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(54) **METHOD AND APPARATUS FOR TEXTURE
TILING IN A GRAPHICS SYSTEM**

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345/630

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(57) **ABSTRACT**

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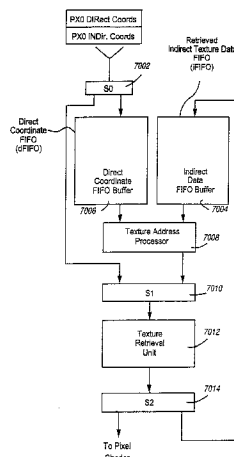
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A graphics system including a custom graphics and audio processor produces exciting 2D and 3D graphics and surround sound. The system includes a graphics and audio processor including a 3D graphics pipeline and an audio digital signal processor. Textured surfaces are created using indirect texture tiling. A set of direct and indirect texture coordinates are defined. The indirect coordinates are used in an indirect lookup operation in an indirect tile index map to obtain tile select offsets. The offsets are used to modify the direct texture coordinates, and the modified texture coordinates are then used to obtain a texture tile from a tile definitions map. The selected tile is then displayed. In another embodiment, the offsets are biased and combined with the direct texture coordinates to produce a second set of modified texture coordinates. The second set is used to obtain a second texture tile from the tile definitions map. The two selected tiles are then blended together to provide a synthetic texture tile having a pseudo-3D effect.

6 Claims, 37 Drawing Sheets



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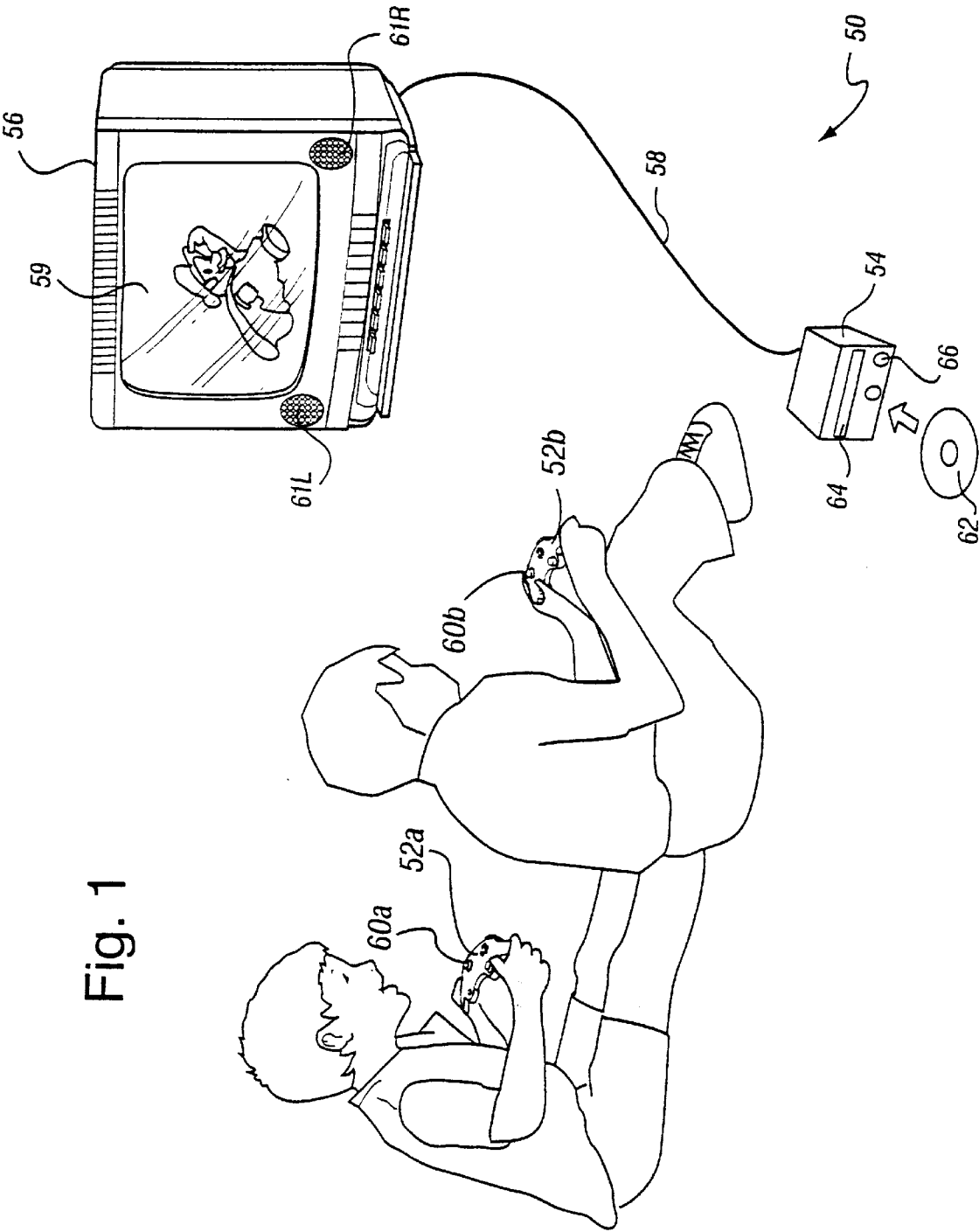
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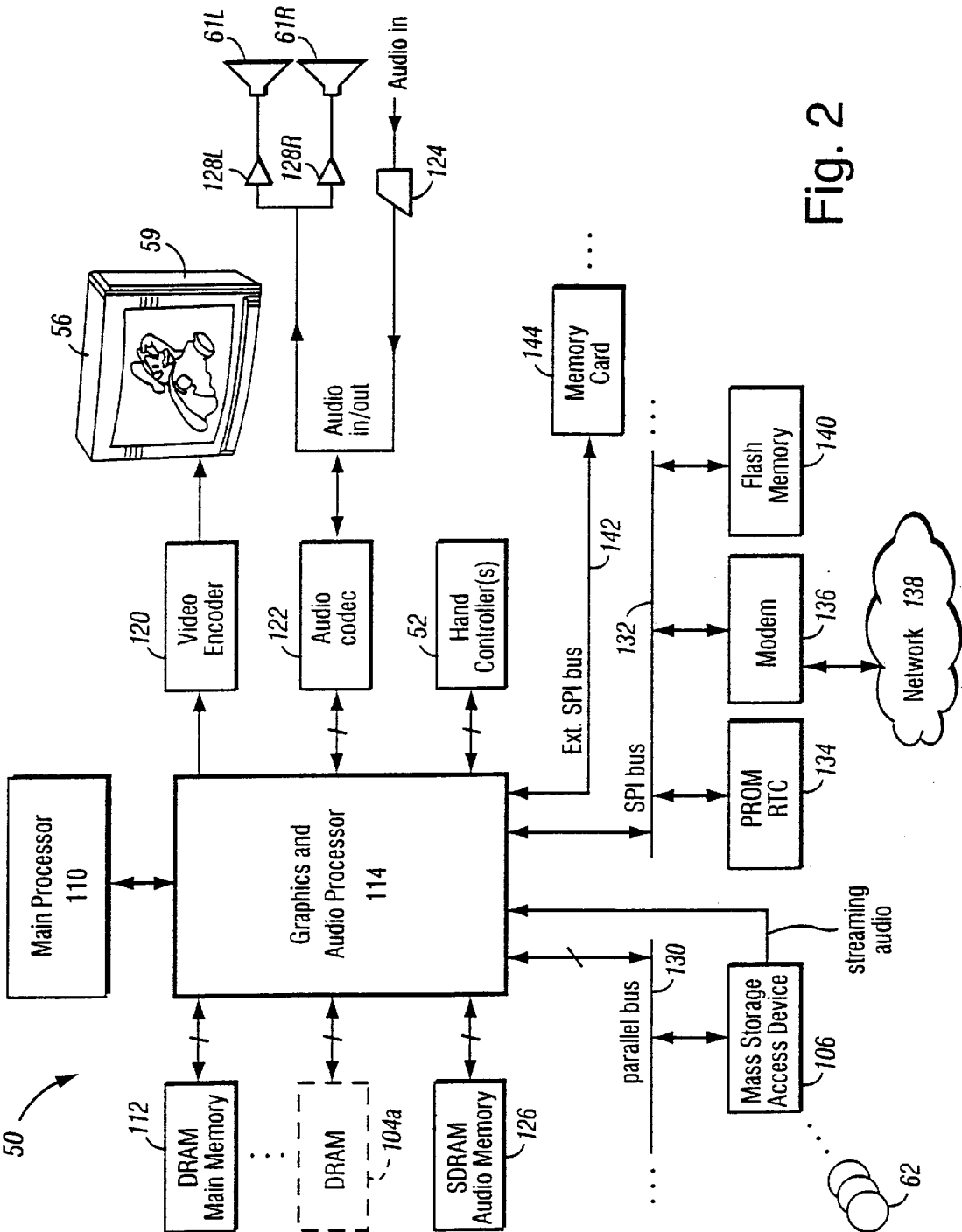
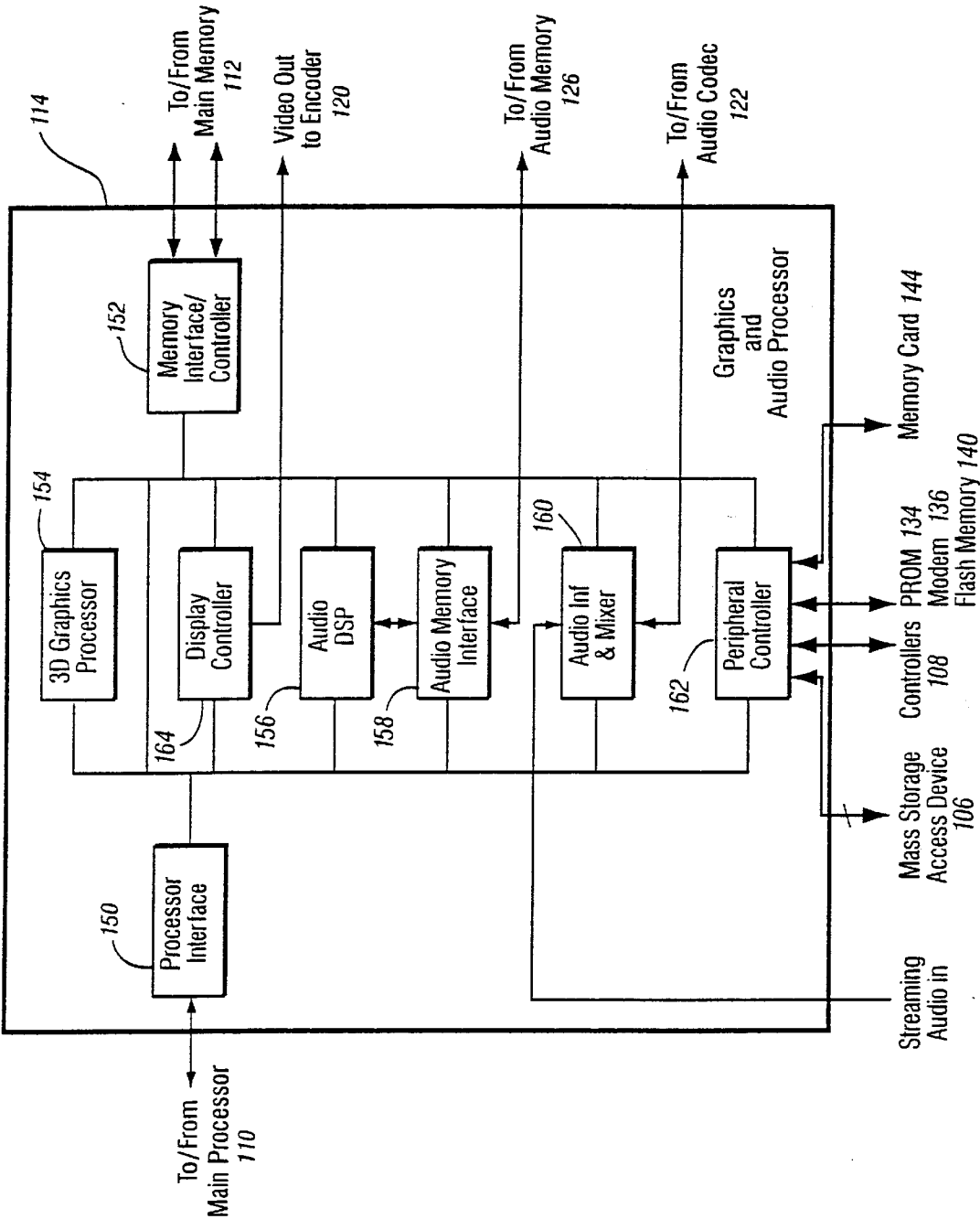


Fig. 2



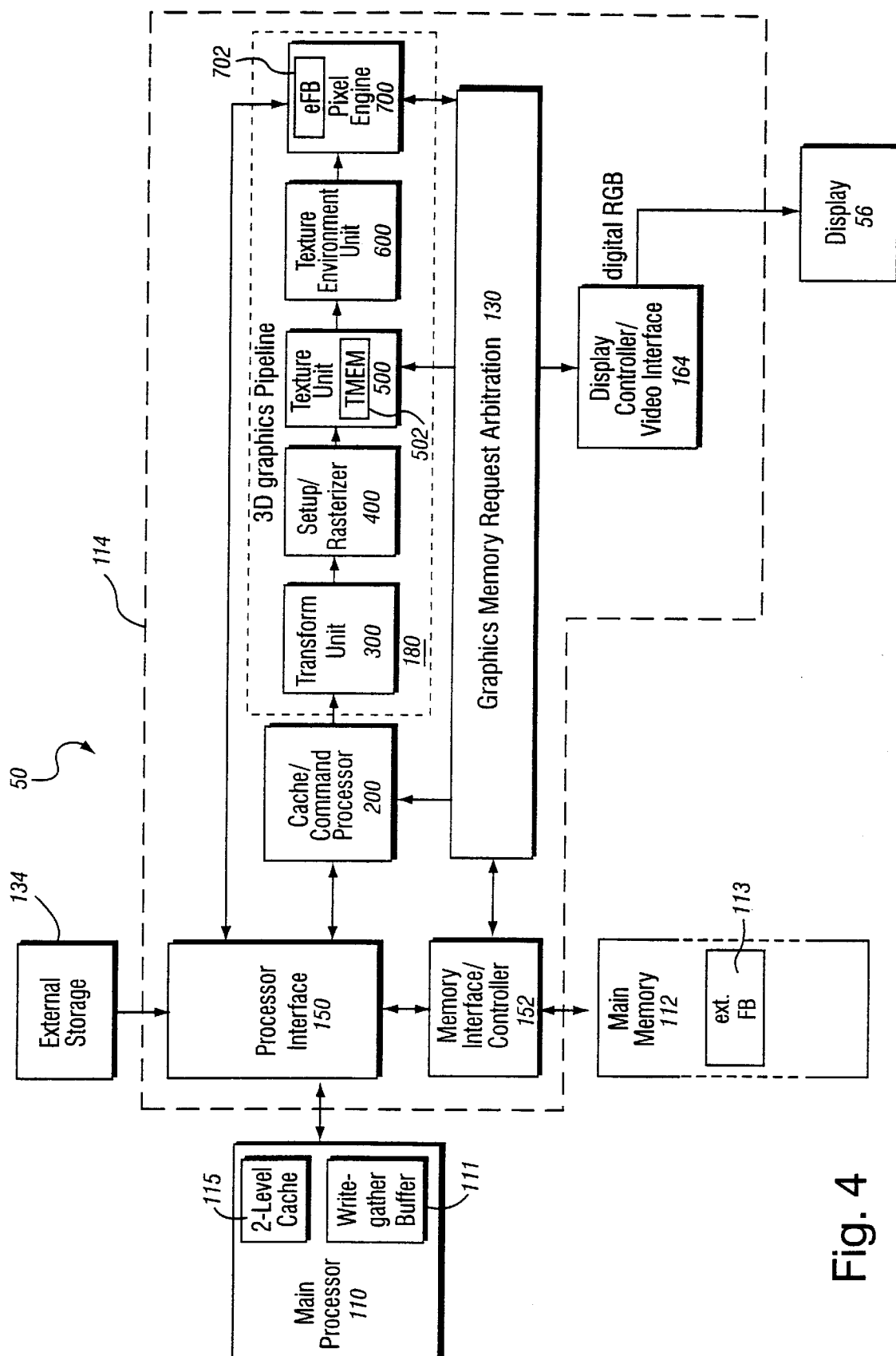


Fig. 4

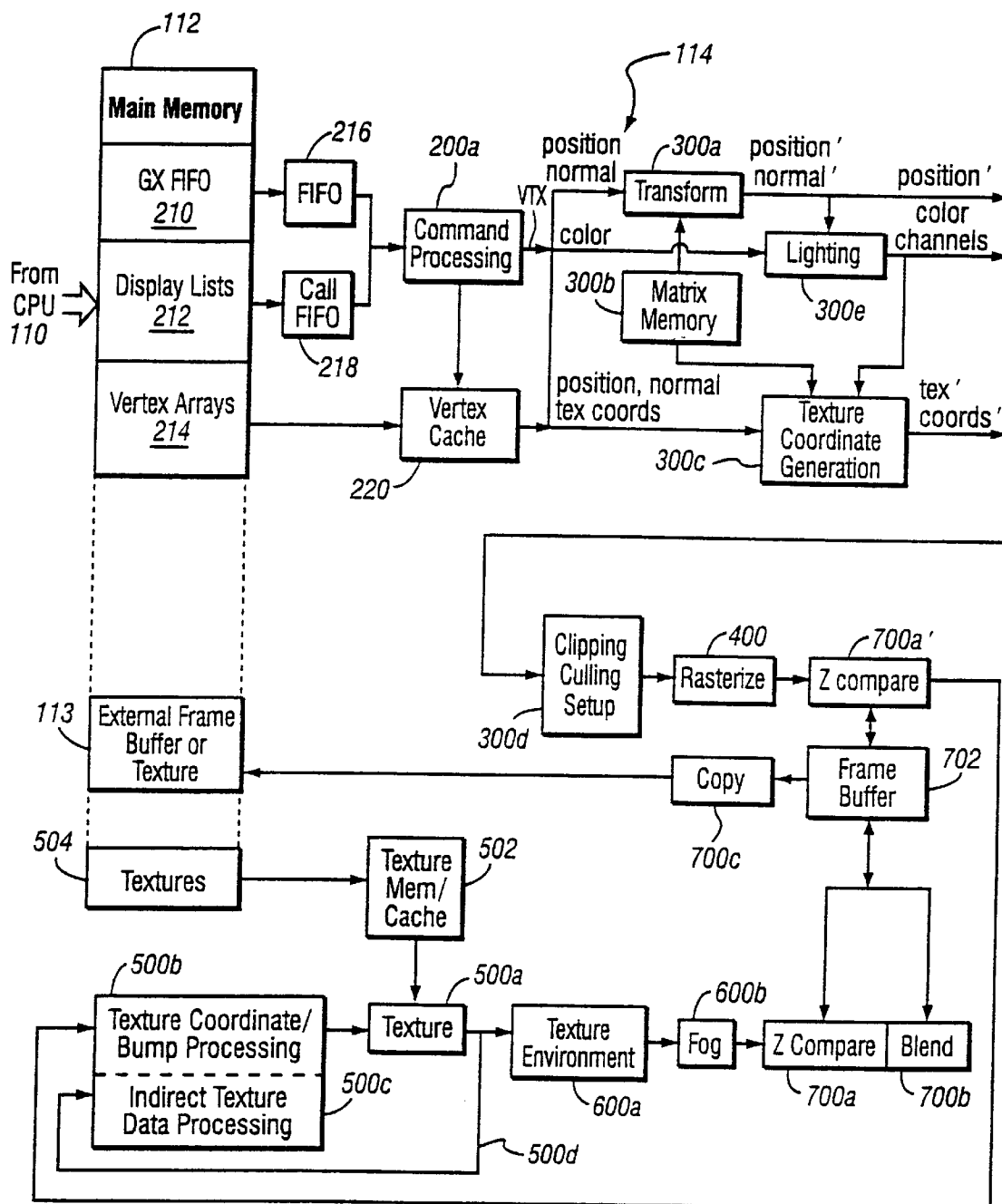
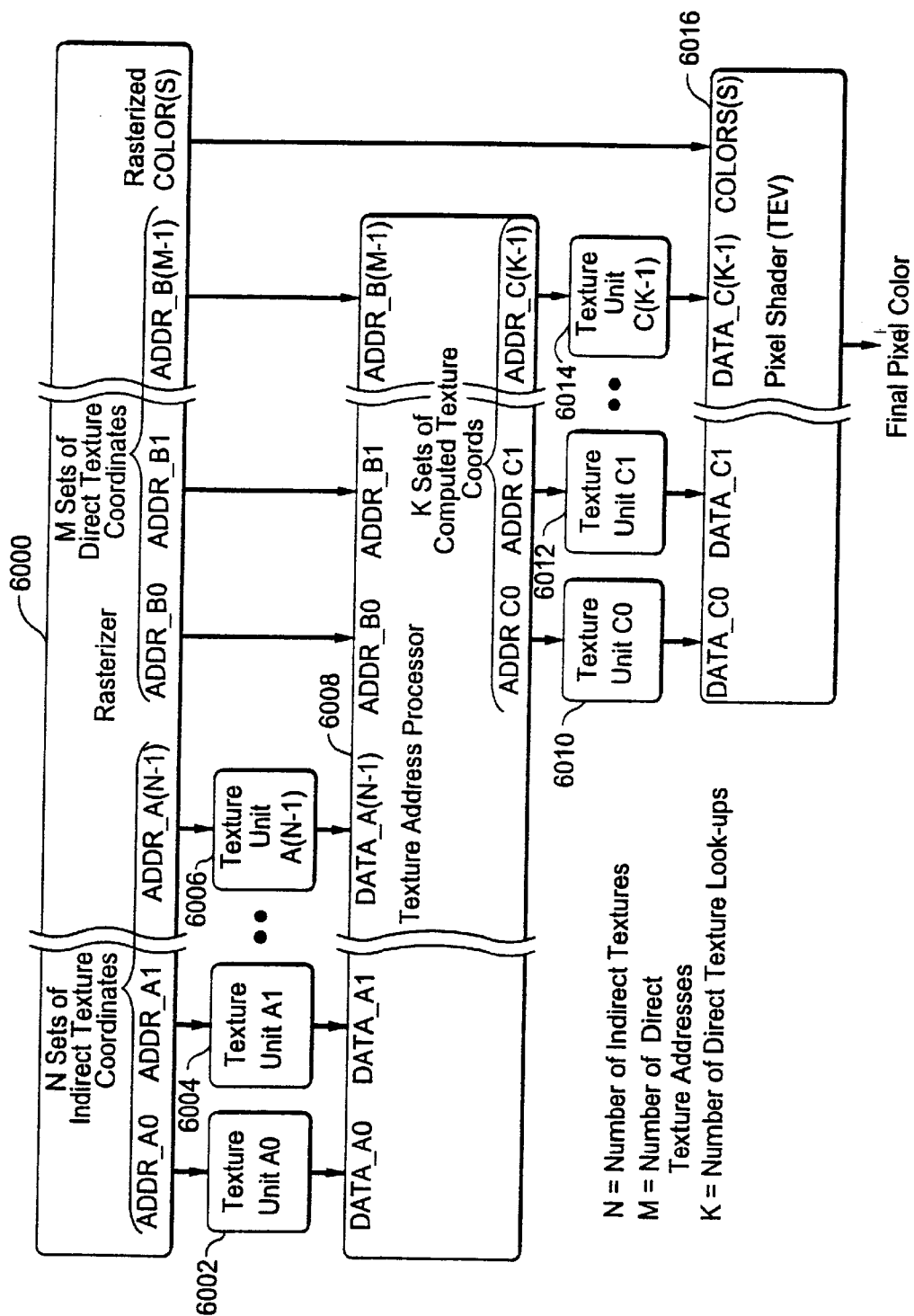


