters is present in the final mosaic. It is up to the judgement of the operator to select a suitable balance. Better results may be obtained if the threshold is made to depend on the tile region. It is particularly beneficial to identify a rectangular area in the target image that contains the target subject matter (e.g. a face that the mosaic is to resemble) and to set a lower threshold for tile regions in that area. The surrounding are of the target image may then have a higher threshold or even have the threshold disabled. This allows the assignment of tile images with good visual similarity (generally low figures of visual difference) in the critical area (with a low threshold), and it allows the assignment candidate tiles of generally difficult to place subject matters (generally high figures of visual difference) in less critical areas (with a high threshold).

[92] In the event that certain subject matters are required to be represented in the composition (as opposed to being optional), during a first set of iterations the above flow is executed with disabled threshold and with matrix D only representing the required sources, until at least the first time that replenishing is required. At this point all required sources appear at least in one position. A second set of iterations of the flow is then commenced, whereby D represents all sources, the required ones as well as the optional ones. Of course, the filled positions from the first set of iterations are omitted. During the second set, the desired threshold is applied. If the flow ends at condition **914** while not all position have been filled, a third set of iterations is commenced with the threshold disabled, ensuring that eventually all positions are filled.

[93] An example shall now illustrate the above. In **Figure 11,** a sample matrix **921** represents figures of visual difference for a case in which there are five subject matters and ten tile regions. Generally there are many more tile regions and many more subject matters, and this selection in this example is made for simplicity of illustration. The figures of difference have been normalized such that they lie in the range $0 \ldots 1$. Element **924** for instance, with a value of 0.69, represents the figure of visual difference between subject matter number three (third column) and position number two (second row). Positions are typically numbered by starting at the top left corner tile region, and traversing the columns of tile regions until the bottom right tile region is reached. A corresponding sorted matrix **923** with associated index matrix **922** are obtained from matrix **921** by executing operation **902** of the flow. Element **926** of matrix **923** represents element **924** and is also located in the third column, considering that each column is sorted independently. Since the value of 0.69 is the highest value in the column, it is placed in the lowest row of **923**. Since it originated in the second row of **921**, element **925**, located in the lowest row of the third column of **922** has a value of 2. As there are more positions than sources, operation **903** of the flow does not reduce the number of sources. In operation **904** two single assignments

are identified, based on elements **927** and **928** in matrix **922**. Element **927** causes an assignment of source number 4 (column 4) to position 1 (element value 1), and element **927** causes an assignment of source number 5 (column 5) to position 6 (element value 6). With reference to a mosaic, the candidate rendition of the subject matter associated with column 4 is thus to be placed in the mosaic at the tile region associated with position 1, and the candidate rendition of the subject matter associated with column 5 is thus to be placed in the mosaic at the tile region associated with position 6.

[94] **Figure 12** illustrates which rows and columns corresponding to the assignments are removed from consideration by operation **904**. In matrix **931** and matrix **932** columns 4 and 5 are stricken out, as they correspond to the assigned sources numbered 4 and 5. Furthermore, element groups **933** and **934** that refer to positions 1 and 6 are stricken out as well. The elements are found by searching for element values 1 and 6 in matrix **931** and by identifying the matching elements in matrix **932**. In the example these element values are lumped, but this is not the case in general.

[95] Condition **906** in the flow leads to the execution of condition **907**, since there are still positions available. More precisely, there are 8 positions available, as is evident from the number of not-stricken rows. Condition **907** leads to the execution of operation **908**, since there are still sources available. More precisely, there are 3 sources available, as is evident from the number of not-strike columns. Through inspection of matrix **931** in operation **908** a multiple assignment with respect to position 7 is identified with $q = 3$.

[96] **Figure 13** illustrates the composition of the sub-matrices for the resulting multiple assignment with $q = 3$. Sub-matrix **941** is obtained from matrix **931**, and sub-matrix **942** is obtained from matrix **932**. Coincidentally, the three rows in **941** are identical, but this is generally not the case. Of the 3^3 possible assignments, only 8 are valid, considering that each position shall only be used once, and each source shall only be used once. A first assignment is source 1 to position 7, source 2 to position 5 and source 3 to position 4. The sum of the corresponding three figures of difference is 0.18+0.22+0.28=0.68. For abbreviated notation, this case is labelled "7/5/4" with sum 0.68. Further assignments are "7/4/5", "5/7/4", "5/4/7", "4/7/5" and "4/5/7". The winning assignments are "7/5/4" and "7/4/5" with equal sums, and of the two, "7/4/5" is selected randomly.

[97] Condition **910** in the flow then leads to the execution of condition 912, since there are still positions available. More precisely, there are 5 positions available. Condition **912** leads to operation **916** since assignments have been made during this iteration. More precisely, 2 single assignments and one triple assignment have been made during the first iteration. Operation **916** replenishes the available sources by re-entering sources 1 to 5. The status of the matrices is illustrated in **Figure 14**. Positions 1,4,5,6 and 7 are clearly not available, whereas all sources are available. Again, these positions are conveniently lumped in the top 5 rows but this is generally not the case. The flow continues past operation **903** without reduction, past operation **904** without a single assignment, to operation **908** for a multiple assignment with $q = 5$. Considering a maximum of $q_{max} = 4$, one column must be dropped. The column sums lead to the conclusion that sources 2,3,4 and 5 shall be considered for the multiple assignment, dropping source 1. The winning assignment is "9/8/3/10", that is source 2 is assigned to position 9, source 3 is assigned to position 8, source 4 is assigned to position 3 and source 5 is assigned to position 10. And in the final iteration of the flow, the remaining single assignment is trivial: source 1 to position 2. The flow ends at condition **906**.

[98] The benefit of the present method for assigning tile images to tile regions in the composition phase of the mosaic generation are now apparent. Not only is it possible to ensure the assignment of a substantial number of mandatory raw source images to the mosaic, it is possible to resolve the cases in which multiple candidate tile images most prefer to be located at a single tile region. A further benefit is that the underlying subject matter of the raw source images is considered which leads to a more effective placement of subject matters, since now it is possible to generate multiple renditions of multiple raw source images covering a single subject matter. A further benefit is that a more evenly distributed frequency of appearance of subject matters may be accomplished, a distribution that closely approaches a uniform distribution. Whereas in prior art the over-usage of an individual tile image is controlled by limiting repeat occurrences of tile images in the mosaic irrespective of the general suitability of the tile image, the present method avoids over-usage by finding the best tile region for each individual subject matter until all subject matters are depleted, and repeating with replenished subject matters until all tile regions are assigned.

[99]

CLAIMS:

1. A method of generating a mosaic representation of a target image, the mosaic representation incorporating a plurality of source images, the method comprising the steps of:

   a) loading the target image into a computer;
   b) generating a database having a library of source images;
   c) dividing the target image into multiple tile regions;
   d) selecting a source image from the library;
   e) comparing the selected source image with each of the tile regions, wherein the comparing comprises calculating figures of visual difference between the selected source image and the tile regions using a processor, wherein the figures of visual difference are based on:
      i) the pixel-by-pixel squared sum Red, Green, Blue (RGB) difference when the source image and the tile regions are represented by RGB pixel values; and
      ii) the grey value difference when the source image and the tile regions are represented by grey value images;
   f) selecting a tile region with a high measurement of visual similarity based on the figures of visual difference to place the selected source image;
   g) positioning the selected source image in the mosaic at the selected tile region; and
   h) repeating steps d) to g) until the mosaic representation is complete.

2. The method according to claim 1 wherein a single source image is selected from the library and wherein a single tile region is located having the highest visual similarity.

3. The method according to claim 1 wherein multiple source images are selected from the library and wherein for each of the source images a tile region is located having a high visual similarity.

4. The method according to claim 1 wherein the source images are subjected to digital image processing to increase the visual similarity.

5. The method according to claim 4 wherein the digital image processing is applied after a region has been located for the source image.

6. The method according to claim 4 wherein the digital image processing is applied before a region has been located for the source image.

7. The method according to claim 4 wherein the digital image processing includes a cropping stage.

8. The method according to claim 4 wherein the digital image processing includes adjustment of brightness and/or contrast.

9. The method according to claim 4 wherein the digital image processing includes adjustment of colour.

10. The method according to claim 4 wherein parameter ranges of the digital imaging processing are determined individually for each source image.

11. The method according to claim 4 wherein parameter ranges of the digital imaging processing are set jointly for multiple source images.

12. The method according to claim 1, with the additional step of producing multiple versions of a source image for use in generating a mosaic representation of a master image, the mosaic representation incorporating a plurality of source images by using the versions of the source images, each of the versions being produced by applying one or more digital image processing schemes to the source image.

13. The method according to claim 12 wherein generating the mosaic comprises of a) selecting a tile region of the master image b) comparing the multiple versions of the source image with the tile region; c) searching through the multiple versions to select a candidate version having a high visual similarity with the tile region; d) using the selected version in replacement of the source image in the mosaic image representation.

14. The method according to claim 12 wherein the digital image processing schemes comprise of a cropping stage.

15. The method according to claim 12 wherein the digital image processing schemes comprise of an adjustment of brightness and/or contrast.

16. The method according to claim 12 wherein the digital image processing schemes comprise of an adjustment of color.

17. The method according to claim 12, wherein the digital image processing schemes are applied before a region has been located for the source image.

18. The method according to claim 12, wherein the digital image processing schemes are applied after a region has been located for the source image.

19. The method according to claim 12 wherein parameter ranges of the digital imaging processing are set individually for each source image.

20. The method according to claim 12 wherein parameter ranges of the digital imaging processing are set jointly for all source images.

21. The method according to claim 1 with the additional step of generating a subject matter index for source images used in a mosaic representation of a master image, the source images being positioned in tile regions of the mosaic representation based on visual similarity compared with corresponding regions of the master image, the method comprising the steps of:

a) dividing the master image into multiple tile regions;
b) assigning a co-ordinate to the location of each tile region;
c) providing a title for the subject matter or each source image; and
d) preparing a list of co-ordinates for each title.

