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Bailey et al.

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(54) **METHOD AND SYSTEM FOR AUTOMATICALLY GENERATING WORLD ENVIRONMENTAL REVERBERATION FROM GAME GEOMETRY**

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(73) Assignee: **Microsoft Corporation**, Redmond, WA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1060 days.

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(51) **Int. Cl.**

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G06F 17/00	(2006.01)
G09G 5/00	(2006.01)
G06T 15/70	(2006.01)
G06G 7/48	(2006.01)

(52) **U.S. Cl.** **381/63**; 381/61; 381/62; 345/418; 345/582; 345/473; 463/30; 463/31; 463/32; 463/33; 463/35; 463/34; 700/94; 703/6

(58) **Field of Classification Search** 381/61–63; 700/94; 84/630; 703/6; 181/284–296; 345/418–428, 345/582–619, 473–475; 463/30–35

See application file for complete search history.

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3D Working Group of the Interactive Audio Special Interest Group, Interactive 3D Audio Rendering Guidelines, Sep. 20, 1999, revision 1.0a, 29 pages, published by MIDI Manufacturers Association, Los Angeles, CA, Copyright 1999 MIDI Manufacturers Association Incorporated, Portions of the Common Property Sets are Copyright 1997 Creative Labs, used with permission, Printed 1999.

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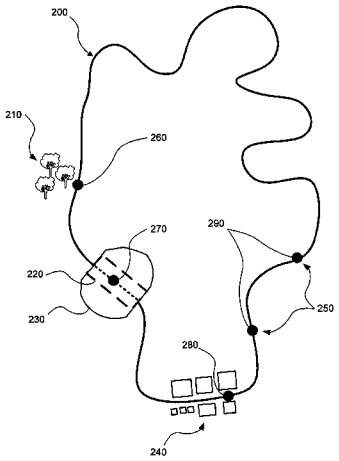
(57) **ABSTRACT**

Reverberation parameters for one or more positions of interest are derived from graphics data used for displaying a computer-generated environment. For each position of interest for which reverberation parameters are desired, environmental parameters including distances and the hardness of features in a range of interest and at points on cubemap faces are automatically determined from the graphics data. The environmental parameters are stored with the graphics data and associated with each position of interest. Upon rendering of the computer-generated environment, reverberation property set values usable by a reverberation engine are calculated or interpolated between predetermined values according to the environmental parameters. Thus, values such as reverb, reverb delay, reflections, decay time, reflection delay, and other reverb parameters are automatically calculated, subject to selective operator tuning, and provide realistic reverberation effects in the sounds heard by a user who is experiencing the rendered environment.