Fig. 5 EXAMPLE GRAPHICS PROCESSOR FLOW



Logical Block Diagram of Indirect Texture Processing

Fig. 6

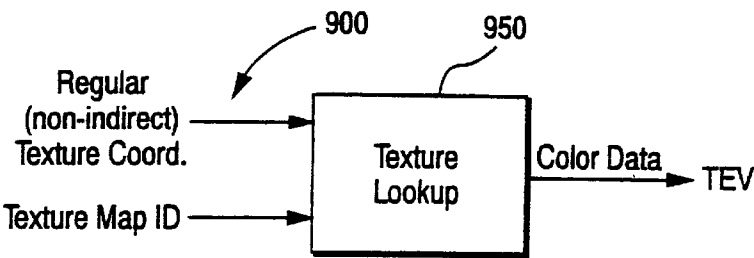


Fig. 7A
REGULAR TEXTURE LOOKUP

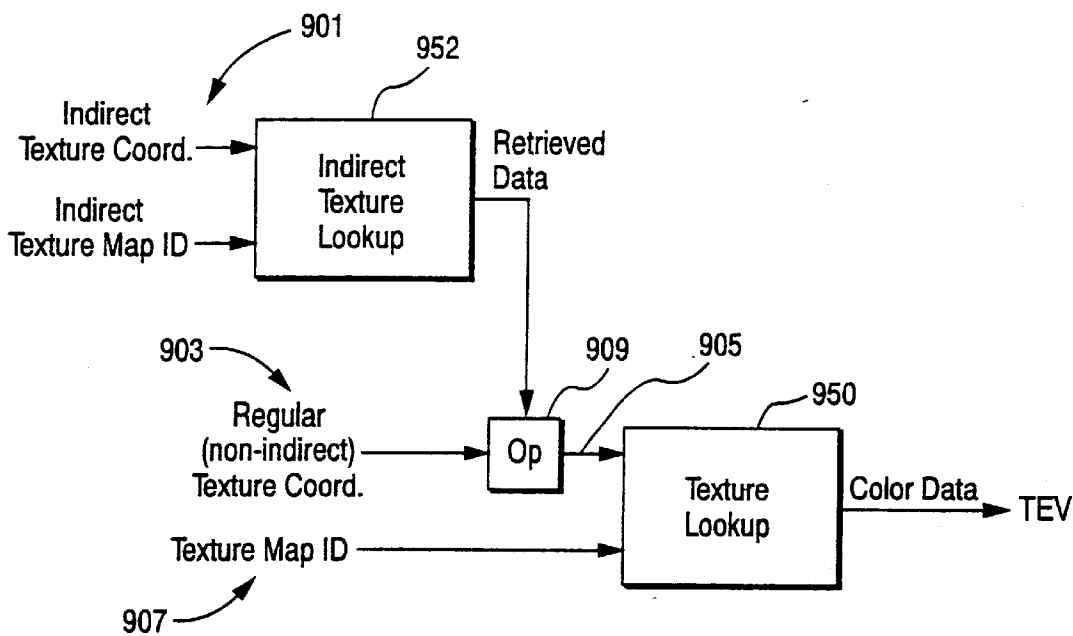
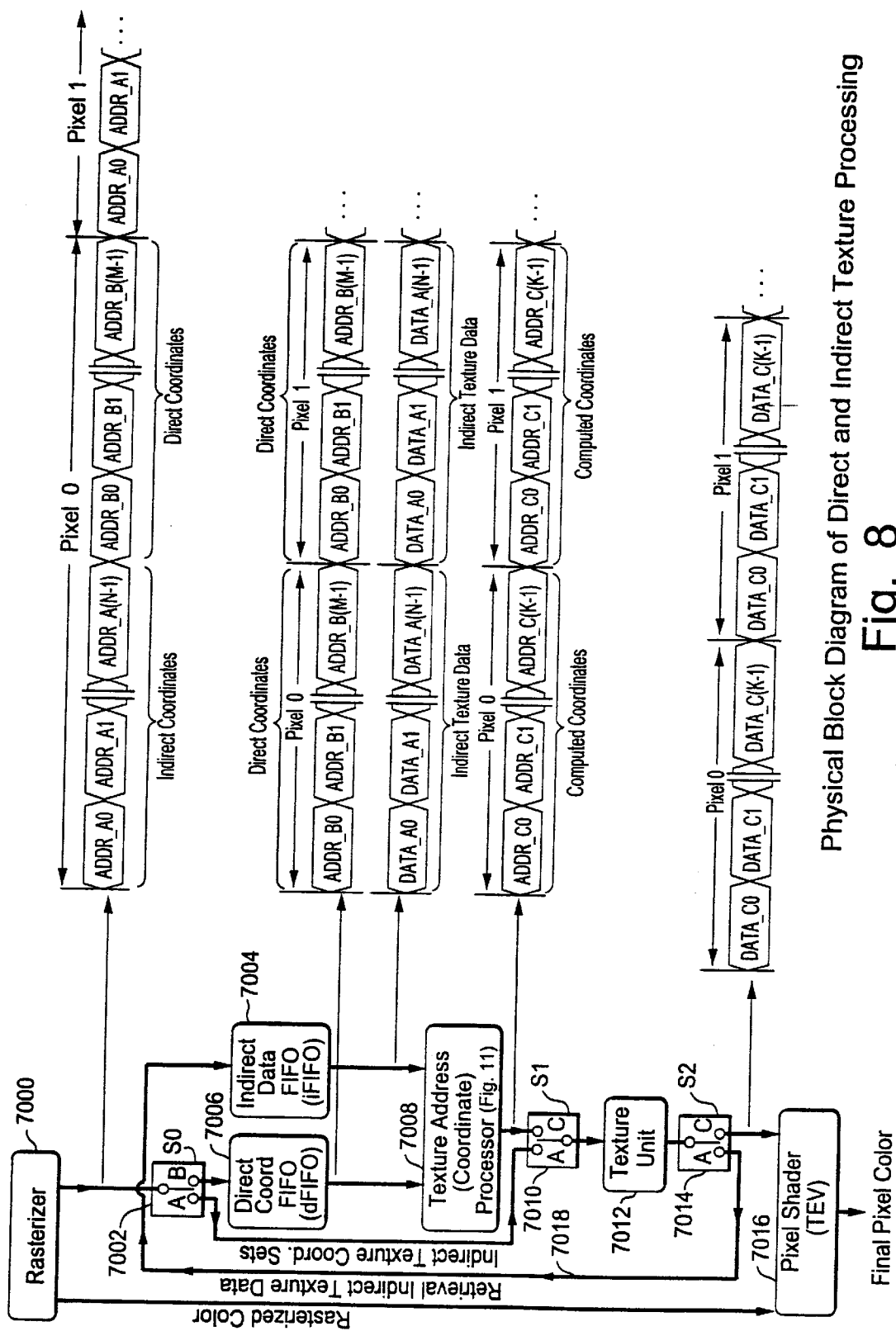