22. A method for generating a mosaic representation of a target image, the mosaic representation incorporating a plurality of source images, the method comprising the steps of:

a) loading the target image into a computer;
b) generating a database having a library of source images;
c) dividing the target image into multiple generally complex tile regions;
d) selecting a tile region of the target image;

e) selecting one or more source images from the library;

f) for each of the selected one or more source images, producing multiple versions of the source image by applying one or more digital image processing schemes to the source image, each of the versions being generally of a same size and generally of a different appearance;

g) comparing each of the multiple versions of the source image with for the selected tile region, wherein the comparing comprises calculating figures of visual difference between the multiple versions of the source image and the selected tile region using a processor, wherein the figures of visual difference are based on:

i) the pixel-by-pixel squared sum Red, Green, Blue (RGB) difference when the multiple versions of the source image and the selected tile regions are represented by RGB pixel values; and

ii) the grey value difference when the multiple versions of the source image and the selected tile regions are represented by grey value images;

h) for the selected tile region, selecting a version from the multiple versions of the source image, that has a high measurement of visual similarity based on the figures of visual difference;

i) positioning the selected version with the high measurement of visual similarity in the mosaic at the selected tile region;

j) repeating steps e) to i) for all the tile regions.

23. The method according to claim 22 wherein the different appearance is attained by a cropping stage in the digital image processing schemes.

24. The method according to claim 22 wherein the different appearance is attained by adjustment of brightness and/or contrast in the digital image processing schemes.

25. The method according to claim 22 wherein the different appearance is attained by adjustment of color in the digital image processing schemes.

26. The method according to claim 22, wherein the digital image processing schemes are applied before a region has been located for the source image.

27. The method according to claim 22, wherein the digital image processing schemes are applied after a region has been located for the source image.

28. The method according to claim 22 wherein parameter ranges or the digital image processing are set individually for each source image.

29. The method according to claim 22 wherein parameter ranges of the digital image processing are set jointly for all source images.