70 Claims, 13 Drawing Sheets



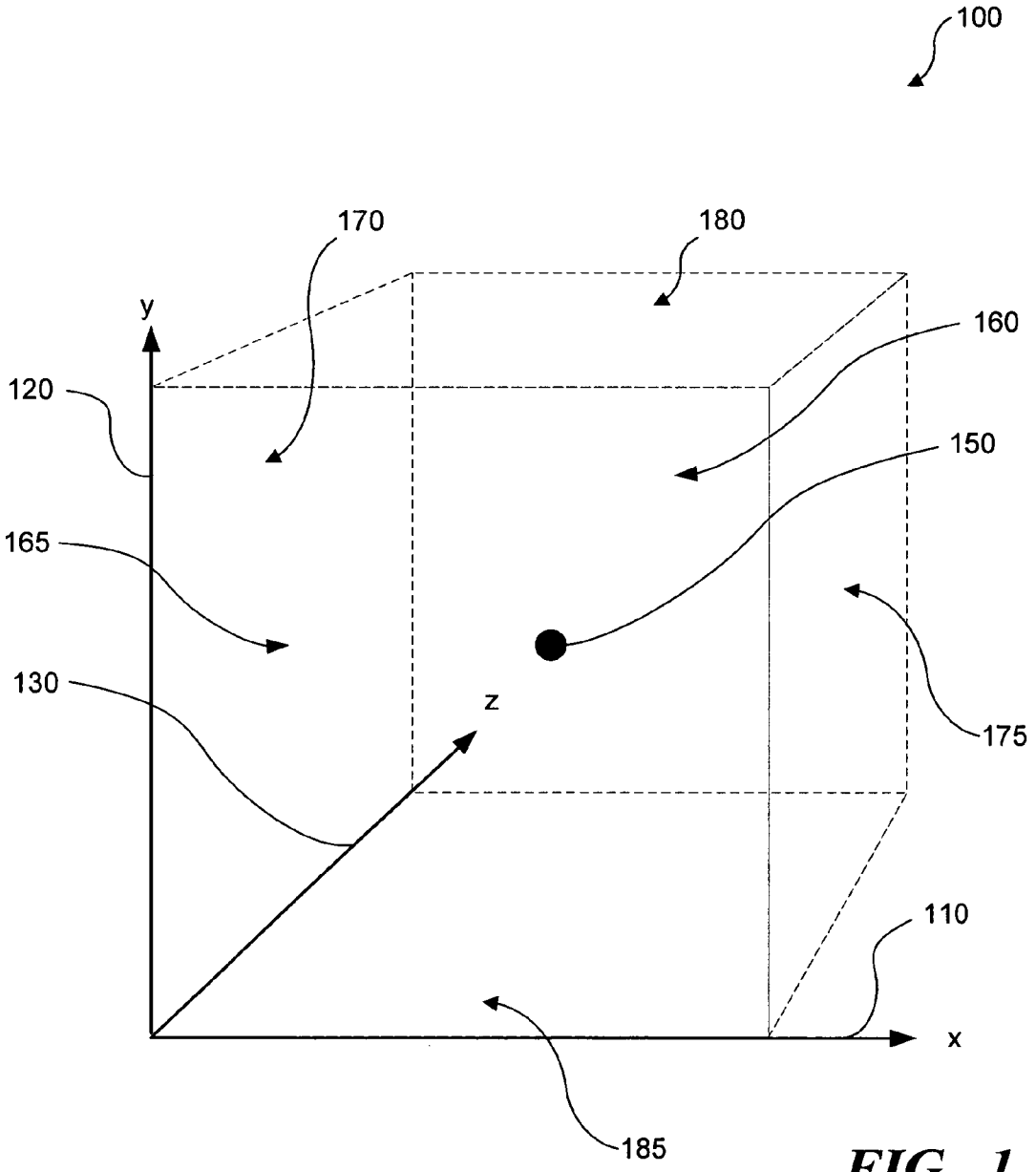


FIG. 1

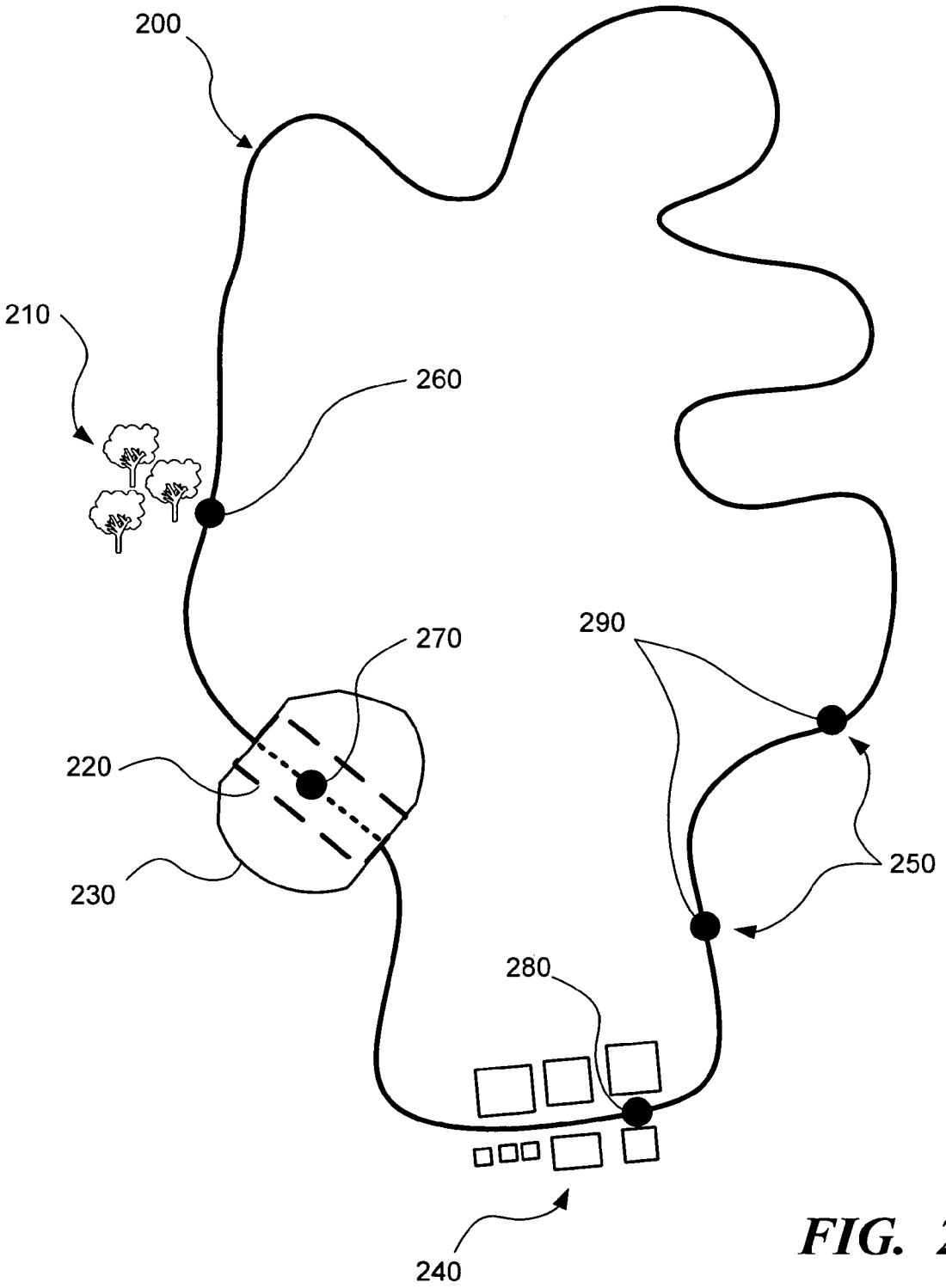


FIG. 2

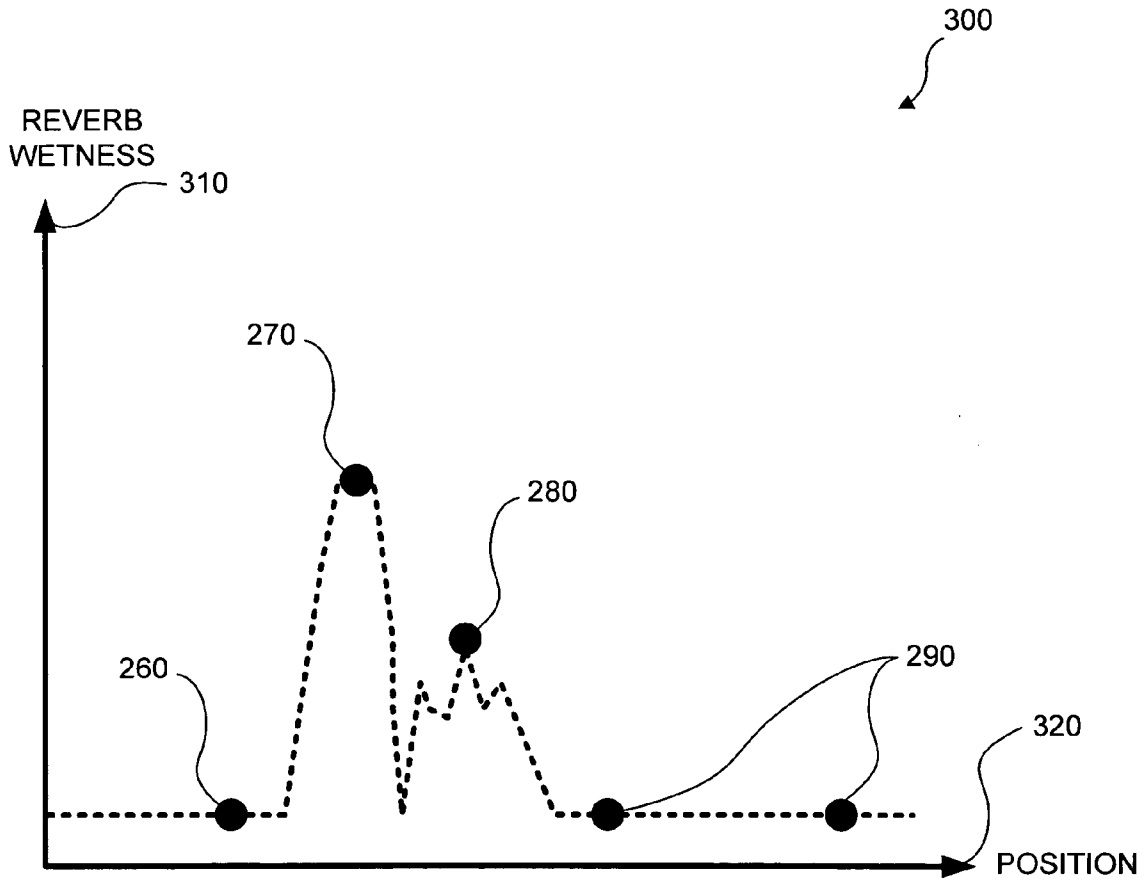


FIG. 3

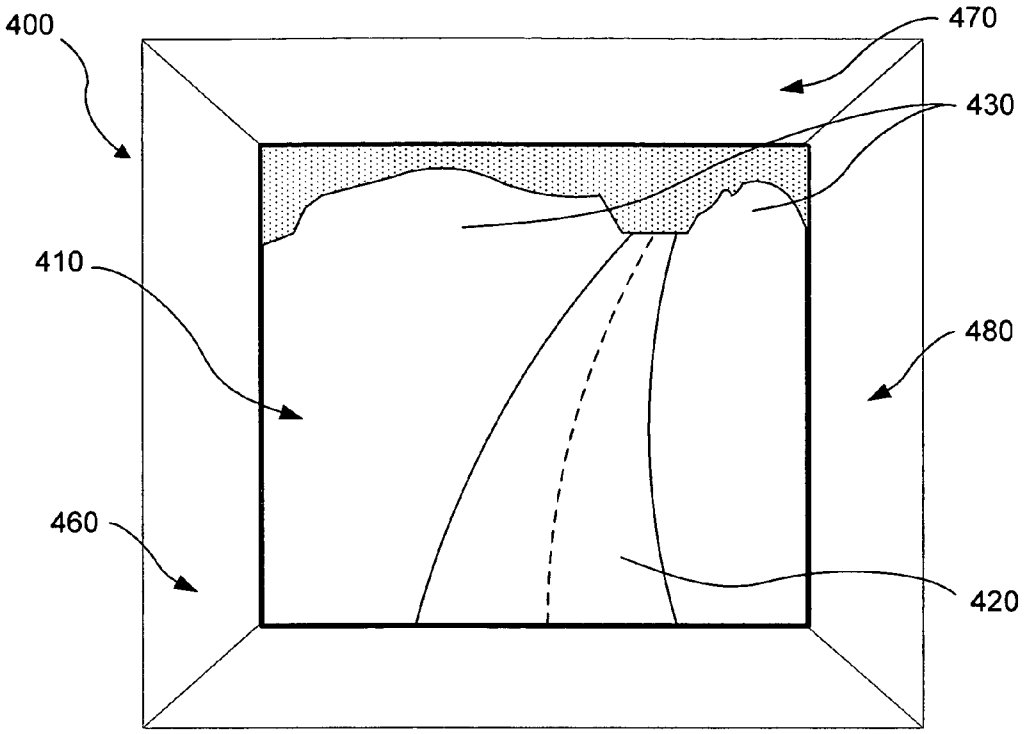


FIG. 4A

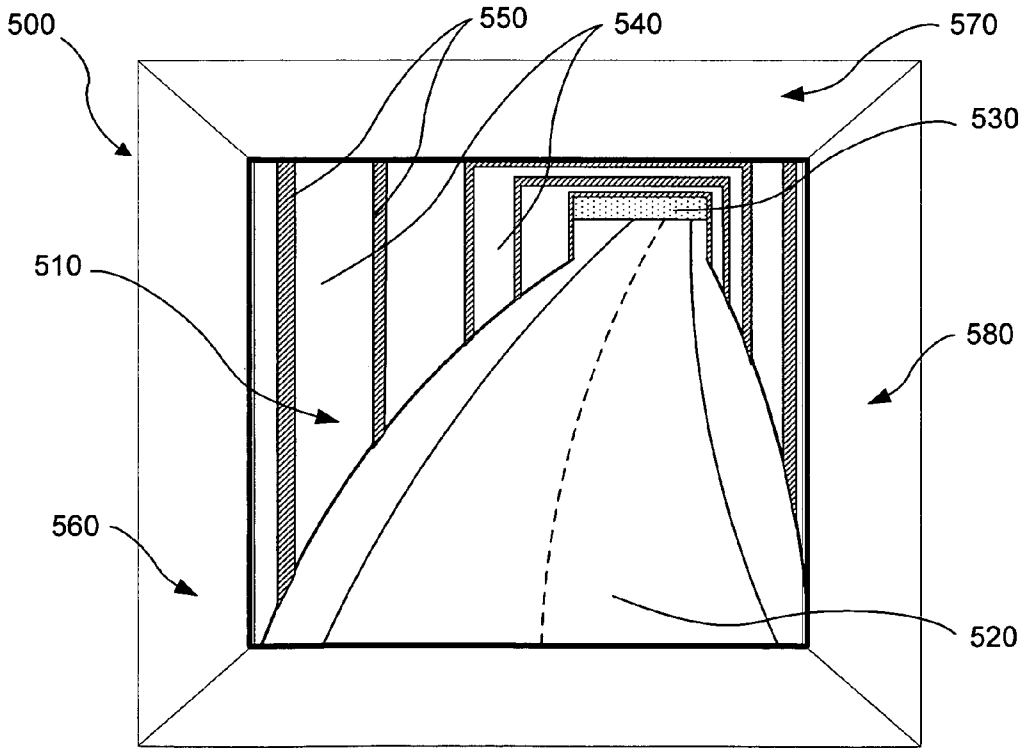


FIG. 5A

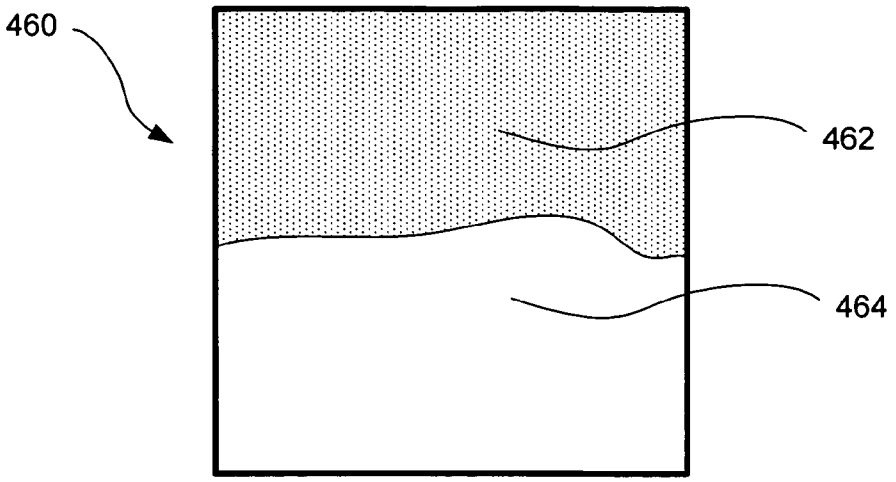


FIG. 4B

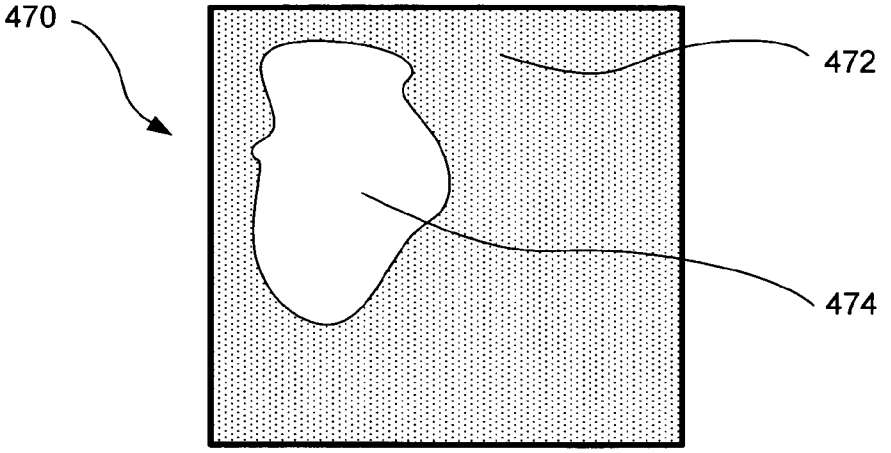


FIG. 4C

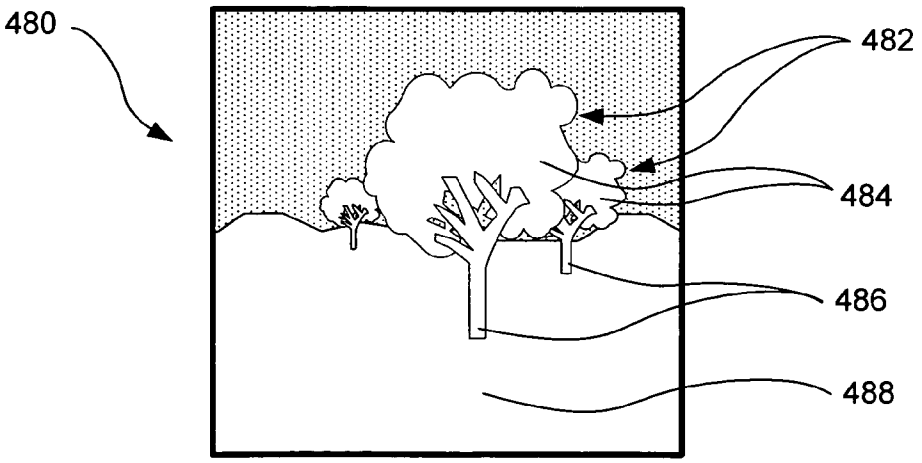


FIG. 4D

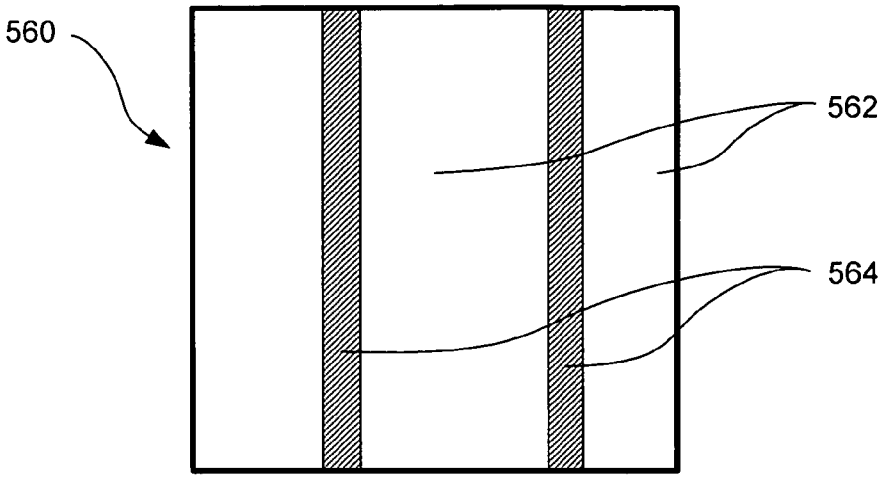


FIG. 5B