Fig. 7B
INDIRECT TEXTURE LOOKUP



Physical Block Diagram of Direct and Indirect Texture Processing
Fig. 8

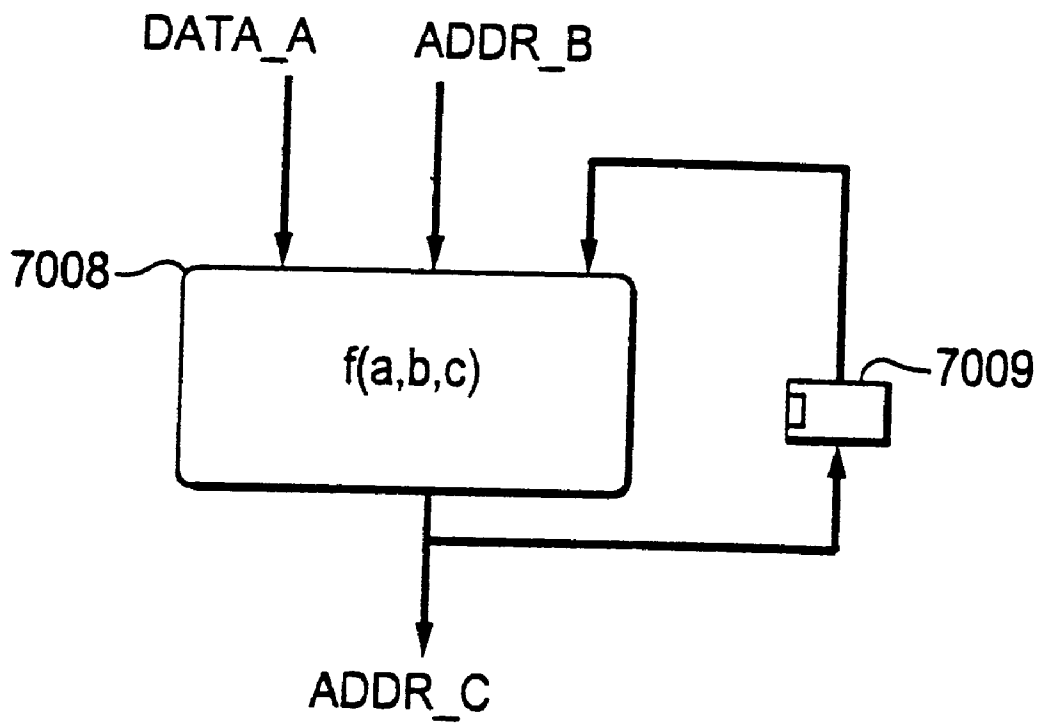


Fig. 9

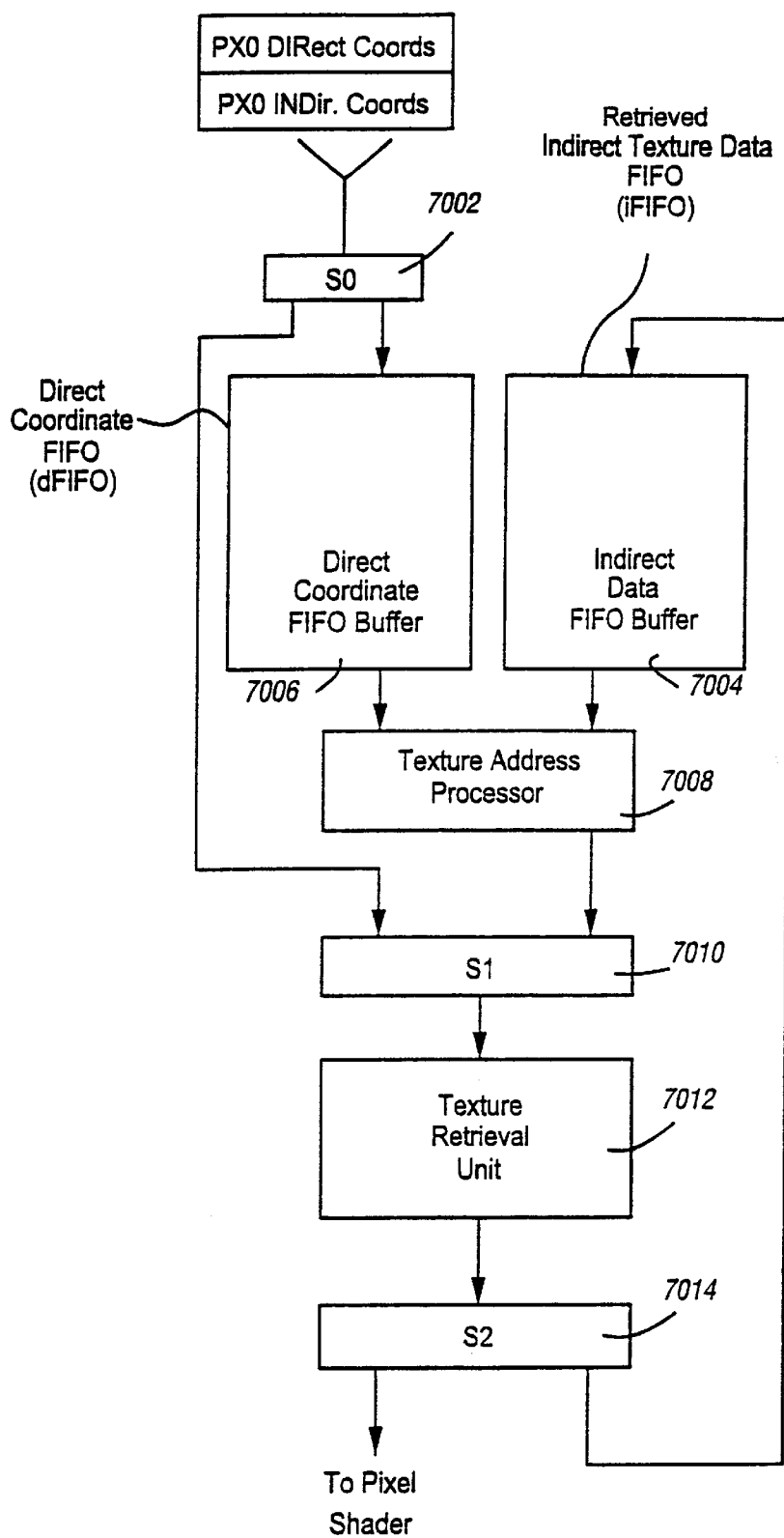


Fig. 10A

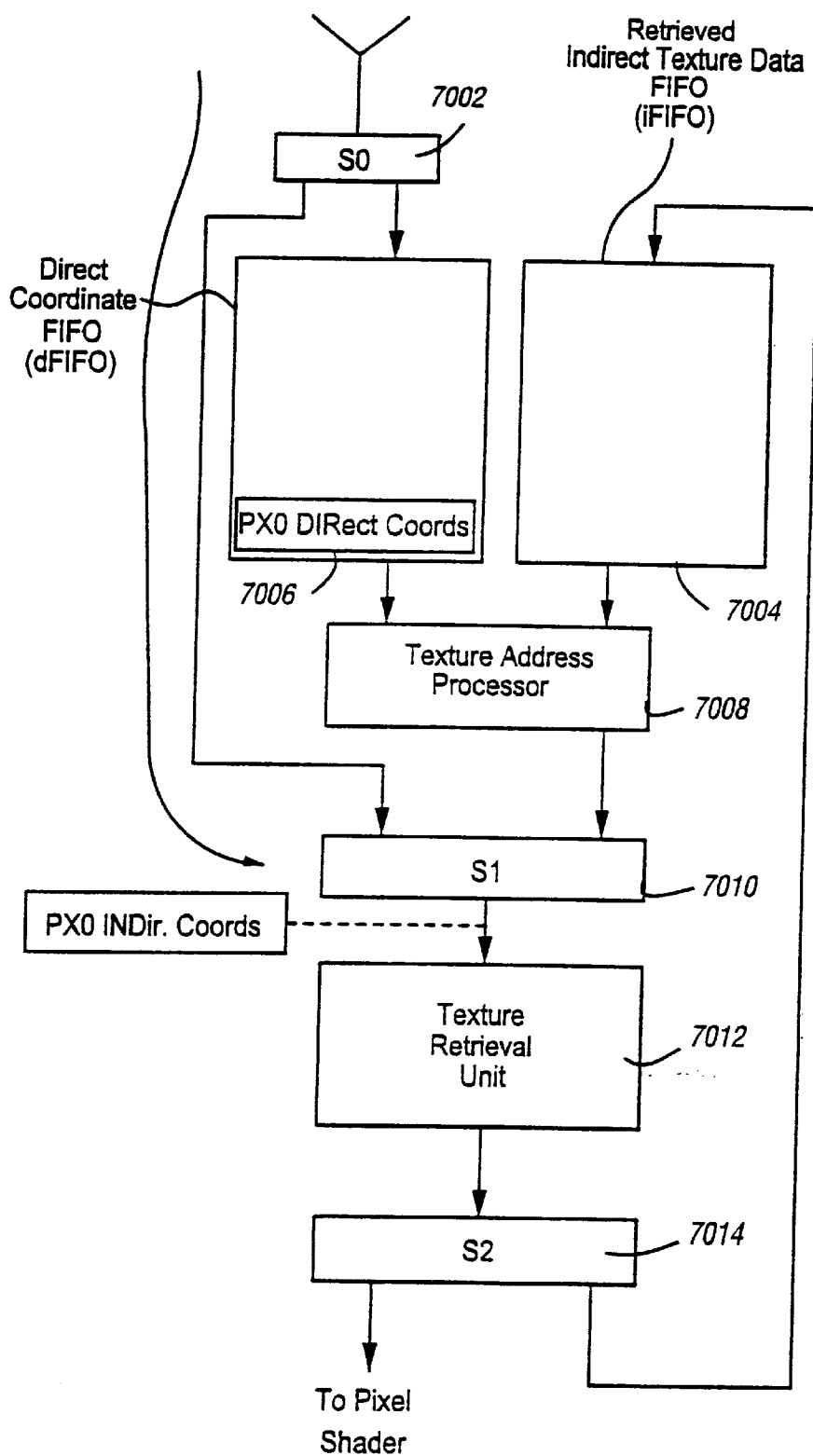


Fig. 10B

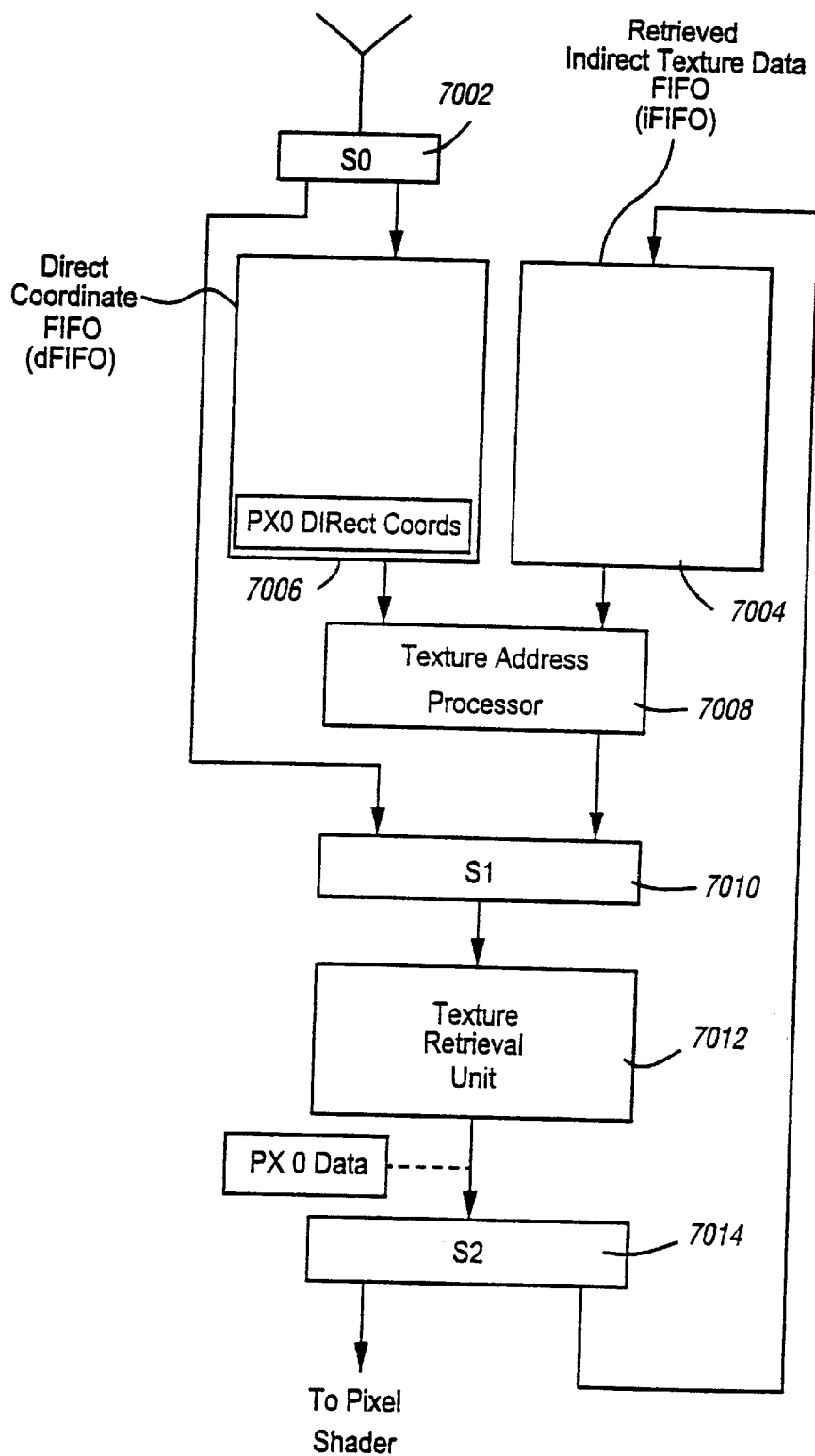


Fig. 10C

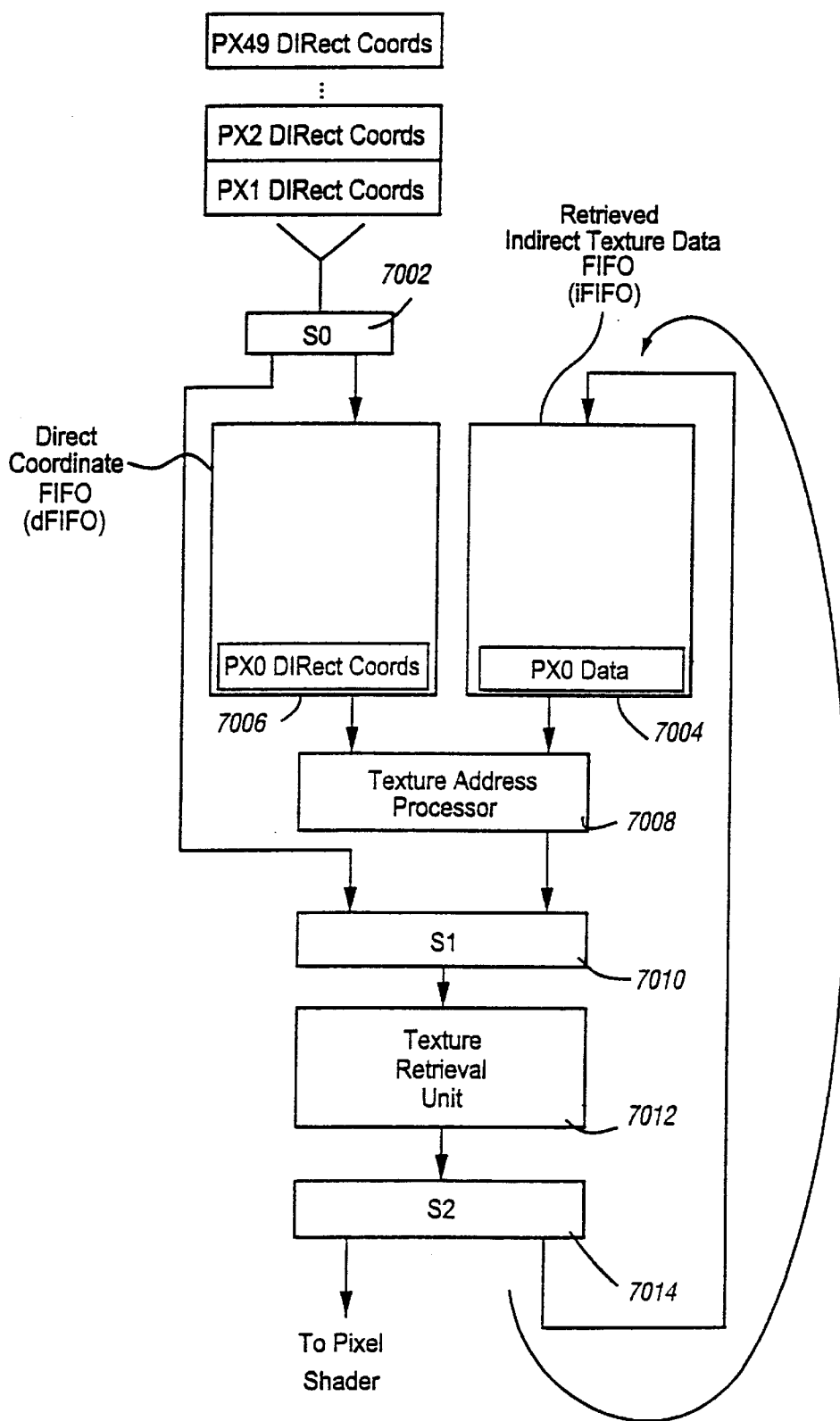


Fig. 10D

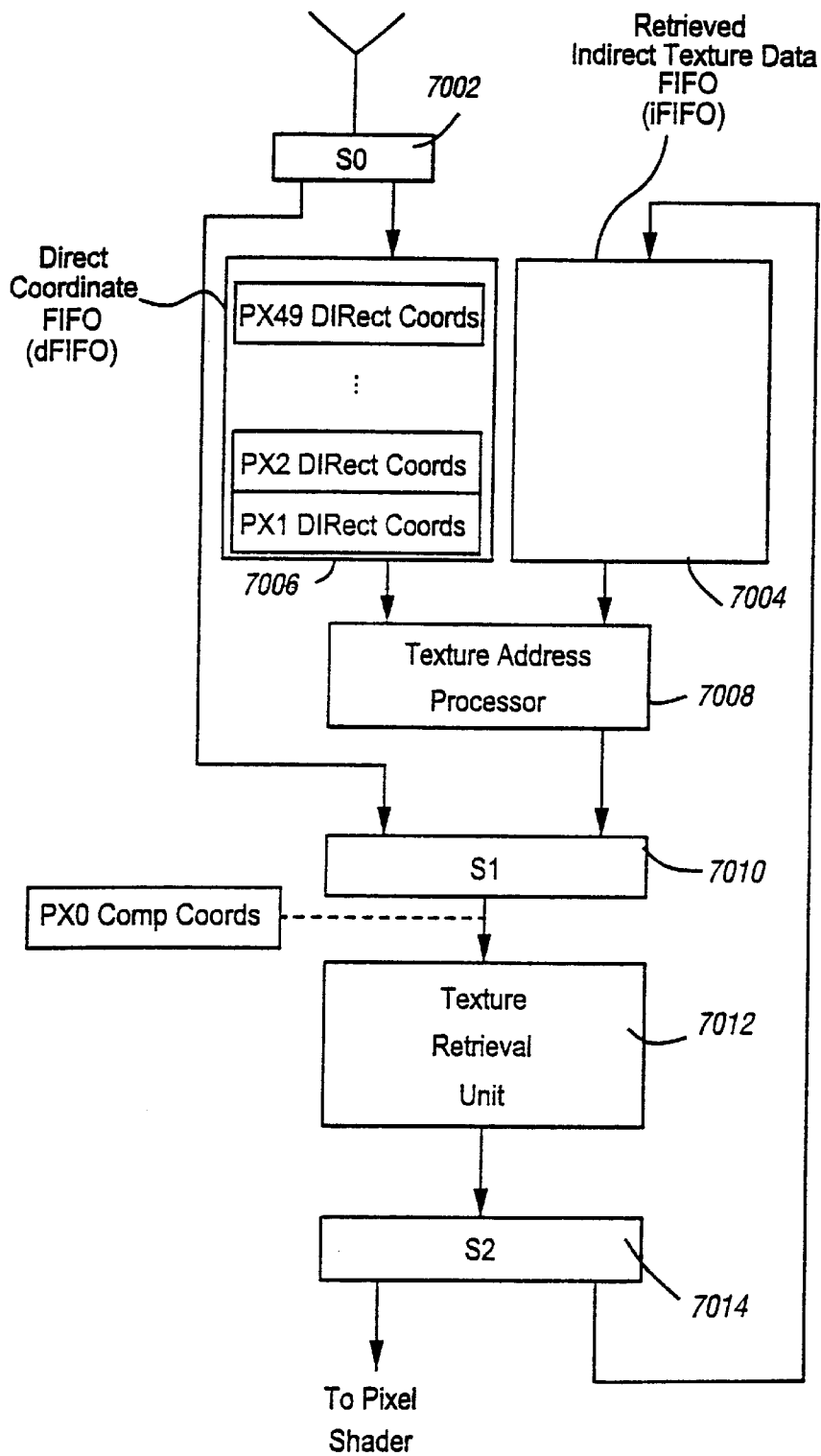


Fig. 10E

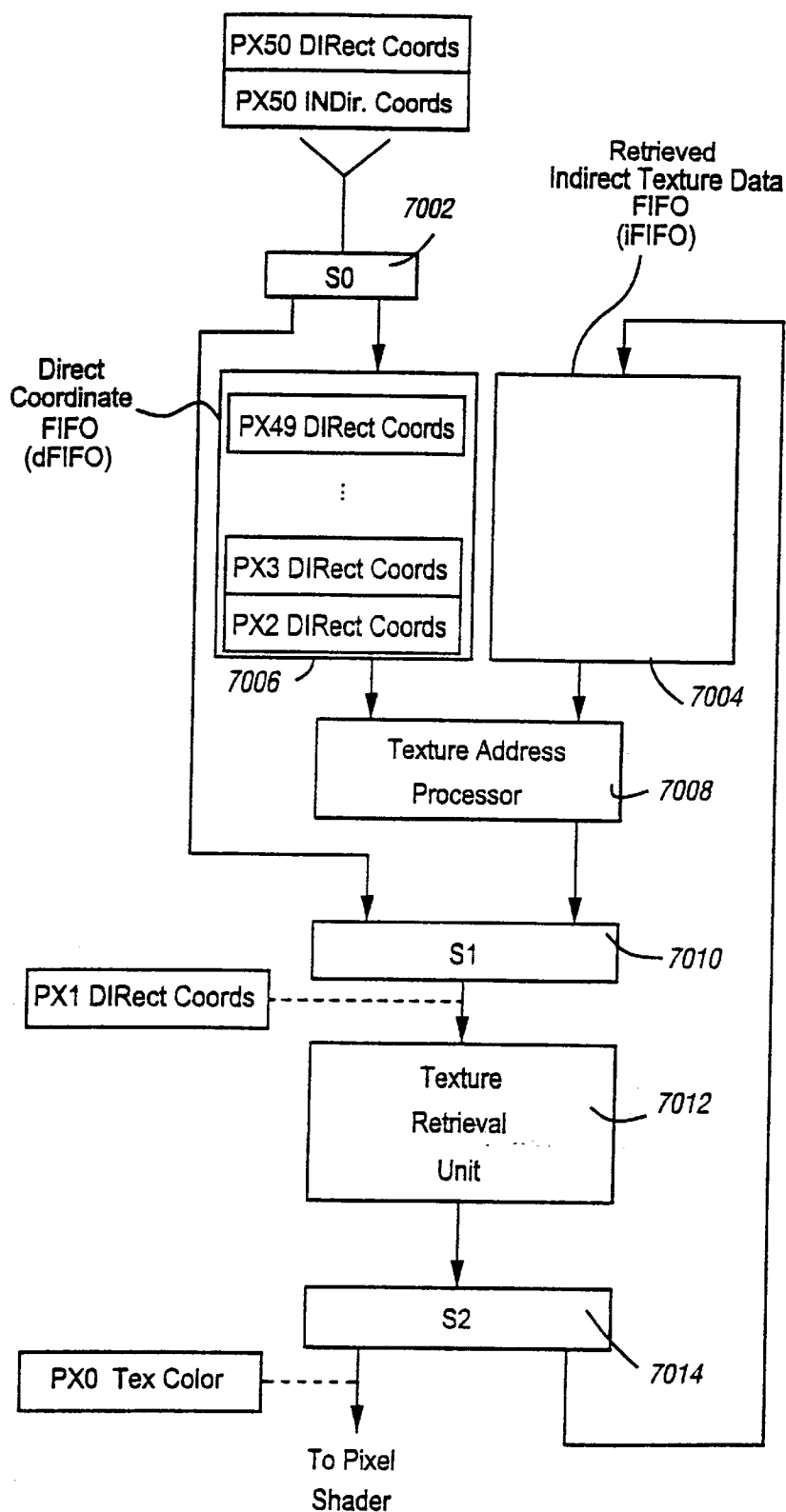


Fig. 10F

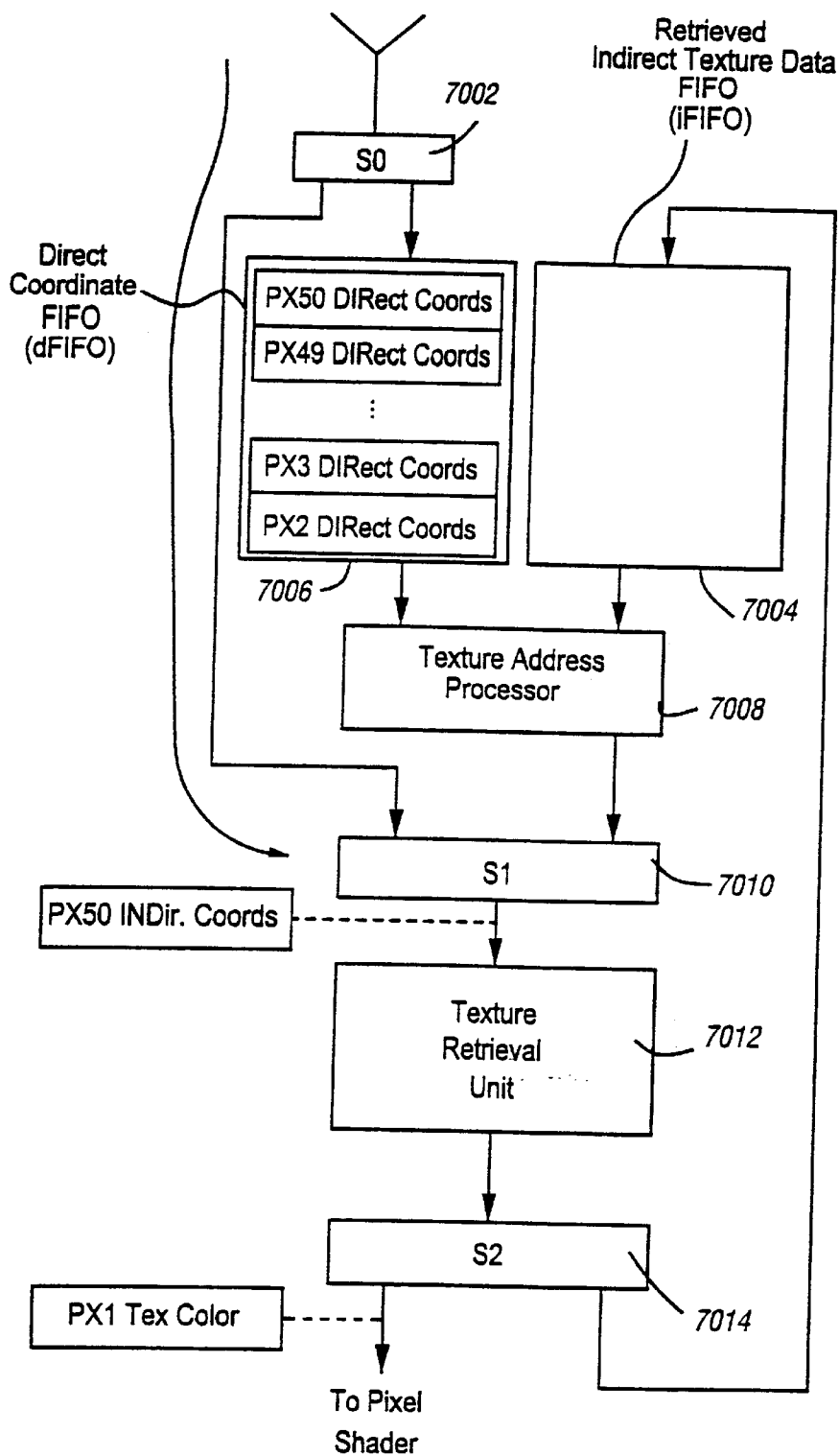


Fig. 10G

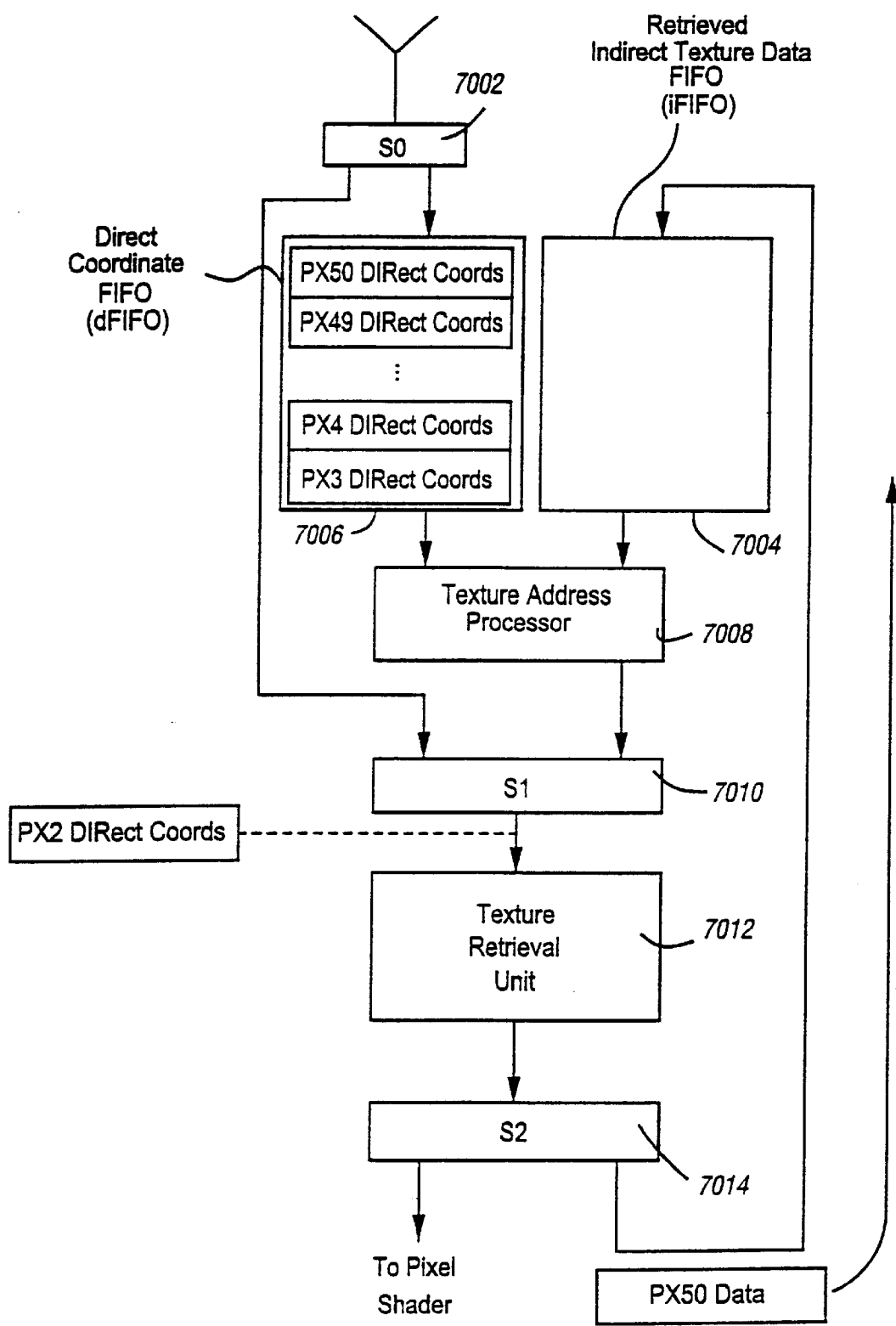


Fig. 10H

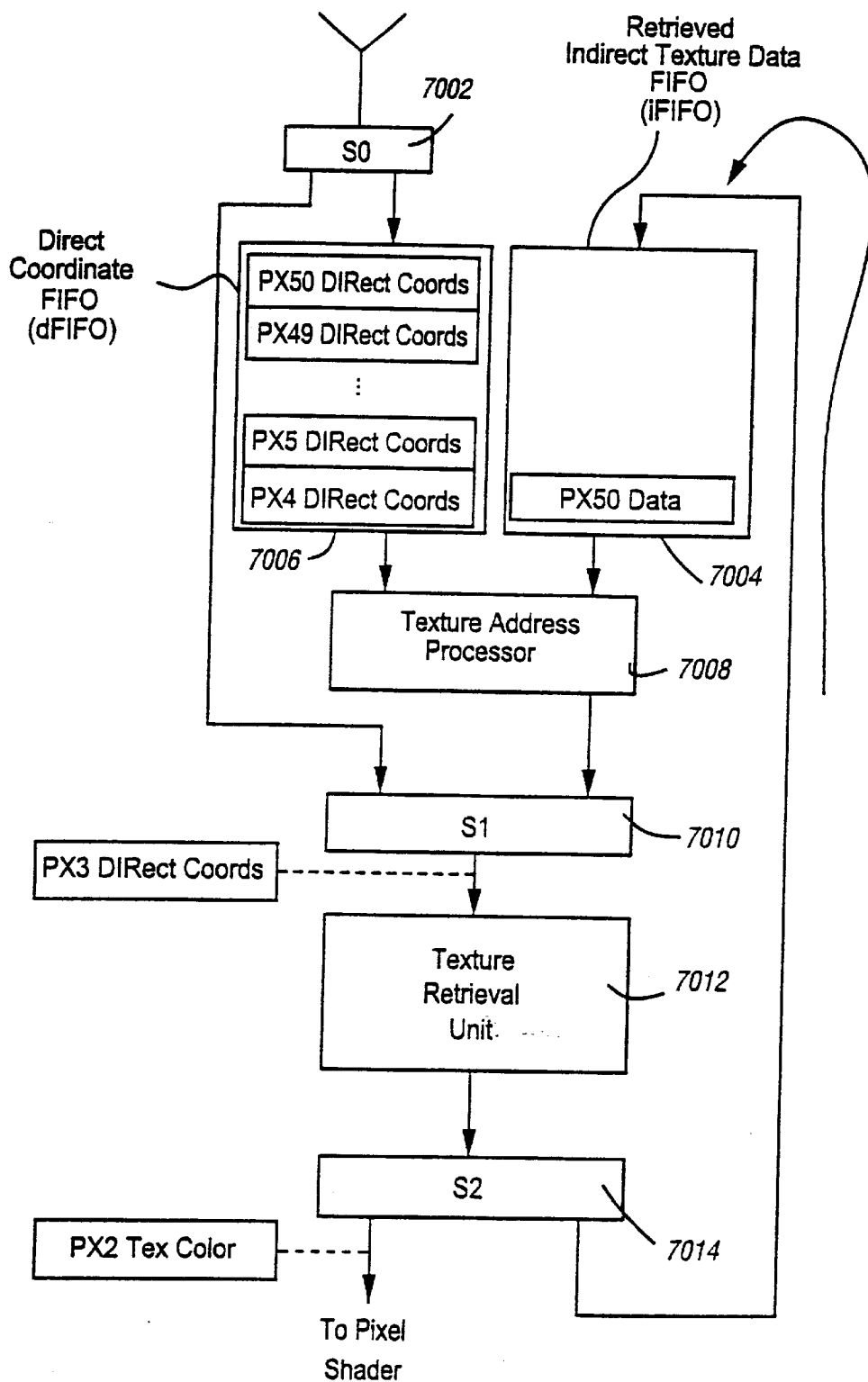


Fig. 10I

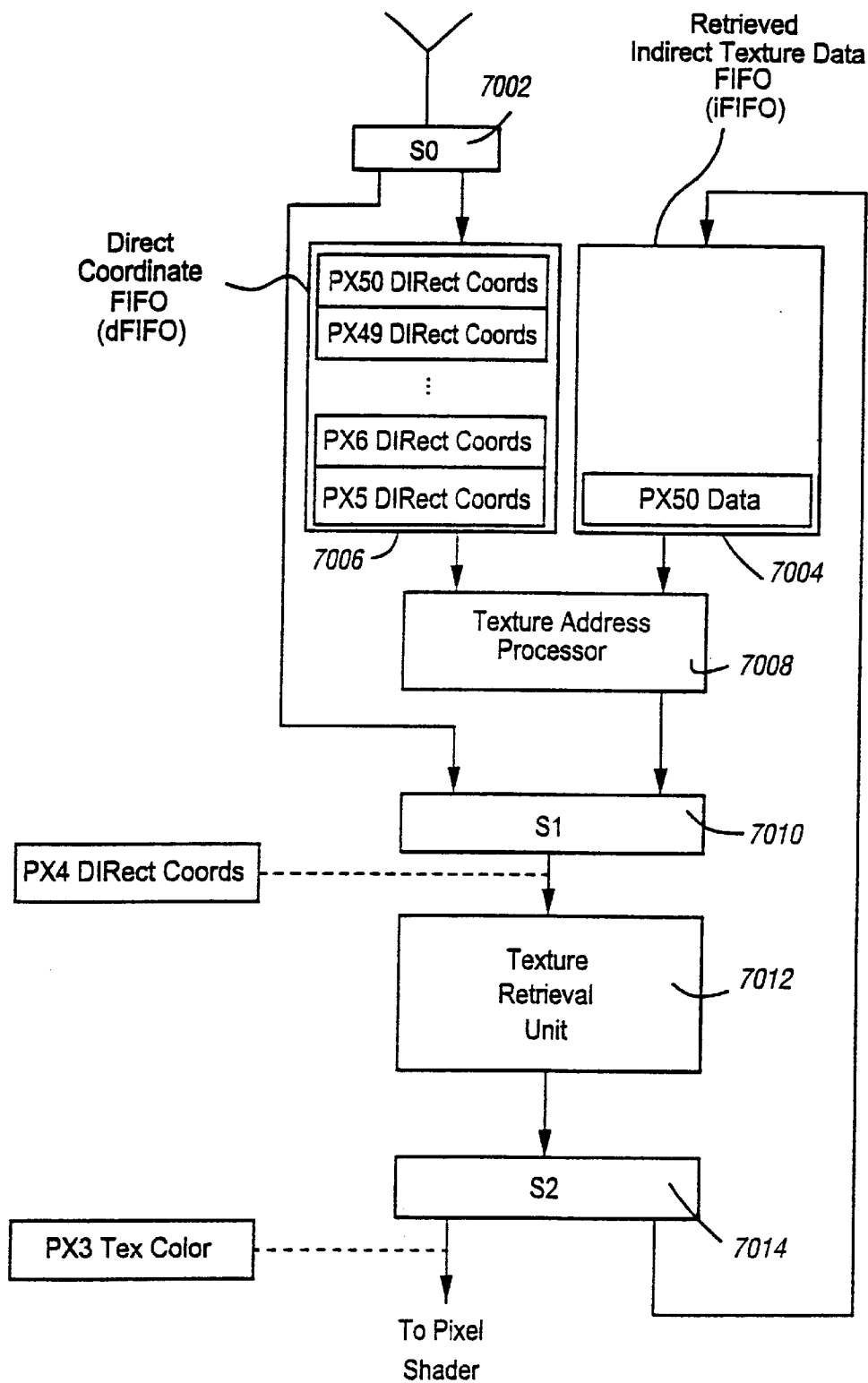