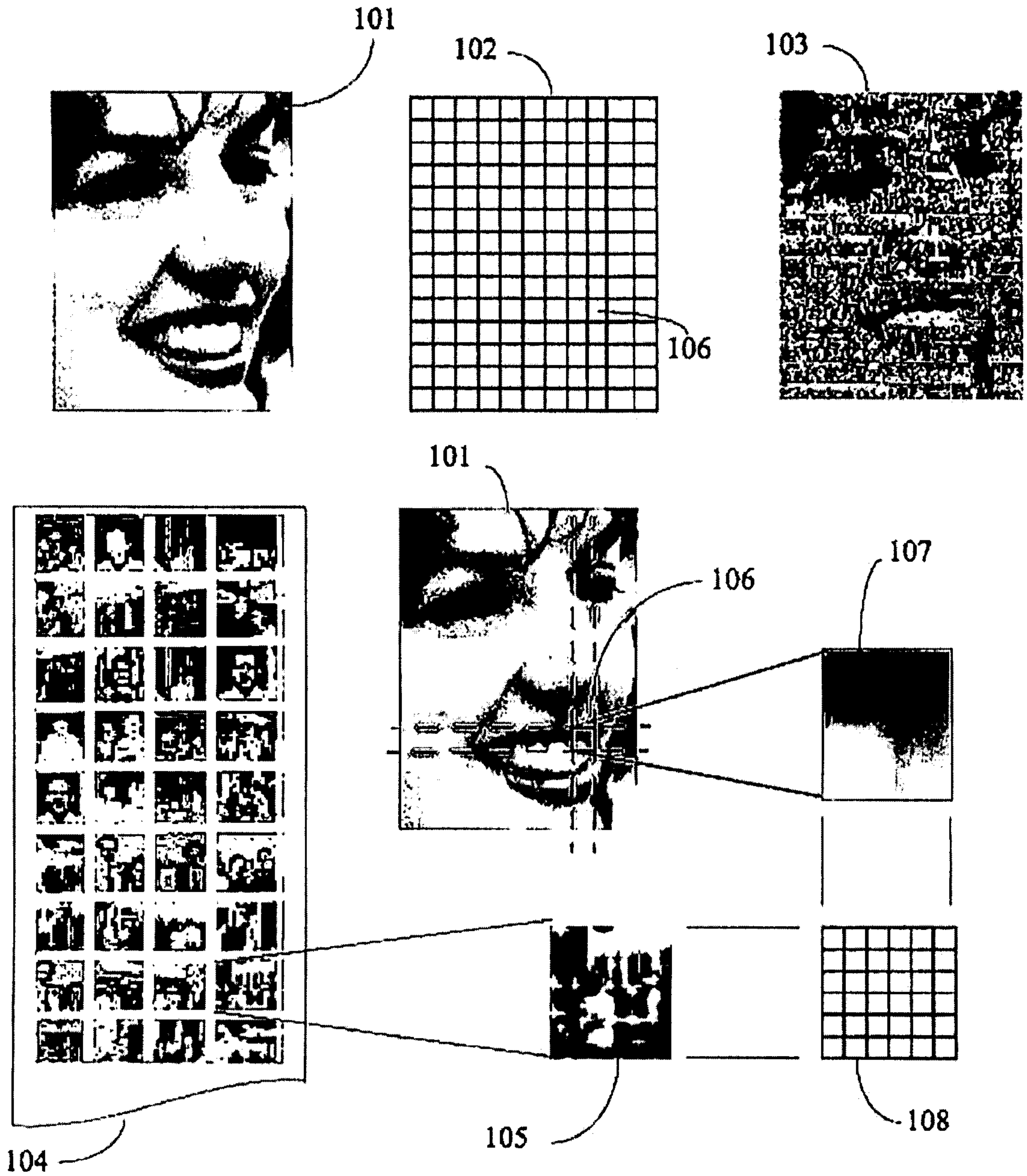


Fig. 1

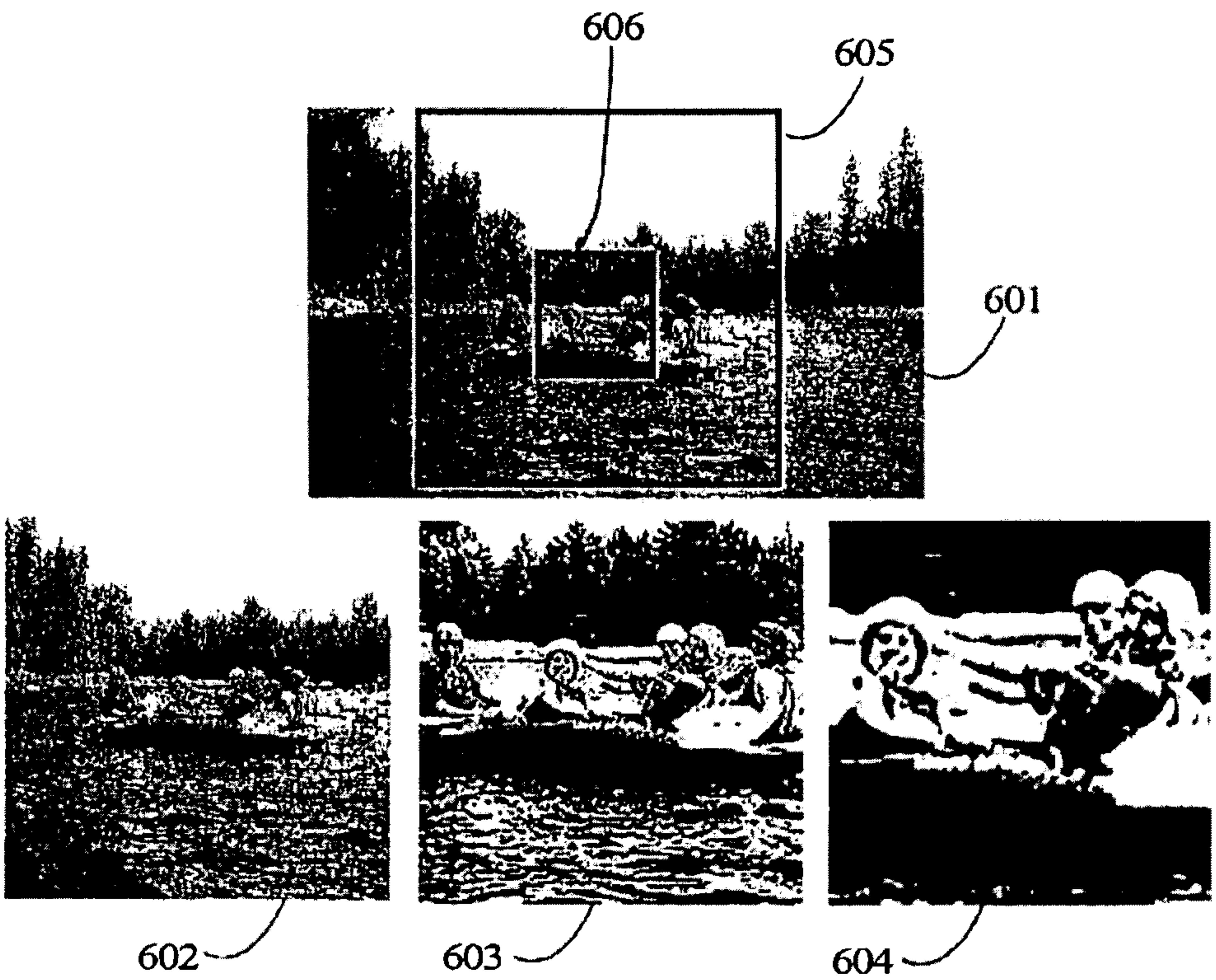


Fig. 2A

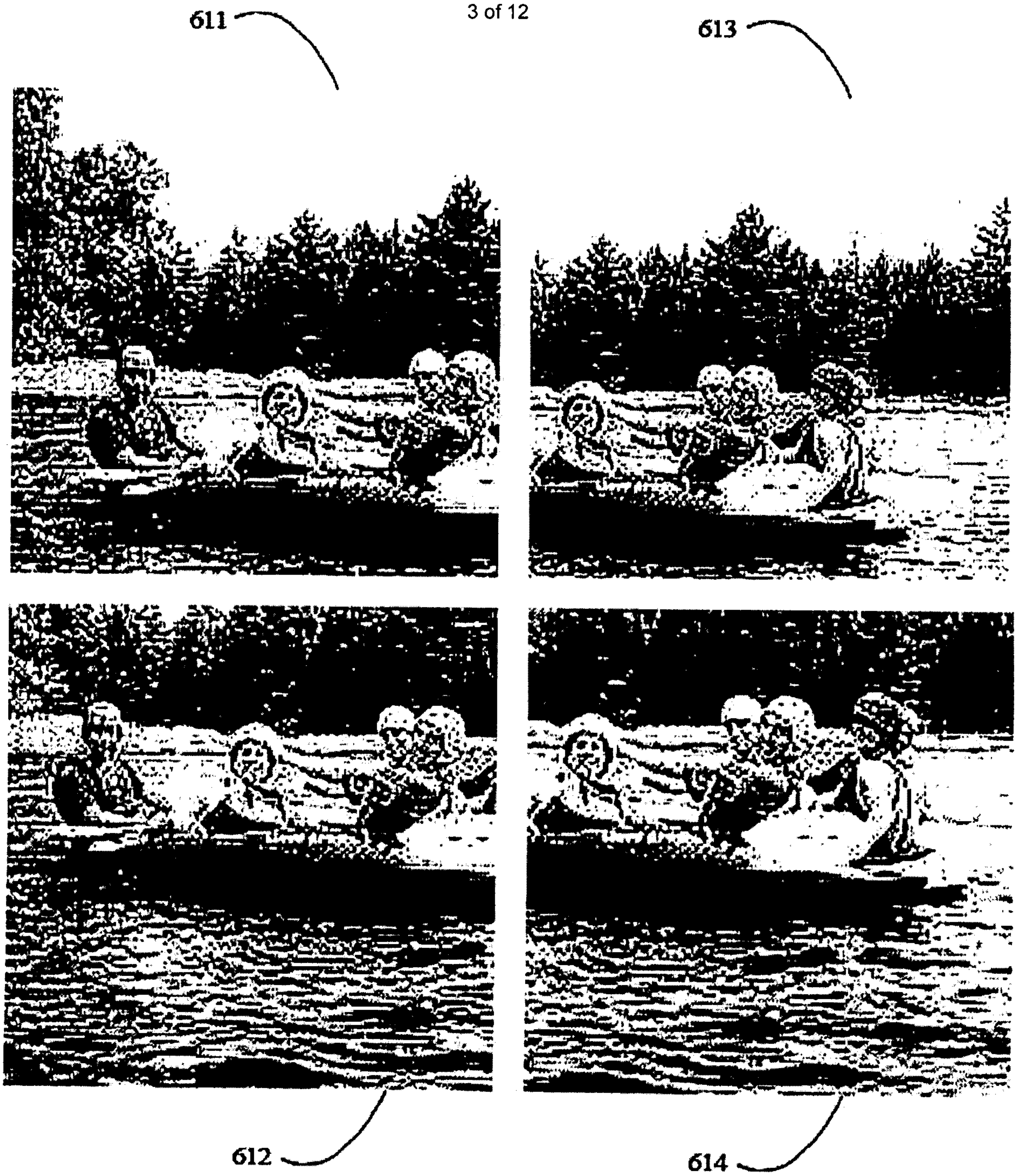


Fig. 2B

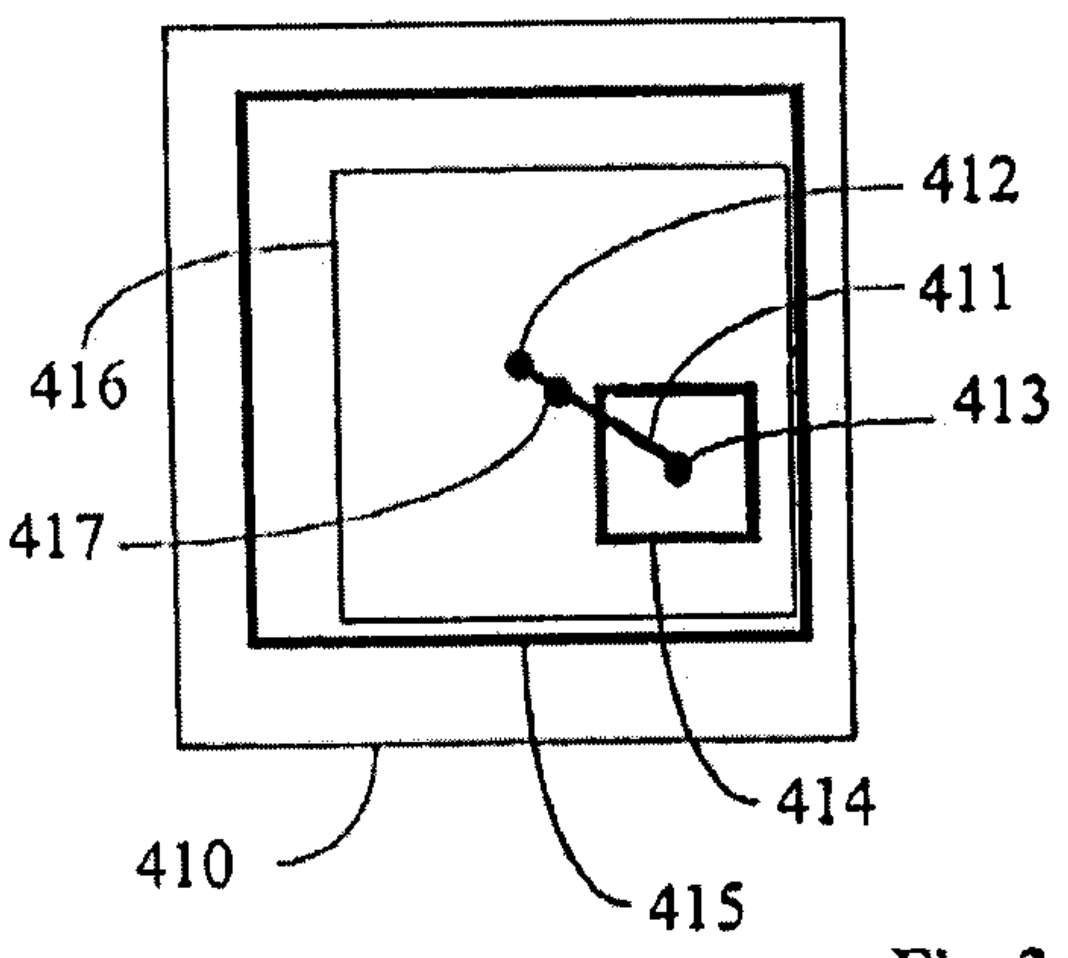


Fig. 3A

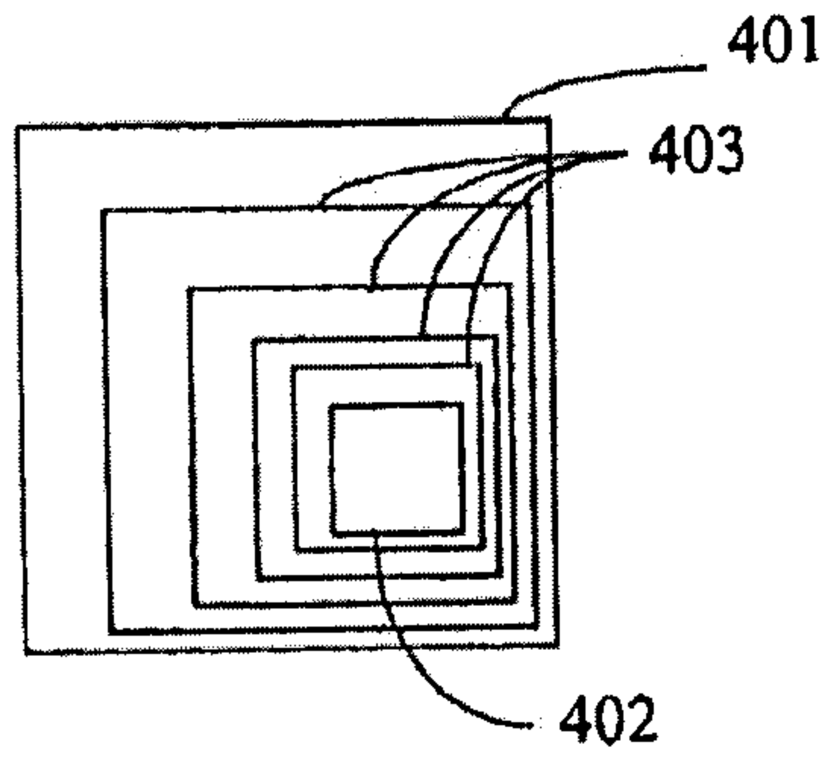


Fig. 3B

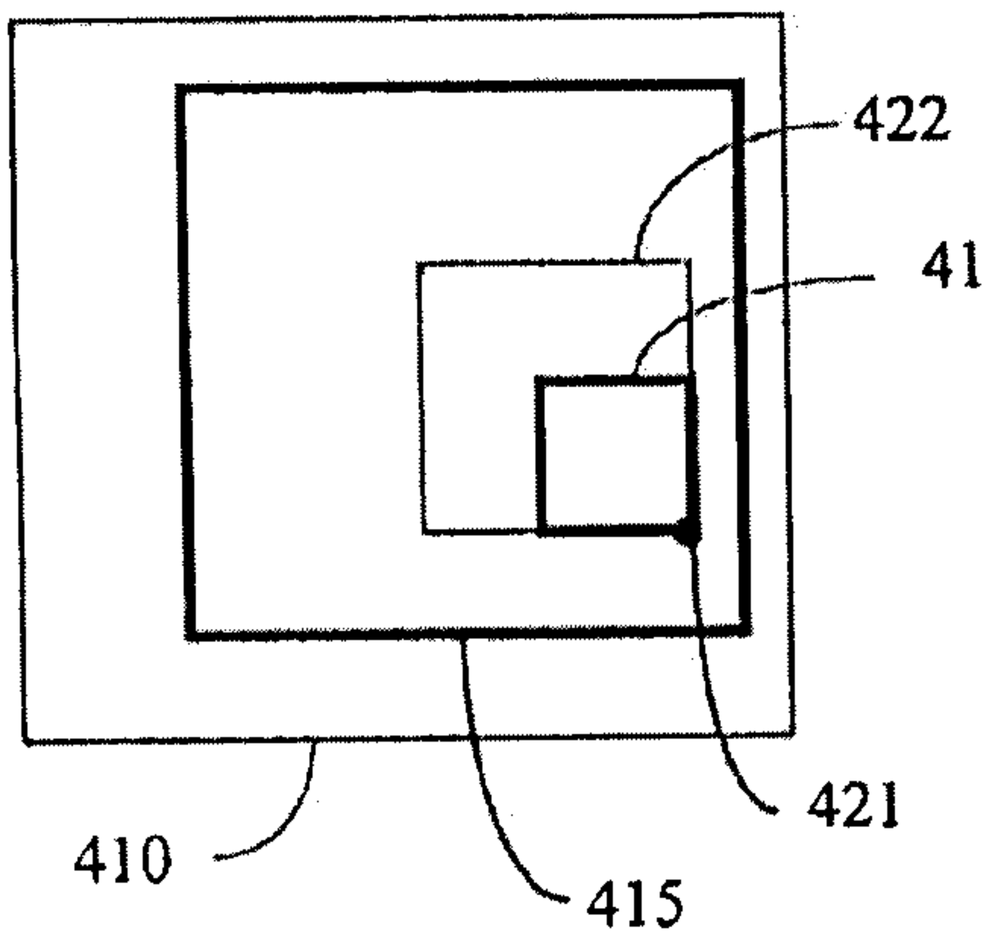


