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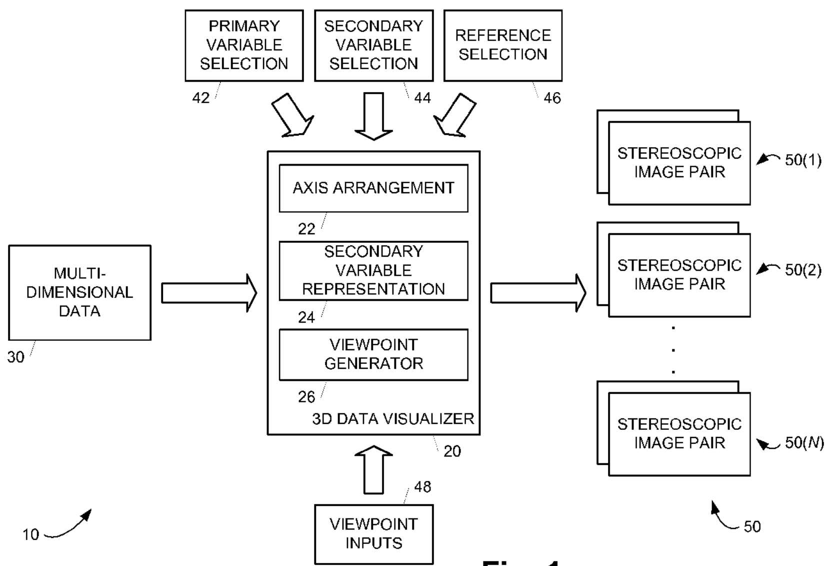

Fig. 1

(57) Abstract: A method of generating a three-dimensional data visualization from multidimensional data includes forming an arrangement of axes in a three dimensional coordinate space such that the axes radiate from a global reference in the three-dimensional coordinate space where the axes are based on a primary variable in the multi-dimensional data. The method also includes forming a representation in the three-dimensional coordinate space for local references on each of the axes where each of the representations is based on a secondary variable in the multi-dimensional data and generating an image pair to include the arrangement and the representations such that the image pair is displayable to produce the three-dimensional data visualization.

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THREE DIMENSIONAL DATA VISUALIZATION

Background

[0001] Data visualizations may be used to illustrate relationships between datasets. These visualizations may organize and present the data in a variety of ways to allow a viewer to better understand the data. Visualizations typically have practical limits regarding the amount of data that can be shown as well as constraints on the arrangement of data. A visualization that shows too much data, for example, may become visually cluttered and difficult for a viewer to process. Similarly, a visualization that includes too many different types of data may prevent relationships between the different types from being observed by the viewer.

Brief Description of the Drawings

[0002] Figure 1 is a block diagram illustrating one example of a three-dimensional (3D) data visualization processing environment.

[0003] Figure 2 is a flowchart illustrating an example of a method for generating a 3D data visualization.

[0004] Figure 3 is a schematic diagram illustrating one example of a 3D data visualization with axes radiating from a surface.

[0005] Figure 4 is a schematic diagram illustrating one example of a 3D data visualization with axes radiating from a line.

[0006] Figure 5 is a schematic diagram illustrating one example of a 3D data visualization with axes radiating from a point.

[0007] Figure 6 is a block diagram illustrating a processing system configured to implement a 3D data visualization processing environment.

Detailed Description

[0008] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration specific embodiments in which the disclosed subject matter may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense, and the scope of the present disclosure is defined by the appended claims.

[0009] As used herein, the term "disparity" refers to the difference in image location of an object seen by the left and the right eyes.

[0010] The terms "axis" and "primary axis" refer to a one-dimensional contour (e.g., straight, curved, or piecewise linear line) in a three-dimensional coordinate space that is based on a function of the values of the one or more primary variables in multi-dimensional data. The function may be the identity function in some examples.

[0011] The term "global reference" refers to a planar or a non-planar surface, a straight or curved line, or a point in a three-dimensional coordinate space.

[0012] The term "representation" refers to a one, two, or three-dimensional shape in a three-dimensional coordinate space that is based on a function of the values of the one or more secondary variables in multi-dimensional data. The function may be the identity function in some examples.

[0013] The term "local reference" refers to a point on an axis that corresponds to a representation.

[0014] The term "connection" refers to a one, two, or three-dimensional shape in a three-dimensional coordinate space that is based on a function of the values of the one or more connection variables in multi-dimensional data. The function may be the identity function in some examples.

[0015] As described herein, a three-dimensional (3D) data visualization processing environment uses disparity as a fundamental variable to allow multi-dimensional data to be visualized with a 3D display system. The environment transforms the multi-dimensional data into a 3D coordinate system by forming an arrangement of axes based on one or more primary variables in the data where the axes radiate from a global reference in the 3D coordinate system and forming representations along the axes based on one or more secondary variables in the data. The primary and secondary variables may overlap in some examples. The environment forms the axes and representations using visual elements that include disparity and generates stereoscopic image pairs that produce a 3D data visualization when displayed by a 3D display system.

[0016] The use of disparity in the 3D data visualizations described herein exploits human beings' innate binocular vision and stereopsis to allow viewers to perceive differences in depth between the axes and / or representations in the visualizations. These differences provide both focus and context to the viewer within the visualization so that the viewer may more readily recognize features in the data (e.g., patterns, trends, outliers, and corner cases), obtain insights into the data, and identify areas for further investigation in the data. The use of disparity along with other visual elements also allows a large amount of data to be included in the visualizations and seen by the viewer all at once while maintaining sufficient spacing of the data and avoiding visual clutter. The presentation of data in 3D may also speed the recognition of data co-occurrences through the use of local 3D spatial patterns.

[0017] Figure 1 is a block diagram illustrating one example of a three-dimensional (3D) data visualization processing environment 10. Environment 10 includes a 3D data visualizer 20 that processes multi-dimensional data 30, a primary variable selection 42, a secondary variable selection 44, a reference selection 46, and viewpoint inputs 48 to generate a set 50 of stereoscopic image pairs 50(1)-50(*N*), where *N* is an integer that is greater than or equal to one, displayable to produce a three-dimensional data visualization of selected portions of multi-dimensional data 30. Environment 10 may be implemented using one or more processing systems (e.g., a processing system 100 shown in Figure 6 and described in additional detail below).