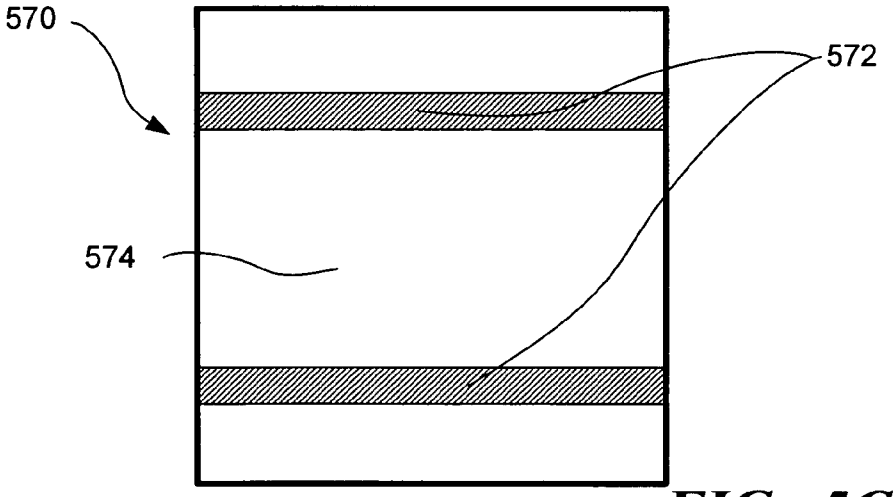


FIG. 5C

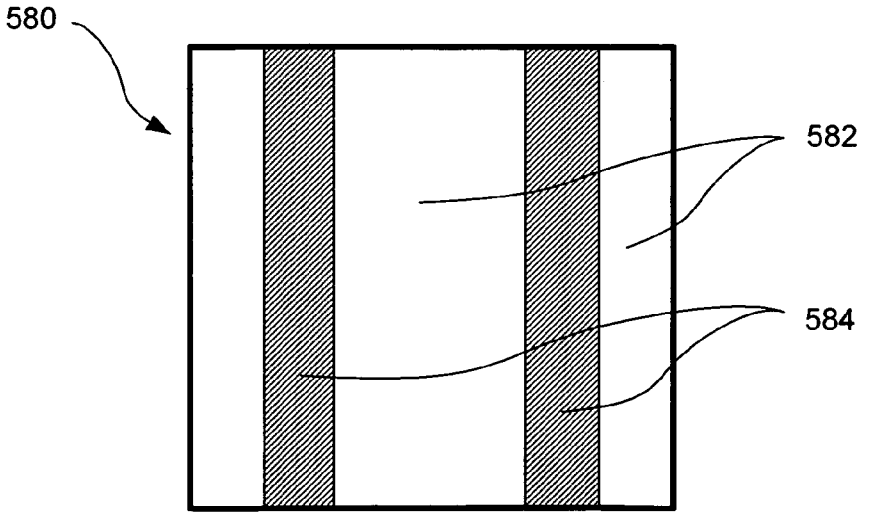


FIG. 5D

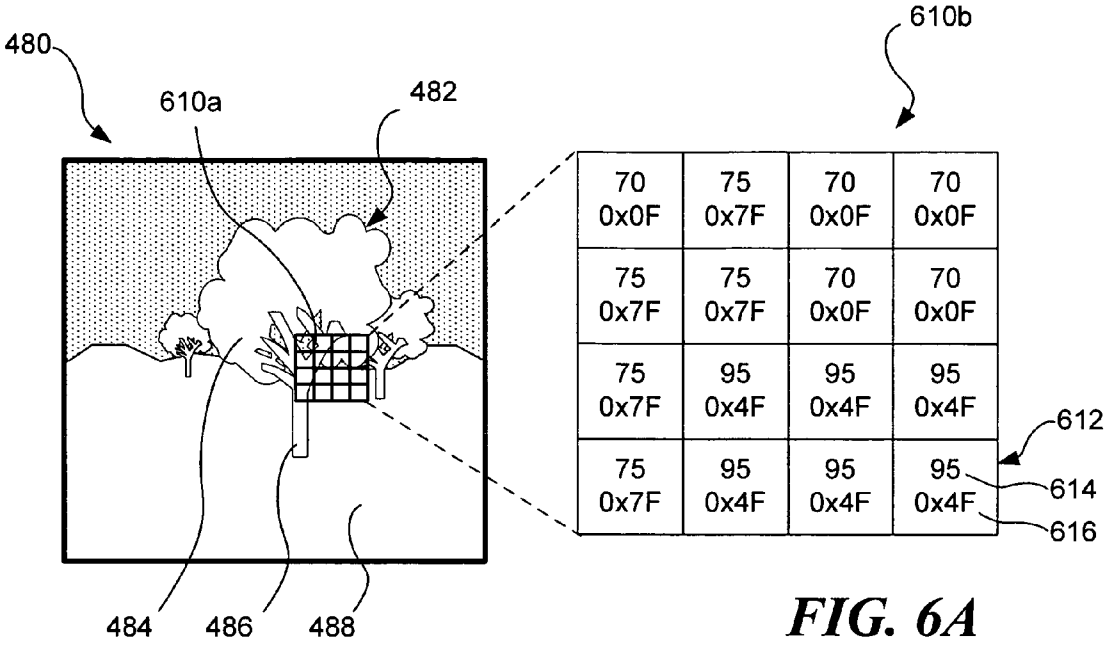

480
610a
482
610b
70 0x0F
75 0x7F
70 0x0F
70 0x0F
75 0x7F
75 0x7F
70 0x0F
70 0x0F
75 0x7F
95 0x4F
95 0x4F
95 0x4F
75 0x7F
95 0x4F
95 0x4F
95 0x4F
612
614
616
484
486
488

FIG. 6A

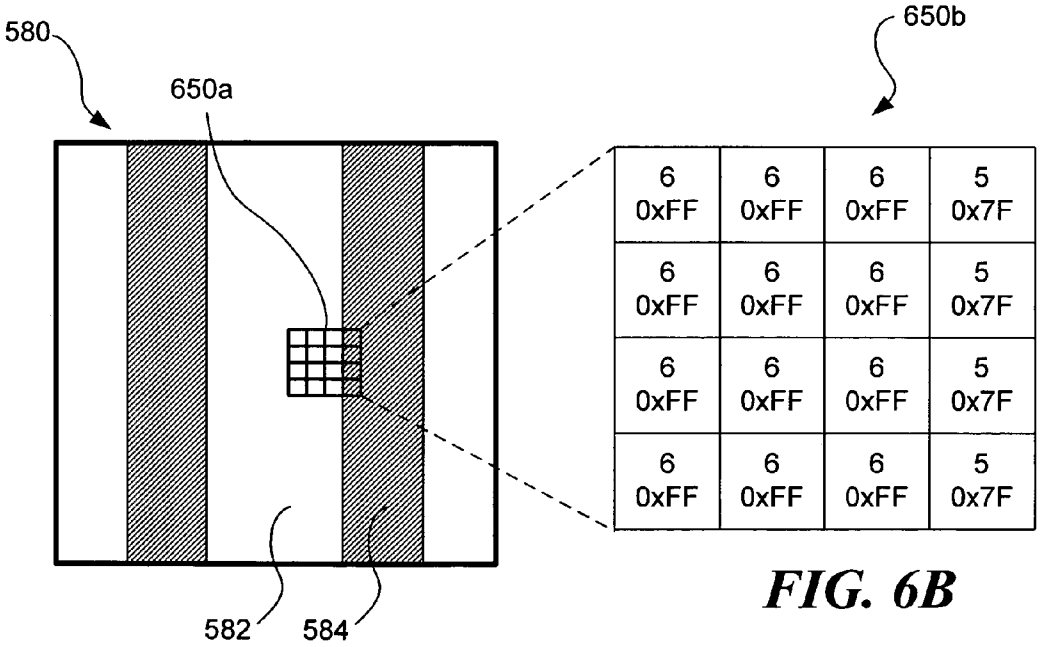

580
650a
650b
6 0xFF
6 0xFF
6 0xFF
5 0x7F
6 0xFF
6 0xFF
6 0xFF
5 0x7F
6 0xFF
6 0xFF
6 0xFF
5 0x7F
6 0xFF
6 0xFF
6 0xFF
5 0x7F
582
584