Fig. 4A

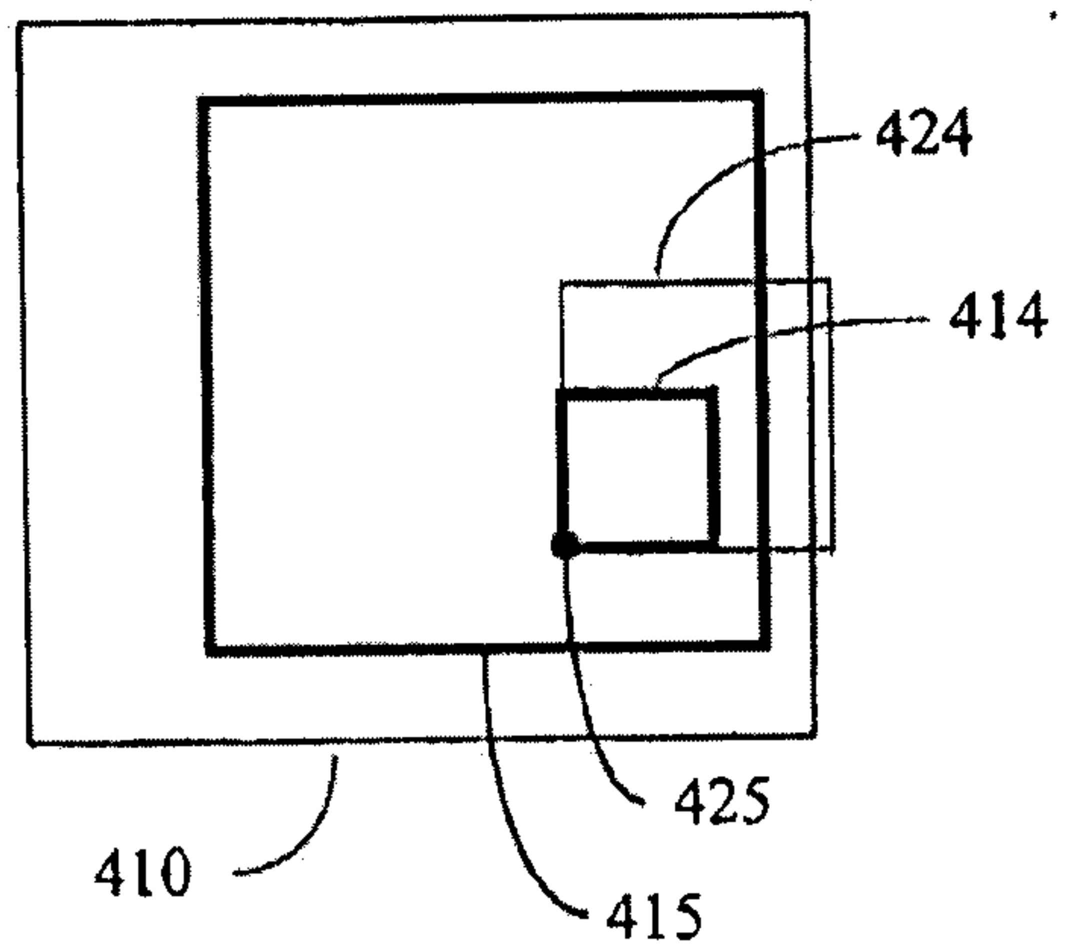


Fig. 4B

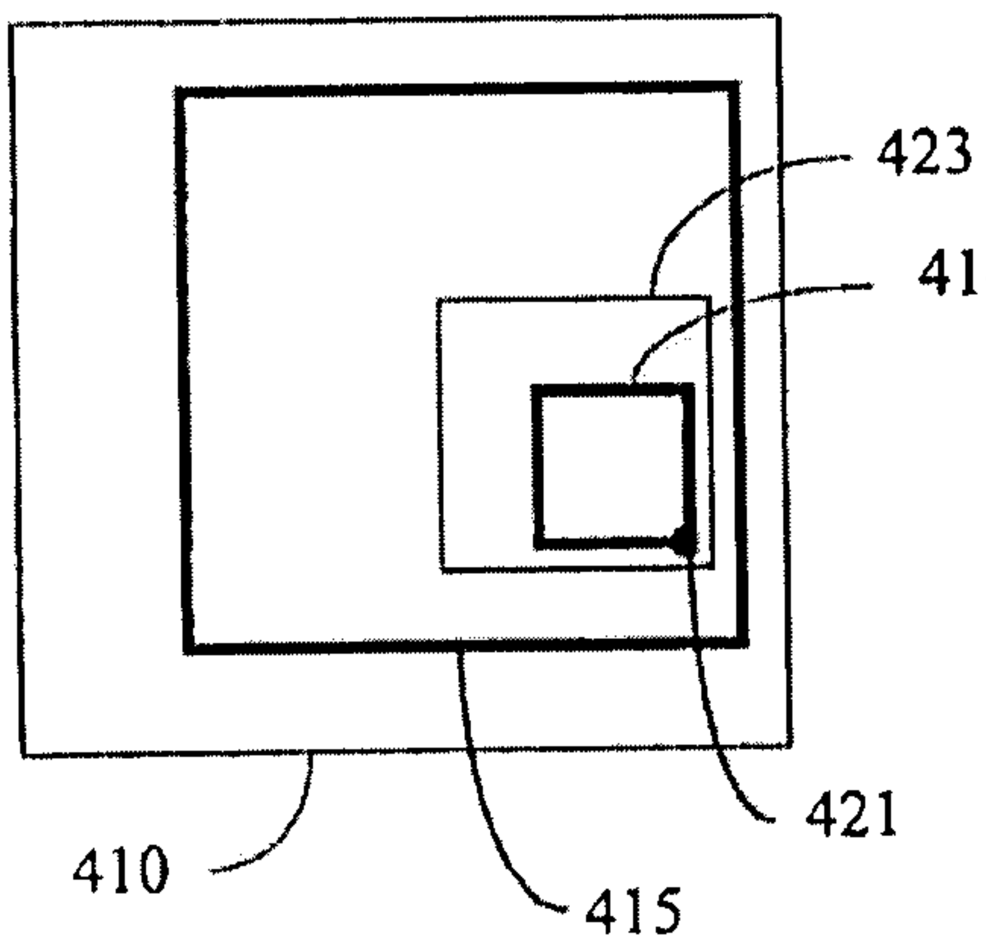


Fig. 4C

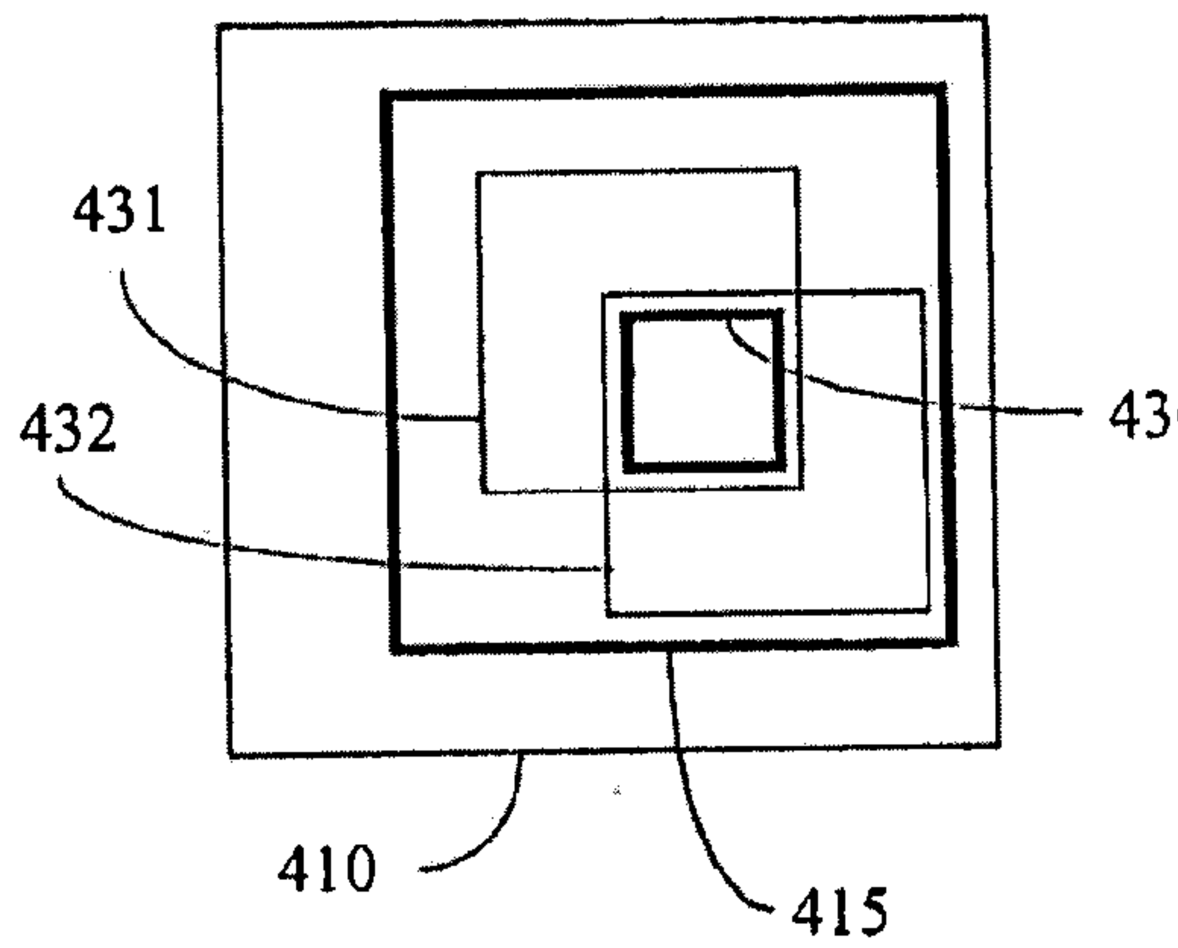


Fig. 4D

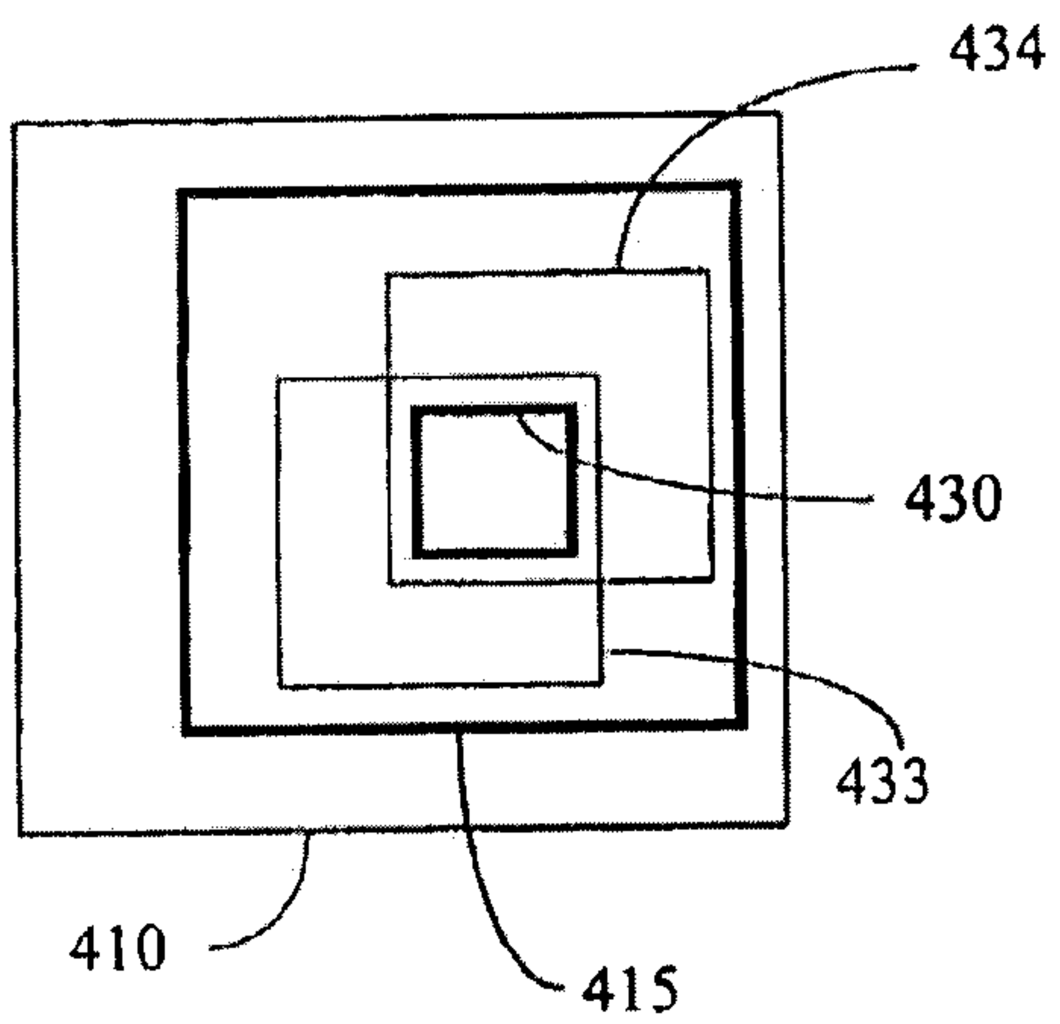


Fig. 4E

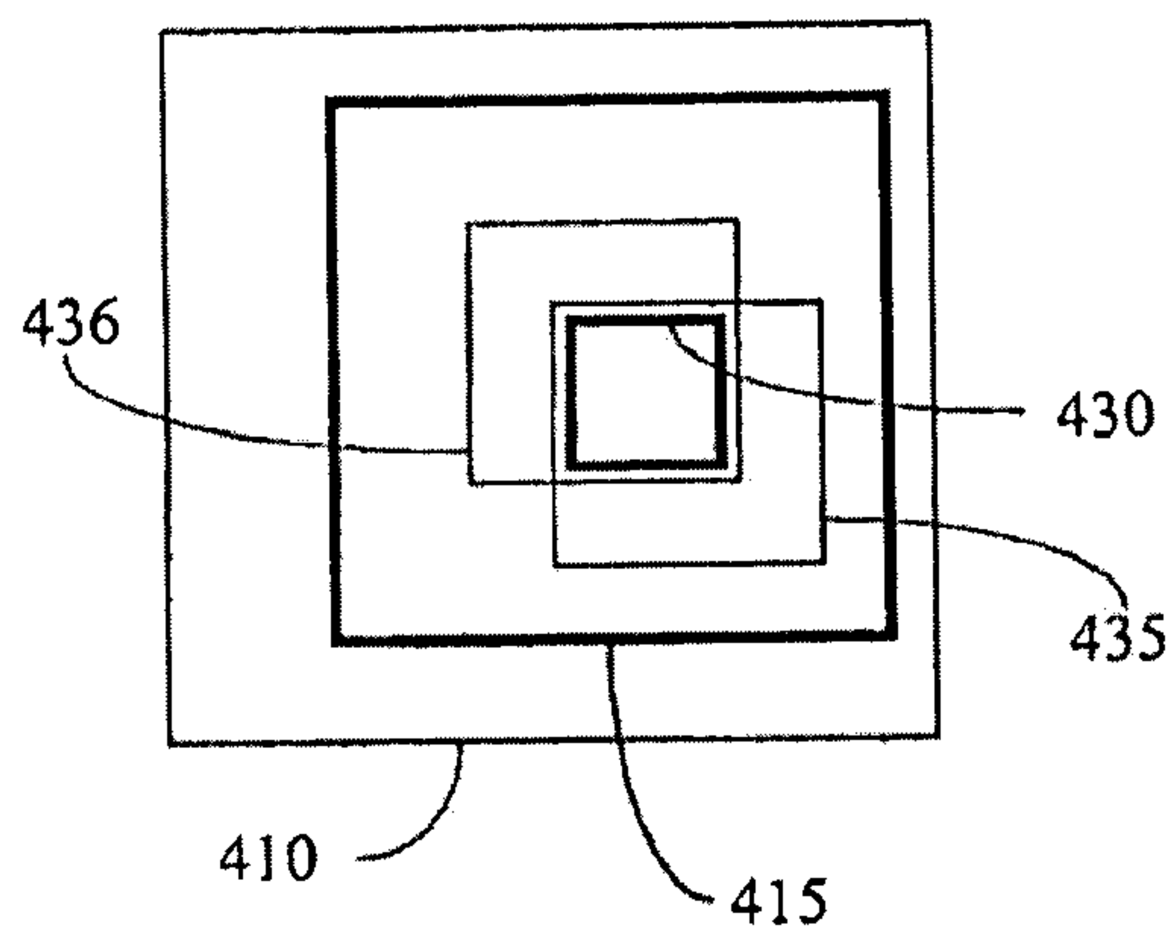


Fig. 4F


703
More Contrast
Neutral Contrast