[0018] 3D data visualizer 20 receives multi-dimensional data 30, a primary variable selection 42, a secondary variable selection 44, a reference selection 46, and viewpoint inputs 48. Multi-dimensional data 30 is a structured and / or unstructured dataset that includes at least two variables. Primary variable selection 42 is an input that identifies a set of one or more primary variables in multi-dimensional data 30 for forming axes. For example, primary variable selection 42 may identify absolute or relative time as a primary variable and axes may be formed based on absolute or relative time. Primary variable selection 42 may also identify one or more functions to be applied to the values of the set of primary variables to form the axes.

[0019] Secondary variable selection 44 is an input that identifies a set of one or more secondary variables in multi-dimensional data 30 for forming representations along the axes. Secondary variable selection 44 may also identify one or more functions to be applied to the set of secondary variables to form the representations. Secondary variable selection 44 may further identify one or more connection variables in multi-dimensional data 30 that may be used in generating connections between corresponding representations of secondary variables as described in additional detail below. Secondary variable selection 44 may also identify one or more functions to be applied to the connection variables to form the representations.

[0020] Reference selection 46 is an input that identifies a global reference in a three-dimensional coordinate space for mapping axes. Reference selection 46 may identify the global reference as a planar or a non-planar surface, a straight or curved line, or a point in the three-dimensional coordinate space. Reference selection 46 may also identify one or more arrangement variables in multi-dimensional data 30 that may be used in generating an arrangement of the axes as described in additional detail below. Reference selection 46 may further identify one or more functions to be applied to the set of arrangement variables to form an arrangement.

[0021] 3D data visualizer 20 includes an axis arrangement unit 22, a secondary variable representation unit 24, and a viewpoint generator 26. The functions of axis arrangement unit 22, secondary variable representation unit 24, and viewpoint generator 26 will be described with reference to Figure 2, which is a flowchart illustrating an example of a method for generating a 3D data visualization.

[0022] Referring to Figures 1 and 2, axis arrangement unit 22 forms an arrangement of axes in a three-dimensional coordinate space such that the axes radiate from a global reference, identified by reference selection 46, in the three-dimensional coordinate space as indicated in a block 52. Axis arrangement unit 22 forms the axes based on the set of primary variables and any functions of the primary variables identified by primary variable selection 42. For example, axis arrangement unit 22 may form axes based on absolute or relative time. Axis arrangement unit 22 forms the arrangement by mapping the position and orientation of the axes in the three-dimensional coordinate space. Axis arrangement unit 22 does so such that each axis radiates from the global reference and either intersects or could be extended to intersect the global reference. Accordingly, axis arrangement unit 22 may specify the position and orientation of each axis based on the actual or theoretical intersection with the global reference and a direction of the axis with respect to the actual or theoretical intersection. Examples of arrangements of axes formed by axis arrangement unit 22 will be described below with reference to Figures 3-5.

[0023] Axis arrangement unit 22 may form the arrangement based on one or more arrangement variables and any functions of the arrangement variables specified by reference selection 46. Axis arrangement unit 22 selects the position and orientation of each axis in the three-dimensional coordinate space using the arrangement variables and any functions. For example, the arrangement variables may be longitude and latitude or cities, and axis arrangement unit 22 may place axes in the arrangement such that the axes correspond to longitude and latitude or cities. In some examples, axis arrangement unit 22 may distribute the axes in the three-dimensional coordinate space based on the results of an analytic function (e.g. a dimension reduction) or a clustering function that identifies relationships between the axes.

[0024] In forming the arrangement, axis arrangement unit 22 uses disparity as an integral variable to allow a viewer of a 3D data visualization that includes the arrangement to perceive differences in depth between the axes. Axis arrangement unit 22 may also use time varying disparity to allow viewers to move through the 3D data visualization emphasizing different depths. Axis arrangement unit 22 may perform a 3D data analysis in forming the arrangement to determine an optimal amount of disparity to include in the arrangement. The 3D data analysis evaluates the type, size, and / or data ranges of the primary variables for the axes as well as external factors such as display size and resolution and viewer distance from the display screen. Based on the analysis, axis arrangement unit 22 may select and optimize the visual elements used to form the arrangement including the position and / or orientation of the global reference in the three-dimensional coordinate space and / or the number, length, position, orientation, color, thickness, transparency, and / or data range of each axis. By doing so, axis arrangement unit 22 selects the combination of visual elements for the arrangement to minimize overcrowding in the visualization and maximize the exploitation of human binocular vision and stereopsis.

[0025] Secondary variable representation unit 24 forms respective representations in the three-dimensional coordinate space for each secondary variable at each local reference on each of the axes as indicated in a block 54. Secondary variable representation unit 24 selects the local references on each of the axes where a representation of a secondary variable is to be included. Secondary variable representation unit 24 forms the representations based on the set of secondary variables and any functions of the secondary variables identified by secondary variable selection 44. From each selected local reference, secondary variable representation unit 24 maps the position and orientation of the representations in the three-dimensional coordinate space.

[0026] Secondary variable representation unit 24 forms each representation as a one, two, or three-dimensional shape based on the secondary variables and any functions of the secondary variables using visual elements such as size, color, transparency, position, orientation, data range, and / or motion. Secondary variable representation unit 24 may select the visual elements based on the magnitude of the values of one or more of the secondary variables. For example, secondary variable representation unit 24 may form a representation as an ellipsoid where the size of the ellipsoid depends on the magnitude of the values of one or more of the secondary variables. As another example, secondary variable representation unit 24 may form a representation to include an offshoot that radiates at a selected angle from a local reference where the size of the offshoot or another shape at the end of the offshoot depends on the magnitude of the values of one or more of the secondary variables. The length of an offshoot, the color of an offshoot, the shape at the end of the offshoot, and the magnitude of the shape at the end of the offshoot may all correspond to different secondary variables in one specific example. Secondary variable representation unit 24 may also change represention over time to represent an additional secondary variable. Motion-based and / or time varying representations may be particularly useful because of the sensitivity of the human visual system to motion.

[0027] In forming the representations, secondary variable representation unit 24 uses disparity as an integral variable to allow a viewer of a 3D data visualization that includes the representations to perceive differences in depth between the representations. Secondary variable representation unit 24 may perform a 3D data analysis in forming the arrangement to determine an optimal amount of disparity to include for the representations. The 3D data analysis evaluates the type, size, and / or data ranges of the secondary variables for the axes. Based on the analysis, secondary variable representation unit 24 may select and optimize the visual elements used to form the representations including the shape, size, position, orientation, motion, and / or data range of each representation. By doing so, secondary variable representation unit 24 selects the combination of visual elements for the representations to minimize overcrowding in the visualization and maximize the exploitation of human binocular vision and stereopsis.