Fig. 10J

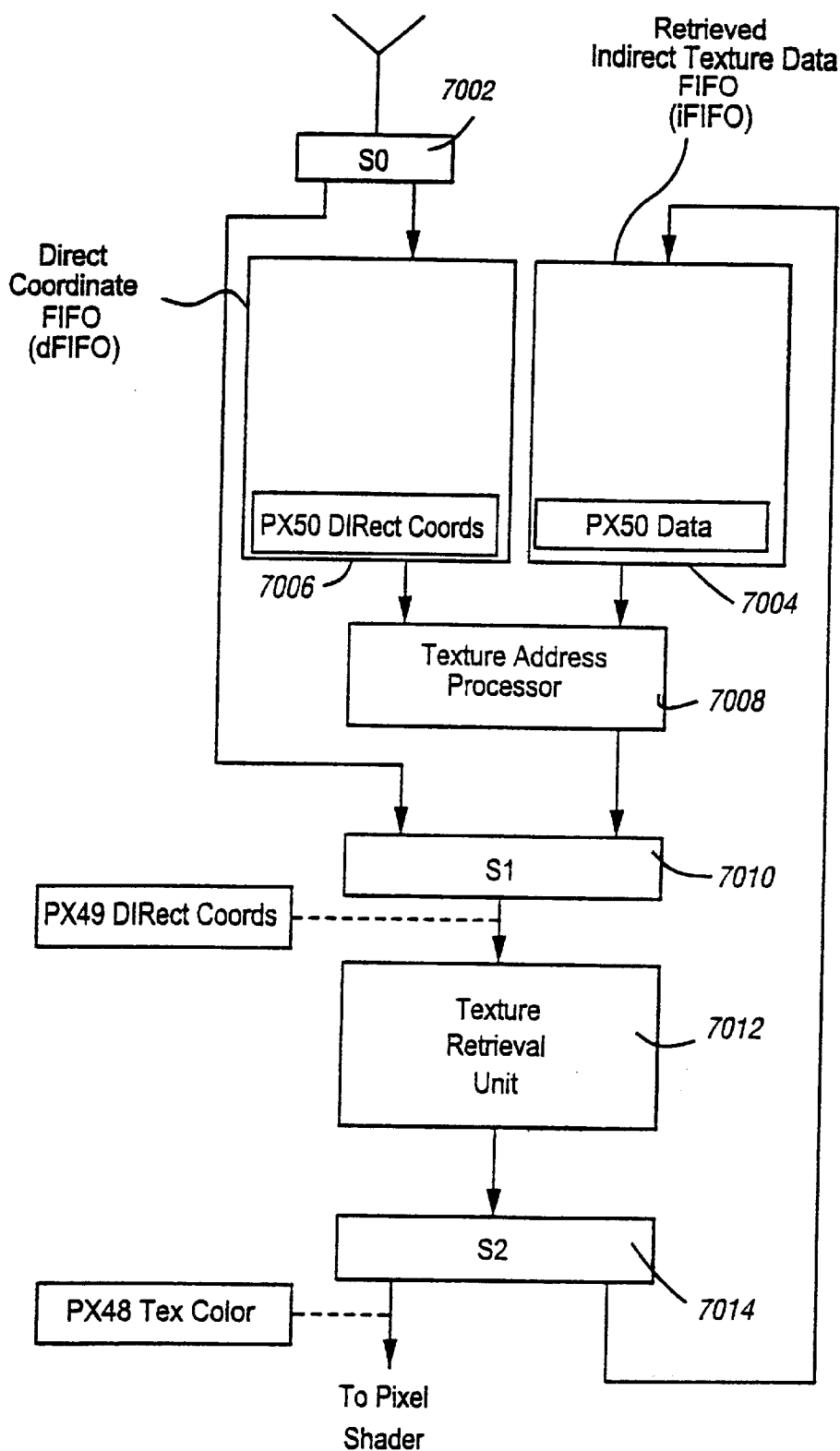


Fig. 10K

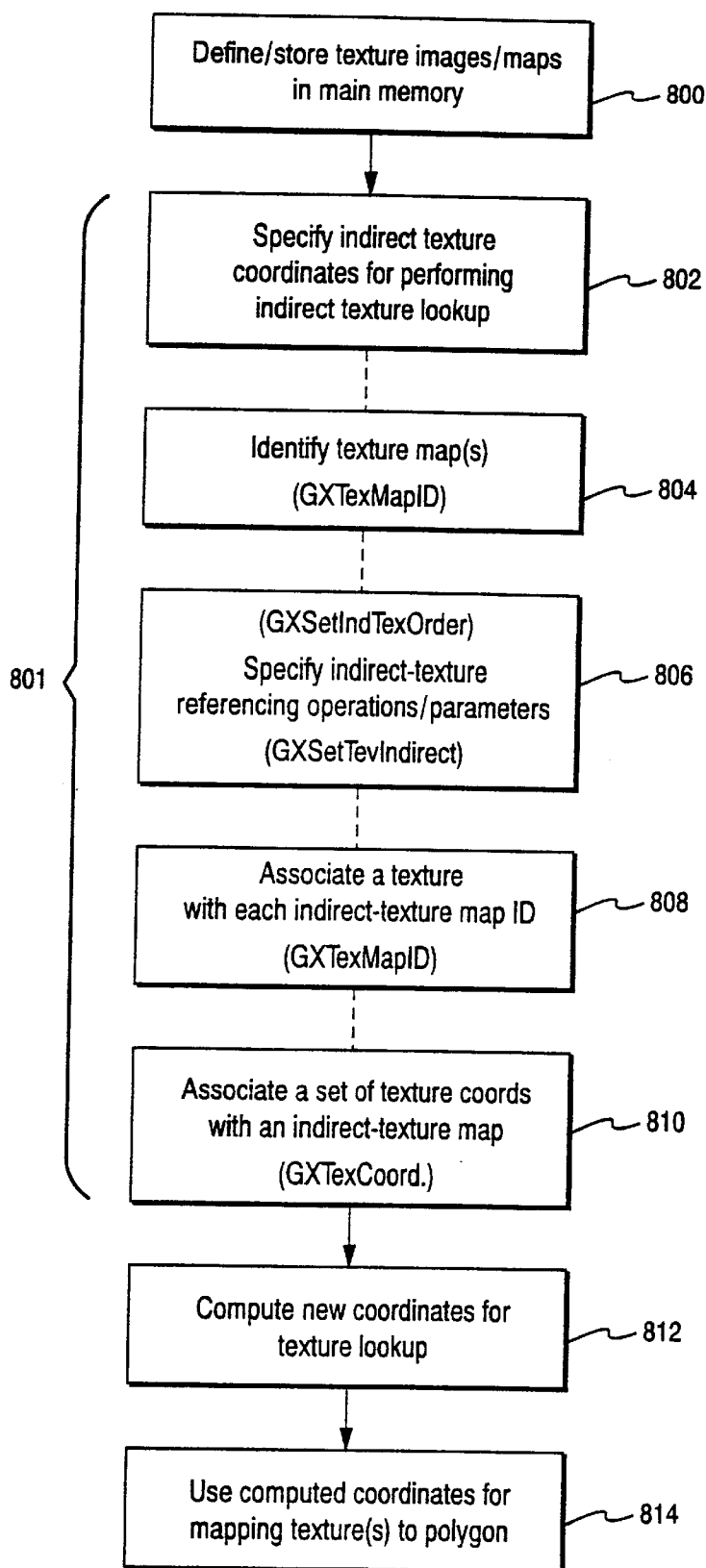


Fig. 11

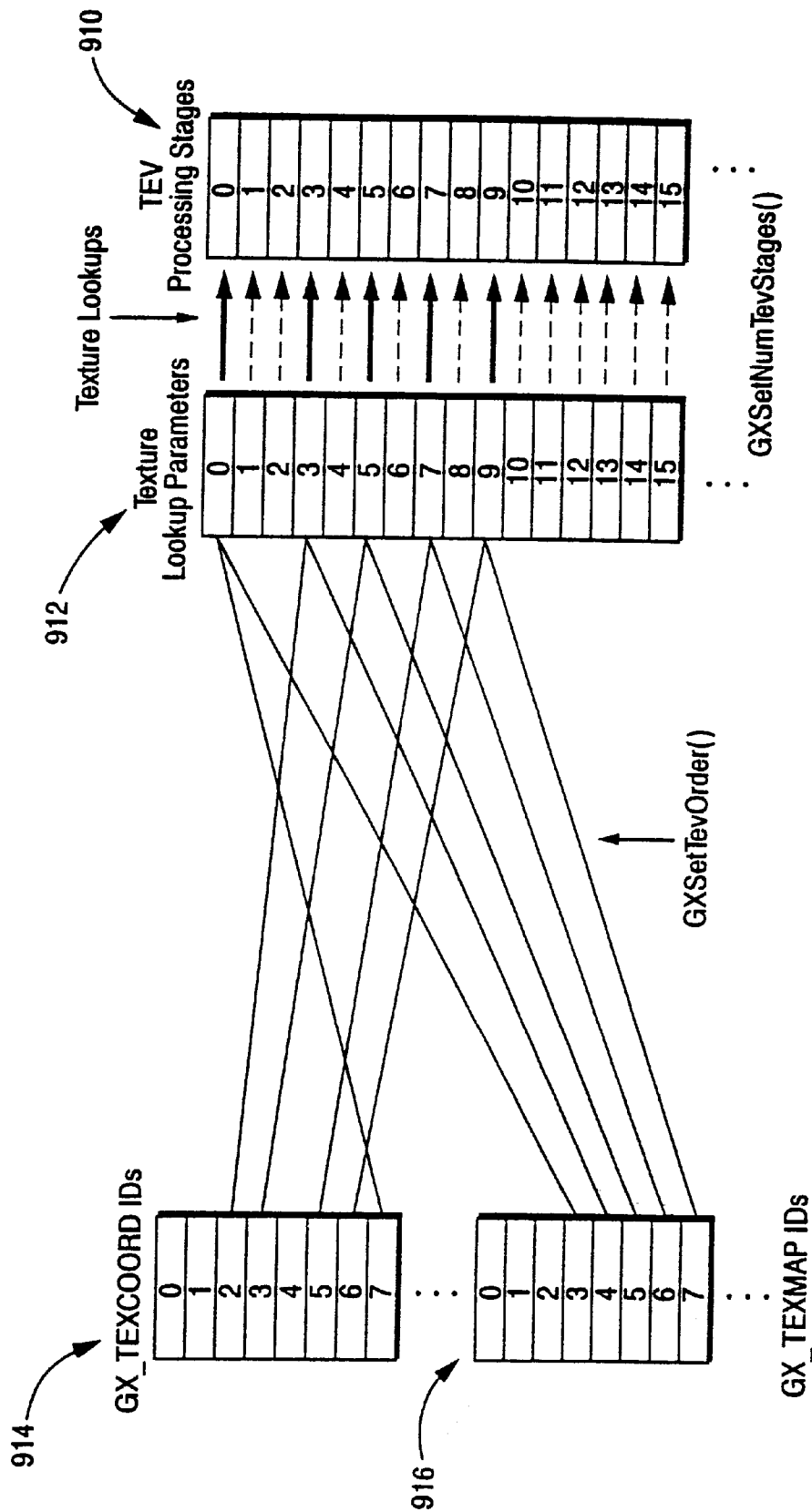


Fig. 12
REGULAR(NON-INDIRECT) TEXTURE PROCESSING

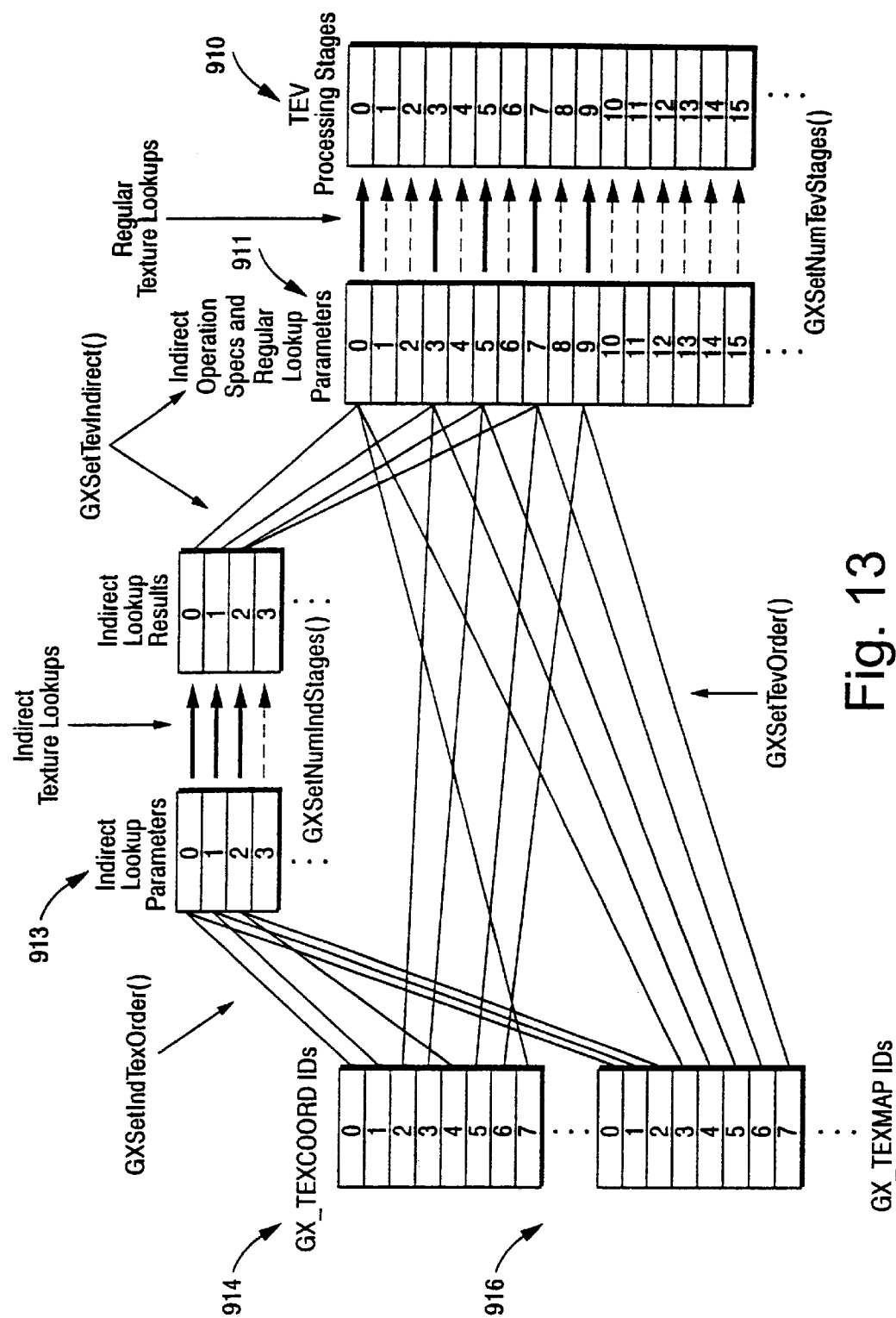


Fig. 13
REGULAR AND INDIRECT
TEXTURE PROCESSING

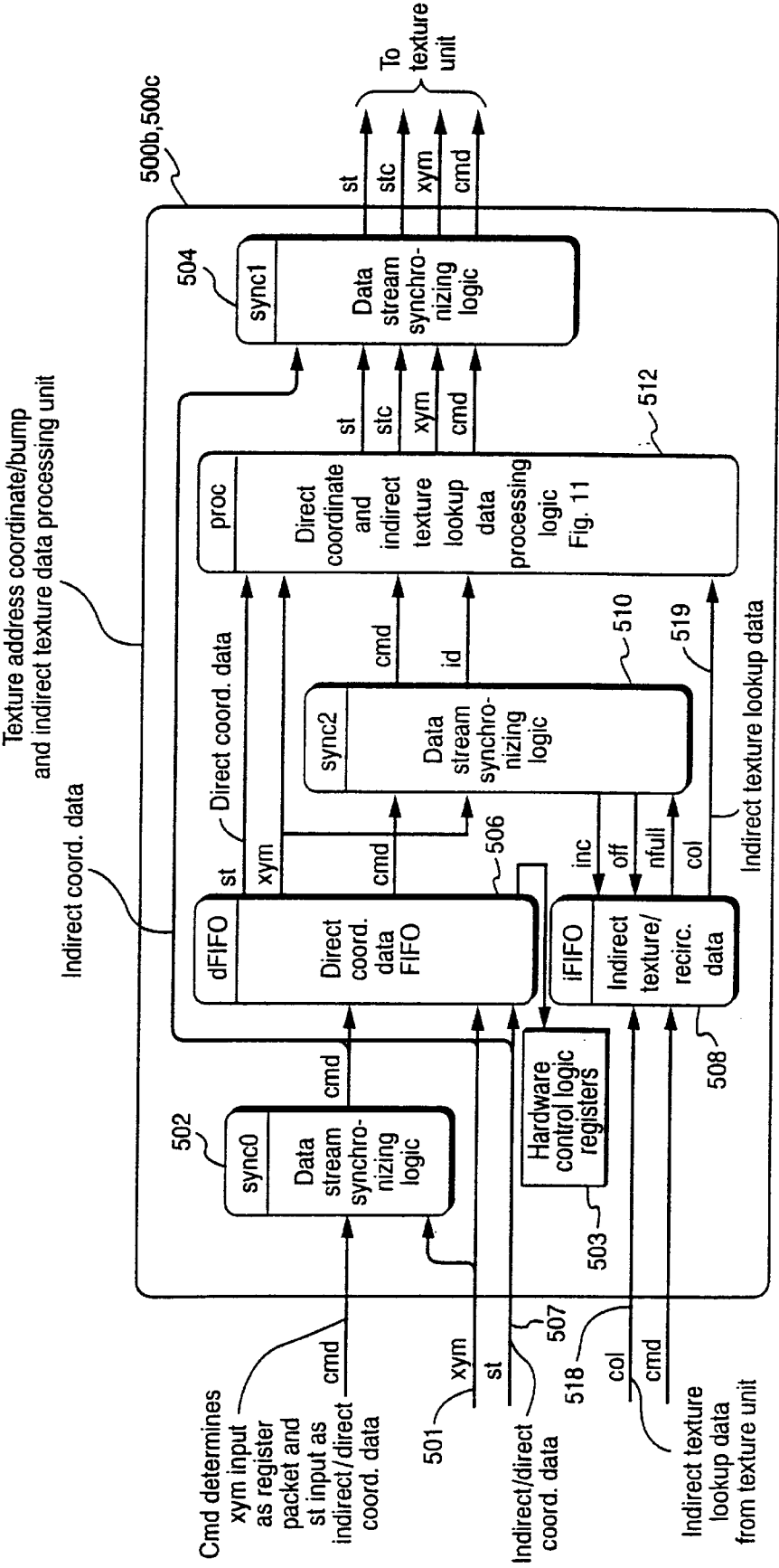


Fig. 14

EXAMPLE BUMP/TEXTURE
COORDINATE PROCESSING UNIT

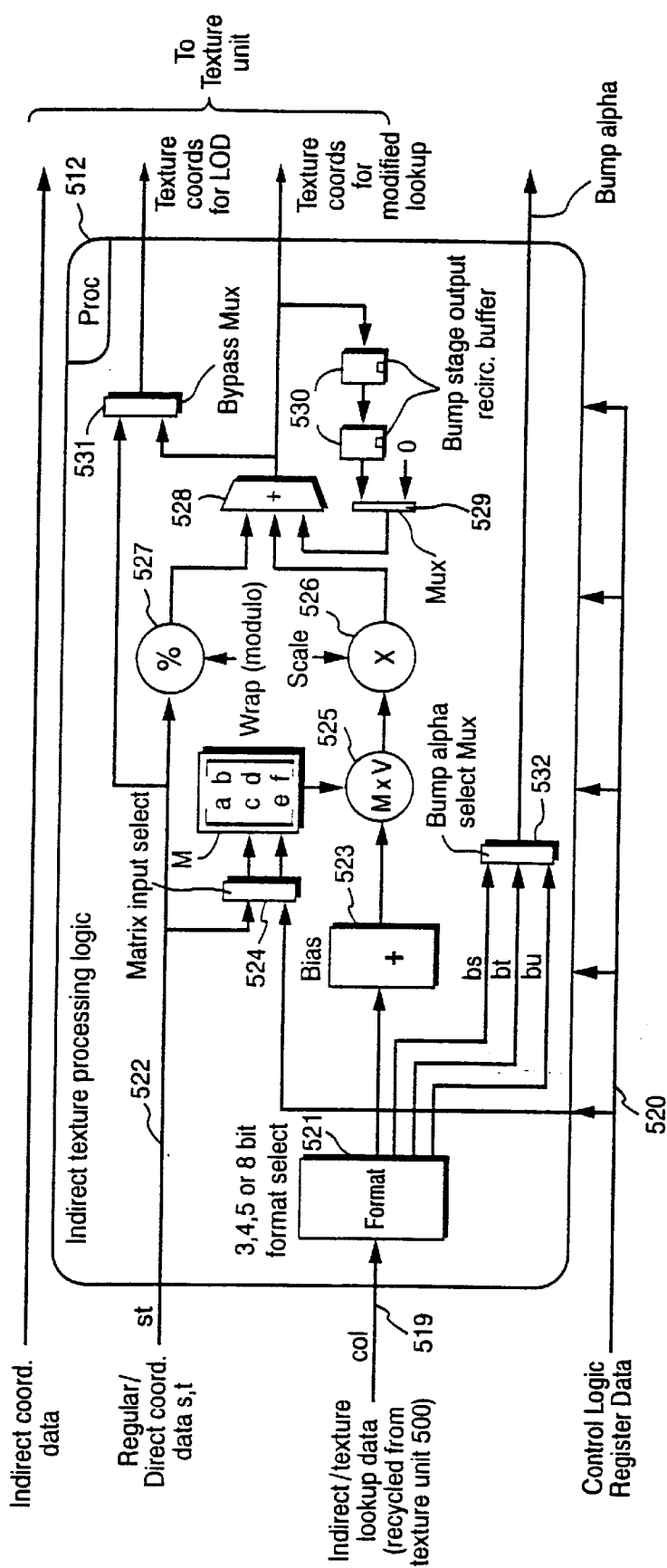


Fig. 15
*EXAMPLE INDIRECT-TEXTURE
LOOKUP DATA PROCESSING LOGIC*

$$\begin{pmatrix} s' \\ t' \end{pmatrix} = \begin{pmatrix} ma & mb \\ mc & md \\ me & mf \end{pmatrix} \cdot \begin{pmatrix} s \\ t \\ u \end{pmatrix}$$