Less Contrast
702
701
Less Brightness
Neutral Brightness
More Brightness

Fig. 5

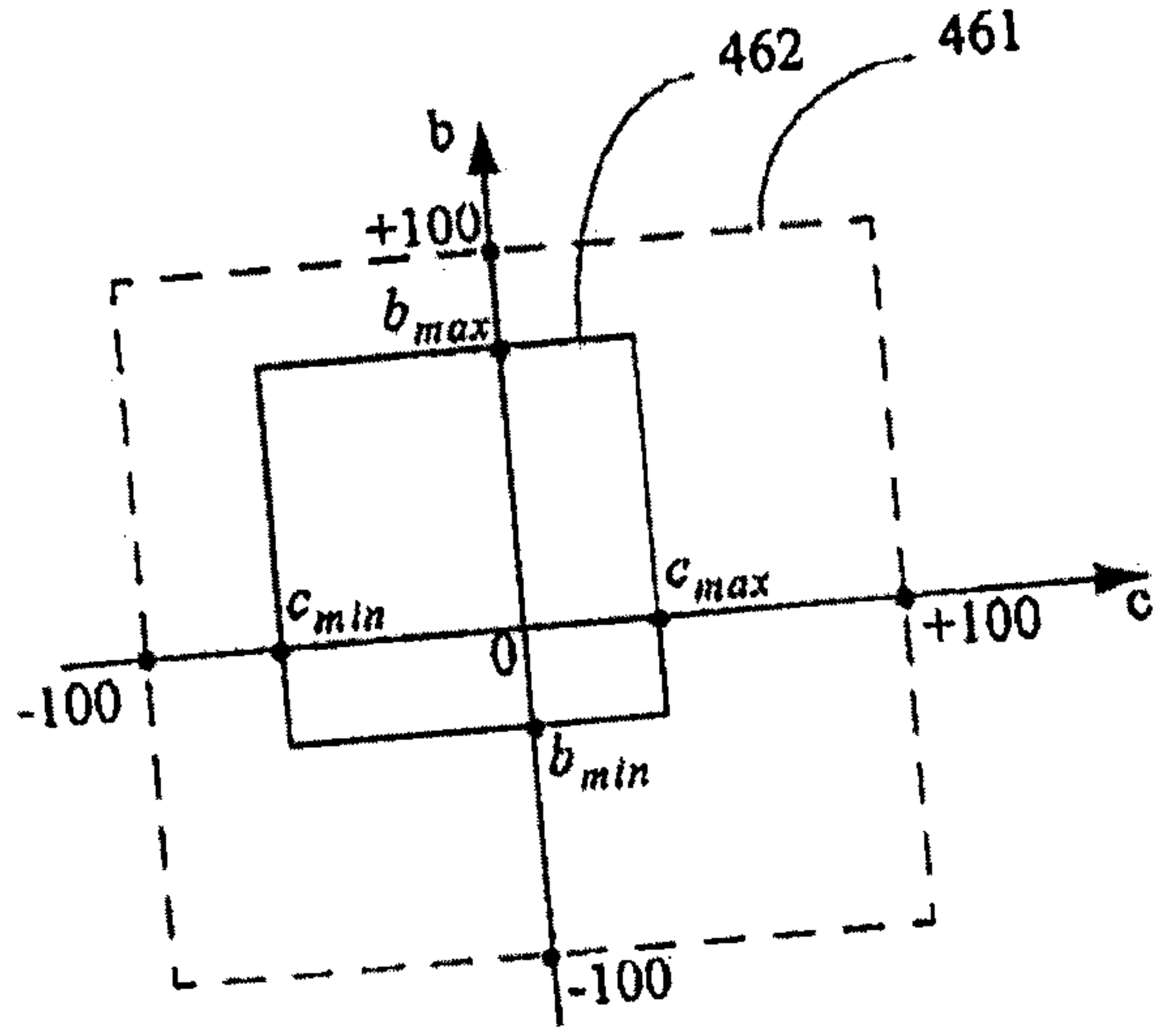

462
461
b
+100
b_{max}
c_{min}
c_{max}
+100
c
-100
0
b_{min}
-100

Fig. 6A

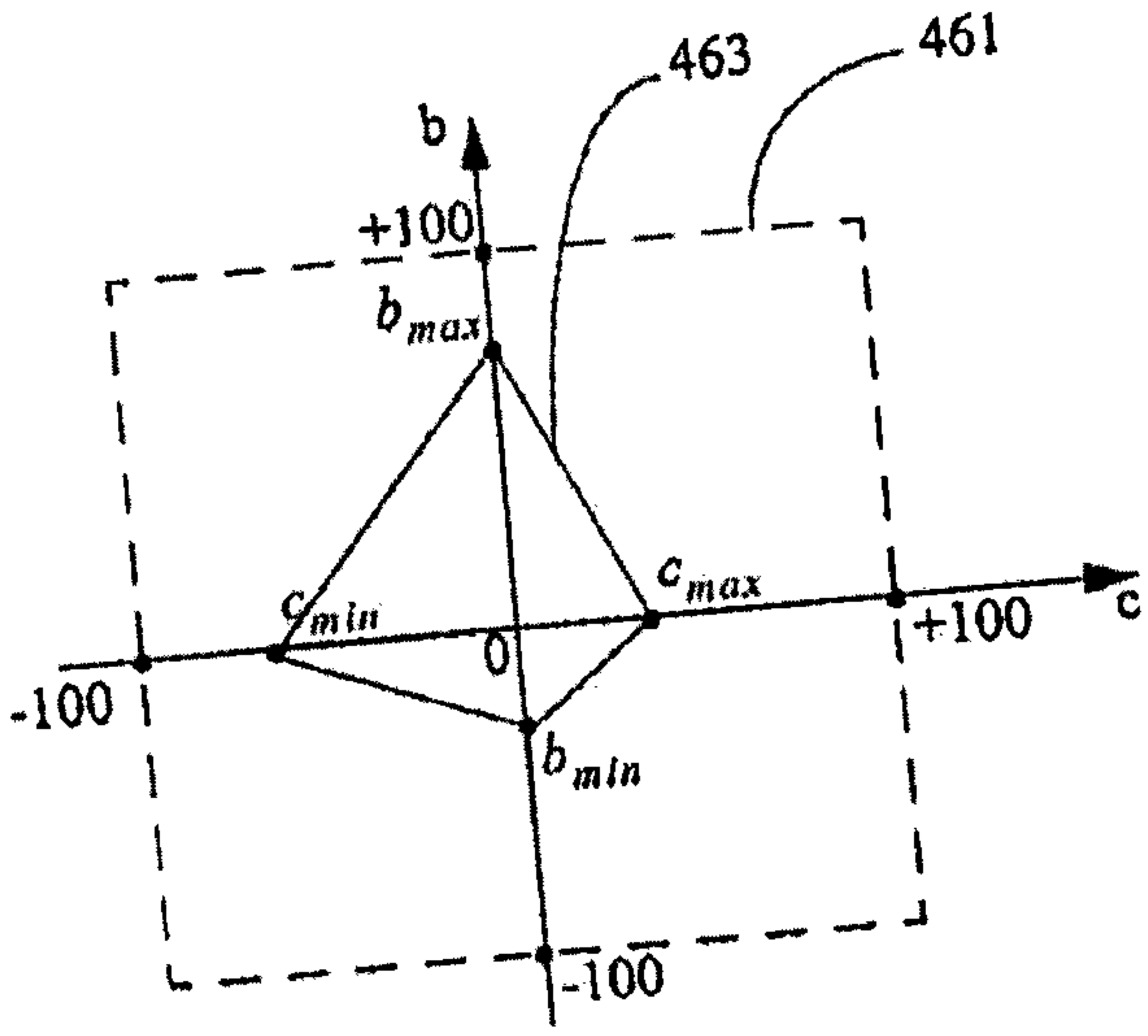

463
461
b
+100
b_{max}
c_{min}
c_{max}
+100
c
-100