[0028] Where connection variables are specified by secondary variable selection 44, secondary variable representation unit 24 forms connections in the three-dimensional coordinate space between representations on different axes. Secondary variable representation unit 24 forms each connection as a one, two, or three-dimensional shape based on the connection variables and any functions of the connection variables using visual elements such as size, color, transparency, position, orientation, motion and / or data range. Secondary variable representation unit 24 maps the position and orientation of the connections in the three-dimensional coordinate space.

[0029] In forming the connections, secondary variable representation unit 24 uses disparity as an integral variable to allow a viewer of a 3D data visualization that includes the connections to perceive differences in depth between the connections and / or representations. Secondary variable representation unit 24 may perform a 3D data analysis in forming the arrangement to determine an optimal amount of disparity to include for the connections. The 3D data analysis evaluates the type, size, and / or data ranges of the secondary variables for the axes. Based on the analysis, secondary variable representation unit 24 may select and optimize the visual elements used to form the connections including the shape, size, position, orientation, motion, and / or data range of each representation. By doing so, secondary variable representation unit 24 selects the combination of visual elements for the connections to minimize overcrowding in the visualization and maximize the exploitation of human binocular vision and stereopsis.

[0030] The primary and secondary variables described above provide first and second levels of data representations using the global and local references, respectively. Any number of additional levels of data representations (e.g., based on tertiary and quaternary variables, etc.) may also be added to a 3D data visualization by defining successive levels of references based on a previous level of reference. For example, a third level reference may be defined based on a local reference (i.e., a second level reference) and representations may be formed based on tertiary variables and mapped relative to the third level reference in the three-dimensional coordinate space. A representation unit (not shown) that forms representations for the additional levels of data representations may selectively include or exclude all or portions of the additional levels of data representations in a 3D data visualization based on a 3D data analysis as described above.

[0031] Viewpoint generator 26 generates one or more image pairs 50 to include the arrangement of axes, representations along the axes, and connections between the representations as indicated in a block 56. Viewpoint generator 26 generates each image pair 50 to include left and right images that are displayable by a 3D display system to produce a 3D viewpoint of the 3D data visualization. Viewpoint generator 26 may generate each image pair 50 based on the type, size, and configuration of the 3D display system. Different images pairs 50 may be generated to produce different 3D viewpoints with the same 3D display system simultaneously. Different images pairs 50 may be generated to produce a succession of 3D viewpoints with the same 3D display system. This change in view point may help provide motion parallax as an additional depth cue to enhance the 3D effect if done in such a way to avoid viewer side effects.

[0032] For multi-view and continuous 3D display systems, viewpoint generator 26 may generate additional views for each image pair 50 to provide one or more images for each view.

[0033] 3D data visualizer 20 receives viewpoint inputs 48 and generates images pairs 50 based on viewpoint inputs 48. Viewpoint inputs 48 identify one or more updates to a 3D data visualization that allow a viewer to select, control, and manipulate data or the orientation of the 3D data visualization. The selection of data may cause one or more levels of data representations to be added or removed from a 3D data visualization, for example. Viewpoint inputs

48 may be received from any suitable user interface device and may take the form of 3D gestures or other input modalities. Responsive to receiving viewpoint inputs 48, 3D data visualizer 20 updates the arrangement of axes, representations along the axes, and / or connections among the representations based on viewpoint inputs 48 and generates updated images pairs 50 that reflect viewpoint inputs 48.

[0034] In some examples, 3D data visualizer 20 may add one, two, or three-dimensional visual guides to a 3D data visualization to assist a viewer with selecting or highlighting data in the visualization. For example, partially transparent lines, surfaces, or shapes may be used to highlight data ranges in various visualizations.

[0035] In some examples, 3D data visualizer 20 may make the axes, representations, and / or connections time varying by generate a series of image pairs 50 for successive display to form a time varying 3D data visualization. Additional information such as visually warbling items, oscillations, flow indicators and vapor trail effects may be used to highlight changes of selected data over time.

[0036] Examples of 3D data visualizations will now be shown and described with reference to Figures 3-5.

[0037] Figure 3 is a schematic diagram illustrating one example of a 3D data visualization 60 with axes 64(1)-64(6) radiating from a global reference that is a surface 62 in the x-y plane in a three-dimensional coordinate space 61. Visualization 60 is based on a "corn-field" model where axes 64(1)-64(6) based on one or more primary variables radiate from surface 62 in parallel in the z-direction. Axes 64(1)-64(2) and 64(4)-64(6) originate at surface 62 and, thus, intersect surface 62. Axis 64(3) is offset from surface 62 (i.e., does not intersect surface 62) but would intersect surface 62 if extended toward surface 62 as indicated by a dashed line 67. 3D representations 66 are formed at various local references (i.e., points) along each axis 64(1)-64(6) where a size of each 3D representation 66 corresponds to a magnitude of one or more values of one or more secondary variables. In addition, a connection 68(1) is formed between representations 66 on axes 64(1)-64(2), and a connection 68(2) is formed between representations 66 on axes 64(3)-64(4). Connections may also be formed between points on axes 64 that do not include a representation 66 (not shown) or between a representation 66 on one axis 64 and a point that does not include a representation on another axis 64 (not shown).

[0038] The arrangement of axes 64(1)-64(6) in visualization 60 may reflect a mapping of axes 64(1)-64(6) based on one or more arrangement variables and any associated functions of the arrangement variables. For example, axes 64(1)-64(6) may be plotted in the x-y plane based on the arrangement variables. As another example, the grouping of axes 64(1)-64(3) and axes 64(4)-64(6) into clusters in the x-y plane may be based on a clustering or other data analysis function.

[0039] Figure 4 is a schematic diagram illustrating one example of a 3D data visualization 70 with axes 74(1)-74(3) radiating from a global reference that is a line 72 that extends in the x direction in a three-dimensional coordinate space 71. Visualization 70 is based on a "tube" model where axes 74(1)-74(3) based on one or more primary variables radiate from line 72 in various y and z directions. Axes 74(1)-74(3) originate at line 72 and, thus, intersect line 72. In other examples, other axes may be offset from line 72 (i.e., may not intersect line 72) but would intersect line 72 if extended toward line 72 (not shown).

[0040] In the example of Figure 4, 3D representations 76 are formed at various local references (i.e., points) along each axis 74(1)-74(3) to include offshoots 77 that radiate from the local references at defined angles in a corresponding plane (or in three dimensions in other examples not shown) that is orthogonal to the corresponding axis 74(1)-74(3). The defined angles may correspond to different ones of the secondary variables. The ends of each offshoot 77 include a further representation 78 where a size of the representation 78 corresponds to a magnitude of one or more values of one or more secondary variables. In other examples, the length, orientation, and / or color of each offshoot 77 may each correspond to a magnitude of one or more values of one or more secondary variables.