FIG. 6B

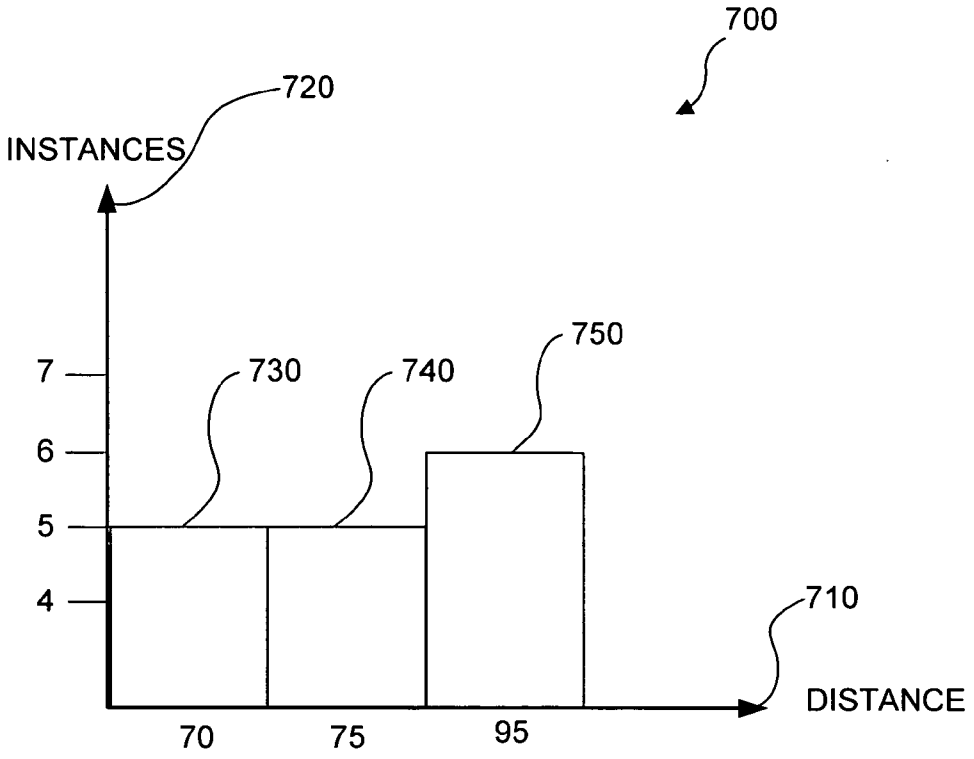

700
720
INSTANCES
750
7
730
740
6
5
4
710
DISTANCE
70
75
95

FIG. 7A

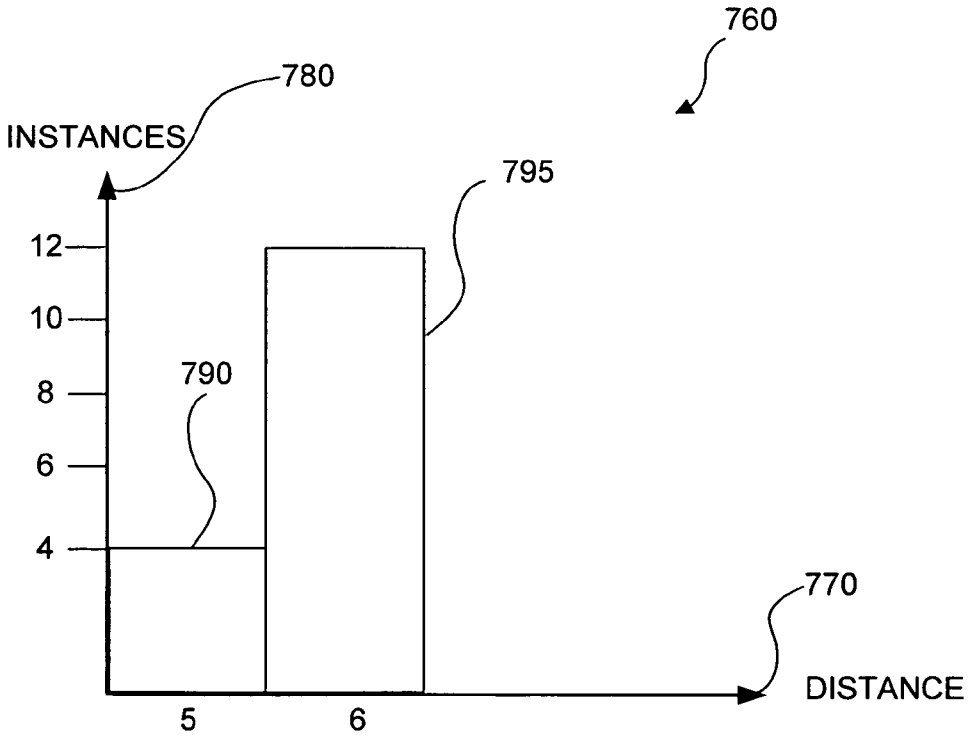

760
780
INSTANCES
795
12
10
790
8
6
4
770
DISTANCE
5
6

FIG. 7B

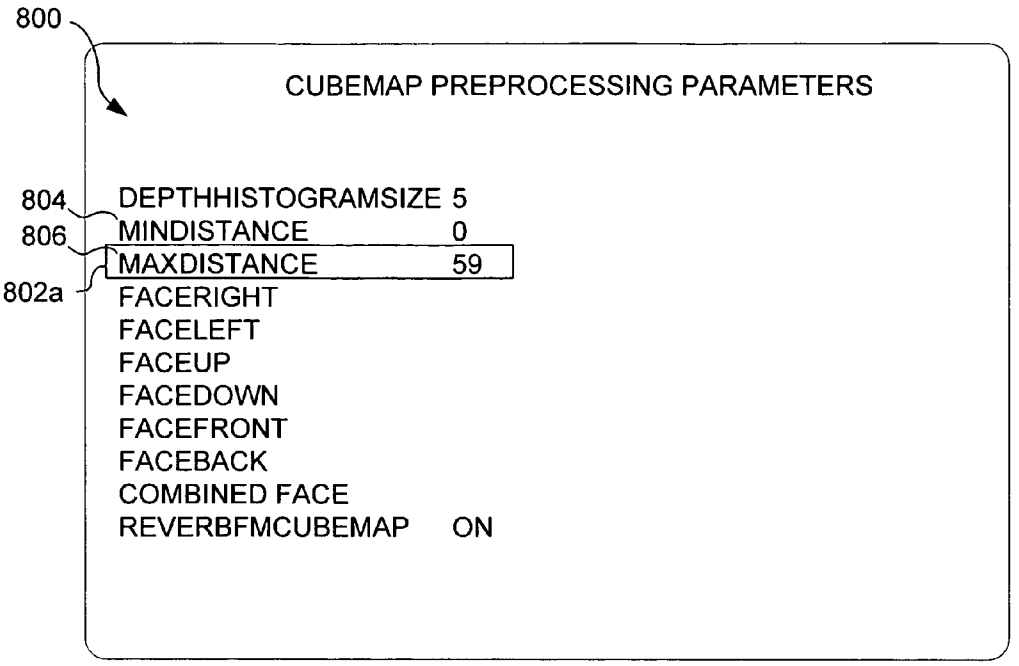

800
CUBEMAP PREPROCESSING PARAMETERS
804
806
802a
DEPTHHISTOGRAMSIZE 5
MINDISTANCE 0
MAXDISTANCE 59
FACERIGHT
FACELEFT
FACEUP
FACEDOWN
FACEFRONT
FACEBACK
COMBINED FACE
REVERBFMCUBEMAP ON

FIG. 8A

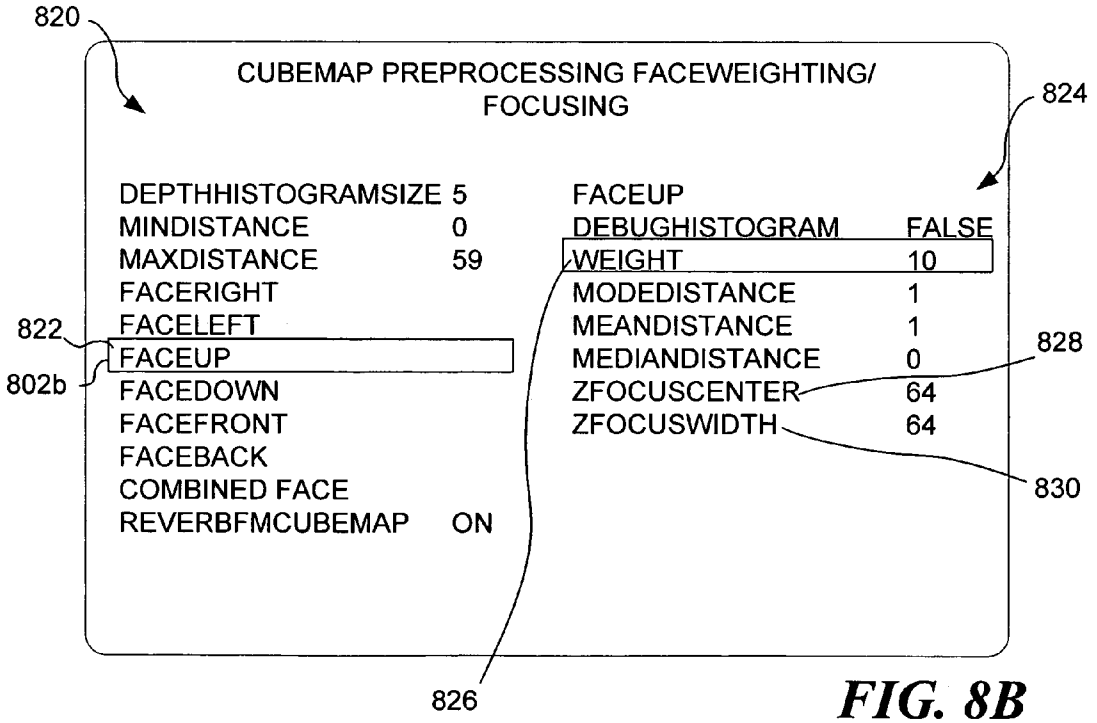

820
CUBEMAP PREPROCESSING FACEWEIGHTING/
FOCUSING
824
822
802b
DEPTHHISTOGRAMSIZE 5
MINDISTANCE 0
MAXDISTANCE 59
FACERIGHT
FACELEFT
FACEUP
FACEDOWN
FACEFRONT
FACEBACK
COMBINED FACE
REVERBFMCUBEMAP ON
FACEUP
DEBUGHISTOGRAM FALSE
WEIGHT 10
MODEDISTANCE 1
MEANDISTANCE 1
MEDIANDISTANCE 0
ZFOCUSCENTER 64
ZFOCUSWIDTH 64
828
830
826