0
b_{min}
-100

Fig. 6B

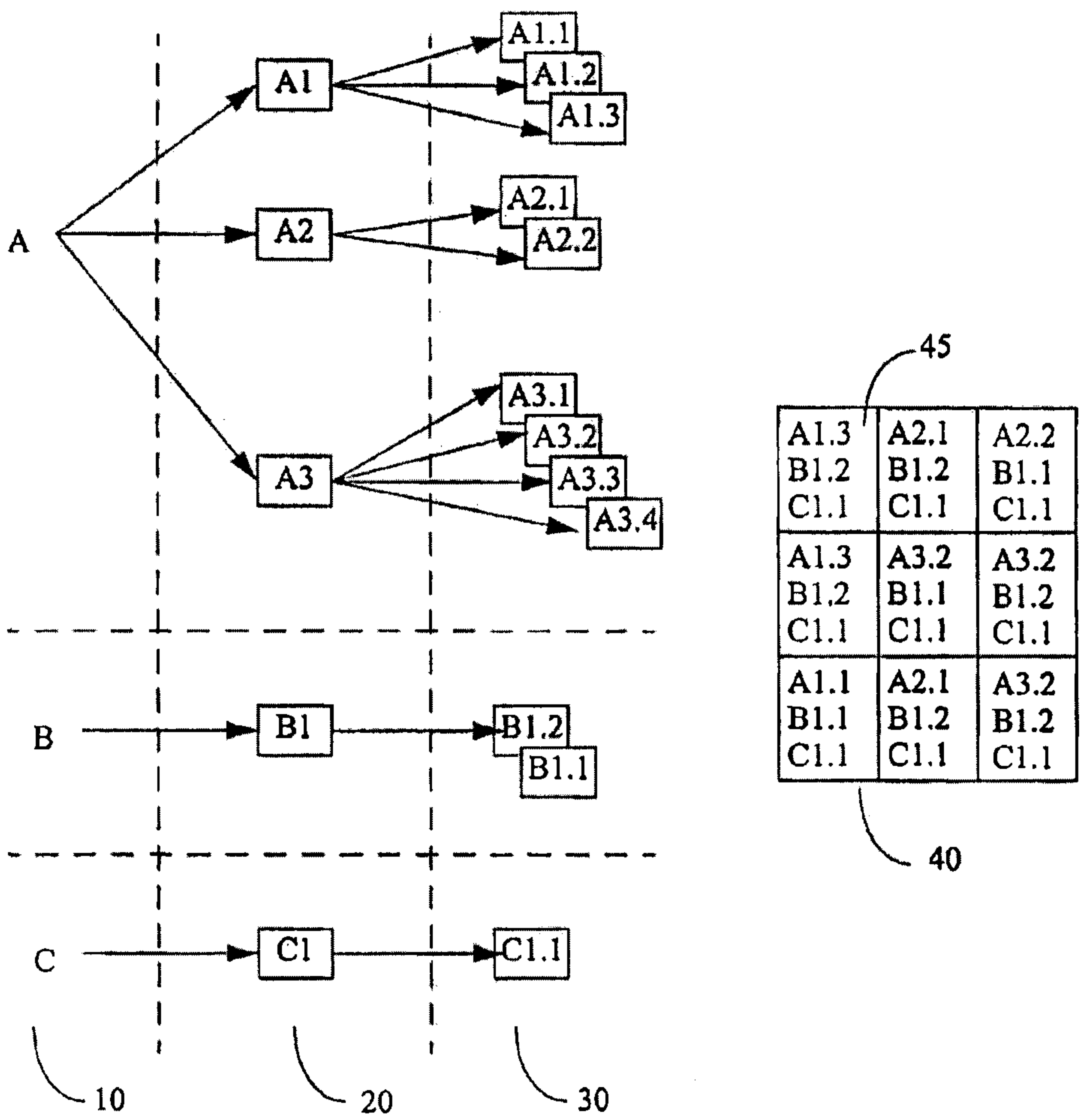

A
A1
A2
A3
A1.1
A1.2
A1.3
A2.1
A2.2
A3.1
A3.2
A3.3
A3.4
B
B1
B1.2
B1.1
C
C1
C1.1
10
20
30
45
A1.3 B1.2 C1.1
A2.1 B1.2 C1.1
A2.2 B1.1 C1.1
A1.3 B1.2 C1.1
A3.2 B1.1 C1.1
A3.2 B1.2 C1.1
A1.1 B1.1 C1.1
A2.1 B1.2 C1.1
A3.2 B1.2 C1.1
40