[0041] The arrangement of axes 74(1)-74(3) in visualization 70 may reflect a mapping of axes 74(1)-74(3) based on one or more arrangement variables and any associated functions of the arrangement variables. For example, axes 74(1)-74(3) may be plotted along line 72 and at radiating directions from line 72 based on the arrangement variables. As another example, 74(1)-74(3) may be grouped into clusters along line 72 and / or at similar radiating directions from line 72 based on a clustering or other data analysis function.

[0042] Figure 5 is a schematic diagram illustrating one example of a 3D data visualization 80 with axes 84(1)-84(4) radiating from a global reference that is a point 82 in a three-dimensional coordinate space 81. Visualization 80 is based on a "starburst" or "dandelion" model where axes 84(1)-84(4) based on one or more primary variables radiate from point 82 in various x, y, and z directions. Axes 84(1)-84(4) originate at point 82 and, thus, intersect point 82. In other examples, other axes may be offset from point 82 (i.e., may not intersect point 82) but would intersect point 82 if extended toward point 82 (not shown). 3D representations 86 are formed at various local references (i.e., points) along each axis 84(1)-84(4) where a size of each 3D representation 86 corresponds to a magnitude of one or more values of one or more secondary variables in the example of Figure 5. In other examples, offshoots may be used at each local reference to illustrate additional secondary variables.

[0043] The illustrations of Figures 3-5 are shown by way of example where many variations on the arrangements of axes, representations, and / or connections may be used.

[0044] Figure 6 is a block diagram illustrating a processing system 100 configured to implement 3D data visualization processing environment 10 (shown in Figure 1). Processing system 100 includes a set of one or more processors 102 and any suitable number of input / output devices 106, display devices 108, and / or communication devices 110. Processors 102, memory system 104, input / output devices 106, display devices 108, and communication devices 110 communicate using a set of interconnections 112 that includes any suitable type, number, and / or configuration of controllers, buses, interfaces, and / or other wired or wireless connections.

[0045] Processing system 100 represents any suitable processing device, or portion of a distributed processing device, configured to implement the functions of 3D data visualizer 20 as described above. A processing device may be a laptop computer, a tablet computer, a desktop computer, a server, or another suitable type of computer system. A processing device may also be a mobile telephone with processing capabilities (i.e., a smart phone), a digital still and / or video camera, a personal digital assistant (PDA), an audio/video device, or another suitable type of electronic device with processing capabilities. Processing capabilities refer to the ability of a device to execute instructions stored in a memory 104 with at least one processor 102.

[0046] Each processor 102 is configured to access and execute instructions stored in memory system 104. Each processor 102 may execute the instructions in conjunction with or in response to information received from input / output devices 106, display devices 108, and / or communication devices 110. Each processor 102 is also configured to access and store data in memory system 104.

[0047] Memory system 104 includes any suitable type, number, and configuration of volatile or non-volatile machine-readable storage media configured to store instructions and data. Examples of machine-readable storage media in memory system 104 include hard disk drives, random access memory (RAM), read only memory (ROM), flash memory drives and cards, and other suitable types of magnetic and / or optical disks. The machine-readable storage media are considered to be part of an article or article of manufacture. An article or article of manufacture refers to one or more manufactured components.

[0048] Memory system 104 stores 3D data visualizer 20, multi-dimensional data 30, primary variable selection 42, secondary variable selection 44, reference selection 46, viewpoint inputs 48, and image pairs 50. 3D data visualizer 20 includes instructions that, when executed by processors 102, causes processors 102 to perform the functions described above with reference to Figures 1-5 to generate 3D data visualizations.

[0049] Input / output devices 106 include any suitable type, number, and configuration of input / output devices configured to input instructions and / or data from a user to processing system 100 and output instructions and / or data from processing system 100 to the user. Examples of input / output devices 106 include a touchscreen, buttons, dials, knobs, switches, a keyboard, a mouse, a touchpad, and a 3D gesture control system.

[0050] Display devices 108 include any suitable type, number, and configuration of display devices configured to output image, textual, and / or graphical information to a user of processing system 100. Examples of display devices 108 include a display screen, a monitor, and a projector. Display devices 108 may form a 3D display system in some embodiments to display image pairs 50 to produce the 3D data visualizations.

[0051] Communications devices 110 include any suitable type, number, and / or configuration of communications devices configured to allow processing system 100 to communicate across one or more wired or wireless networks, ports, or connections.

[0052] Communications devices 110 may be used by processing system 100 to provide image pairs 50 to one or more a 3D display systems (not shown) in some examples. For example, image pairs 50 may be provided to a large scale, high resolution, scalable 3D display system that includes two or more projectors and a display surface. In one particular example, the display screen may be life-size (e.g., 11 feet wide by 6 feet tall) and include four commodity-off-the-shelf projectors driven by a workstation. A content system that forms processing system 100 derives and renders the different stereoscopic visualizations in side-by-side format for the display. This platform can scale the output to different resolutions and sizes. The interaction control software, including possible gesturing and viewpoint manipulation, runs on the same content system. The size, resolution, and aspect ratio of the 3D display system is scalable and dependent on the application. For instance, it may be desirable to view the 3D data visualizations on a double-wide 2xHD (3840x1080) 3D display screen to provide sufficient resolution to see content side-by-side.

CLAIMS

What is claimed is:

1. A method of generating a three-dimensional data visualization from multi-dimensional data performed by a processing system, the method comprising:

forming an arrangement of first and second axes in a three-dimensional coordinate space such that the first and the second axes radiate from a global reference in the three-dimensional coordinate space, the first and the second axes based on a primary variable in the multi-dimensional data;

forming respective first representations in the three-dimensional coordinate space for first and second local references on each of the first and the second axes, each of the first representations based on a first secondary variable in the multi-dimensional data; and

generating an image pair to include the arrangement and the first representations such that the image pair is displayable to produce the three-dimensional data visualization.

2. The method of claim 1 wherein the global reference is one of a point, a line, or a surface in the three-dimensional coordinate space.

3. The method of claim 1 wherein the first and the second axes are based on a function of values of the primary variable.

4. The method of claim 1 further comprising:

forming the arrangement of the first and the second axes based on an arrangement variable in the multi-dimensional data.