FIG. 8B

840

PROPERTY SCALING FOR RUNTIME DATA

	DECAYTIMENORM	0
	DECAYTIMENORMMIN	0
	DECAYTIMENORMMAX	0.242188
	DECAYTIMELERP	0
842	REVERBVOLUMENORM	0
844	REVERBVOLUMENORMMIN	0
846	REVERBVOLUMENORMMAX	0.242188
843	REVERBVOLUMELERP	0
	REVERBDISTANCE	0
	REVERBDISTANCEMIN	0.5
	REVERBDISTANCEMAX	25.1563
	REVERBDELAYLERP	0
	ROOMHFHARDNESS	0
	ROOMHFHARDNESSMIN	0
	ROOMHFHARDNESSMAX	0.0625
	ROOMHFHARDNESSLERP	0
	DECAYHFHARDNESS	0
	DECAYHFHARDNESSMIN	0

FIG. 8C

860

I3DL2 PARAMETER WET-DRY SCALING

	ROOM	10000
	ROOMHF	10000
	ROOMROLLOFFFACTOR	0
862	DECAYTIME	1
	DECAYHFRATIO	1
	REFLECTIONS	10000
	REFLECTIONSDELAY	0
	REVERB	10000
	REVERBDELAY	0
	DIFFUSION	0
	DENSITY	0
	HFREFERENCE	5000

FIG. 8D

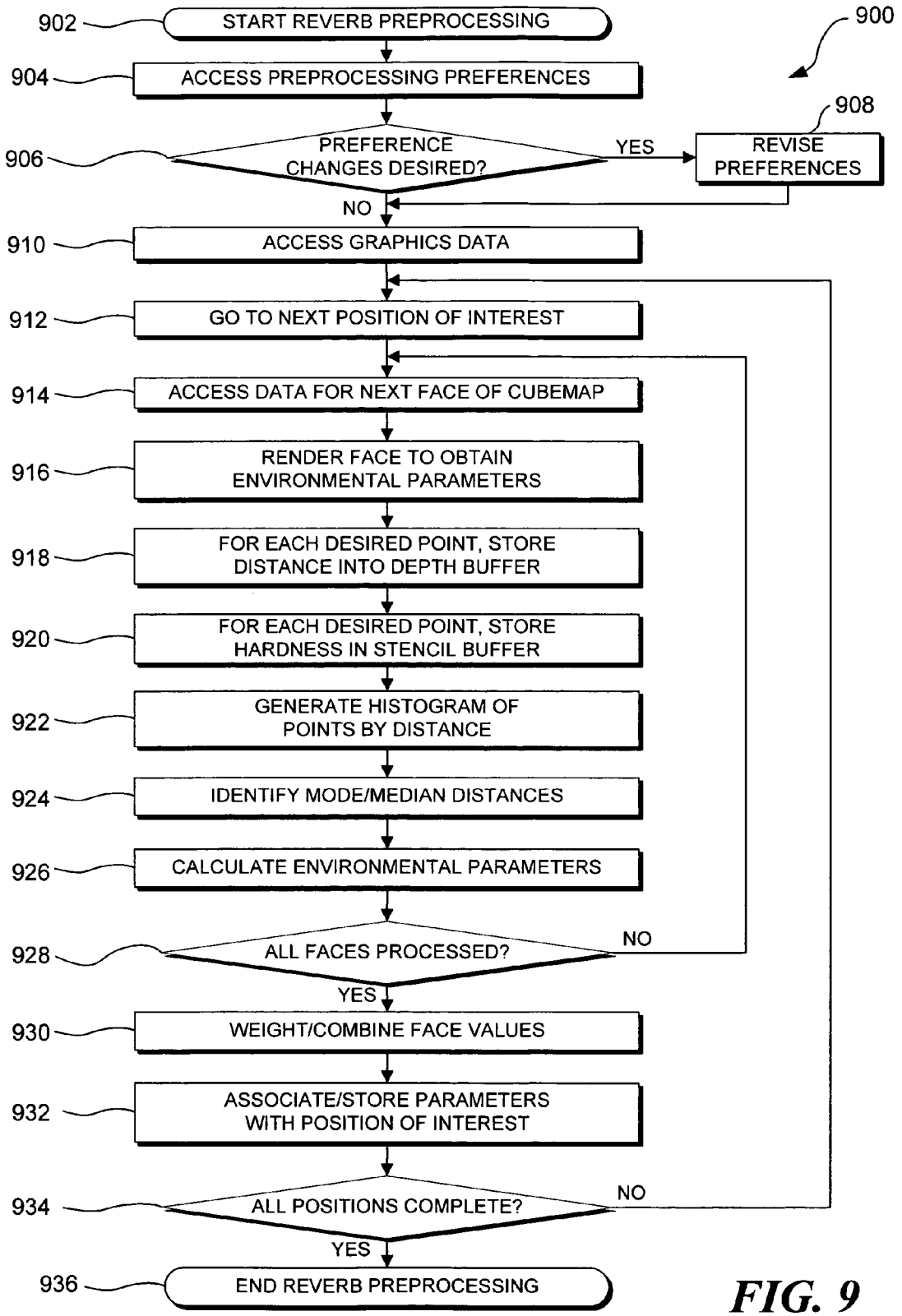

900
902
START REVERB PREPROCESSING
904
ACCESS PREPROCESSING PREFERENCES
906
PREFERENCE CHANGES DESIRED?
YES
908
REVISE PREFERENCES
NO
910
ACCESS GRAPHICS DATA
912
GO TO NEXT POSITION OF INTEREST
914
ACCESS DATA FOR NEXT FACE OF CUBEMAP
916
RENDER FACE TO OBTAIN ENVIRONMENTAL PARAMETERS
918
FOR EACH DESIRED POINT, STORE DISTANCE INTO DEPTH BUFFER
920
FOR EACH DESIRED POINT, STORE HARDNESS IN STENCIL BUFFER
922
GENERATE HISTOGRAM OF POINTS BY DISTANCE
924
IDENTIFY MODE/MEDIAN DISTANCES
926
CALCULATE ENVIRONMENTAL PARAMETERS
928
ALL FACES PROCESSED?
NO
YES
930
WEIGHT/COMBINE FACE VALUES
932
ASSOCIATE/STORE PARAMETERS WITH POSITION OF INTEREST
934
ALL POSITIONS COMPLETE?
NO
YES
936
END REVERB PREPROCESSING

FIG. 9

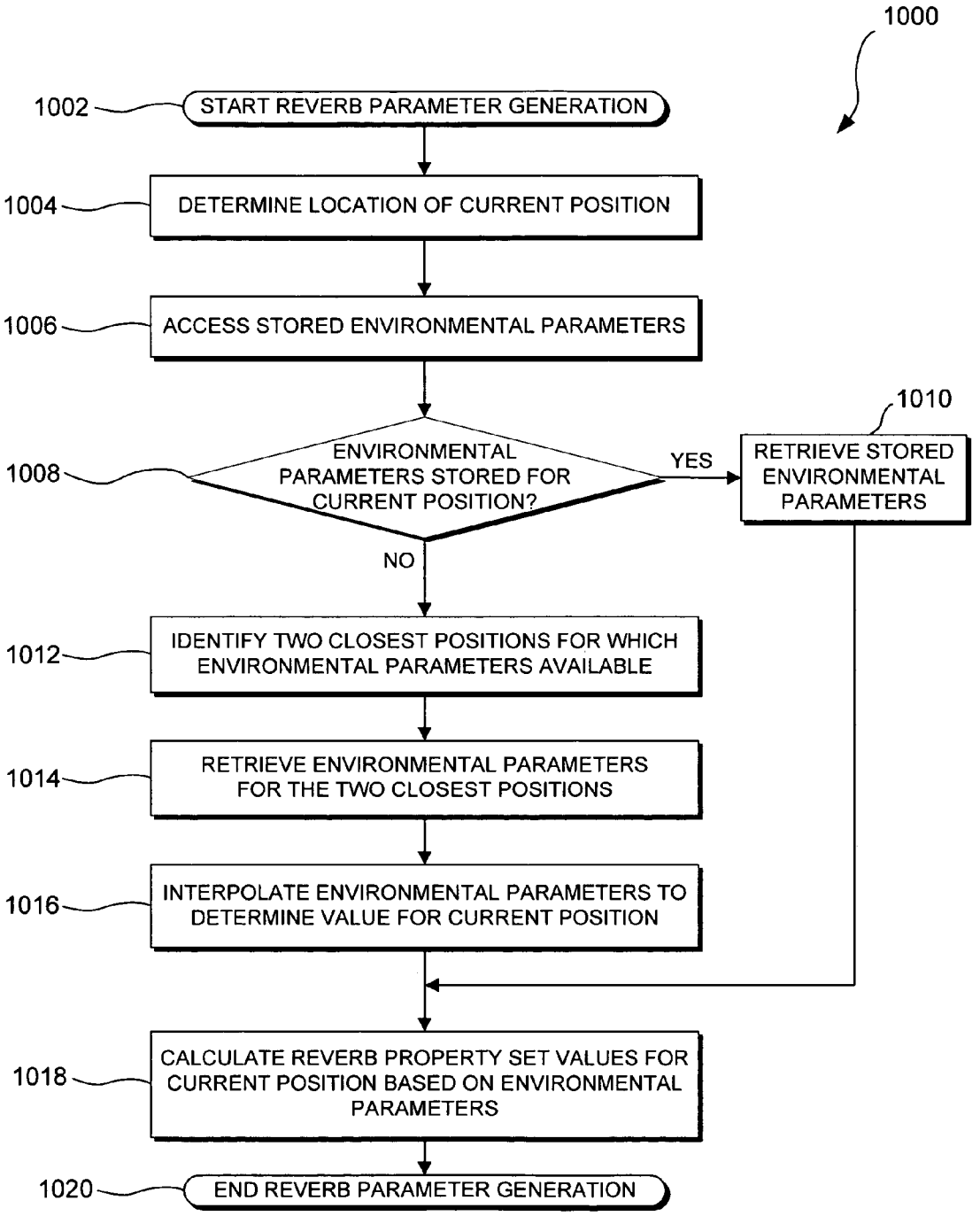

1000
1002
START REVERB PARAMETER GENERATION
1004
DETERMINE LOCATION OF CURRENT POSITION
1006
ACCESS STORED ENVIRONMENTAL PARAMETERS
1008
ENVIRONMENTAL PARAMETERS STORED FOR CURRENT POSITION?
YES
1010
RETRIEVE STORED ENVIRONMENTAL PARAMETERS
NO
1012
IDENTIFY TWO CLOSEST POSITIONS FOR WHICH ENVIRONMENTAL PARAMETERS AVAILABLE
1014
RETRIEVE ENVIRONMENTAL PARAMETERS FOR THE TWO CLOSEST POSITIONS
1016
INTERPOLATE ENVIRONMENTAL PARAMETERS TO DETERMINE VALUE FOR CURRENT POSITION
1018
CALCULATE REVERB PROPERTY SET VALUES FOR CURRENT POSITION BASED ON ENVIRONMENTAL PARAMETERS
1020
END REVERB PARAMETER GENERATION