M

V

Fig. 16A

EXAMPLE TEXTURE
OFFSET MATRICES

Matrix A

$$\begin{pmatrix} s/256 & t/256 \\ 0 & 0 \\ 0 & 0 \end{pmatrix}$$

Matrix B

$$\begin{pmatrix} 0 & 0 \\ s/256 & t/256 \\ 0 & 0 \end{pmatrix}$$

Fig. 16B

EXAMPLE TEXTURE
OFFSET MATRICES





MTXA _i	s _i (1:0)	mb _i (10:0)				ma _i (10:0)			
MTXB _i	s _i (3:2)	md _i (10:0)				mc _i (10:0)			
MTXC _i	s _i (5:4)	mf _i (10:0)				me _i (10:0)			
CMD _i		fb _i		tw _i	sw _i	m _i		bias _i	fmt _i bt _i
⋮									
								imask (7:0)	
GEN MODE		nbmp			ntev			ntex	

Fig. 17

EXAMPLE CONTROL
LOGIC REGISTERS

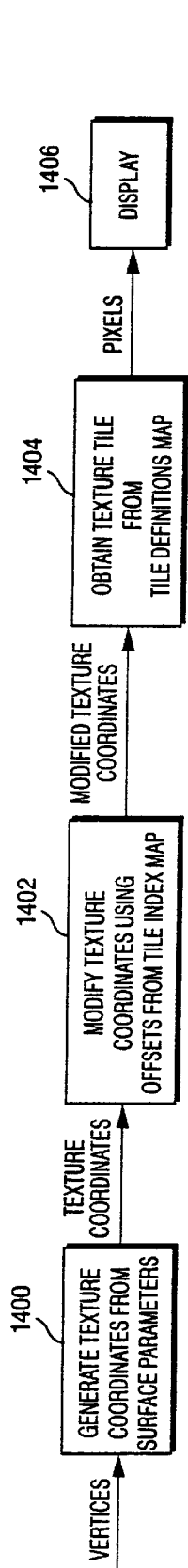


Fig. 18A
(INDIRECT TILING METHOD)

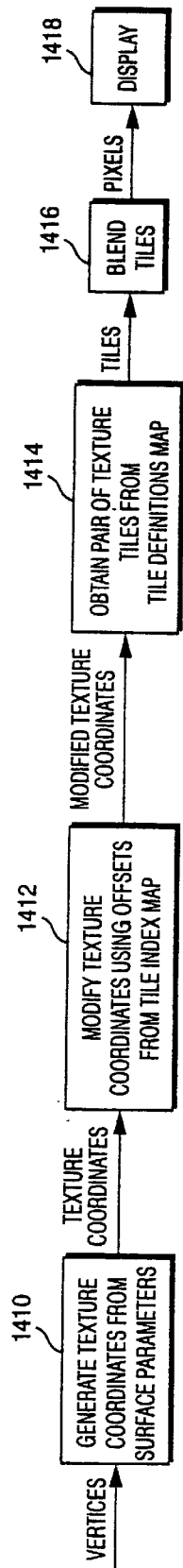


Fig. 18B
(PSEUDO 3-D TILE TEXTURES)

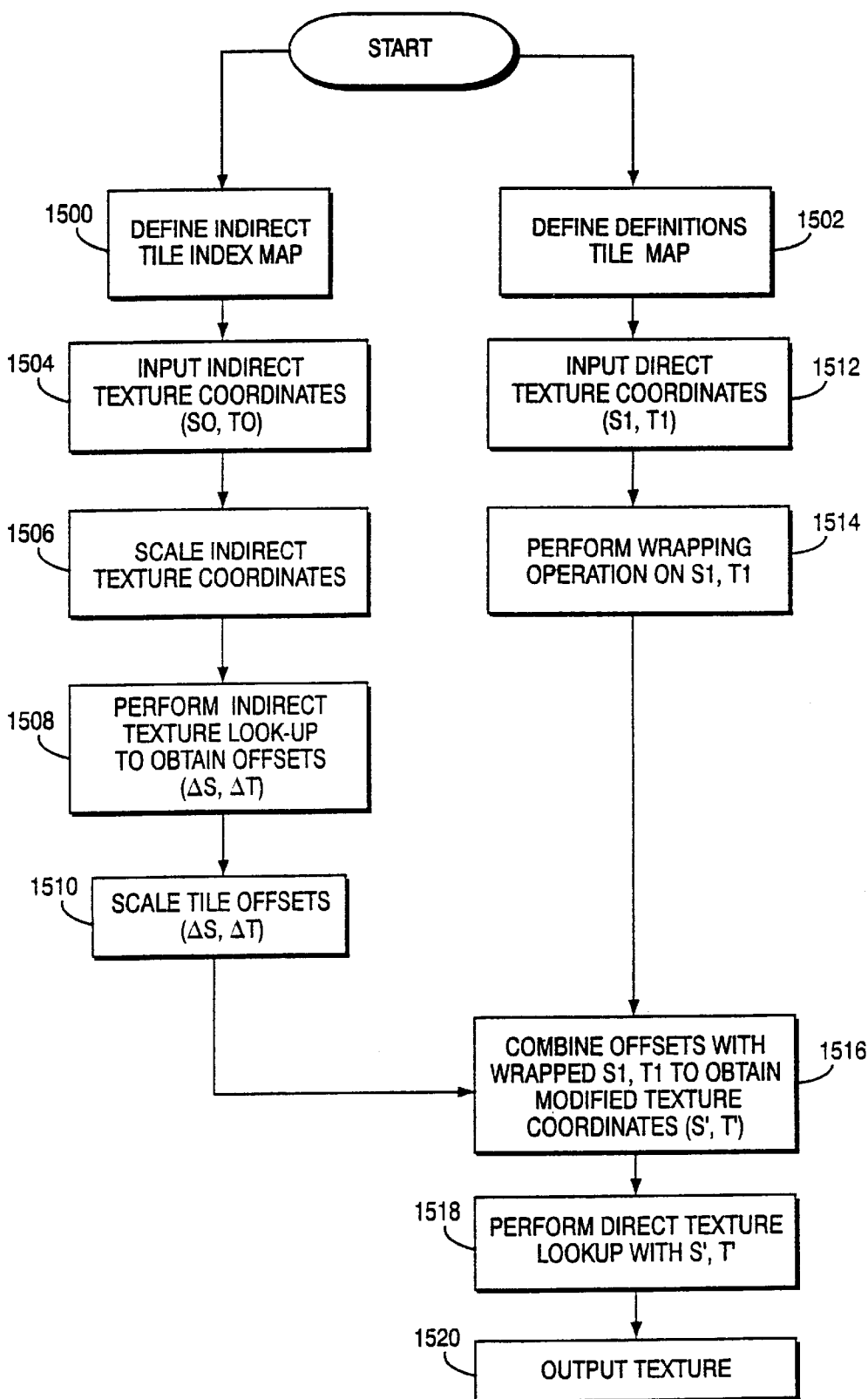


FIG. 19
(TILING METHOD 1)

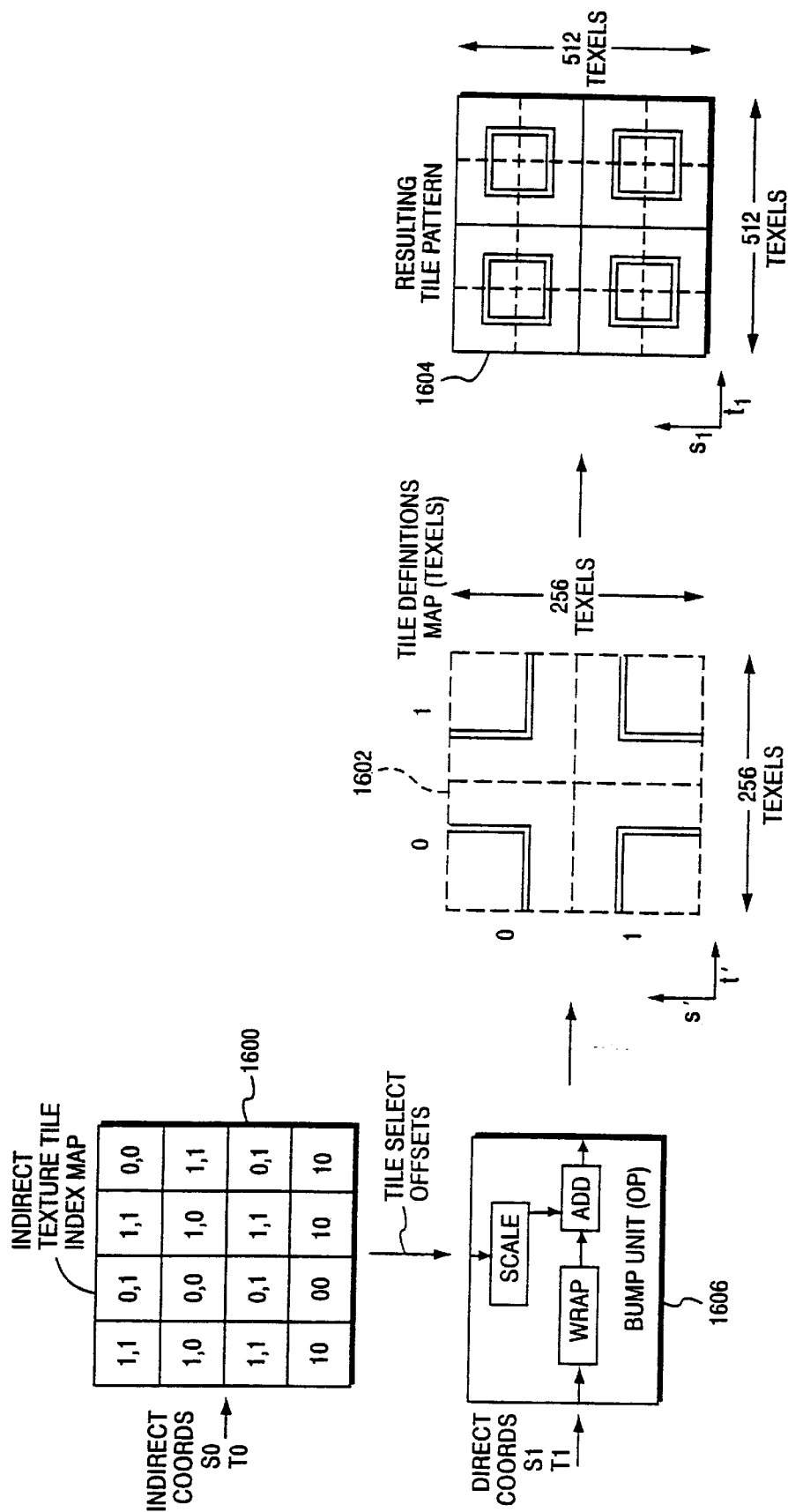


FIG. 20A
(TILING METHOD 1)

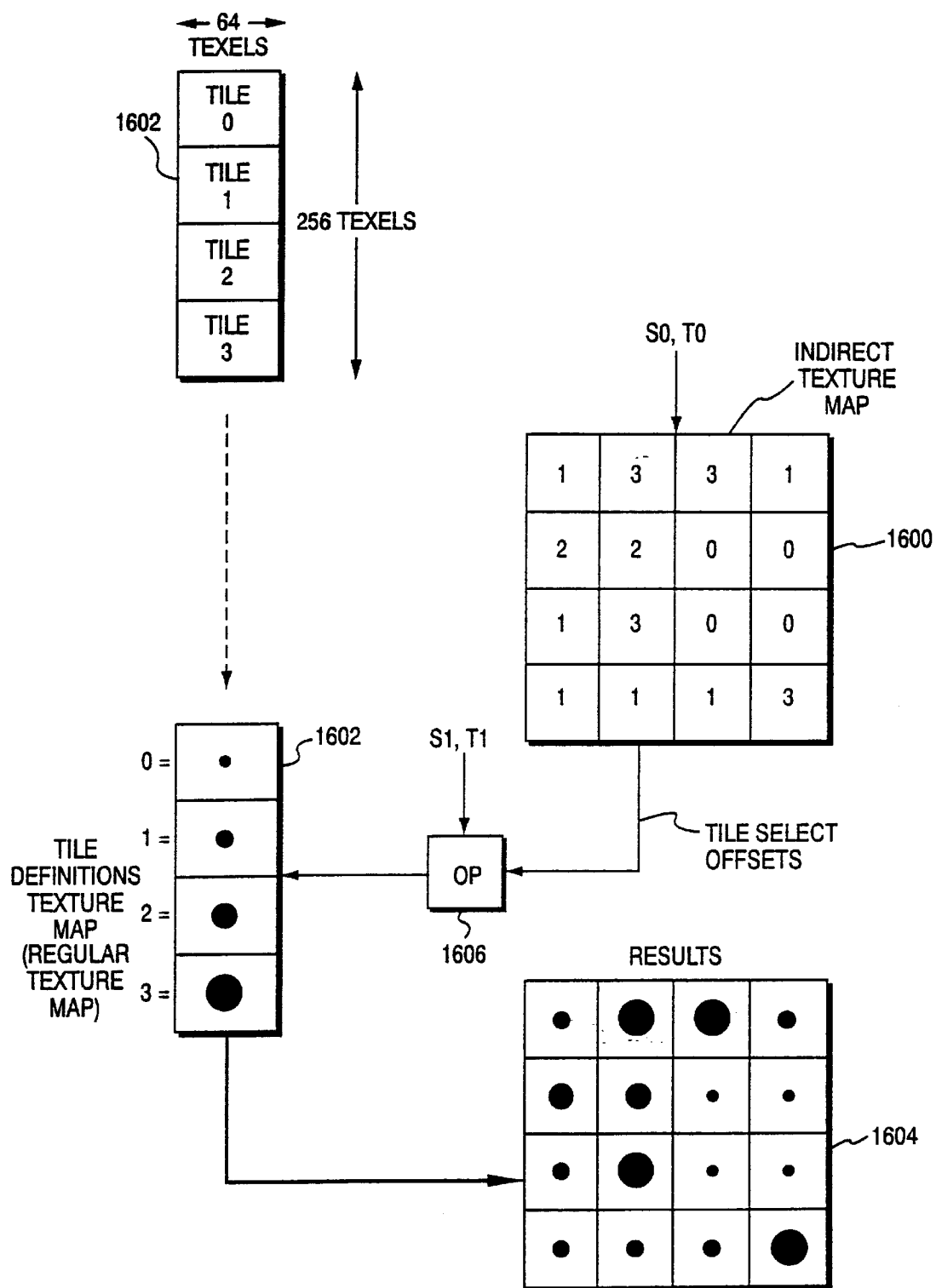


FIG. 20B
(2ND EXAMPLE OF TILING METHOD 1)

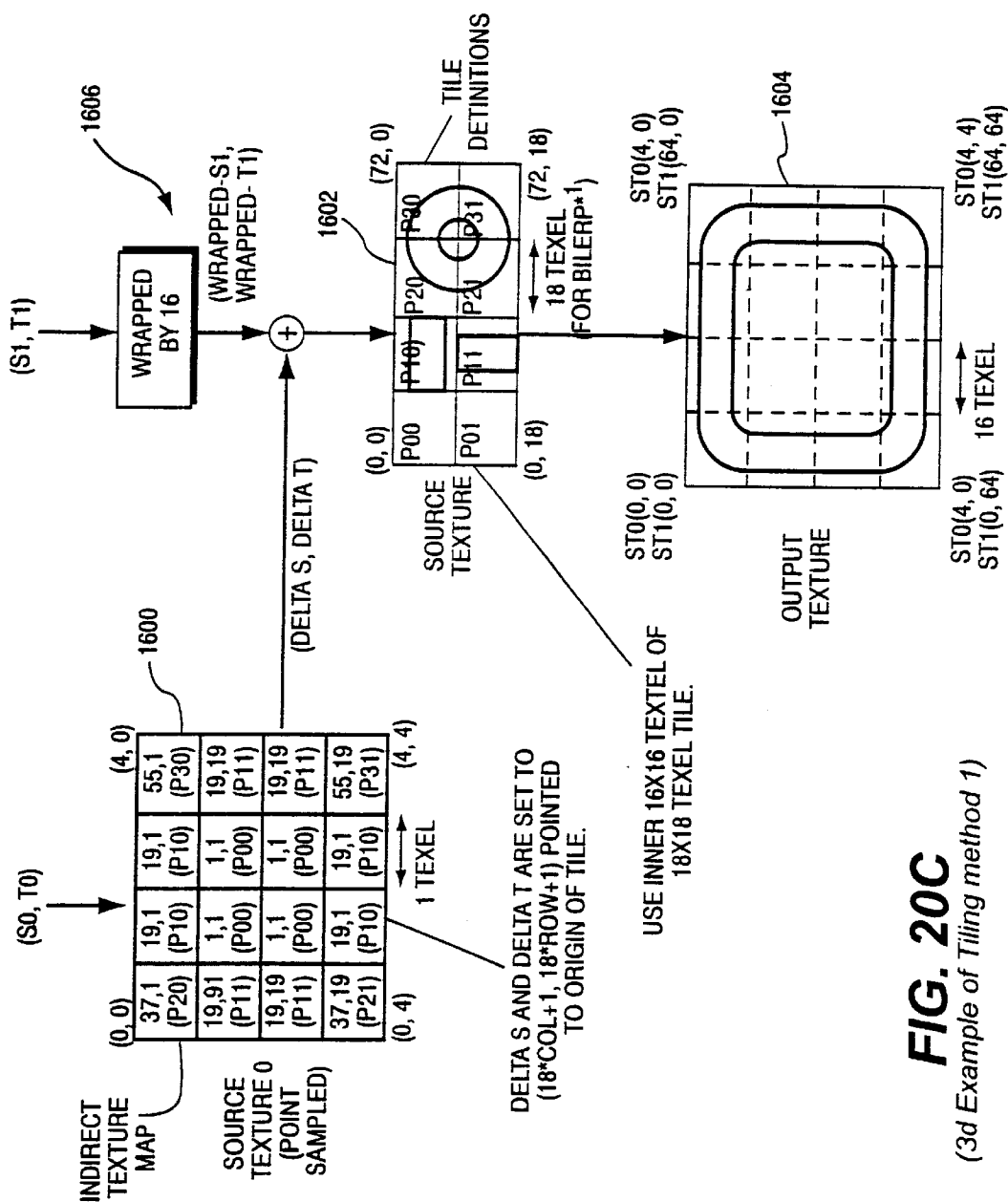


FIG. 20C
(3d Example of Tiling method 1)

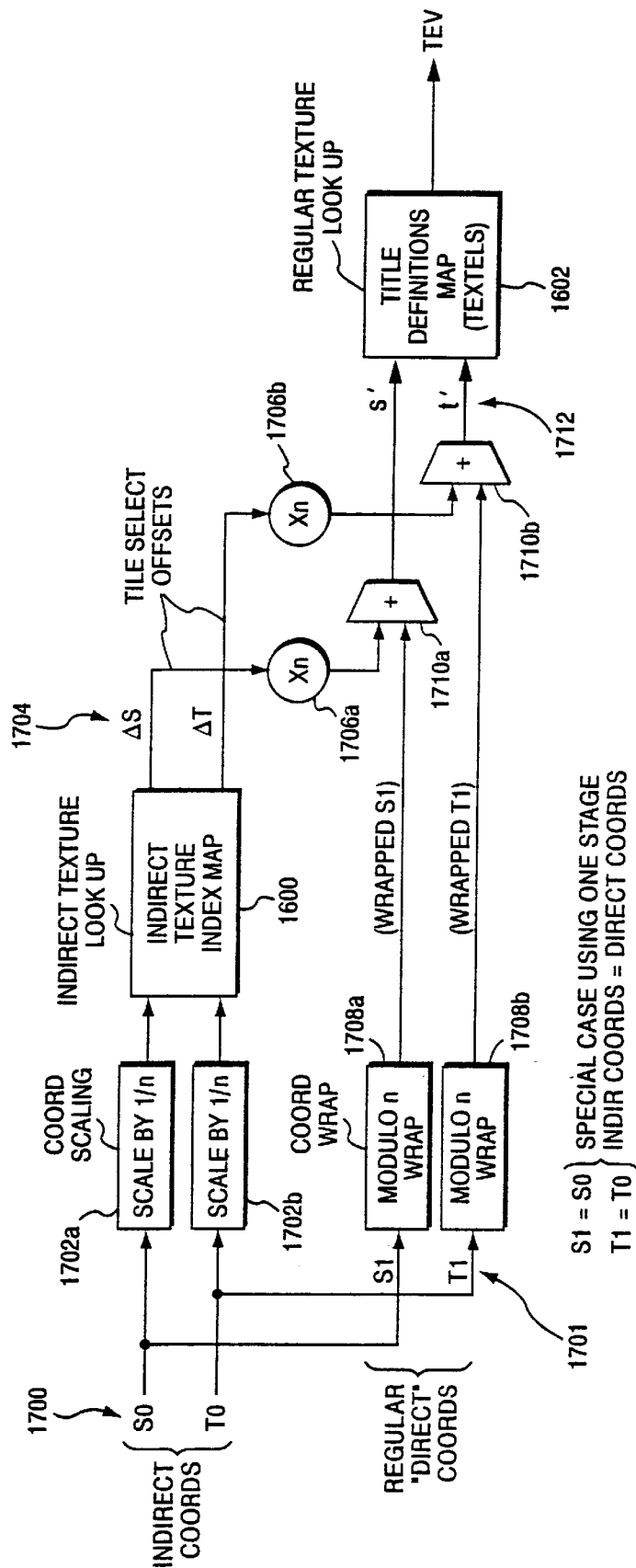


FIG. 21
(TILING METHOD 1)