5. The method of claim 1 wherein each of the first representations is based on a function of values of the first secondary variable.

6. The method of claim 1 further comprising:

forming a second representation in the three-dimensional coordinate space for the first and the second local references on each of the first and the second axes, each of the second representations based on a second secondary variable in the multi-dimensional data and offset from corresponding ones of the first representations in the three-dimensional coordinate space; and

generating the image pair to include the arrangement and the first and the second representations such that the image pair is displayable to produce the three-dimensional data visualization.

7. The method of claim 1 further comprising:

forming a connection in the three-dimensional coordinate space between the first local reference on the first axis and the second local reference on the second axis based on a connection variable in the multi-dimensional data.

8. The method of claim 1 further comprising:

updating the image pair in response to receiving a viewpoint input.

9. An article comprising at least one machine-readable storage medium storing instructions that, when executed by a processing system, cause the processing system to:

select first and second pluralities of local references on respective first and second axes, the first and the second axes radiating from a global reference in a three-dimensional coordinate space and based on a primary variable in multi-dimensional data;

form a respective first three-dimensional representation in the three-dimensional coordinate space for each of the first and the second pluralities of secondary local references, each of the first three-dimensional representations based on a first secondary variable in the multi-dimensional data; and generate an image pair to include the first three-dimensional representations along the first and the second axes such that the image pair is displayable to produce a three-dimensional data visualization.

10. The article of claim 9, wherein each of the first representations is based on a magnitude of a corresponding value of the first secondary variable.

11. The article of claim 9, wherein each of the first three-dimensional representations includes corresponding first offshoots that radiate from corresponding local references at corresponding first angles.

12. The article of claim 11, wherein the instructions, when executed by the processing system, cause the processing system to:

form a second three-dimensional representation in the three-dimensional coordinate space for each of the first and the second pluralities of secondary local references, each of the second three-dimensional representations based on a second secondary variable in the multi-dimensional data, and each of the second three-dimensional representations including corresponding second offshoots that radiate from corresponding local references at corresponding second angles that differ from the corresponding first angles.

13. A method of generating a three-dimensional data visualization from multi-dimensional data performed by a processing system, the method comprising:

performing a three-dimensional analysis on a set of one or more primary variables and a set of one or more secondary variables of the multi-dimensional data with reference to a three-dimensional coordinate space;

forming an arrangement of first and second axes in a three-dimensional coordinate space based on the three-dimensional analysis such that the first and the second axes radiate from a global reference in the three-dimensional coordinate space, the first and the second axes each based on the set of primary variables;

forming respective representations in the three-dimensional coordinate space for first and second local references on each of the first and the second axes based on the three-dimensional analysis, each of the representations based on the set of secondary variables; and

generating an image pair to include the arrangement and the representations such that the image pair is simultaneously displayable to produce the three-dimensional data visualization.

14. The method of claim 13 further comprising:

forming the arrangement of the first and the second axes in the three-dimensional coordinate space based on the three-dimensional analysis using disparity to allow a viewer of the 3D data visualization to perceive differences in depth between the first and the second axes.

15. The method of claim 13 further comprising:

forming the representation in the three-dimensional coordinate space for the first and the second local references on each of the first and the second axes based on the three-dimensional analysis using disparity to allow a viewer of the 3D data visualization to perceive differences in depth between representations on the first and the second axes.

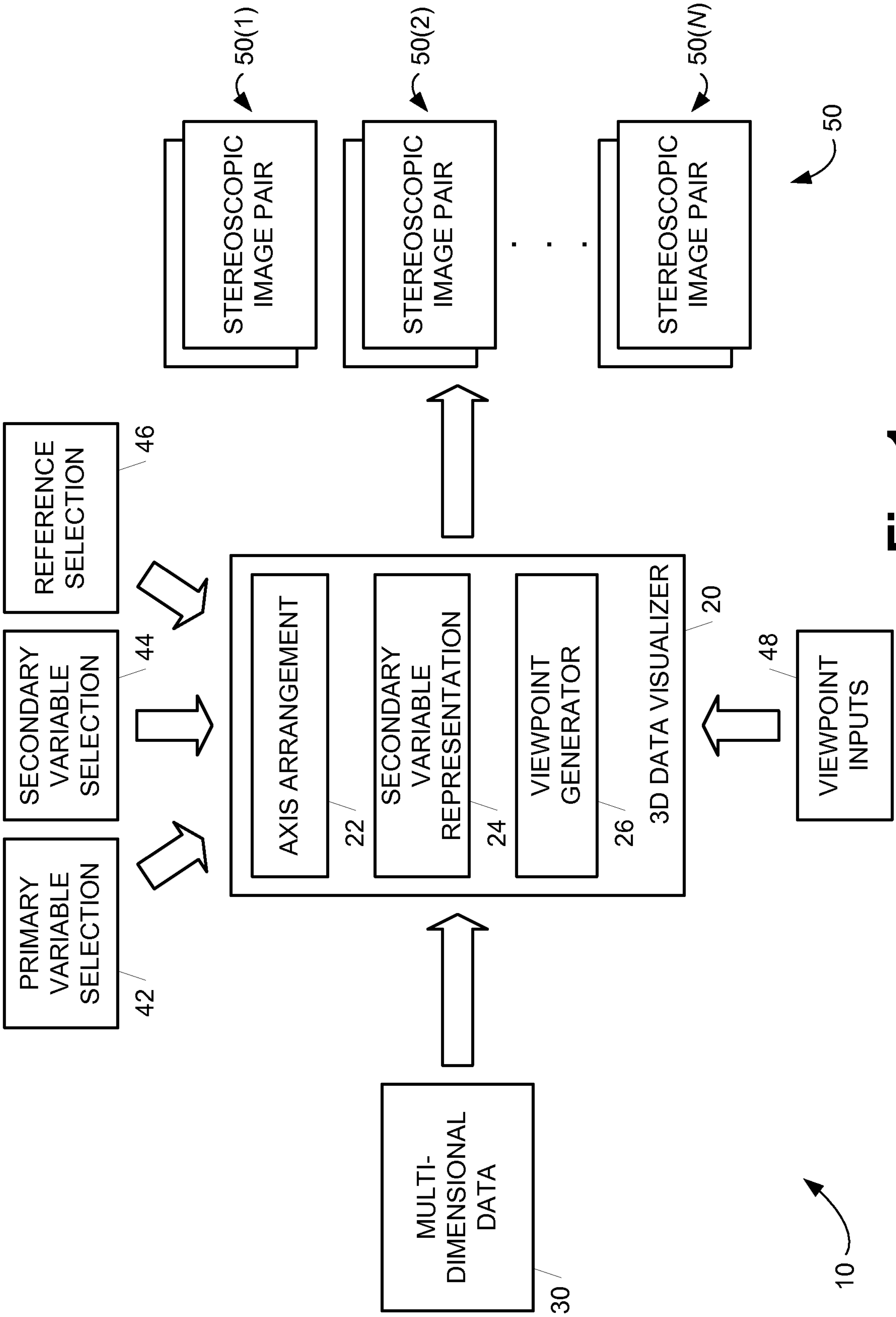
MULTI-DIMENSIONAL DATA
30
PRIMARY VARIABLE SELECTION
42
SECONDARY VARIABLE SELECTION
44
REFERENCE SELECTION
46
AXIS ARRANGEMENT
22
SECONDARY VARIABLE REPRESENTATION
24
VIEWPOINT GENERATOR
26
3D DATA VISUALIZER
20
VIEWPOINT INPUTS
48
STEREOSCOPIC IMAGE PAIR
50(1)
STEREOSCOPIC IMAGE PAIR
50(2)
STEREOSCOPIC IMAGE PAIR
50(N)
50
10