FIG. 10

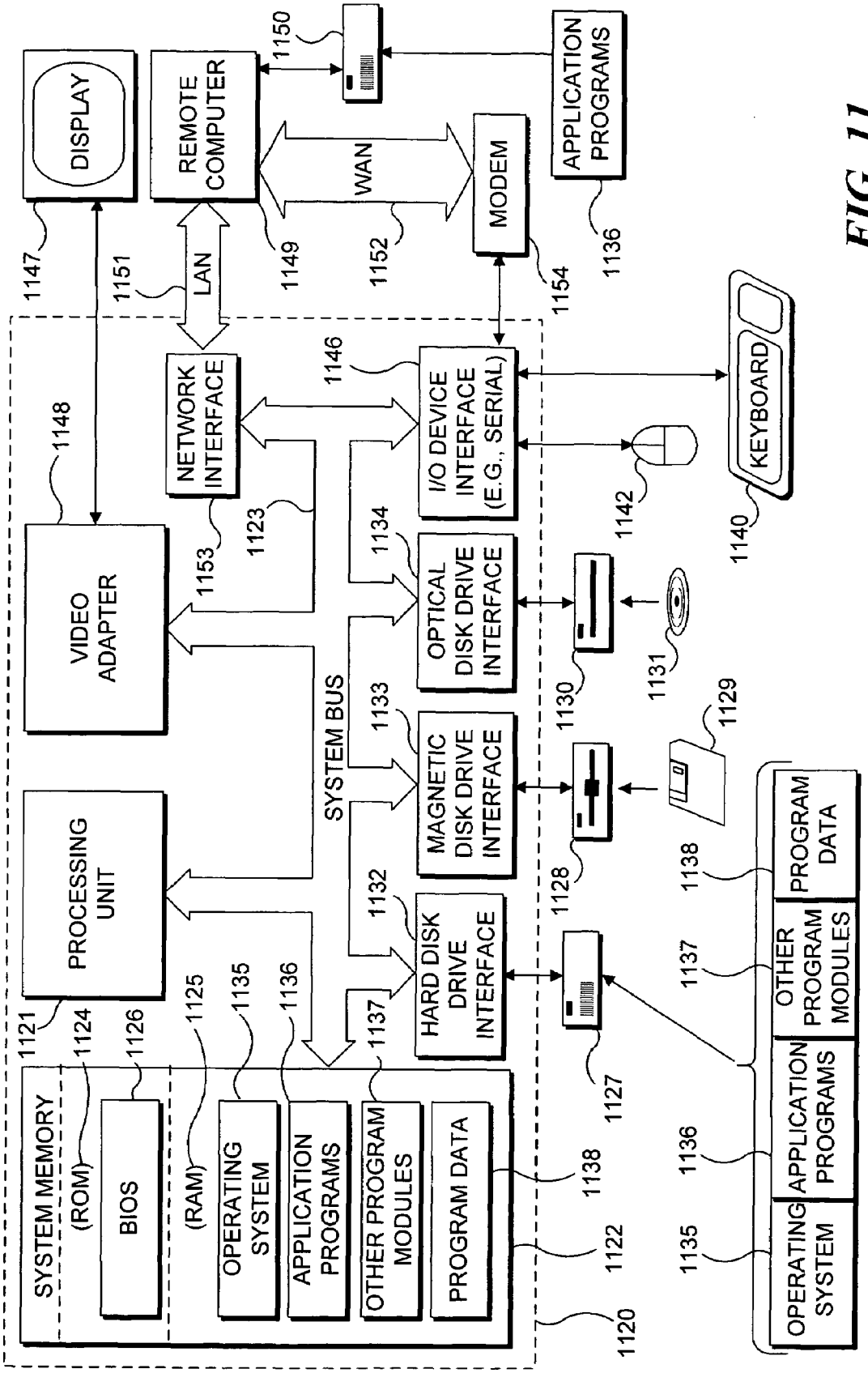

DISPLAY
REMOTE COMPUTER
APPLICATION PROGRAMS
WAN
MODEM
LAN
NETWORK INTERFACE
I/O DEVICE INTERFACE (E.G., SERIAL)
KEYBOARD
VIDEO ADAPTER
OPTICAL DISK DRIVE INTERFACE
SYSTEM BUS
MAGNETIC DISK DRIVE INTERFACE
PROCESSING UNIT
HARD DISK DRIVE INTERFACE
SYSTEM MEMORY
(ROM)
BIOS
(RAM)
OPERATING SYSTEM
APPLICATION PROGRAMS
OTHER PROGRAM MODULES
PROGRAM DATA
OPERATING SYSTEM
APPLICATION PROGRAMS
OTHER PROGRAM MODULES
PROGRAM DATA
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
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FIG. 11

METHOD AND SYSTEM FOR AUTOMATICALLY GENERATING WORLD ENVIRONMENTAL REVERBERATION FROM GAME GEOMETRY

FIELD OF THE INVENTION

The present invention generally pertains to computer-generated audio, and more specifically, to a method and system for adjusting reverberation of computer-generated sounds.

BACKGROUND OF THE INVENTION

The tremendous advancements made in computer technology and price/performance over the past few decades has revolutionized computer graphics. For example, early personal computers featured games that provided only monochromatic images, or chalky, low-resolution images including only a few colors at a time. By contrast, today's video games present realistic, three-dimensional images in thousands of colors. Sports games feature likenesses of players that are so accurate and detailed that the players' faces actually can be recognized in the computer animation. In fact, such clarity is possible not only on personal computers, but on video game systems retailing for less than $150. Similarly, movie studios continually expand their use of computer graphics in creating feature films, making the unreal believable. Computer graphics have been used to create increasingly better special effects, as well as entirely computer-generated feature films. Still more films feature live actors in movies where one or more of the other characters are entirely computer-generated, and/or some or all of the backdrops are computer-generated.

In support of improved computer graphics, computer audio hardware systems have improved a great deal. Instead of a single tinny-sounding internal speaker used to generate beeps and monophonic tones in early personal computers, current audio hardware is able to generate high fidelity music and multi-channel surround sound. For example, the Microsoft Corporation's XBOX™ gaming system includes a media communications processor (MCP) with a pair of digital signal processors capable of processing billions of instructions per second. In addition to providing network access and performing other functions, the MCP includes an audio system capable of driving a six-speaker, surround sound audio system. Furthermore, the audio system is capable of precisely controlling audio reverberation for generating three-dimensional audio in conformance with the Interactive Audio Special Interest Group (IASIG) of the MIDI Manufacturers Association Interactive 3D Audio Rendering Guidelines—Level 2.0 Specification (I3DL2). This specification is also recognized by personal computer-based audio systems, such as Microsoft Corporation's DirectSound™ audio specification, as well as by other audio systems.

Audio systems adhering to the I3DL2 specification (and other audio systems) can provide very realistic three-dimensional sound. For example, the I3DL2 specification recognizes twelve different input values that can be set to precisely tailor audio effects, including: ROOM, ROOM_HF, ROOM_ROLLOFF_FACTOR, DECAY_TIME, DECAY_HF_RATIO, REFLECTIONS, REFLECTIONS_DELAY, REVERB, REVERB_DELAY, DIFFUSION, DENSITY, and HF_REFERENCE.

The ROOM value generally adjusts the potential loudness of non-reverb sounds by setting an intensity level and low-pass filter for the room effect, with a value ranging between −10000 mB and 0 mB. The default value is −10000 mB. The

ROOM_HF value determines the proportion of reverberation that includes high frequency sounds versus low frequency sounds. More specifically, ROOM_HF specifies the attenuation of reverberation at high frequencies relative to the intensity at low frequencies. ROOM_HF can be a value between −10000 mB and 0 mB. The default value is 0 mB. The ROOM_ROLLOFF_FACTOR value determines how quickly sound intensity attenuates over distance, in the environment. For example, ROOM_ROLLOFF_FACTOR might be used to model an environment consisting of warm, moist air, which squelches sound more quickly than cool, dry air. ROOM_ROLLOFF_FACTOR is a ratio that can include a value between 0.0 and 10.0, and the default value is 0.0.

In addition to these values that control propagation effects of sound, other values more specifically relate to the reverberation of sound. The DECAY_TIME value specifies the decay time of low frequency sounds until the sound becomes inaudible and can be set between 0.1 and 20.0 seconds, with a default value of 1.0 seconds. The DECAY_HF_RATIO value determines how much faster high frequency sounds decay than do low frequency sounds. DECAY_HF_RATIO can be set between 0.1 and 2.0, with a default value of 0.5.

The REFLECTIONS value determines the intensity of initial reflections relative to the ROOM value and can be set between −10000 mB and 1000 mB, with a default value equal to −10000 mB. The REFLECTIONS_DELAY value specifies the delay time of the first sound reflection, relative to the directly received sound and can be set between 0.0 and 0.3 seconds, with a default value of 0.02 seconds. The REVERB value determines the intensity of later reverberations, relative to the ROOM value or, generally, how "wet" the reverberation level is in terms of the overall sound. REVERB can be set to a value between −10000 mB and 2000 mB, and the default value is −10000 mB. The REVERB_DELAY value specifies the time limit between the early reflections and the late reverberation, relative to the time of the first reflection. REVERB_DELAY can be set between 0.0 and 0.1 seconds, with a default value of 0.04 seconds. The DIFFUSION value controls the amplitude intensity of reverberation in the late reverberation decay and can be set between 0.0% and 100.0%, with a default value of 100.0%. The DENSITY value represents the percentage of the modal density in the late reverberation decay, which can be thought of as the portion of surfaces reverberating distinct sounds. Density can be a value between 0.0% and 100.0%, with a default value of 100.0%. Finally, the HF_REFERENCE value sets the delineation point between which sounds are considered high frequency as opposed to low frequency, for purposes of any frequency-based distinction, such as applied in the DECAY_HF_RATIO. HF_REFERENCE can be set anywhere in the audible range between 20.0 Hz and 20,000.0 Hz. The default value is 5000.0 Hz.