Fig. 7

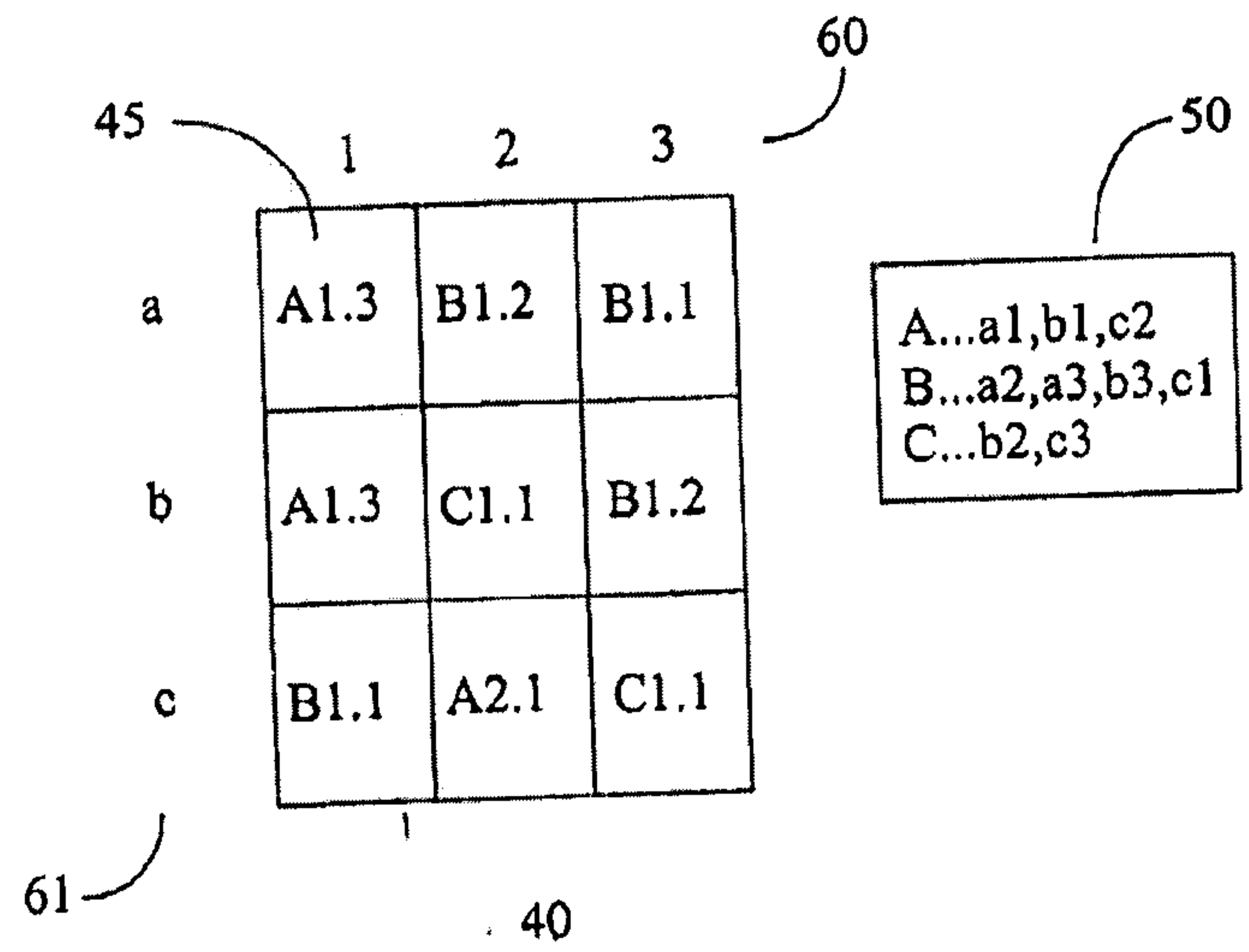

45
60
50
1
2
3
a
b
c
A1.3
B1.2
B1.1
A1.3
C1.1
B1.2
B1.1
A2.1
C1.1
A...a1,b1,c2
B...a2,a3,b3,c1
C...b2,c3
61
40

Fig. 8

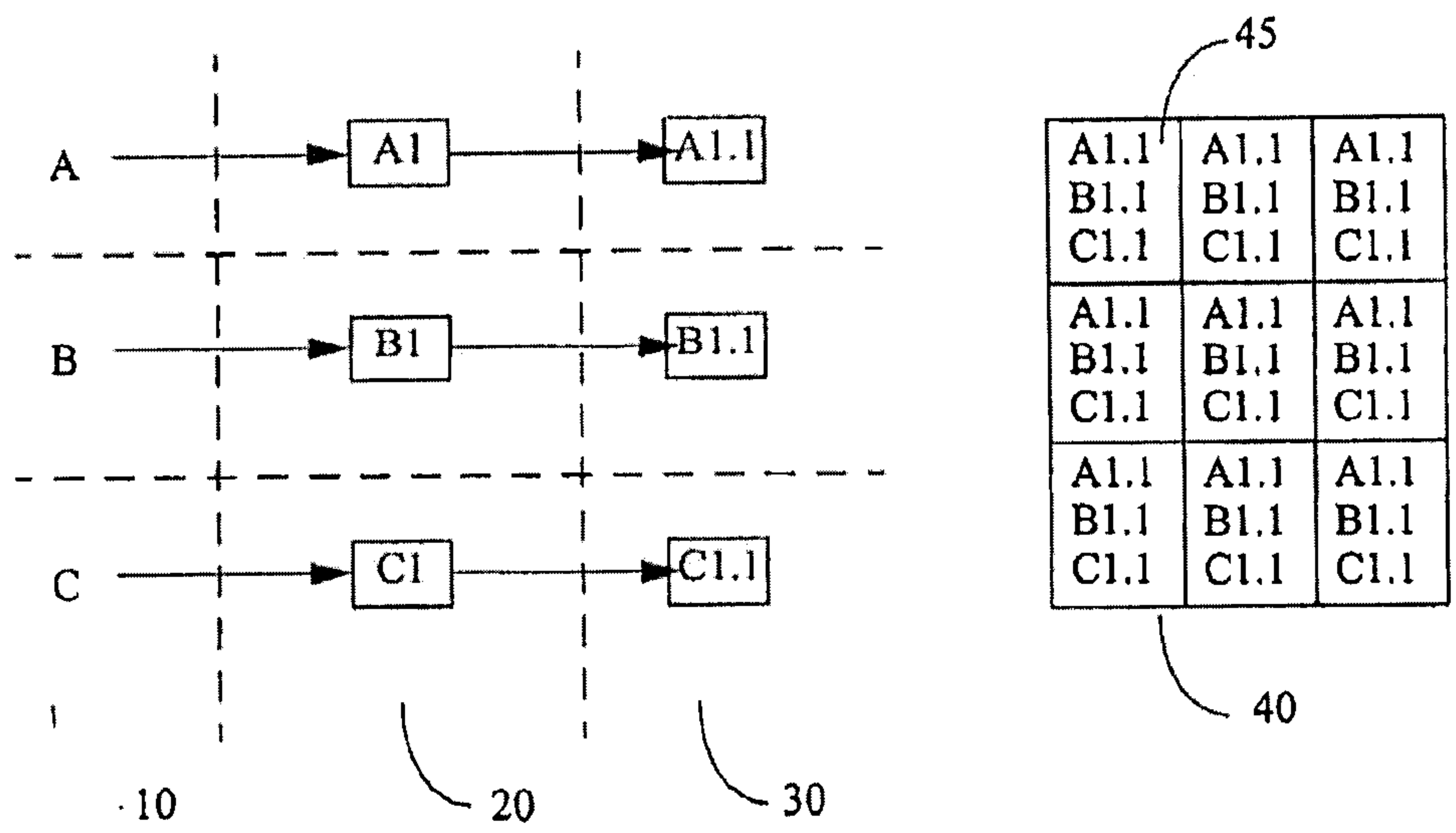

A
B
C
A1
B1
C1
A1.1
B1.1
C1.1
45
40
10
20
30

Fig. 9

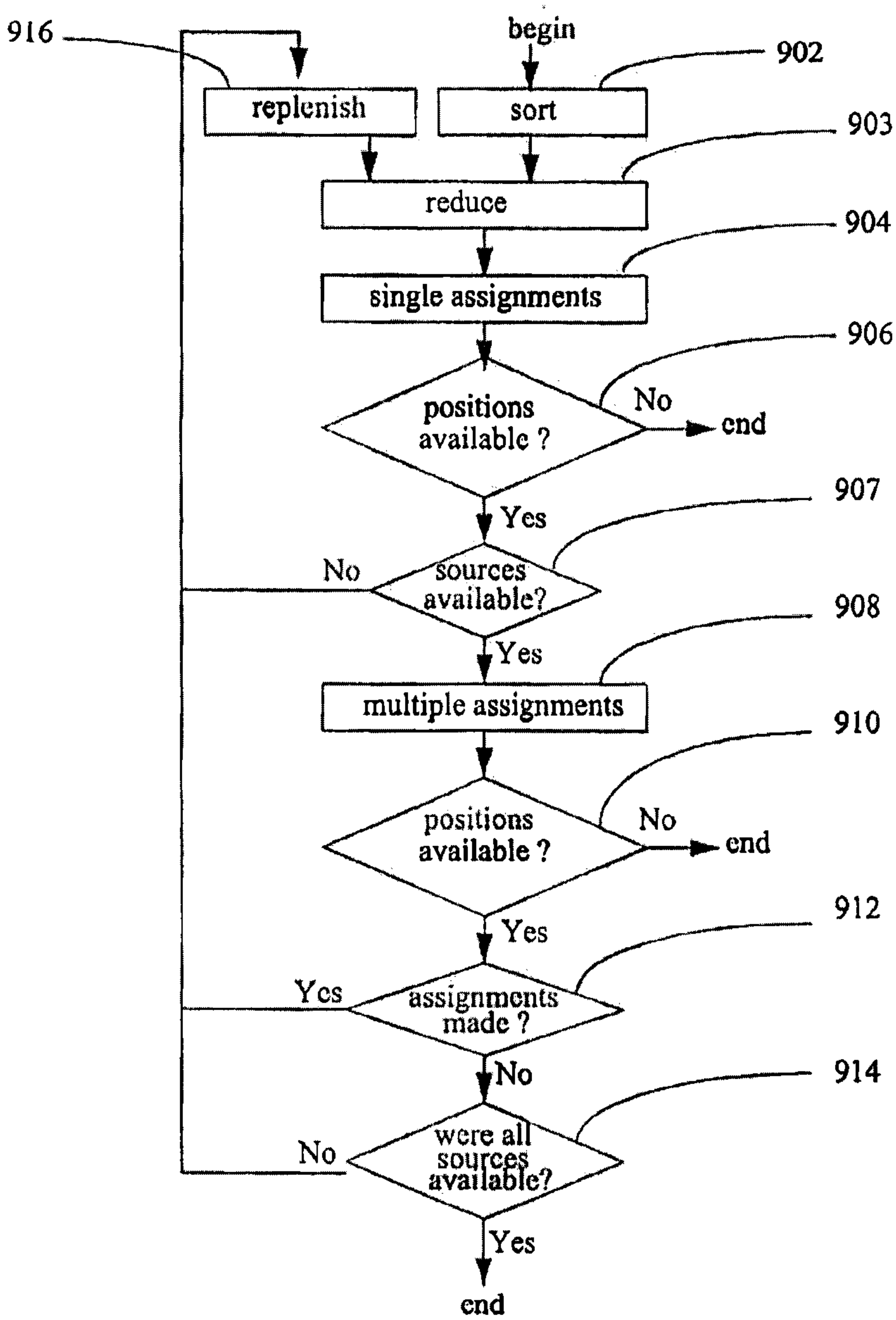

916
begin
902
replenish
sort
903
reduce
904
single assignments
906
positions available ?
No
end
Yes
907
No
sources available?
Yes
908
multiple assignments
910
positions available ?
No
end
Yes
912
Yes
assignments made ?
No
914
No
were all sources available?
Yes
end