Fig. 1

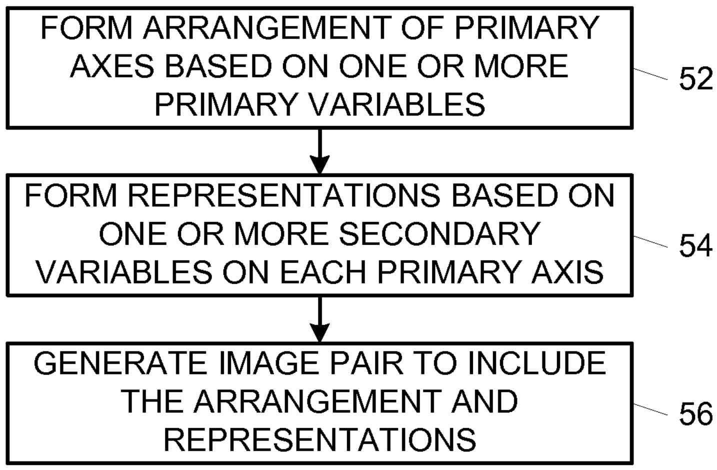
FORM ARRANGEMENT OF PRIMARY AXES BASED ON ONE OR MORE PRIMARY VARIABLES
52
FORM REPRESENTATIONS BASED ON ONE OR MORE SECONDARY VARIABLES ON EACH PRIMARY AXIS
54
GENERATE IMAGE PAIR TO INCLUDE THE ARRANGEMENT AND REPRESENTATIONS
56