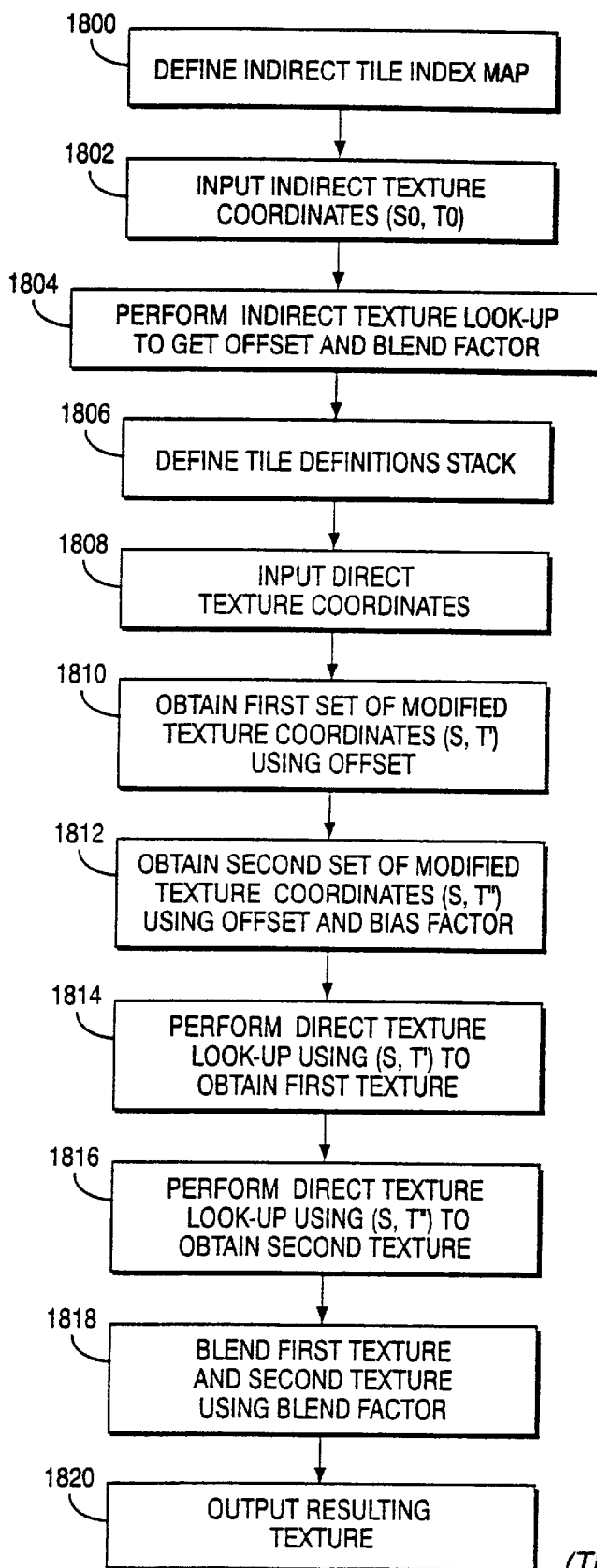


FIG. 22
(TILING METHOD 2)

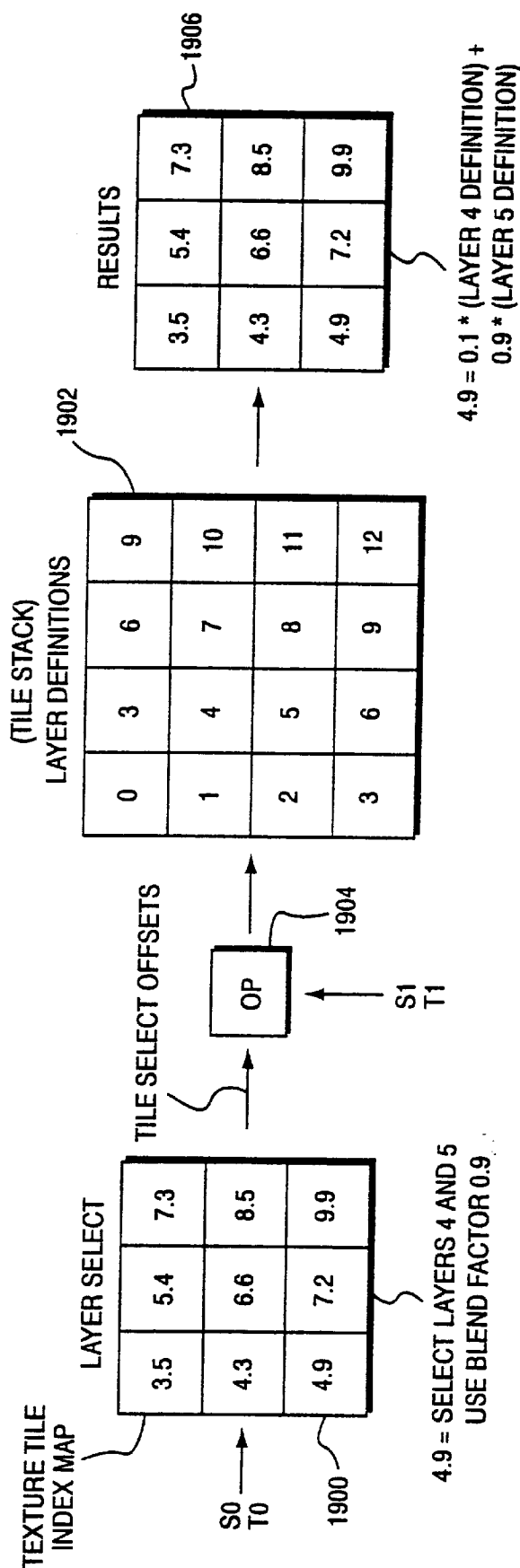
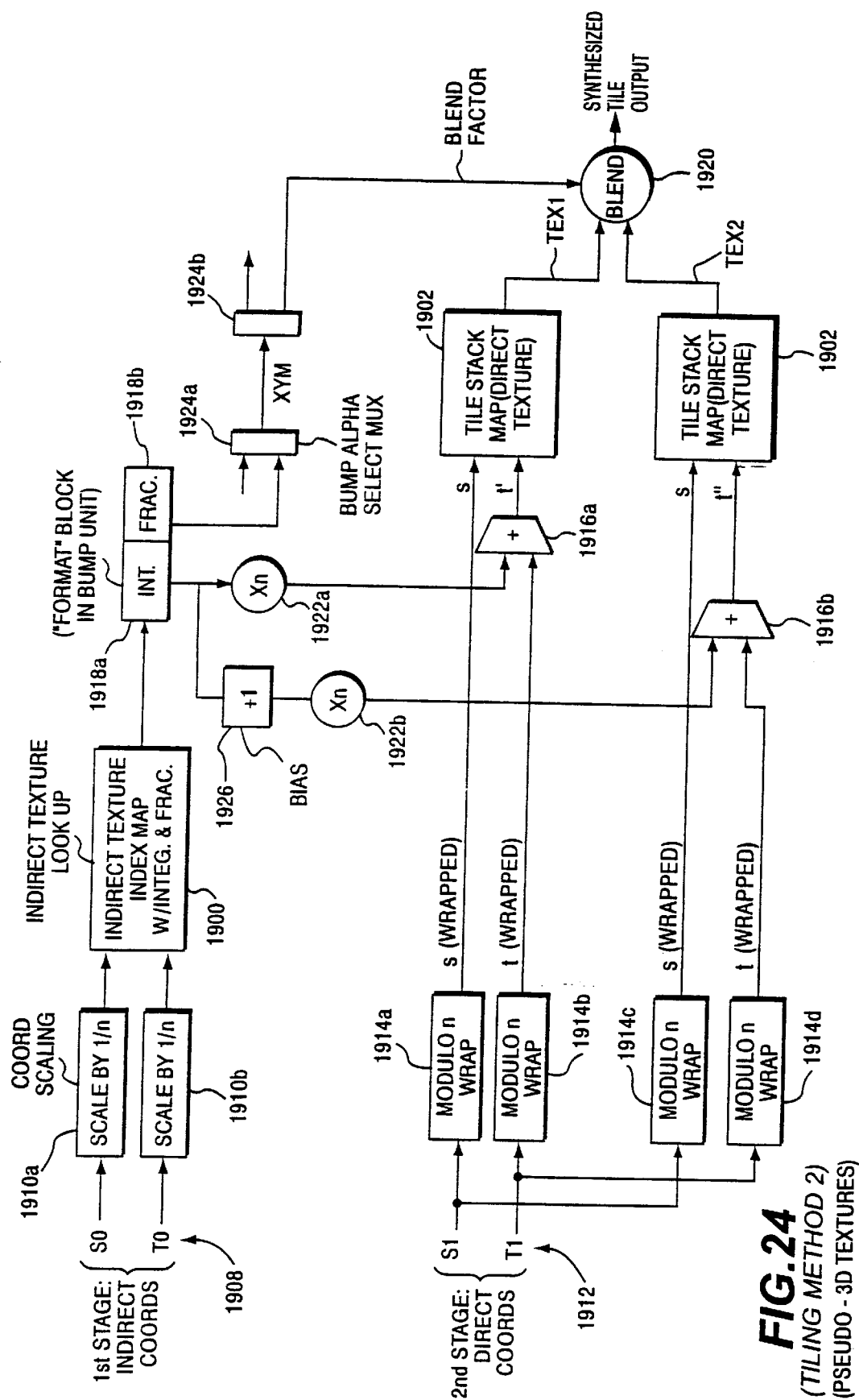


FIG. 23
(TILING METHOD 2)
(PSEUDO - 3D TEXTURES)



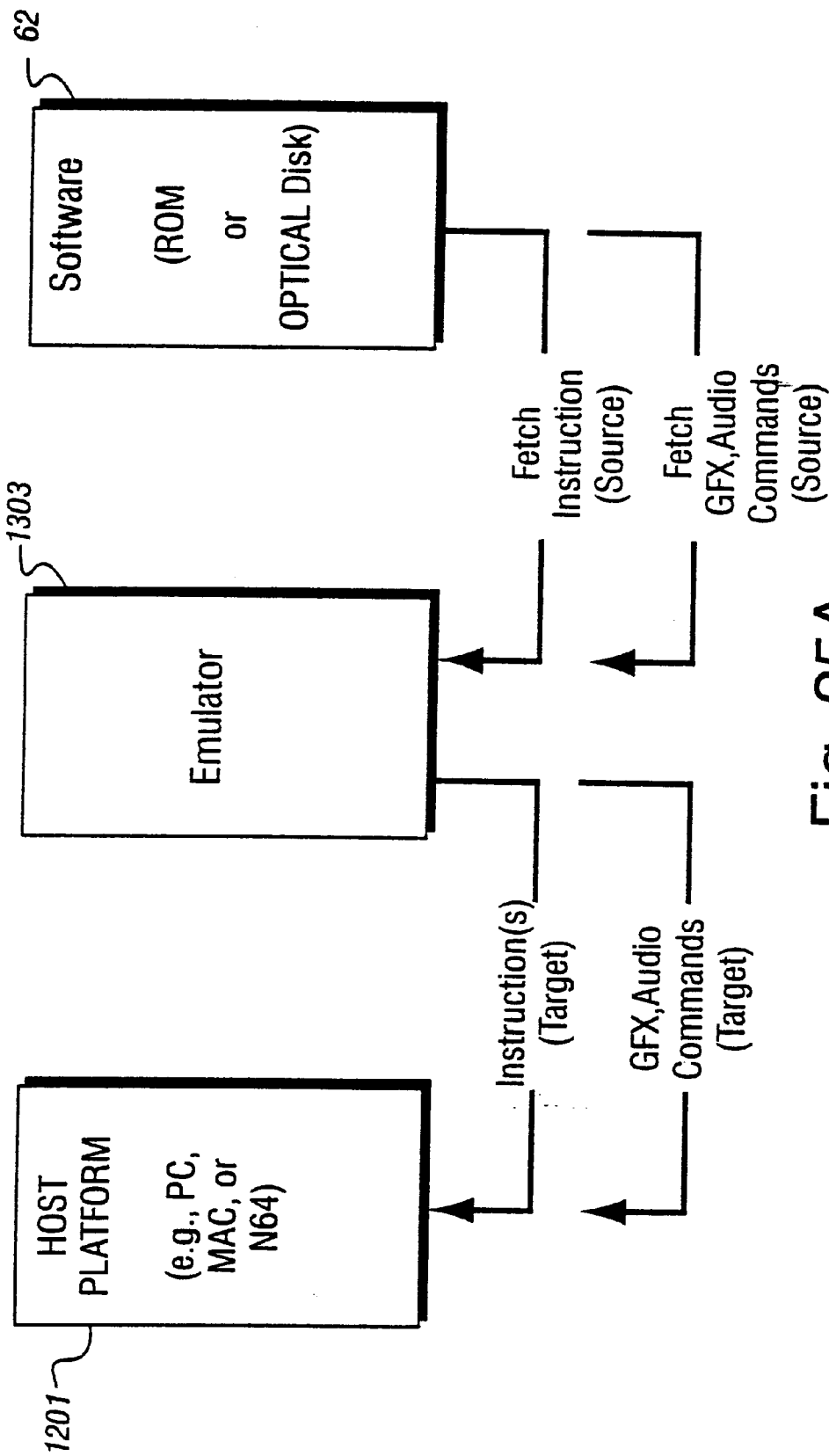


Fig. 25A

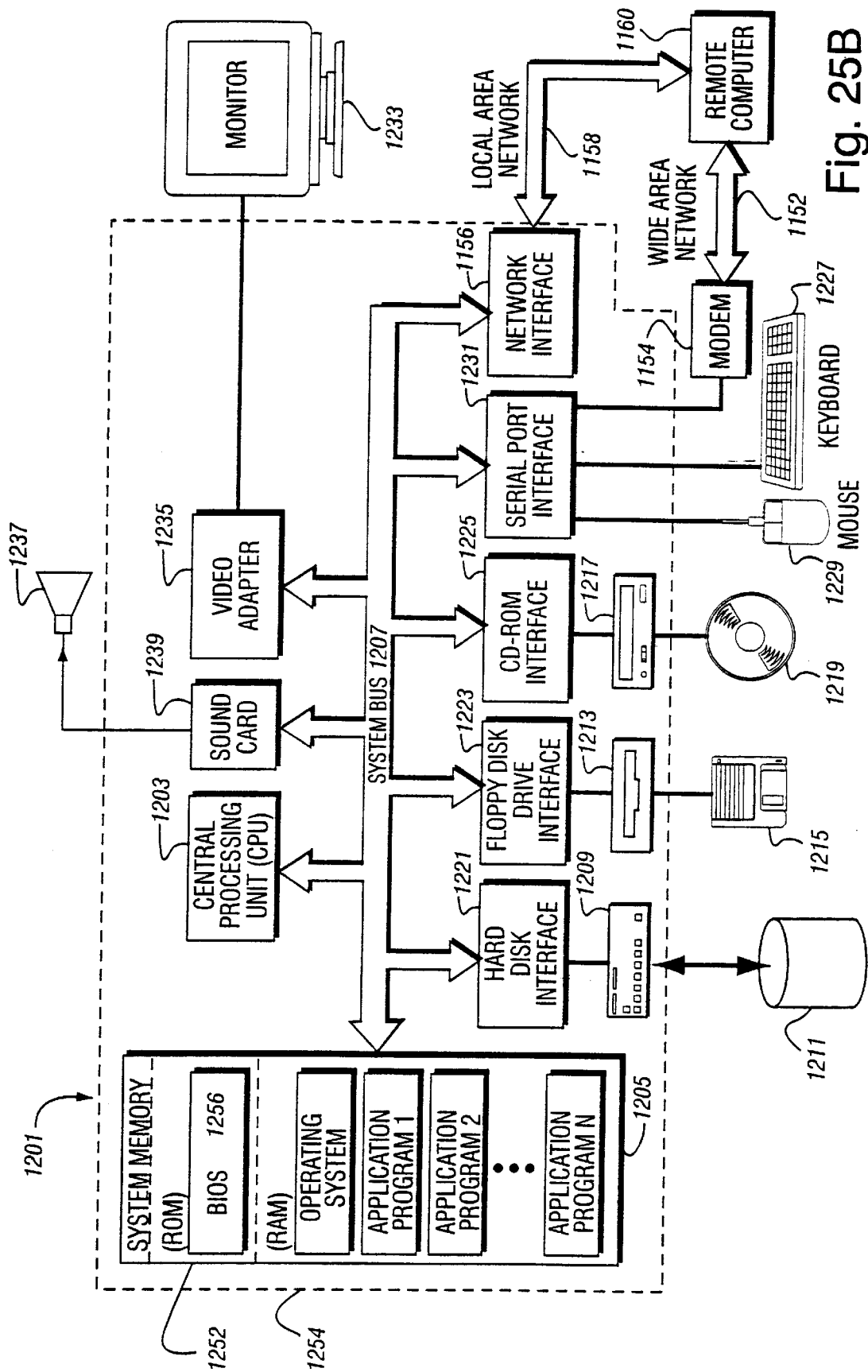


Fig. 25B

1

METHOD AND APPARATUS FOR TEXTURE TILING IN A GRAPHICS SYSTEM

SPECIFICATION

This application is filed in accordance with 35 U.S.C. §119(e)(1) and claims the benefit of the provisional application Ser. No. 60/227,033 filed on Aug. 23, 2000, entitled "Method And Apparatus For Texture Tiling In A Graphics System."

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to the following co-pending applications identified below (by title and attorney docket number), which focus on various aspects of the graphics system described herein. Each of the following applications are hereby incorporated herein by reference.

- provisional Application No. 60/161,915, filed Oct. 28, 1999 and its corresponding utility application Ser. No. 09/465,754, filed Dec. 17, 1999, both entitled "Vertex Cache For 3D Computer Graphics",
- provisional Application No. 60/226,912, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/726,215, filed Nov. 28, 2000, both entitled "Method and Apparatus for Buffering Graphics Data in a Graphics System",
- provisional Application No. 60/226,889, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,419, filed Nov. 28, 2000, both entitled "Graphics Pipeline Token Synchronization",
- provisional Application No. 60/226,891, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,382, filed Nov. 28, 2000, both entitled "Method And Apparatus For Direct and Indirect Texture Processing In A Graphics System",
- provisional Application No. 60/226,888, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,367, filed Nov. 28, 2000, both entitled "Recirculating Shade Tree Blender For A Graphics System",
- provisional Application No. 60/226,892, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/726,218, filed Nov. 28, 2000, both entitled "Method And Apparatus For Efficient Generation Of Texture Coordinate Displacements For Implementing Emboss-Style Bump Mapping In A Graphics Rendering System",
- provisional Application No. 60/226,893, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,381 filed Nov. 28, 2000, both entitled "Method And Apparatus For Environment-Mapped Bump-Mapping In A Graphics System",
- provisional Application No. 60/227,007, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/726,216, filed Nov. 28, 2000, both entitled "Achromatic Lighting in a Graphics System and Method",
- provisional Application No. 60/226,900, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/726,226, filed Nov. 28, 2000, both entitled "Method And Apparatus For Anti-Aliasing In A Graphics System",
- provisional Application No. 60/226,910, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,380, filed Nov. 28, 2000, both entitled "Graphics System With Embedded Frame Buffer Having Reconfigurable Pixel Formats",

2

- utility Application Ser. No. 09/585,329, filed Jun. 2, 2000, entitled "Variable Bit Field Color Encoding",
- provisional Application No. 60/226,890, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/726,227, filed Nov. 28, 2000, both entitled "Method And Apparatus For Dynamically Reconfiguring The Order Of Hidden Surface Processing Based On Rendering Mode",
- provisional Application No. 60/226,915, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/726,212 filed Nov. 28, 2000, both entitled "Method And Apparatus For Providing Non-Photorealistic Cartoon Outlining Within A Graphics System",
- provisional Application No. 60/227,032, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/726,225, filed Nov. 28, 2000, both entitled "Method And Apparatus For Providing Improved Fog Effects In A Graphics System",
- provisional Application No. 60/226,885, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,664, filed Nov. 28, 2000, both entitled "Controller Interface For A Graphics System",
- provisional Application No. 60/226,899, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,667, filed Nov. 28, 2000, both entitled "Method And Apparatus For Pre-Caching Data In Audio Memory",
- provisional Application No. 60/226,913, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,378, filed Nov. 28, 2000, both entitled "Z-Texturing",
- provisional Application No. 60/227,031, filed Aug. 23, 2000 entitled "Application Program Interface for a Graphics System",
- provisional Application No. 60/227,030, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,663, filed Nov. 28, 2000, both entitled "Graphics System With Copy Out Conversions Between Embedded Frame Buffer And Main Memory",
- provisional Application No. 60/226,886, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,665, filed Nov. 28, 2000, both entitled "Method and Apparatus for Accessing Shared Resources",
- provisional Application No. 60/226,894, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/726,220, filed Nov. 28, 2000, both entitled "Graphics Processing System With Enhanced Memory Controller",
- provisional Application No. 60/226,914, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,390, filed Nov. 28, 2000, both entitled "Low Cost Graphics System With Stitching Hardware Support For Skeletal Animation", and
- provisional Application No. 60/227,006, filed Aug. 23, 2000 and its corresponding utility application Ser. No. 09/722,421, filed Nov. 28, 2000, both entitled "Shadow Mapping In A Low Cost Graphics System".

FIELD OF THE INVENTION

The present invention relates to computer graphics, and more particularly to interactive graphics systems such as home video game platforms. Still more particularly this invention relates to an improved texture tiling method and apparatus which uses indirect texture index maps to reference texture tiles in a tile definition map and map the texture

tiles onto a rendered primitive. The invention further enables synthesized (blended) texture tiles to be created from a tile definitions map and mapped onto a primitive in a manner which prevents the appearance of repeating texture patterns.

BACKGROUND AND SUMMARY OF THE INVENTION

Many of us have seen films containing remarkably realistic dinosaurs, aliens, animated toys and other fanciful creatures. Such animations are made possible by computer graphics. Using such techniques, a computer graphics artist can specify how each object should look and how it should change in appearance over time, and a computer then models the objects and displays them on a display such as your television or a computer screen. The computer takes care of performing the many tasks required to make sure that each part of the displayed image is colored and shaped just right based on the position and orientation of each object in a scene, the direction in which light seems to strike each object, the surface texture of each object, and other factors.

Because computer graphics generation is complex, computer-generated three-dimensional graphics just a few years ago were mostly limited to expensive specialized flight simulators, high-end graphics workstations and supercomputers. The public saw some of the images generated by these computer systems in movies and expensive television advertisements, but most of us couldn't actually interact with the computers doing the graphics generation. All this has changed with the availability of relatively inexpensive 3D graphics platforms such as, for example, the Nintendo 64® and various 3D graphics cards now available for personal computers. It is now possible to interact with exciting 3D animations and simulations on relatively inexpensive computer graphics systems in your home or office.