Fig. 10

924, 921

$$D = \begin{pmatrix} 0.20 & 0.01 & 0.04 & 0.04 & 0.20 \\ 0.85 & 0.66 & 0.69 & 0.61 & 0.45 \\ 0.74 & 0.55 & 0.58 & 0.50 & 0.34 \\ 0.44 & 0.25 & 0.28 & 0.20 & 0.04 \\ 0.41 & 0.22 & 0.25 & 0.17 & 0.01 \\ 0.40 & 0.21 & 0.24 & 0.16 & 0.00 \\ 0.18 & 0.01 & 0.02 & 0.06 & 0.22 \\ 0.67 & 0.48 & 0.51 & 0.43 & 0.27 \\ 0.82 & 0.63 & 0.66 & 0.58 & 0.42 \\ 0.78 & 0.59 & 0.62 & 0.54 & 0.38 \end{pmatrix}$$

923, 926

$$D_s' = \begin{pmatrix} 0.18 & 0.01 & 0.02 & 0.04 & 0.00 \\ 0.20 & 0.01 & 0.04 & 0.06 & 0.01 \\ 0.40 & 0.21 & 0.24 & 0.16 & 0.04 \\ 0.41 & 0.22 & 0.25 & 0.17 & 0.20 \\ 0.44 & 0.25 & 0.28 & 0.20 & 0.22 \\ 0.67 & 0.48 & 0.51 & 0.43 & 0.27 \\ 0.74 & 0.55 & 0.58 & 0.50 & 0.34 \\ 0.78 & 0.59 & 0.62 & 0.54 & 0.38 \\ 0.82 & 0.63 & 0.66 & 0.58 & 0.42 \\ 0.85 & 0.66 & 0.69 & 0.61 & 0.45 \end{pmatrix}$$

922, 927, 928, 925

$$D_x' = \begin{pmatrix} 7 & 7 & 7 & 1 & 6 \\ 1 & 1 & 1 & 7 & 5 \\ 6 & 6 & 6 & 6 & 4 \\ 5 & 5 & 5 & 5 & 1 \\ 4 & 4 & 4 & 4 & 7 \\ 8 & 8 & 8 & 8 & 8 \\ 3 & 3 & 3 & 3 & 3 \\ 10 & 10 & 10 & 10 & 10 \\ 9 & 9 & 9 & 9 & 9 \\ 2 & 2 & 2 & 2 & 2 \end{pmatrix}$$

Fig. 11

932 934 933 931

$$D_s = \begin{pmatrix} 0.18 & 0.01 & 0.02 & 0.04 & 0.00 \\ 0.20 & 0.01 & 0.04 & 0.06 & 0.01 \\ 0.40 & 0.21 & 0.24 & 0.16 & 0.04 \\ 0.41 & 0.22 & 0.25 & 0.17 & 0.20 \\ 0.44 & 0.25 & 0.28 & 0.20 & 0.22 \\ 0.67 & 0.48 & 0.51 & 0.43 & 0.27 \\ 0.74 & 0.55 & 0.58 & 0.50 & 0.34 \\ 0.78 & 0.59 & 0.62 & 0.54 & 0.38 \\ 0.82 & 0.63 & 0.66 & 0.58 & 0.42 \\ 0.85 & 0.66 & 0.69 & 0.61 & 0.45 \end{pmatrix} \qquad D_x = \begin{pmatrix} 7 & 7 & 7 & 1 & 6 \\ 1 & 1 & 1 & 7 & 5 \\ 6 & 6 & 6 & 6 & 4 \\ 5 & 5 & 5 & 5 & 1 \\ 4 & 4 & 4 & 4 & 7 \\ 8 & 8 & 8 & 8 & 8 \\ 3 & 3 & 3 & 3 & 3 \\ 10 & 10 & 10 & 10 & 10 \\ 9 & 9 & 9 & 9 & 9 \\ 2 & 2 & 2 & 2 & 2 \end{pmatrix}$$

Fig. 12

942 941

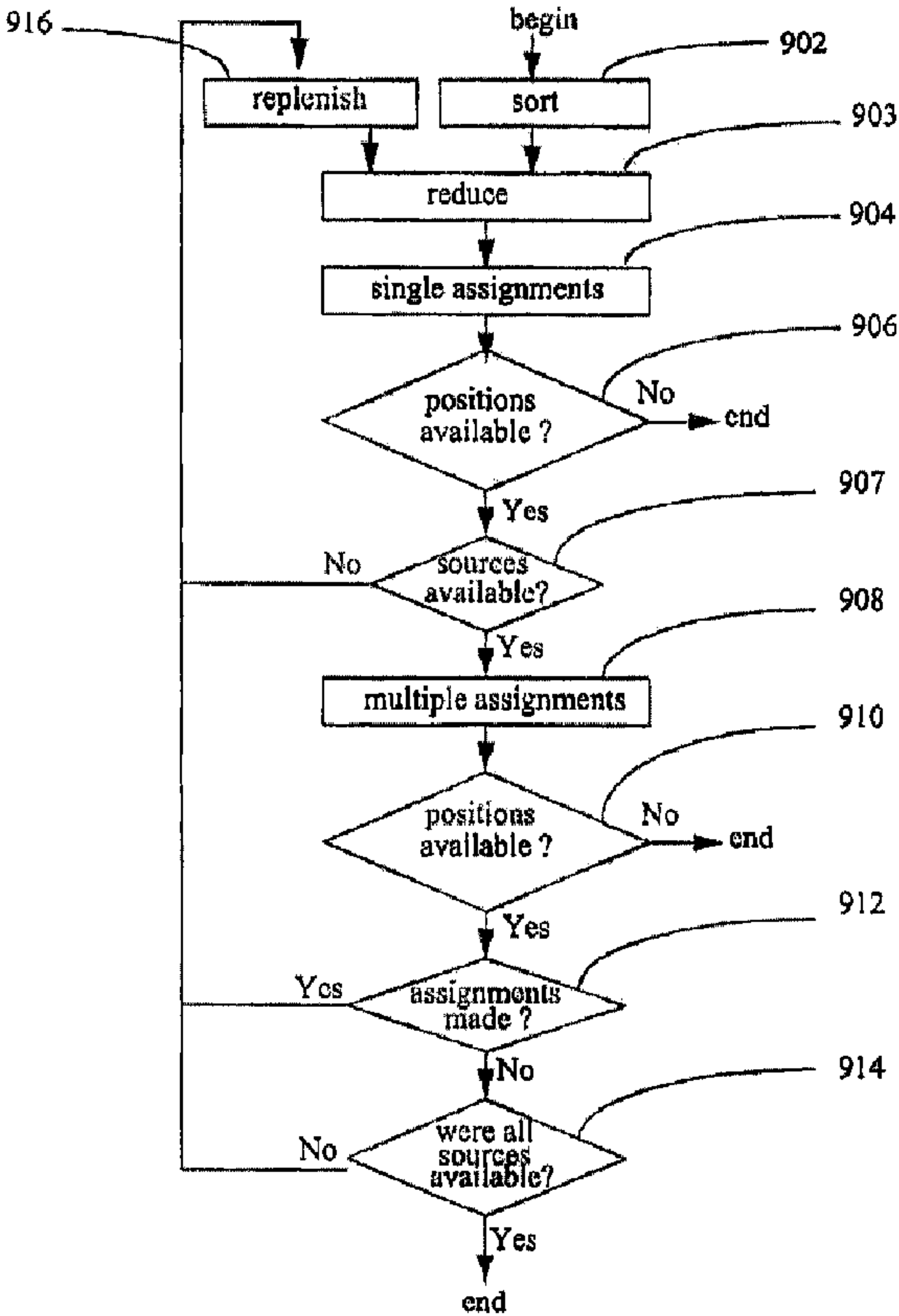
$$\tilde{D}_s = \begin{pmatrix} 0.18 & 0.01 & 0.02 \\ 0.41 & 0.22 & 0.25 \\ 0.44 & 0.25 & 0.28 \end{pmatrix} \qquad \tilde{D}_x = \begin{pmatrix} 7 & 7 & 7 \\ 5 & 5 & 5 \\ 4 & 4 & 4 \end{pmatrix}$$

Fig. 13

932 931

$$D_s = \begin{pmatrix} 0.18 & 0.01 & 0.02 & 0.04 & 0.00 \\ 0.20 & 0.01 & 0.04 & 0.06 & 0.01 \\ 0.40 & 0.21 & 0.24 & 0.16 & 0.04 \\ 0.41 & 0.22 & 0.25 & 0.17 & 0.20 \\ 0.44 & 0.25 & 0.28 & 0.20 & 0.22 \\ 0.67 & 0.48 & 0.51 & 0.43 & 0.27 \\ 0.74 & 0.55 & 0.58 & 0.50 & 0.34 \\ 0.78 & 0.59 & 0.62 & 0.54 & 0.38 \\ 0.82 & 0.63 & 0.66 & 0.58 & 0.42 \\ 0.85 & 0.66 & 0.69 & 0.61 & 0.45 \end{pmatrix} \qquad D_x = \begin{pmatrix} 7 & 7 & 7 & 1 & 6 \\ 1 & 1 & 1 & 7 & 5 \\ 6 & 6 & 6 & 6 & 4 \\ 5 & 5 & 5 & 5 & 1 \\ 4 & 4 & 4 & 4 & 7 \\ 8 & 8 & 8 & 8 & 8 \\ 3 & 3 & 3 & 3 & 3 \\ 10 & 10 & 10 & 10 & 10 \\ 9 & 9 & 9 & 9 & 9 \\ 2 & 2 & 2 & 2 & 2 \end{pmatrix}$$

Fig. 14


916
begin
902
replenish
sort
903
reduce
904
single assignments
906
positions available ?
No
end
Yes
907
No
sources available?
Yes
908
multiple assignments
910
positions available ?
No
end
Yes
912
Yes
assignments made ?
No
914
No
were all sources available?
Yes
end