Fig. 2

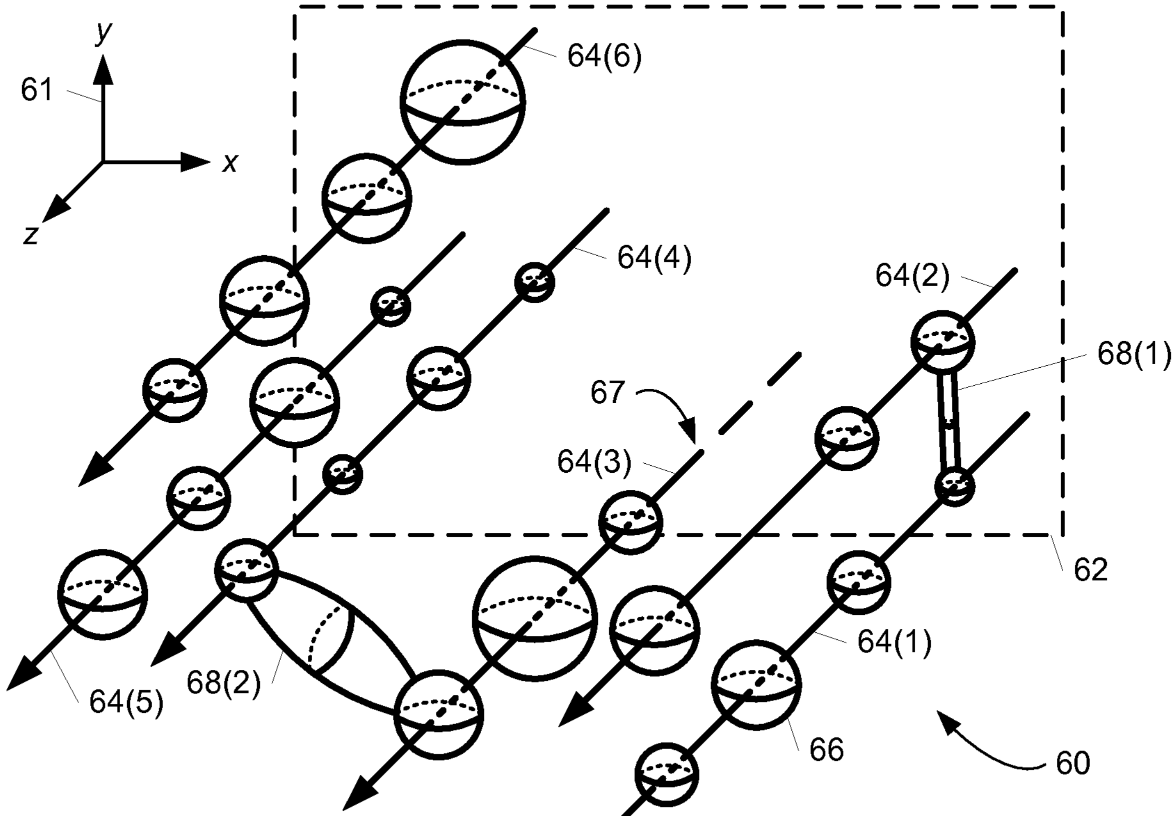

Fig. 3

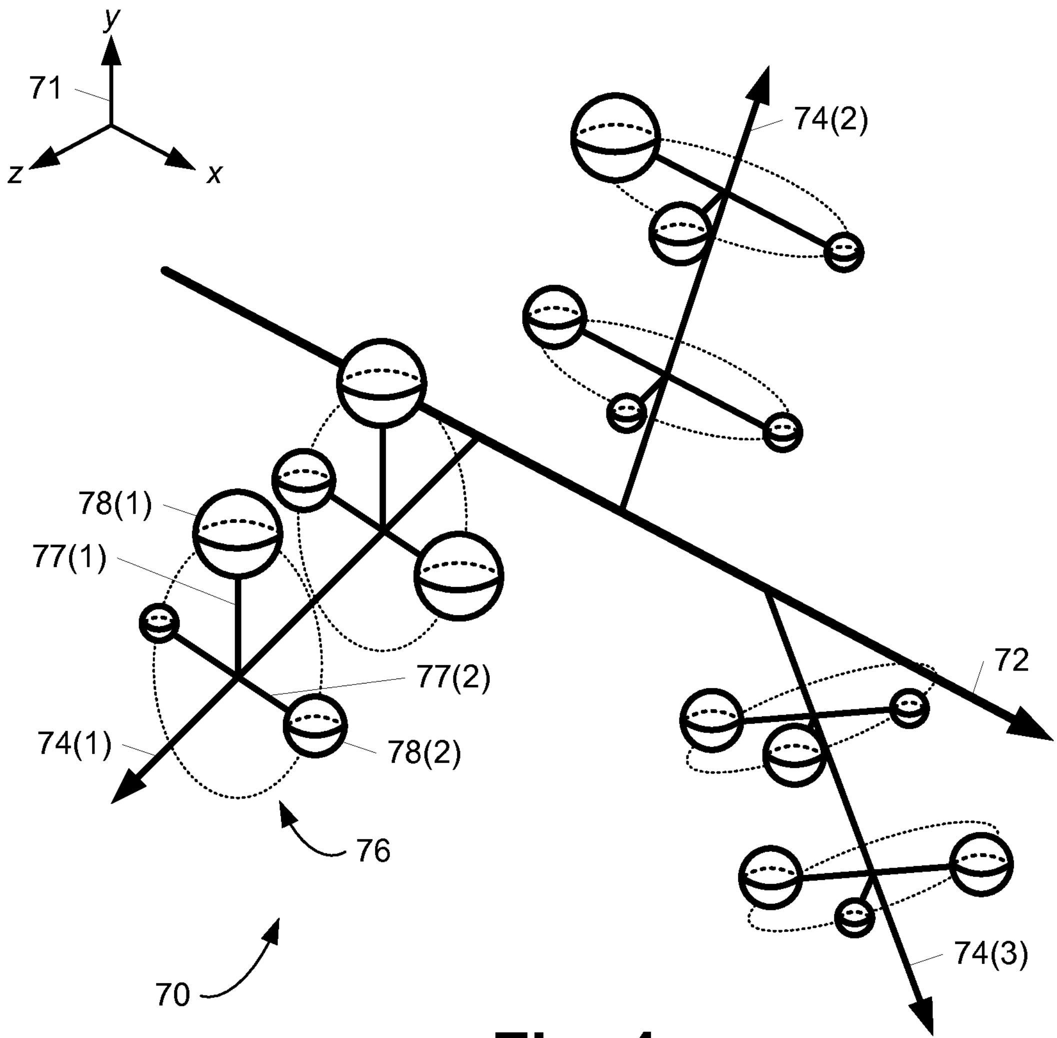

Fig. 4

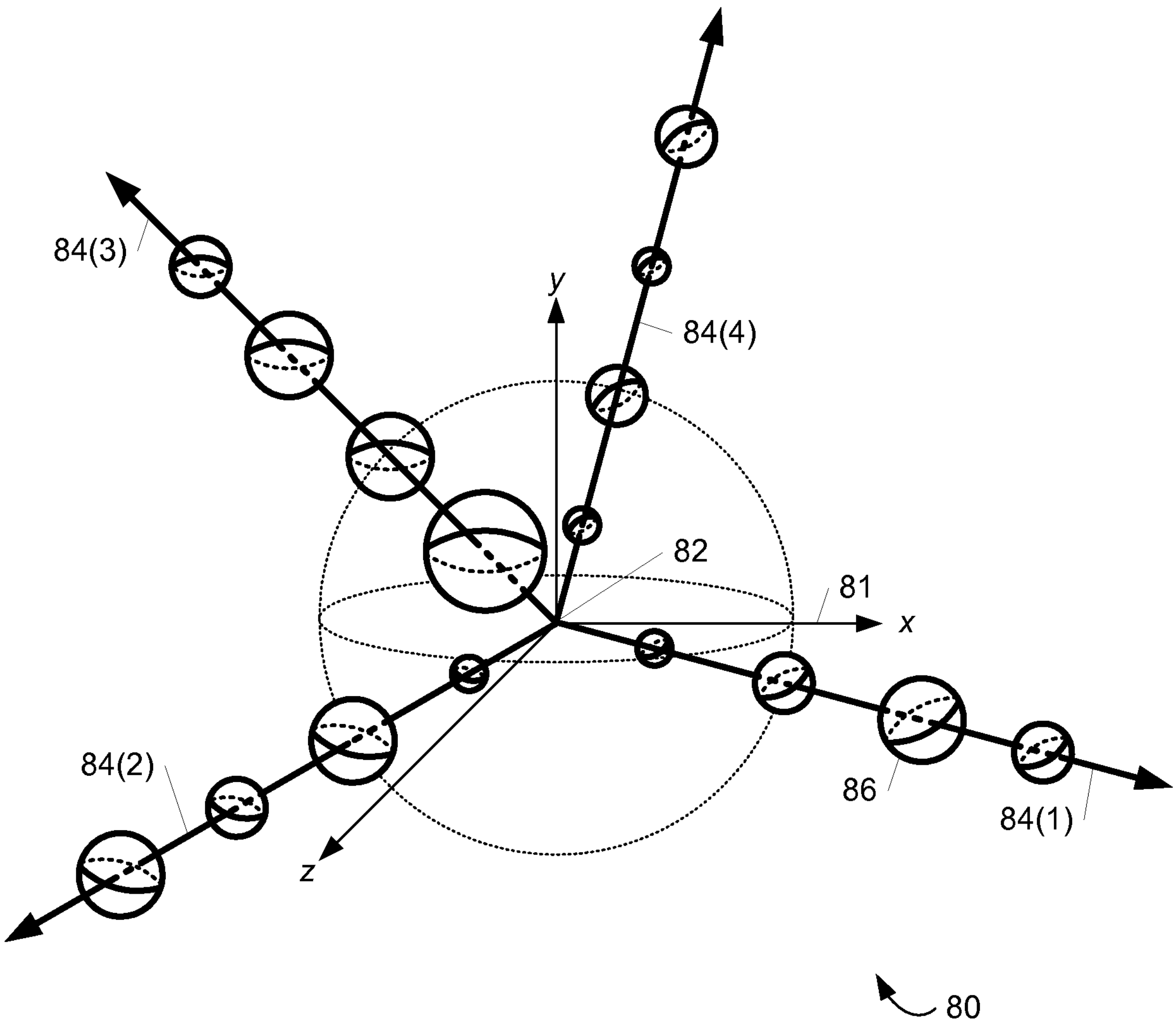

Fig. 5

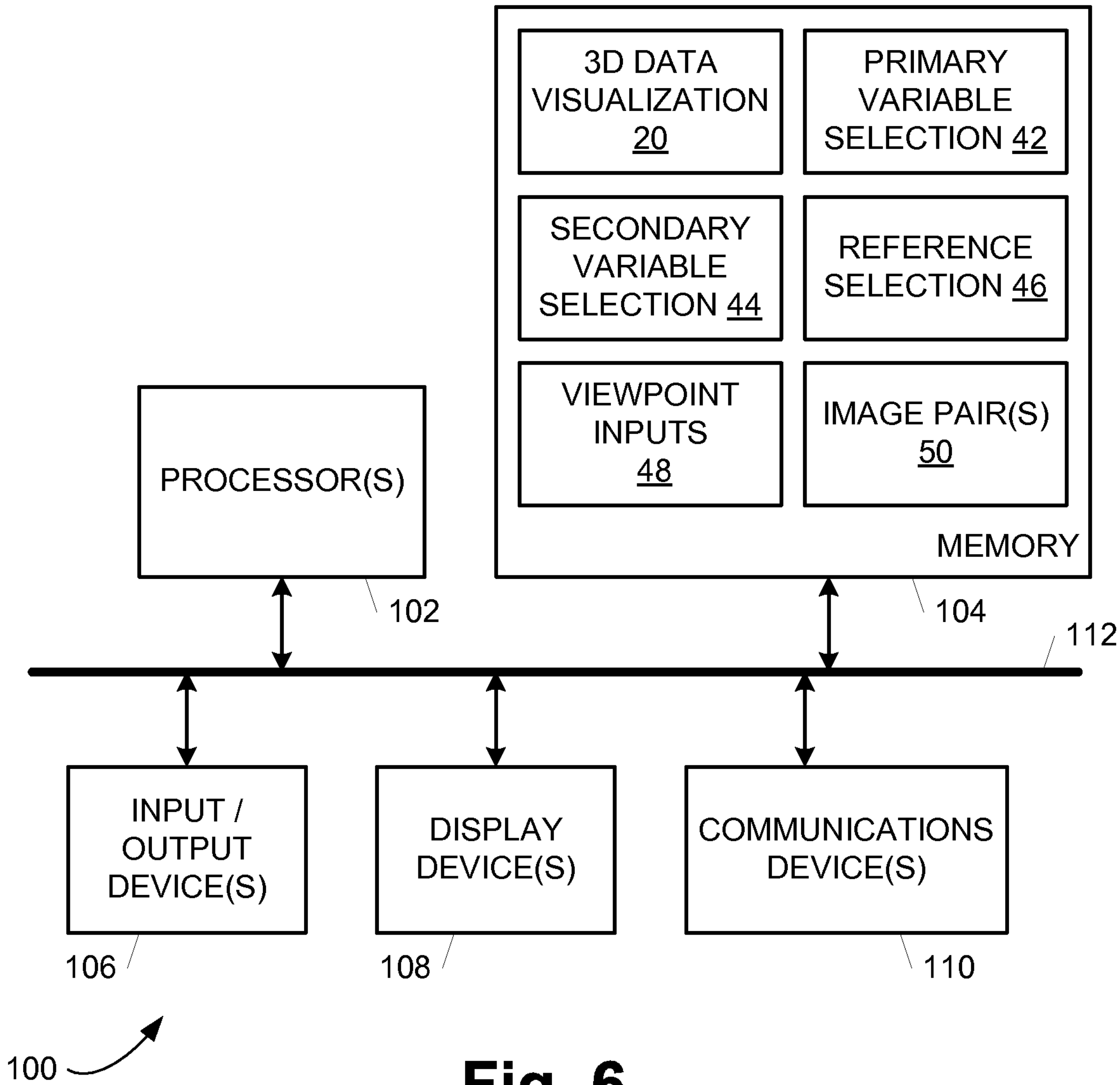
3D DATA VISUALIZATION 20
PRIMARY VARIABLE SELECTION 42
SECONDARY VARIABLE SELECTION 44
REFERENCE SELECTION 46
VIEWPOINT INPUTS 48
IMAGE PAIR(S) 50
MEMORY
PROCESSOR(S)
102
104
112
INPUT / OUTPUT DEVICE(S)
DISPLAY DEVICE(S)
COMMUNICATIONS DEVICE(S)
106
108
110
100

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/027525

A. CLASSIFICATION OF SUBJECT MATTER

G06T 19/00(2011.01)i, G06T 17/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06T 19/00; G06F 3/048; G06F 17/00; G06F 7/00; G06F 17/30; G06T 15/00; G06T 17/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: dimension, data, visualization, type, arrangement, representation

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008-0270946 A1 (JOHN S. RISCH et al.) 30 October 2008 See paragraph [0125]; claim 1; and figures 7, 14.	1-15
A	US 2009-0217147 A1 (ERIK C. THOMSEN et al.) 27 August 2009 See paragraphs [0065], [0069]; and figures 14, 16.	1-15
A	US 2013-0031142 A1 (JOACHIM WESTER) 31 January 2013 See paragraphs [0044]-[0045]; claims 1-2; and figures 7-8.	1-15
A	US 2011-0169819 A1 (RANA IAN) 14 July 2011 See paragraphs [0115]-[0116]; and figures 9B, 10.	1-15
A	US 2012-0191704 A1 (ROBERT F. JONES) 29 July 2012 See abstract; paragraphs [0054]-[0056]; and figures 11, 12.	1-15

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
04 November 2013 (04.11.2013)	**05 November 2013 (05.11.2013)**

Name and mailing address of the ISA/KR	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/027525

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		US 7373612 B2	13/05/2008
		US 8132121 B2	06/03/2012
		US 8132122 B2	06/03/2012
US 2009-0217147 A1	27/08/2009	US 2009-0138428 A1	28/05/2009
		US 7631005 B2	08/12/2009
		US 7797320 B2	14/09/2010
US 2013-0031142 A1	31/01/2013	WO 2013-017296 A1	07/02/2013
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US 2012-0191704 A1	26/07/2012	None	