A problem graphics system designers confronted in the past was how to create realistic looking surface detail on a rendered object without resorting to explicit modeling of the desired details with polygons or other geometric primitives. Although surface details can be simulated, for example, using myriad small triangles with interpolated shading between vertices, as the desired detail becomes finer and more intricate, explicit modeling with triangles or other primitives places high demands on the graphics system and becomes less practical. An alternative technique pioneered by E. Catmull and refined by J. F. Blinn and M. E. Newell is to "map" an image, either digitized or synthesized, onto a surface. (See "A Subdivision Algorithm for Computer Display of Curved Surfaces" by E. Catmull, Ph.D. Thesis, Report UTEC-CSc-74-133, Computer Science Department, University of Utah, Salt Lake City, Utah., December 1994 and "Texture and Reflection in Computer Generated Images" by J. F. Blinn and M. E. Newell, CACM, 19(10), October 1976, 452-457). This approach is known as texture mapping (or pattern mapping) and the image is called a texture map (or simply referred to as a texture). Alternatively, the texture map may be defined by a procedure rather than an image.

Typically, the texture map is defined within a 2D rectangular coordinate space and parameterized using a pair of orthogonal texture coordinates such as, for example, (u, v) or (s, t). Individual elements within the texture map are often called texels. At each rendered pixel, selected texels are used either to substitute for or to scale one or more material properties of the rendered object surface. This process is often referred to as texture mapping or "texturing."

Most 3-D graphics rendering systems now include a texturing subsystem for retrieving textures from memory

and mapping the textures onto a rendered object surface. A problem confronting graphics system designers is how to provide more sophisticated texture related effects such as "texture tiling" in an efficient and advantageous manner.

Texture tiling generally involves mapping textures in the form of texture tiles on a tile-by-tile basis onto a rendered object surface, such as a 2-D surface. A texture tile can be defined by a tile shaped portion of a texture stored in texture memory. An array or matrix of different tiles can be defined in texture memory. The size and shape of the tile can be selected to facilitate mapping of the tile onto a particular rendered surface. The tile size can vary and can be defined such that numerous tiles are required to cover a rendered surface. Once defined, texture tiles can be placed in specific locations over the rendered surface to create a textured surface.

This tiling effect has been achieved in the past by, for example, drawing a polygon for each desired tile. However, this technique can be expensive in terms of processing overhead and memory usage. In addition, a problem resulting from prior art tiling techniques is that the tiled surface can have a repeating pattern that can be visually perceived by the viewer. Repeating patterns result from the fact that there is generally a limited number of different texture tiles available to the programmer when tiling a surface. Thus, large surfaces, such as walls, floors, ground cover or the like, will use the same texture tiles numerous times in order to completely cover the surface. Such repeated use of the same tiles can detract from the realism of a rendered scene, due to the fact that, in many instances, the human eye can pick up on and see the repeating texture pattern resulting from the tiling process. A further problem confronting graphics systems designers is how to take advantage of indirect texturing processing to perform texture tiling operations. Thus, while significant work has been done in the past in connection with texture tiling, further improvements are possible and desirable.

The present invention solves this problem by providing techniques and arrangements that can be used to efficiently implement texture tiling in a graphics system. The present invention further enables more realistic texture tiled surfaces to be created that reduce or even eliminate the ability of a viewer of the displayed textured surface to notice any repeating patterns in the texture. The invention also enables pseudo-3D textures to be created by blending between texture tiles. The invention further enables indirect texture processing hardware to be used in an efficient and effective manner to achieve texture tiling.

In accordance with one aspect provided by the invention, the texture tiling method includes:

- generating texture coordinates;
- modifying the texture coordinates using an indirect tile index map;
- using the modified texture coordinate to select a texture tile from a tile definitions map; and
- displaying the selected texture tile.

In accordance with another aspect of the invention, the pseudo-3D tiling method includes:

- defining a set of direct texture coordinates;
- defining a set of indirect texture coordinates;
- using the indirect texture coordinates to obtain an offset value;
- combining the offset value with at least one of the direct texture coordinates to produce a first set of modified texture coordinates;

using the first set of modified texture coordinates to obtain a first texture tile from a tile definitions map
biasing the offset value;
modifying the direct texture coordinates using the biased offset value;
combining the modified offset value with at least one of the direct texture coordinates to produce a second set of modified texture coordinates;
using the second set of modified texture coordinates to obtain a second texture tile from the tile definitions map; and
blending the first texture tile and the second texture tile to produce a synthesized texture tile.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages provided by the invention will be better and more completely understood by referring to the following detailed description of presently preferred embodiments in conjunction with the drawings, of which:

FIG. 1 is an overall view of an example interactive computer graphics system;

FIG. 2 is a block diagram of the FIG. 1 example computer graphics system;

FIG. 3 is a block diagram of the example graphics and audio processor shown in FIG. 2;

FIG. 4 is a block diagram of the example 3D graphics processor shown in FIG. 3;

FIG. 5 is an example logical flow diagram of the FIG. 4 graphics and audio processor;

FIG. 6 is block diagram illustrating a logical overview of indirect texture processing in accordance with the present invention;

FIG. 7A is a functional block diagram illustrating a simple basic example of a regular (non-indirect) texture lookup;

FIG. 7B is a functional block diagram illustrating a simple basic example of an indirect texture lookup in accordance with the present invention;

FIG. 8 is a block diagram illustrating an overview of an example physical configuration for implementing indirect texture processing in accordance with the present invention;

FIG. 9 is a block diagram illustrating a logical overview of the texture address (coordinate/data) processor operation;

FIGS. 10A–10K are a series of block diagrams illustrating the relative progression of pixel direct coordinate data and pixel indirect texture data in the example texturing pipeline implementation as a result of interleaved direct and indirect texture processing;

FIG. 11 is a flow chart illustrating example steps for implementing indirect texture processing in accordance with the present invention;

FIG. 12 is a functional operations diagram illustrating an example of regular (non-indirect) texture processing in accordance with the present invention;

FIG. 13 is a functional operations diagram illustrating an example of both regular (non-indirect) and indirect texture processing in accordance with the present invention;

FIG. 14 is a block diagram showing a detailed example of the texture coordinate/bump processing unit shown in FIG. 5;

FIG. 15 is a block diagram showing a detailed example of the indirect texture lookup data/coordinate processing logic (proc) shown in FIG. 14;

FIGS. 16A and 16B show example texture offset matrices used by processing logic circuit (proc) of FIG. 15;

FIG. 17 is a block diagram illustrating example data field formats of control logic registers for controlling the operations within the processing circuitry of FIG. 15;

FIG. 18a is a general functional block diagram of a first tiling method in accordance with a preferred embodiment of the instant invention;

FIG. 18b is a general functional block diagram of a second tiling method in accordance with a preferred embodiment of the instant invention;

FIG. 19 is a more detailed functional block diagram of the first tiling method of FIG. 18a;

FIGS. 20a–20c show three examples of the first tiling method of the instant invention;

FIG. 21 is an example logical block diagram of the first tiling method of the instant invention;

FIG. 22 is a flowchart of the second tiling method of FIG. 14b;

FIG. 23 is an example of the second tiling method of the present invention;

FIG. 24 is an example logical block diagram of the second tiling method of the instant invention;

FIGS. 25A and 25B show example alternative compatible implementations.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS OF THE INVENTION

FIG. 1 shows an example interactive 3D computer graphics system 50. System 50 can be used to play interactive 3D video games with interesting stereo sound. It can also be used for a variety of other applications.

In this example, system 50 is capable of processing, interactively in real time, a digital representation or model of a three-dimensional world. System 50 can display some or all of the world from any arbitrary viewpoint. For example, system 50 can interactively change the viewpoint in response to real time inputs from handheld controllers 52a, 52b or other input devices. This allows the game player to see the world through the eyes of someone within or outside of the world. System 50 can be used for applications that do not require real time 3D interactive display (e.g., 2D display generation and/or non-interactive display), but the capability of displaying quality 3D images very quickly can be used to create very realistic and exciting game play or other graphical interactions.

To play a video game or other application using system 50, the user first connects a main unit 54 to his or her color television set 56 or other display device by connecting a cable 58 between the two. Main unit 54 produces both video signals and audio signals for controlling color television set 56. The video signals are what controls the images displayed on the television screen 59, and the audio signals are played back as sound through television stereo loudspeakers 61L, 61R.

The user also needs to connect main unit 54 to a power source. This power source may be a conventional AC adapter (not shown) that plugs into a standard home electrical wall socket and converts the house current into a lower DC voltage signal suitable for powering the main unit 54. Batteries could be used in other implementations.

The user may use hand controllers 52a, 52b to control main unit 54. Controls 60 can be used, for example, to specify the direction (up or down, left or right, closer or

further away) that a character displayed on television 56 should move within a 3D world. Controls 60 also provide input for other applications (e.g., menu selection, pointer/cursor control, etc.). Controllers 52 can take a variety of forms. In this example, controllers 52 shown each include controls 60 such as joysticks, push buttons and/or directional switches. Controllers 52 may be connected to main unit 54 by cables or wirelessly via electromagnetic (e.g., radio or infrared) waves.

To play an application such as a game, the user selects an appropriate storage medium 62 storing the video game or other application he or she wants to play, and inserts that storage medium into a slot 64 in main unit 54. Storage medium 62 may, for example, be a specially encoded and/or encrypted optical and/or magnetic disk. The user may operate a power switch 66 to turn on main unit 54 and cause the main unit to begin running the video game or other application based on the software stored in the storage medium 62. The user may operate controllers 52 to provide inputs to main unit 54. For example, operating a control 60 may cause the game or other application to start. Moving other controls 60 can cause animated characters to move in different directions or change the user's point of view in a 3D world. Depending upon the particular software stored within the storage medium 62, the various controls 60 on the controller 52 can perform different functions at different times.

Example Electronics of Overall System

FIG. 2 shows a block diagram of example components of system 50. The primary components include:

- a main processor (CPU) 110,
- a main memory 112, and
- a graphics and audio processor 114.

In this example, main processor 110 (e.g., an enhanced IBM Power PC 750) receives inputs from handheld controllers 108 (and/or other input devices) via graphics and audio processor 114. Main processor 110 interactively responds to user inputs, and executes a video game or other program supplied, for example, by external storage media 62 via a mass storage access device 106 such as an optical disk drive. As one example, in the context of video game play, main processor 110 can perform collision detection and animation processing in addition to a variety of interactive and control functions.

In this example, main processor 110 generates 3D graphics and audio commands and sends them to graphics and audio processor 114. The graphics and audio processor 114 processes these commands to generate interesting visual images on display 59 and interesting stereo sound on stereo loudspeakers 61R, 61L or other suitable sound-generating devices.

Example system 50 includes a video encoder 120 that receives image signals from graphics and audio processor 114 and converts the image signals into analog and/or digital video signals suitable for display on a standard display device such as a computer monitor or home color television set 56. System 50 also includes an audio codec (compressor/decompressor) 122 that compresses and decompresses digitized audio signals and may also convert between digital and analog audio signaling formats as needed. Audio codec 122 can receive audio inputs via a buffer 124 and provide them to graphics and audio processor 114 for processing (e.g., mixing with other audio signals the processor generates and/or receives via a streaming audio output of mass storage access device 106). Graphics and audio processor 114 in this example can store audio related information in an audio

memory 126 that is available for audio tasks. Graphics and audio processor 114 provides the resulting audio output signals to audio codec 122 for decompression and conversion to analog signals (e.g., via buffer amplifiers 128L, 128R) so they can be reproduced by loudspeakers 61L, 61R.

Graphics and audio processor 114 has the ability to communicate with various additional devices that may be present within system 50. For example, a parallel digital bus 130 may be used to communicate with mass storage access device 106 and/or other components. A serial peripheral bus 132 may communicate with a variety of peripheral or other devices including, for example:

- a programmable read-only memory and/or real time clock 134,
- a modem 136 or other networking interface (which may in turn connect system 50 to a telecommunications network 138 such as the Internet or other digital network from/to which program instructions and/or data can be downloaded or uploaded), and
- flash memory 140.

A further external serial bus 142 may be used to communicate with additional expansion memory 144 (e.g., a memory card) or other devices. Connectors may be used to connect various devices to busses 130, 132, 142.

Example Graphics And Audio Processor

FIG. 3 is a block diagram of an example graphics and audio processor 114. Graphics and audio processor 114 in one example may be a single-chip ASIC (application specific integrated circuit). In this example, graphics and audio processor 114 includes:

- a processor interface 150,
- a memory interface/controller 152,
- a 3D graphics processor 154,
- an audio digital signal processor (DSP) 156,
- an audio memory interface 158,
- an audio interface and mixer 160,
- a peripheral controller 162, and
- a display controller 164.

3D graphics processor 154 performs graphics processing tasks. Audio digital signal processor 156 performs audio processing tasks. Display controller 164 accesses image information from main memory 112 and provides it to video encoder 120 for display on display device 56. Audio interface and mixer 160 interfaces with audio codec 122, and can also mix audio from different sources (e.g., streaming audio from mass storage access device 106, the output of audio DSP 156, and external audio input received via audio codec 122). Processor interface 150 provides a data and control interface between main processor 110 and graphics and audio processor 114.

Memory interface 152 provides a data and control interface between graphics and audio processor 114 and memory 112. In this example, main processor 110 accesses main memory 112 via processor interface 150 and memory interface 152 that are part of graphics and audio processor 114. Peripheral controller 162 provides a data and control interface between graphics and audio processor 114 and the various peripherals mentioned above. Audio memory interface 158 provides an interface with audio memory 126.

Example Graphics Pipeline

FIG. 4 shows a more detailed view of an example 3D graphics processor 154. 3D graphics processor 154 includes,

among other things, a command processor **200** and a 3D graphics pipeline **180**. Main processor **110** communicates streams of data (e.g., graphics command streams and display lists) to command processor **200**. Main processor **110** has a two-level cache **115** to minimize memory latency, and also has a write-gathering buffer **11** for uncached data streams targeted for the graphics and audio processor **114**. The write-gathering buffer **111** collects partial cache lines into full cache lines and sends the data out to the graphics and audio processor **114** one cache line at a time for maximum bus usage.

Command processor **200** receives display commands from main processor **110** and parses them—obtaining any additional data necessary to process them from shared memory **112**. The command processor **200** provides a stream of vertex commands to graphics pipeline **180** for 2D and/or 3D processing and rendering. Graphics pipeline **180** generates images based on these commands. The resulting image information may be transferred to main memory **112** for access by display controller/video interface unit **164**—which displays the frame buffer output of pipeline **180** on display **56**.

FIG. **5** is a logical flow diagram of graphics processor **154**. Main processor **110** may store graphics command streams **210**, display lists **212** and vertex arrays **214** in main memory **112**, and pass pointers to command processor **200** via bus interface **150**. The main processor **110** stores graphics commands in one or more graphics first-in-first-out (FIFO) buffers **210** it allocates in main memory **110**. The command processor **200** fetches:

- command streams from main memory **112** via an on-chip FIFO memory buffer **216** that receives and buffers the graphics commands for synchronization/flow control and load balancing,
- display lists **212** from main memory **112** via an on-chip call FIFO memory buffer **218**, and
- vertex attributes from the command stream and/or from vertex arrays **214** in main memory **112** via a vertex cache **220**.

Command processor **200** performs command processing operations **200a** that convert attribute types to floating point format, and pass the resulting complete vertex polygon data to graphics pipeline **180** for rendering/rasterization. A programmable memory arbitration circuitry **130** (see FIG. **4**) arbitrates access to shared main memory **112** between graphics pipeline **180**, command processor **200** and display controller/video interface unit **164**.

FIG. **4** shows that graphics pipeline **180** may include:

- a transform unit **300**,
- a setup/rasterizer **400**,
- a texture unit **500**,
- a texture environment unit **600**, and
- a pixel engine **700**.

Transform unit **300** performs a variety of 2D and 3D transform and other operations **300a** (see FIG. **5**). Transform unit **300** may include one or more matrix memories **300b** for storing matrices used in transformation processing **300a**. Transform unit **300** transforms incoming geometry per vertex from object space to screen space; and transforms incoming texture coordinates and computes projective texture coordinates (**300c**). Transform unit **300** may also perform polygon clipping/culling **300d**. Lighting processing **300e** also performed by transform unit **300b** provides per vertex lighting computations for up to eight independent lights in one example embodiment. Transform unit **300** can

also perform texture coordinate generation (**300c**) for embossed type bump mapping effects, as well as polygon clipping/culling operations (**300d**).

Setup/rasterizer **400** includes a setup unit which receives vertex data from transform unit **300** and sends triangle setup information to one or more rasterizer units (**400b**) performing edge rasterization, texture coordinate rasterization and color rasterization.

Texture unit **500** (which may include an on-chip texture memory (TMEM) **502**) performs various tasks related to texturing including for example:

- retrieving textures **504** from main memory **112**,
- texture processing (**500a**) including, for example, multi-texture handling, post-cache texture decompression, texture filtering, embossing, shadows and lighting through the use of projective textures, and BLIT with alpha transparency and depth,
- bump map processing for computing texture coordinate displacements for bump mapping, pseudo texture and texture tiling effects (**500b**), and
- indirect texture processing (**500c**)

FIGS. **6** through **17** illustrate example texture processing for performing regular (non-indirect) and indirect texture lookup operations. A more detailed description of the example graphics pipeline circuitry and procedures for performing regular and indirect texture look-up operations is disclosed in commonly assigned co-pending patent application, Ser. No. 60/226,891, entitled “Method And Apparatus For Direct And Indirect Texture Processing In A Graphics System”, the entire contents of which are incorporated herein by reference.

Texture unit **500** outputs filtered texture values to the texture environment unit **600** for texture environment processing (**600a**). Texture environment unit **600** blends polygon and texture color/alpha/depth, and can also perform texture fog processing (**600b**) to achieve inverse range based fog effects. Texture environment unit **600** can provide multiple stages to perform a variety of other interesting environment-related functions based for example on color/alpha modulation, embossing, detail texturing, texture swapping, clamping, and depth blending. For more details concerning the texture environment unit **600**, see concurrently filed commonly assigned application Ser. No. 60/226,888 entitled “Recirculating Shade Tree Blender for a Graphics System”, incorporated by reference herein.

Pixel engine **700** performs depth (z) compare (**700a**) and pixel blending (**700b**). In this example, pixel engine **700** stores data into an embedded (on-chip) frame buffer memory **702**. Graphics pipeline **180** may include one or more embedded DRAM memories **702** to store frame buffer and/or texture information locally. Z compares **700a'** can also be performed at an earlier stage in the graphics pipeline **180** depending on the rendering mode currently in effect (e.g., z compares can be performed earlier if alpha blending is not required). The pixel engine **700** includes a copy operation **700c** that periodically writes on-chip frame buffer **702** to main memory **112** for access by display/video interface unit **164**. This copy operation **700c** can also be used to copy embedded frame buffer **702** contents to textures in the main memory **112** for dynamic texture synthesis effects. Anti-aliasing and other filtering can be performed during the copy-out operation. The frame buffer output of graphics pipeline **180** (which is ultimately stored in main memory **112**) is read each frame by display/video interface unit **164**. Display controller/video interface **164** provides digital RGB pixel values for display on display **102**.

Overview of Example Texture Tiling Procedures

The instant invention provides two different tiling methods, both of which preferably use indirect texture tile

maps. The first method provides an indirect texture tiling method, and the second method enables unique texture tiles to be created by blending between multiple tiles to achieve, for example, a pseudo-3D texture effect.

FIG. 18a shows an example procedure for the indirect texture tiling method of the instant invention. In accordance with this exemplary first procedure, texture coordinates are generated from surface parameters of a rendered object (block 1400). An tile index map is used to obtain tile select offsets which are used to modify the texture coordinates (block 1402). The modified texture coordinates are then used to select a texture tile from a tile definitions map (block 1404). The texture tile may contain any type of texture that is desired for use in a tiling operation, such as bricks, grass, or any other suitable pattern or portion of a larger pattern. The resulting tile textured image is then displayed (block 1406).

FIG. 18b shows an example procedure for the texture blending or pseudo 3-D texture method of the instant invention. In accordance with this exemplary second procedure, texture coordinates are also generated from surface parameters (block 1410). The texture coordinates are then used to obtain at least one texture select offset which is used to modify the texture coordinates (block 1412). The modified texture coordinates are then used to select multiple texture tiles from a tile definitions map (block 1414). The tiles are then blended together to form a synthesized tile texture (block 1416). The resulting synthesized tile textured image is then displayed (Block 1418).

Both of the above described tiling methods of the present invention will be described separately in greater detail below. Both of the tiling methods described herein are preferably implemented through the use of the indirect texture processing system as described in the above-referenced co-pending patent application. However, any suitable processing system incorporating, for example, recirculating, multiple parallel channel or other processing circuitry can be used in accordance with the instant invention.

Example Indirect Texture Tiling (First Tiling Method)

FIG. 19 shows a more detailed exemplary block diagram of the instant indirect texture tiling method as shown in FIG. 18a. In accordance with this method, an indirect tile index map and a tile definitions map are defined (blocks 1500, 1501). The tile definitions map holds the base definitions for a variety of tiles. The indirect tile index map identifies specific locations for specific tiles on the surface of the object being textured. In order to map the tiles on the object in this manner, a pair of indirect texture coordinates (S0,T0) are generated (block 1504). In this example, the indirect texture coordinates are based on a scale for the textured surface not the index map. This advantageously enables the same texture coordinates to be used for the direct texture coordinates and the indirect texture coordinates. Thus, the indirect texture coordinates are appropriately scaled to the index map by, for example, dividing the coordinates by the respective dimensions of the tiles being used (block 1506). The scaled texture coordinates are then used to perform a look-up operation in the texture index map to obtain appropriate tile select offsets (ΔS , ΔT) for the current texture coordinates (block 1508). The tile select offsets are then rescaled to the subject texture scale by, for example, multiplying the offsets by the respective dimensions of the tiles being used (block 1510).

A set of direct texture coordinates (S1,T1) are also defined (block 1512). As explained above, the indirect and direct texture coordinates are actually the same in this example embodiment. A wrapping operation is performed on the direct texture coordinates (block 1514). In this example, the wrapping operation is modulo n wrap, where n is the dimension of the tile being used.

Once the appropriately scaled tile offsets (ΔS , ΔT) and wrapped texture coordinates (S1, T1) are obtained, they are combined (block 1516) to produce a set of modified texture coordinates (S',T'). The modified texture coordinates (S',T') are then used to perform a look-up operation in the tile definitions map (block 1518), in order to obtain the desired texture tile for the current texture coordinates. The selected texture tile is then output for display (block 1520) (or possibly for use in further texture processing operations).

FIG. 20a shows a first example of the indirect tiling method of the instant invention. As shown in FIG. 20a, a texture tile index map 1600 is defined which identifies specific tiles in a tile definitions map 1602 for each tile location on a resulting texture 1604. In this example, a two dimensional (2x2) tile definitions map 1602 is used. Thus, the tile definition map includes four tiles which, in this example, each comprise a different and complimentary portion of a larger intended texture pattern. In this example, the resulting pattern 1604 is 512x512 texels in size. The indirect tile index map 1600 is a 4x4 matrix, wherein each matrix element identifies one of the four tiles in the tile definitions map 1602. Each tile in the tile definitions map is 128x128 texels in size. Thus, by using each of the 16 indexes in the index map 1600 to map a tile, the resulting image 1604 will include 16 tiles (512x512 texels) in the desired configuration as determined by the tile index map. As can be seen in FIG. 20a, the resulting tile pattern 1604 in this example includes a pattern containing four squares made up of 16 texture tiles.