Clearly, sound engines recognizing the I3DL2 specification and similar specifications provide software designers and creators tremendous control in tailoring the reverberation of sound to provide a realistic three-dimensional auditory experience. Unfortunately, however, with all of the capabilities provided by the I3DL2 specification and other such specifications, the capability of the audio system and other computer components affecting sound tends to be underutilized. Although systems recognizing the I3DL2 specification provide great control, I3DL2 also imposes a tremendous amount of work for software engineers to determine and set the myriad of values needed to appropriately generate realistic sound effects within a computer-generated environment.

For example, consider a street racing game in which a user controls an automobile as it races around in a city. The track or course followed by the auto will pass through open areas,

past buildings, under bridges, and encounter various types of objects. As any driver of an actual automobile will readily understand, objects in the nearby environment affect how the sound generated by the automobile reverberates and how the quality of the sound heard inside the automobile changes as the automobile passes near and past the objects. Thus, to create "believable" reverb effect for sound in such a game, as the automobile is driven around the track, the different parameters provided in the I3DL2 specification all need to be appropriately set—either at spaced apart intervals, or for each object or set of objects encountered by the auto in the virtual environment. This process can literally involve person years to accomplish for a single game. Therefore, unfortunately, when deadlines approach or budgets dwindle as the coding of a game reaches the deadline for completion, the resources devoted to setting these parameters may be reduced or cut. As a result, the quality and realism of the reverb sounds experienced by users of the game may be unsatisfactory, or at least unremarkable.

Not only is setting these reverb parameters incredibly labor intensive, but it also is prone to human bias and error, so that the results can be unpredictable and unrealistic. As a further example, a game might involve a character that moves through different rooms of a building. Creation of the reverb parameters for a single environment might be divided between multiple audio designers. Unfortunately, each of the designers may have different predispositions and preferences regarding the audio quality. As a result, as the character passes from a room configured by a first audio designer to a room configured by a second audio designer, even if the rooms are very similar, the reverberations may be noticeably different. Certainly, in a well-designed game, movement between areas should be as seamless as possible, and significant shifts in audio effects should only occur when moving between significantly different types of spaces. Unwarranted shifts in audio quality thus detract from the realism and the user's appreciation and enjoyment of the game.

Thus, although the capabilities exist in computer systems and gaming systems to provide for realistic three-dimensional audio, the reality of achieving these capabilities may exceed the resources of programmers and designers creating a game or other form of virtual environment. As a result, the dimensional qualities of the audio generated may be somewhat unrealistic.

It would thus be highly desirable to improve the method used for creating computer-generated audio to enable a realistic sound quality to be achieved. Specifically, it would be desirable to simplify the process of setting audio parameters to provide for reverb effects that appropriately match the virtual environment portrayed in the video portion of the computer generation. This approach should greatly reduce the resources, time, and cost involved by eliminating the need for manually setting these parameters. Further, it would be desirable to automatically set the parameters so as to ensure smooth consistent transitions in the sound produced by the computer when moving between different portions of the computer-generated virtual environment.

SUMMARY OF THE INVENTION

One of the advantages of the present invention is that it provides a fast, non-labor-intensive method for setting reverb parameters for a computer-generated environment. As described above, to simulate the physical world, computer systems such as personal computers include reverb engines, but these reverb engines can require that as many as a dozen or more parameters be set to fully and realistically control the reverberation of sounds relative to the environment in which the sounds appear to be heard. In the physical world, the reverberation of sounds is determined by a combination of factors, including the composition of objects that reflect the sounds and the location of those objects relative to the source of the sounds and the listener. Comparably, for a computer-generated environment, embodiments of the present invention determine how objects present in the computer-generated environment would cause sound to reverberate as if in the real world and generate resulting reverberation parameters that can be applied to produce corresponding realistic sounding reverberation effects when the game is executed by a user. The reverberation parameters are created and stored for different points throughout a computer-generated environment. Thus, when the computer-generated environment is rendered, the reverberation parameters are retrieved and applied when generating sounds in the environment.

In addition to simplifying the process of setting reverberation parameters, embodiments of the present invention also ensure that reverberation parameters are set more consistently than might occur if the parameters were subjectively manually set, particularly if set by different persons. Setting reverberation parameters manually can yield inconsistent results. The settings of the reverberation parameters manually applied by a human designer in different parts of the environment may result in unnatural-sounding reverb when the listener's (i.e., the user's) point of hearing passes from one part of the virtual environment to another. The juxtaposition of the sets of parameters resulting from a user passing from one area to the other may expose unnatural changes in the degree of reverberation, reverb delay, decay time, proportion of high frequency reverberations, and other attributes. Moreover, multiple human audio designers working with different portions of a computer-generated environment may have significantly different tendencies and preferences that may be revealed only when the computer-generated environment is rendered, when those differences result in clearly audible discontinuities. By contrast, embodiments of the present invention automatically generate reverberation parameters based on features existing in the computer-generated environment, and thus, the parameters are consistently based on structures in the virtual environment and not subjective preferences of human designers that can vary dramatically between designers.

One aspect of the present invention is thus directed to a method for automatically deriving reverberation characteristics for a computer-generated environment from graphics data describing visually displayable contents of the computer-generated environment. A position of interest is selected in the computer-generated environment. The graphics data describing a portion of the computer-generated environment viewable from the position of interest when the computer-generated environment is rendered are accessed. Reverberation characteristics are derived for the position of interest from the graphics data describing each of a plurality of points in the portion of the computer-generated environment. The reverberation characteristics are derived at least in part from a distance of each point from the position of interest and a hardness value associated with the point.

The reverberation characteristics include at least one of property set values usable by a reverberation engine, and a plurality of environmental parameters from which the property set values are calculable when the computer-generated environment is rendered. The property set values are configured to be supplied to a reverberation engine conforming to at least one of the IA3DL2 specification and the EAX specification. The environmental parameters for the points include

at least one of a mean distance to the points, a mode distance to the points, a median distance to the points, a mean hardness associated with the points, and a total number of points in the portion of the computer-generated environment. A subset of the points may be selected that describe the portion of the computer-generated environment viewable from the position of interest, the subset including points within at least one of a distance range from the position of interest and a lateral range relative to the position of interest. A plurality of subsets of points describing the portion of the computer-generated environment may be identified, with each of the plurality of subsets of points including points at a plurality of mode distances from the position of interest and having a plurality of mode hardnesses of points at a particular distance. Separate delay lines relating to each of the plurality of subsets of points may be used in developing the reverberation characteristics for the position of interest. The environmental parameters also may include a total number of points within the subset.

A portion of the property set values are derived in proportion to the total number of points within the subset relative to the total number of points. The property set values so derived preferably include at least one of a reverb decay time and a reverb volume. A portion of the property set values are proportional to the mean hardness of the points, including at least one of a decay high frequency ratio, a room high frequency attenuation, and a reflections delay time. In addition, a portion of the property set values are proportional to the distances to the points from the position of interest, the portion of the property set values including at least one of a decay time, a reflections intensity, a reflections delay time, and a reverb intensity.

The graphics data may include a cubemap describing the visually displayable contents of the computer-generated environment viewable from the position of interest. The reverberation characteristics for the position of interest are thus based on points representable on a plurality of faces of the cubemap. The reverberation characteristics derived from each of the plurality of faces is weighted according to at least one of a face with which the point is associated, and a position within the face with which the point is associated.

The hardness value is derivable from a feature with which the point is associated and may be retrieved from a hardness value table listing hardness values associated with compositions of features potentially included in the computer-generated environment.

A plurality of reverberation characteristics for the position of interest from the graphics data may be derived to correspond to a plurality of aspects of the position of interest. Each of the plurality of reverberation characteristics then are applied to audio channels corresponding to the aspects of the position of interest upon execution of the computer-generated environment. The aspects of the position of interest may correspond to at least one of lateral sides of the position of interest and forward and rearward faces of the position of interest. The plurality of reverberation characteristics for the position of interest may be determined by identifying a plurality of secondary positions of interest corresponding to the aspects of the position of interest, and determining the reverberation characteristics for each of the secondary positions of interest.

The reverberation characteristics may be derived in a preprocessing step performed before the computer-generated environment is visually rendered. The distance from the position of interest to each of the plurality of points is stored in a depth buffer, and the hardness of each of the plurality of points is stored in a stencil buffer. The reverberation characteristics are stored in association with the position of interest such that the reverberation characteristics are retrievable when the computer-generated environment is visually rendered.

A series of reverberation characteristics for a plurality of positions of interest within the computer-generated environment may be calculated, where the plurality of positions include at least one of a plurality of positions selected by an operator, and a plurality of positions at predetermined intervals along an exemplary path through the computer-generated environment. Reverberation characteristics for an additional position for which the reverberation characteristics were not previously calculated are derivable by interpolating the reverberation characteristics for at least two other positions of interest proximate to the additional position.

An operator can be enabled to adjust at least one of an allowable range of reverberation characteristics and operands used in deriving the property set values from the reverberation characteristics. Reverberation characteristics may be adjusted for the position of interest by using reverberation characteristics for an alternate position of interest that is either ahead or behind the position of interest in the computer-generated environment.