As explained above, certain scaling, wrapping and/or adding operations are performed on the direct and indirect coordinates as indicated by the bump unit (OP) block 1606 in FIG. 20a. In this example, the indirect texture is initially scaled down by dividing the indirect texture coordinates by 128 (the dimension of the tiles) in order to address the 4x4 index matrix 1600 and obtain the offsets for the particular texture coordinates. The offsets are then scaled up by multiplying the offsets by 128 (the dimension of the tiles). The scaled up offsets are then combined with the results of the wrapping operation on the texture coordinates in order to obtain the modified texture coordinates for use in obtaining a texture from the tile definitions map 1602.

FIG. 20b shows a second example of the indirect tiling method of the present invention, wherein like reference numerals correspond to similar parts as described above. In this example, the tile definitions map 1602 is a one dimensional map instead of the two dimensional map as used in the first example of FIG. 20a. As a result, the indirect texture map 1600 only uses single offset values rather than a pair of offsets values as in the first example. Thus, the particular offset value selected can be used to modify either the wrapped S1 or T1 values (S1 in this example), depending on how the tile definitions map is constructed (vertically or horizontally stacked). In this example, the textures tiles are 64x64 tiles in size. Thus, the wrapping and scaling parameters used in the bump unit 1606 (OP) are 64 rather than 128 as in the first example. It is noted that any suitable size texture tiles can be used depending on the particular application in which the invention is used. In addition, any suitably sized indirect texture map and resulting texture can be defined using the instant invention.

FIG. 20c shows a third example of the indirect tiling method of the present invention, which again uses like reference numerals to designate similar parts as described above. This example uses a 2x4 tile definitions map 1602 containing eight 18x18 texel tiles. The indirect tile index map 1600 is similar to the index map of the first example above. In this example, however, only the inner 16x16 texels of the 18x18 texel tiles are used in creating the resulting tile pattern 1604. Thus, as this example demonstrates, any suitable tile size can be used, regardless of the size of the tile definitions.

FIG. 21 shows a logical block diagram of the exemplary indirect tiling method described above with respect to FIGS. 19 and 20a-20c. As can be seen in FIG. 21, the instant tiling method can take advantage of using the same initial texture coordinates for the direct coordinates and the indirect coordinates (i.e. $S1=S0$ and $T1=T0$). However, other arrangements are possible where the coordinates are not the same. For example, indirect texture coordinates may be used which do not need to be scaled in order to properly address the tile index map. However, when the same texture coordinates are used, as in this example, the indirect texture coordinates 1700 ($S0, T0$) are first scaled, as indicated by scaling blocks 1702a and 1702b, in order to conform to the scale of the indirect texture index map 1600. The properly scaled indirect coordinates are then used to perform a look up operation in the tile index map in order to obtain the tile select offsets 1704 ($\Delta S, \Delta T$). For tiling the desired texture coordinate scale is the tile size multiplied by the size of the indirect tile index map. The tile size is then divided out for use in accessing the indirect map.

The tile select offsets are scaled up to the original scale to correspond with the scale of the direct texture coordinates, as indicated by multipliers 1706a and 1706b. The offsets are then ready to be combined with the regular texture coordinates 1701 ($S1, T1$), after the direct coordinates are wrapped, as indicated by the modulo n wrapping blocks 1708a and 1708b. The wrapped direct coordinates and the scaled offsets are then combined by adders 1710a and 1710b, thereby producing the modified texture coordinates 1712 (S', T'). The modified texture coordinates are then used to perform the regular textures look up in the tile definition map 1602, thereby selecting a tile for output as a texture to the TEV unit. It is noted that the logical block diagram of FIG. 21 shows an embodiment where offsets are provided for both the $S1$ and $T1$ coordinates which, in this example, enables a two dimensional tile definitions map to be used. However, other arrangements are possible in accordance with the invention where only a one dimensional tile index map is used, such as in the example of FIG. 20b.

Example Pseudo 3D Texture Tiling (Second Tiling Method)

FIG. 22 shows a more detailed block diagram of the second indirect tiling method of the instant invention (see FIG. 18b), which is referred to herein as pseudo 3D textures. This second method enables multiple indirectly indexed tiles to be blended together to form synthetic tiles that are mapped onto a surface. In other words, in this method the tiling mapping can be extended to provide a pseudo-3D effect. In this method, all of the tiles are considered to be part of a stack. Rather than selecting a single tile from the tile definitions map, as in the first example above, in this example, one can select multiple tiles (2 adjacent tiles in the example below) and blend the tiles together in order to produce a synthesized texture tile. This technique can be used, for example, to cover a large surface with non-

repeating patterns that blend smoothly together. By allowing blending of texture tiles, the programmer is not limited to specific tiles in a tile definitions map when covering a surface. Instead new tiles can be synthesized from existing tiles in order to greatly increase the number of possible texture tiles that can be used to cover a surface, without requiring larger texture definition maps. By using synthesized tiles, the appearance of repeating texture patterns can be avoided, thereby improving the realism of the image. This method can be used, for example, to cover a beach with a tiled texture where the layers vary in appearance from fine sand to small pebbles to large rocks. The blending feature can be used to provides a pseudo-3D appearance for the resulting texture.

As shows in FIG. 22, an indirect tile index map is defined which includes indexes to tiles in the tile definitions stack (block 1800). Indirect texture coordinates are defined (block 1802) to obtain a texture select offset and a blending factor (block 1804). The texture tile definitions are defined in the form of a stack (block 1806). If pseudo-3D effects are desired, the tiles are preferably defined, in this example, such that adjacent tiles will blend well together to provide a layering effect, as will be further understood from the description below. Of course, as explained above, the indirect coordinates may be scaled prior to performing the indirect look up operation, such as when the one desires to have the indirect coordinates equal to the direct coordinates.

Direct coordinates are defined (block 1808), and are combined with the offset to produce a first set of modified texture coordinates (s, t') (block 1810). The offset is then modified (biased) in a predetermined manner, such as by incrementing the offset by one tile, and a second set of modified texture coordinates (s, t'') (block 1812) is then defined by combining the modified offset with the direct texture coordinates. A first texture is then looked up in the tile definitions stack using the first set of modified texture coordinates (s, t') to obtain a first texture tile (block 1814). A second texture is then looked up in the tile definitions stack using the second set of modified texture coordinates (s, t'') to obtain a second texture tile (block 1816). The first and second texture tiles are then blended to create a synthesized texture (block 1818). In this example, the blending factor for use in the blending operation is obtained along with the tile select offset(s) from the tile index map. The synthetic texture is then output for display (Block 1820) (or possibly for use in further texture processing operations).

FIG. 23 shows an example of the pseudo-3D texturing method of the instant invention. In this example, the texture tile index map 1900 includes indexes to the tile stack 1902 as well as a blending factor. Specifically, in this example, the tile index map includes indexes including an integer component and a fraction component. For example, the lower left hand corner element in the index map 1900 is "4.9". In this example embodiment, the integer component (i.e. "4") provides the layer select offset, and the fractional component (i.e. "0.9") provides the blending factor. Thus, the indirect texture coordinates are used to look up a layer select offset and a blending factor. The offset is then scaled (if necessary for the particular implementation) and combined with the direct texture coordinates (after being wrapped), using bump block 1904, to produce a first set of modified texture coordinates. The first set of modified texture coordinates are then used in a look up operation in the tile definition stack 1902 to obtain a first texture tile. The bump unit also generates a second set of modified coordinates by performing a biasing operation on the tile select offset and combining the biased offset with the wrapped direct texture coor-

dinates. The biasing operation may simply increase the offset by a given amount, such as by one tile, or it may perform any other suitable operation in the offset so that the resulting tile will be different from the resulting tile without the biasing. The second set of modified texture coordinates are then used to look up a second tile from the tile definitions stack 1902. The two selected tiles are then blended together using the blending factor provided by the indirect index tile index map 1900, thereby producing a synthesized texture tile for use in the resulting texture 1906. In this example, the resulting texture 4.9 indicates that the layer definition 4 and layer definition 5 are blended together using a blending factor 0.9, i.e. $4.9 = 0.1 * (\text{layer 4 definition}) + 0.9 * (\text{layer 5 definition})$. It is noted that in this example, a only one offset is provided. Thus, in this example, the tile definitions map is treated as a one dimensional stack and the offset is used to modify the S1 or T1 component of the direct texture coordinates. Other arrangements are possible where the index map provides a pair of offsets, as well as a blending factor. In other embodiments, the blending factor may be a constant or otherwise defined in a manner other than by the tile index map 1900. However, by enabling the blending factor to be programmed into the tile index map, different blending factors can be conveniently defined to create large variety of synthetic tiles. It is also noted that in this example, the bias factor for the offset is one tile. Thus, once the primary tile is defined, the secondary tile is defined as the next tile in the stack. Other arrangements are possible where the bias causes the second tile to have a different relationship to the first tile.

FIG. 24 shows and exemplary logical block diagram of this second tiling method described above in connection with FIGS. 22 and 23. As shown in FIG. 24, the indirect coordinates (S0, T0) are determined and then appropriately scaled, as indicated by scaling blocks 1910a and 1910b. The scaling is done for the same reasons explained above in connection with the first method of the invention. This example also takes advantage of using the same values for the direct and indirect texture coordinates. However, as explained above, other arrangements are possible and the scaling operations can be adjusted or eliminated depending on the particular implementation. In this example, the scaled indirect coordinates 1908 (S0,T0) are used to perform a look up operation in the indirect texture index map 1900 in order to obtain an integer 1918a representing a tile select offset and a fraction (1918b) representing a blending factor. The integer (offset) is then rescaled, as indicated by multiplier 1922, and sent to adder 1916a for use as a modifier for the direct texture coordinates. The direct texture coordinates 1912 (S1,T1) are wrapped, as indicated by modulo n wrap blocks 1914a and 1914b. The offset is then combined with the t component of the wrapped coordinates to produce a first set of modified texture coordinates (s,t'), which are then used to perform a look up in the tile definitions stack 1902 to obtain a first texture tile (Tex1).

The tile select offset provided by the integer 1918a is also used to obtain a second set of modified texture coordinates. This is done by biasing the offset, as indicated by block 1926. In this example, the biasing involves adding 1 to the offset prior to resealing the offset at multiplier 1922b. The biased offset is then sent to adder 1916b. The biased offset is combined with the wrapped t component of the direct texture coordinates by adder 1916b in order to produce a second set of modified texture coordinates (s, t''). The second set of modified texture coordinates are then used to perform a second look up in the tile definitions map 1902 in order to obtain a second texture tile (Tex2).

The first texture tile (tex1) and the second texture tile (tex2) are then sent to the blending block 1920. The fraction component (1918b) obtained from the indirect texture index map 1900 is sent through multiplexers 1924a and 1924b for delivery to the blending block 1920. Thus, the blender then has the two texture tiles and the appropriate blending factor. A blending operation is then performed to combine the two texture tiles based on the blending factor to produce a synthesized tile for output to the display (or possibly for use in a further texture processing operation).

Example API Indirect Texture Tiling Function Commands

As shown in FIGS. 7–9, one or more graphics API functions are preferably used to set up and initiate indirect texture look up operations and indirect texture processing. Example API functions for setting up indirect texture operations and parameters for performing Indirect texture tiling and pseudo-3D texture tiling, as described above, may be defined as follows:

GXSetTevIndTile

This function may be used to implemented tiled texturing using indirect textures. Note that the regular texture map only specifies tile definitions. The actual number of texels to be applied to the polygon is a function of the base tile size and the size of the indirect map. In order to set the proper texture coordinate scale, one must call GXSetTexCoordScaleManually. One can also use GXSetIndTexScale in order to use the same texcoord for the indirect stage as the regular TEV stage.

Example Arguments

tevs_stage	The TEV stage that is being affected.
ind_stage	The indirect stage results to use with this TEV stage.
tilesize_s	Indicates the size of the tile in the S dimension.
tilesize_t	Indicates the size of the tile in the T dimension.
tilspacing_s	Indicates the spacing of the tiles in the S dimension.
tilspacing_t	Indicates the spacing of the tiles in the T dimension.
Format	Indicates which indirect texture format to use.
matrix_sel	Indicates which indirect matrix and scale value to multiply the offsets with.
bias_sel	Indicates the tile stacking direction for pseudo-3D textures.
alpha_sel	Indicates which offset component will supply the indirect "bump" alpha, if any (for pseudo-3D textures).

Example Usage

```
void GXSetTevIndTile(  GXTevStageID tevs_stage,
                       GXIndTexStageID ind_stage,
                       u16 tilesize_s,
                       u16 tilesize_t,
                       u16 tilspacing_s,
                       u16 tilspacing_t,
                       GXIndTexFormat format,
                       GXIndTexMtxID matrix_sel,
                       GXIndTexBiasSel bias_sel,
                       GXIndTexAlphaSel alpha_sel);
```

The above function can be used to specify the indirect texture tiling method or the pseudo-3D texture tiling method described above. It is noted that one can specify tile size and spacing separately. An exemplary reason for using spacing

which is larger than the tile size is to allow borders for mipmapping purposes. depending upon the height of the mipmap stack, texels outside of the tile area may be included in the filtering calculations for mipmapping. This function will set up the matrix and scale value appropriately based upon the given inputs; one need only specify which matrix slot to use. The biasSel and alphaSel parameters are used only for pseudo-3D lookups. They are set to GX_ITB_NONE and GX_ITBA_OFF (respectively) for normal 2D tiling. It is noted that texture tiling can take advantage of using the same texture coordinates for the indirect map and the regular (direct) map. However, the desired scale values for the regular texture coordinates are not directly related to the size of the regular map which contains the tile definitions. Normally, the scale size for a texture coordinate will be set to the size of the map being looked up, with preference to the regular map size if a texture coordinate is being shared. Since with texture tiling, as different scale is needed, the following functions can be use:

GXSetTexCoordScaleManually

Arguments

GXTexCoordID	TexCoord	//Name of the texcoord being affected
GXBool	enable	//GX_True = manual scaling; //GX_False = automatic scaling
u16	ss	//Manual scale value for S dimension
u16	ts	//Manual scale value for T dimension.

Once GXSetTexCoordScaleManually has been called with enable set to GX_True, the given texture coordinate scale values are fixed until the function is called again. If the function is called with enable set to GX_False, then automatic texture coordinate scaling takes over once again for that texcoord. For texture tiling, the desired texture coordinate scale is the tile size times the size of the indirect map. One then uses GXSetIndTexCoordScale to divide out the tile size for use in accessing the indirect map.

In order to support pseudo-3D texture lookup, one must, in this example, call GXSetTevIndTile for two adjacent TEV stages. The first stage resembles a normal 2D tiling specification. For the second stage, one specifies a bias select and alpha select. The bias is used to select the tile stacking direction. One uses GX_ITB_S when the next tile is offset in the S dimension, and GX_ITB_T when the next tile is offset in the T dimension. One then chooses a bump alpha in order to blend between the tile from the first lookup and the tile from the second lookup. It is noted that in this example, one cannot use the 8-bit format for pseudo-3D textures. Instead, one can use the 3, 4 and 5-bit formats. These formats use a bias value of +1 instead of -128. The +1 bias is used to get the "next" tile in the second stage.

Other Example Compatible Implementations

Certain of the above-described system components 50 could be implemented as other than the home video game console configuration described above. For example, one could run graphics application or other software written for system 50 on a platform with a different configuration that emulates system 50 or is otherwise compatible with it. If the other platform can successfully emulate, simulate and/or provide some or all of the hardware and software resources of system 50, then the other platform will be able to successfully execute the software.

As one example, an emulator may provide a hardware and/or software configuration (platform) that is different from the hardware and/or software configuration (platform) of system 50. The emulator system might include software and/or hardware components that emulate or simulate some or all of hardware and/or software components of the system for which the application software was written. For example, the emulator system could comprise a general purpose digital computer such as a personal computer, which executes a software emulator program that simulates the hardware and/or firmware of system 50.

Some general purpose digital computers (e.g., IBM or Macintosh personal computers and compatibles) are now equipped with 3D graphics cards that provide 3D graphics pipelines compliant with DirectX or other standard 3D graphics command APIs. They may also be equipped with stereophonic sound cards that provide high quality stereophonic sound based on a standard set of sound commands. Such multimedia-hardware-equipped personal computers running emulator software may have sufficient performance to approximate the graphics and sound performance of system 50. Emulator software controls the hardware resources on the personal computer platform to simulate the processing, 3D graphics, sound, peripheral and other capabilities of the home video game console platform for which the game programmer wrote the game software.

FIG. 25A illustrates an example overall emulation process using a host platform 1201, an emulator component 1303, and a game software executable binary image provided on a storage medium 62. Host 1201 may be a general or special purpose digital computing device such as, for example, a personal computer, a video game console, or any other platform with sufficient computing power. Emulator 1303 may be software and/or hardware that runs on host platform 1201, and provides a real-time conversion of commands, data and other information from storage medium 62 into a form that can be processed by host 1201. For example, emulator 1303 fetches "source" binary-image program instructions intended for execution by system 50 from storage medium 62 and converts these program instructions to a target format that can be executed or otherwise processed by host 1201.

As one example, in the case where the software is written for execution on a platform using an IBM PowerPC or other specific processor and the host 1201 is a personal computer using a different (e.g., Intel) processor, emulator 1303 fetches one or a sequence of binary-image program instructions from storage medium 62 and converts these program instructions to one or more equivalent Intel binary-image program instructions. The emulator 1303 also fetches and/or generates graphics commands and audio commands intended for processing by the graphics and audio processor 114, and converts these commands into a format or formats that can be processed by hardware and/or software graphics and audio processing resources available on host 1201. As one example, emulator 1303 may convert these commands into commands that can be processed by specific graphics and/or or sound hardware of the host 1201 (e.g., using standard DirectX, OpenGL and/or sound APIs).

An emulator 1303 used to provide some or all of the features of the video game system described above may also be provided with a graphic user interface (GUI) that simplifies or automates the selection of various options and screen modes for games run using the emulator. In one example, such an emulator 1303 may further include enhanced functionality as compared with the host platform for which the software was originally intended.

In the case where particular graphics support hardware within an emulator does not include the example indirect texture referencing features and functions illustrated by FIGS. 7 through 24, the emulator designer has a choice of either:

translating the indirect-texture referencing commands into other graphics API commands the graphics support hardware understands, or

implementing indirect-texture referencing in software with a potential corresponding decrease in performance depending upon the speed of the processor, or

“stubbing” (i.e., ignoring) the indirect-texture referencing commands to provide a rendered image that does not include effects utilizing indirect-texture referencing.

While the logical diagrams of FIGS. 21 and 24 can be implemented entirely in software, entirely in hardware or by a combination of hardware and software, the preferred embodiment performs most of the calculations in hardware (using bump unit 500b) to obtain increased speed performance and other advantages. Nevertheless, in other implementations (e.g. where a very fast processor is available), some of all of the processing described herein may be implemented in software to provide similar or identical imaging results.

FIG. 25B illustrates an emulation host system 1201 suitable for use with emulator 1303. System 1201 includes a processing unit 1203 and a system memory 1205. A system bus 1207 couples various system components including system memory 1205 to processing unit 1203. System bus 1207 may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. System memory 1207 includes read only memory (ROM) 1252 and random access memory (RAM) 1254. A basic input/output system (BIOS) 1256, containing the basic routines that help to transfer information between elements within personal computer system 1201, such as during start-up, is stored in the ROM 1252. System 1201 further includes various drives and associated computer-readable media. A hard disk drive 1209 reads from and writes to a (typically fixed) magnetic hard disk 1211. An additional (possible optional) magnetic disk drive 1213 reads from and writes to a removable “floppy” or other magnetic disk 1215. An optical disk drive 1217 reads from and, in some configurations, writes to a removable optical disk 1219 such as a CD ROM or other optical media. Hard disk drive 1209 and optical disk drive 1217 are connected to system bus 1207 by a hard disk drive interface 1221 and an optical drive interface 1225, respectively. The drives and their associated computer-readable media provide nonvolatile storage of computer-readable instructions, data structures, program modules, game programs and other data for personal computer system 1201. In other configurations, other types of computer-readable media that can store data that is accessible by a computer (e.g., magnetic cassettes, flash memory cards, digital video disks, Bernoulli cartridges, random access memories (RAMs), read only memories (ROMs) and the like) may also be used.

A number of program modules including emulator 1303 may be stored on the hard disk 1211, removable magnetic disk 1215, optical disk 1219 and/or the ROM 1252 and/or the RAM 1254 of system memory 1205. Such program

modules may include an operating system providing graphics and sound APIs, one or more application programs, other program modules, program data and game data. A user may enter commands and information into personal computer system 1201 through input devices such as a keyboard 1227, pointing device 1229, microphones, joysticks, game controllers, satellite dishes, scanners, or the like. These and other input devices can be connected to processing unit 1203 through a serial port interface 1231 that is coupled to system bus 1207, but may be connected by other interfaces, such as a parallel port, game port Fire wire bus or a universal serial bus (USB). A monitor 1233 or other type of display device is also connected to system bus 1207 via an interface, such as a video adapter 1235.

System 1201 may also include a modem 1154 or other network interface means for establishing communications over a network 1152 such as the Internet. Modem 1154, which may be internal or external, is connected to system bus 123 via serial port interface 1231. A network interface 1156 may also be provided for allowing system 1201 to communicate with a remote computing device 1150 (e.g., another system 1201) via a local area network 1158 (or such communication may be via wide area network 1152 or other communications path such as dial-up or other communications means). System 1201 will typically include other peripheral output devices, such as printers and other standard peripheral devices.

In one example, video adapter 1235 may include a 3D graphics pipeline chip set providing fast 3D graphics rendering in response to 3D graphics commands issued based on a standard 3D graphics application programmer interface such as Microsoft’s DirectX 7.0 or other version. A set of stereo loudspeakers 1237 is also connected to system bus 1207 via a sound generating interface such as a conventional “sound card” providing hardware and embedded software support for generating high quality stereophonic sound based on sound commands provided by bus 1207. These hardware capabilities allow system 1201 to provide sufficient graphics and sound speed performance to play software stored in storage medium 62.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims.

We claim:

1. A method of texture tiling, comprising;

defining a set of direct texture coordinates;

defining a set of indirect texture coordinates;

using the indirect coordinates to obtain an offset value;

combining the offset value with at least one of the direct texture coordinates to produce a first set of modified texture coordinates;

using the first set of modified texture coordinates to obtain a first texture tile form a tile definitions map;

biasing the offset value;

modifying the direct texture coordinates using the biased offset value;

combining the modified offset value with at least one of the direct texture coordinated of produce a second set of modified texture coordinates;

21

using the second set of modified texture coordinates to
obtain a second texture tile form the tile definitions
map; and
blending the first texture tile and the second texture tile to
produce a synthesized texture tile.
2. The method of claim 1, wherein using the indirect
coordinates includes looking up the offset value from an
indirect tile index map.
3. The method of claim 1, wherein the indirect texture
coordinates are the same as the direct texture coordinates.

22

4. The method of claim 1, further including using a
blending factor when blending which determines a ratio of
blend between the first texture tile and the second texture
tile.
5. The method of claim 2, further including obtaining the
blending factor from the indirect texture index map when
performing the looking up step.
6. The method of claim 2, further including defining the
tile definitions map as a tile layer definitions stack.

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