Another aspect of the present invention is directed to a memory medium having machine executable instructions stored for carrying out steps and a system configured to execute steps that are generally consistent with the steps of the method described above.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

FIG. **1** is a perspective diagram of a bare cubemap in a coordinate space for a position of interest;

FIG. **2** is a spline joining a plurality of positions of interest in an exemplary computer-generated environment;

FIG. **3** is a line graph of a potentially desired wetness versus dryness of a reverb pattern for the plurality of positions of interest along the spline of FIG. **2**;

FIGS. **4**A-**4**D represent faces of a cubemap encompassing a first position of interest along the spline of FIG. **2**;

FIGS. **5**A-**5**D represent faces of a cubemap encompassing a second position of interest along the spline of FIG. **2**;

FIGS. **6**A-**6**B are portions of arrays derived from graphics data used to determine environmental parameters surrounding a position of interest;

FIGS. **7**A-**7**B are distance or depth histograms used in deriving median and mode distances from the arrays of FIGS. **6**A-**6**B;

FIGS. **8**A-**8**D are screen shots from an interface enabling an operator to adjust ranges and values used in determining reverberation characteristics;

FIG. **9** is a flow diagram illustrating logical steps for preprocessing environmental parameters for a computer-generated environment;

FIG. **10** is a flow diagram illustrating logical steps for deriving reverberation property value sets from environmental parameters stored with data describing a computer-generated environment; and

FIG. **11** is a functional block diagram of a generally conventional computing device or personal computer (PC) that is suitable for generating reverberation parameters in practicing the present invention and for applying the reverberation

parameters to produce sound when rending the computer generated environment for which the reverberation parameters were generated.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Identifying Visually Representable Features in Generating Reverberation Parameters

FIG. **1** is a perspective diagram of a bare cubemap **100** in a coordinate space defined by axes **110**, **120**, and **130** for a position of interest **150**, that is within the cubemap. Axes **110** and **120** are conventional x- and y-axes, respectively, defining a conventional two-dimensional plane. Orthogonal to x-axis **110** and y-axis **120** is a z-axis **130**. For purposes of this description, z-axis **130** generally indicates a direction of motion through a computer-generated environment, i.e., a virtual environment. Although movement is possible along x-axis **110** and y-axis **120**, the predominant direction of motion will be considered to be along z-axis **130** that, for example, lies along a track in a racing simulation that is described in greater detail below.

Position of interest **150** is at the center of cubemap **100**. Cubemap **100** includes six faces, one for each face of the described cube. With z-axis **130** indicating the direction of motion, a face **160** is a forward face of cubemap **100** and a face **165** is a rear face of the cubemap **100**. Thus, while traveling forward in the computer-generated environment, a user sees forward face **160** while rear face **165** lies behind the user. Similarly, a left face **170** and a right face **175** indicate what appears to the sides of the user as the user proceeds through the computer-generated environment, while an upper face **180** and a lower face **185** indicate what lies above and below the user, respectively. To those familiar with computer-generated environments, cubemap **100** represents a complete environment around position of interest **150** such that, as the user turns a field of view horizontally or vertically, faces **160-185** fully represent a simulated three-dimensional space about the position of interest.

FIG. **2** is a spline **200** joining a plurality of positions of interest in an exemplary computer-generated environment. In the example illustrated in FIG. **2**, the computer-generated environment presents an automobile track in a racing simulation. It will be appreciated that the environment could also represent a maze, a series of buildings, a region of free space, or any other simulated environment, and the spline would represent an expected path through that environment. Alternatively, the computer-generated environment is not restricted to one where an expected path might be followed, and the plurality of positions of interest may include a two-dimensional or three-dimensional array of positions of interest throughout a computer-generated environment.

As shown in FIG. **2**, the track represented by spline **200** passes by a group of trees **210**, passes through a tunnel **220** under a mountain **230**, passes through a town or other grouping of buildings **240**, as well as through a number of open spaces **250**. As will be familiar to automobile drivers, the reverberation of sounds produced by the automobile that is heard by the driver is very different when the auto is on an open section of road, compared to when it is passing between buildings, passing through a tunnel, or passing by or through other structures. When an automobile passes a position of interest **280** between buildings **240**, sound generated by the automobile will reverberate more than it does at positions of interest **290**, which are located on a section of open road **250**. On either side of position of interest **280**, the reverberation may vary as a function of the proximity to the auto of buildings on either side of the automobile, as well as the width or height of the buildings, and the presence of space between buildings for cross-streets or other openings. Reverberation also may change as a result of the hardness of the materials from which the buildings and other nearby objects are constructed or comprise. It will be appreciated that the reverberation experienced while passing a building covered in wood shingles or siding will be markedly different from the reverberation experienced when passing a building covered in stone or brick, for example. Further alternatively, passing by a group of trees **210** that is alongside the road at position of interest **260** may result in no or little reverberation of sound from the trees. Passing through position of interest **270**, through tunnel **220** under mountain **230**, in contrast, may result in a very substantial reverberation due to the reflection of sounds from the rigid, nearby surfaces inside the tunnel.

In describing reverberation, positions where reverberation is high are referred to as "wet," while positions where reverberation is low are referred to as "dry." FIG. **3** is a line graph **300** of a reverb wetness **310** plotted versus a position **320**, for the positions of interest along the spline of FIG. **2**. At position of interest **260**, the distance and/or relatively soft composition of trees **210** (FIG. **2**) results in no appreciable increase in the reverb wetness. However, when passing through position of interest **270** in tunnel **220**, the reverb wetness peaks as a result of the automobile passing through a space that is bounded by hard materials that do not absorb sound. It should be noted that the reverb wetness also increases upon approaching tunnel **220** and while moving away from the tunnel as a result of sound reverberating from the hard materials comprising the face of tunnel **220** and/or the surface of mountain **230**. The reverb wetness decreases between position of interest **270**, but increases again upon passing between buildings **240** surrounding position of interest **280**. The reverb wetness also varies based on the size, spacing, composition, and position of buildings **240**. Upon leaving position of interest **280** and reaching positions of interest **290** in open country **250**, reverb wetness **310** declines to a fully dry level, i.e., to a level where the reverberation is virtually nil.

In computer-generated environments it is desirable to accurately recreate or simulate these reverb effects to add to the realism, drama, and/or ambiance of the computer-generated environment. As described above, with so many reverberation parameters to set, manual calibration of reverberation parameters responsive to features **210-250** would represent a highly labor-intensive task, open to undesirable variations based solely on individual designer predispositions or preferences. Embodiments of the present invention determine position and characteristics of features such as **210-250** and then automatically generate appropriate reverberation characteristics that are applied when the computer-generated environment is rendered.

Determining Reverberation Characteristics from Graphics Data

For purposes of illustration, FIG. **4**A shows a rendering of a forward face **410** of a cubemap **400** associated with point **260** (FIG. **2**). Forward face **410** shows open road ahead with no nearby prominent features that could cause sound to reverberate. Distant topographical features **430** are too far away to have much affect on local reverberation. By contrast, FIG. **5**A shows a rendering of a forward face **510** of a cubemap **500** associated with point **270**. Forward face **510** depicts not only road **520**, but also an open end **530** of tunnel **230**, as well as tunnel walls **540** and support beams **550**. In the environment depicted in cubemap **500**, tunnel walls **540** are rendered as

made of concrete buttressed by wooden support beams **550**. The presence of these features in an actual physical environment would change the reverberation from sounds generated by the automobile relative to the reverberation outside the tunnel. Accordingly, the present invention is able to detect these objects and properly select the reverberation parameters accordingly.

Furthermore, as is true in an actual physical environment, it is not only the features appearing ahead that may have an affect on reverberation of sound, but also, for example, features on left faces **460** and **560**, overhead faces **470** and **570**, and right faces **480** and **580**. FIGS. **4**B-**4**D respectively illustrate a left face **460** of cubemap **400**, an overhead face **470** of cubemap **400**, and a right face **480** of cubemap **400**. The features represented in cubemap **400** can have little effect on the reverberation of sound. Left face **460** includes only open sky **462** and open terrain **464**. Overhead face **470** includes only more open sky **472** and a distant cloud **474**. Right face **480** does include a number of deciduous trees **482**, each having leafy branches **484** atop a wooden trunk **486**, growing in a grassy field **488**. From the vantage point of a moving automobile, for example, faces **460**, **470**, and **480** include very few surfaces from which sound might reverberate. Nothing in open sky **462** and open terrain **464** to the left should reflect sound. Similarly, nothing in open sky **472** or cloud cover **474** overhead should reflect sound. Finally, while hard wooden trunks **486** of deciduous trees **482** may reflect some sound, trees **482** make up only a relatively small portion of the content of right face **480**. Further, the leafy branches **484** atop trunks **486** might absorb most or all of the reflected sound. Also, trees **482** may not be close enough to the automobile to result in any appreciate reflected sound.

By contrast, in the case of cubemap **500** (FIG. **5**A), the presence of concrete walls **540** buttressed by wooden support beams **550** on all faces **510**, **560**, **570**, and **580** will result in a high degree of reflected sound. On left face **560**, which is shown in FIG. **5**B, concrete wall surfaces **562** are surrounded by wooden support beams **564**. On overhead face **570** (FIG. **5**C), which is slightly closer to the automobile, more concrete surfaces **572** and more wooden support beams **574** are present. Finally, as shown in FIG. **5**D, closest of all to an automobile traveling in a right-hand lane, right face **580** includes more concrete walls **582** and more wooden support beams **584**. All these features, as a result of their relative proximity to the automobile, their hardness, and the near field coverage of faces **560**, **570**, and **580**, will reflect sound to a substantial degree.

As described above, while personal computer systems and gaming systems include reverberation engines that enable reverberation of sounds to be modeled, these reverberation engines may require as many as a dozen or more properties to be set in order to control of the reverberation effects. Embodiments of the present invention, however, use the environmental information obtainable from the graphics data to identify features in the computer-generated environment, around successive points of interest, that will reflect sound and derive the reverberation characteristics needed to control a reverberation engine for each point of interest as necessary when the computer generated environment reaches that point of interest.

In one embodiment of the present invention, reverberation characteristics are preferably derived in a pre-processing step. Once the graphics data controlling the appearance of the computer-generated environment have been created, an embodiment of the present invention derives reverberation characteristics for one or more positions of interest in the computer-generated environment. These reverberation characteristics can then be applied when the computer-generated environment is rendered and experienced by a user, so that the sound heard at each location includes a realistic reverberation. In one embodiment of the present invention, reverberation characteristics are derived in preprocessing for a plurality of positions of interest, and when the computer-generated environment is executed, reverberation attributes for a present position of interest are derived by interpolating reverberation characteristics for the present position from a number of proximate positions of interest for which preprocessed reverberation characteristics previously were derived.

Alternatively, in a suitably capable processing system, reverberation characteristics are derivable in real time as the graphics data is rendered for viewing when the computer-generated environment is executed. Reverberation characteristics thus are derived for each specific position of interest. Thus, as changed in the computer-generated environment occur, such as a wall being exploded or otherwise removed from a user, the reverberation characteristics are adjusted accordingly, in real time. It will be appreciated that a real time generation of such reverberation characteristics are derived from the graphics data in a manner comparable to the way that the reverberation characteristics are derived from the graphics data in preprocessing. It also should be appreciated that real time derivation of reverberation characteristics, although increasing demand for computing resources upon executing the computer-generated environment that would be involved in interpolating between predetermined values, will result in reverberation characteristics that may be more accurate to the computer-generated environment than interpolated values derived from preprocessed values.

As is well understood in computer graphics, visually representable features are comprised of a plurality of points. To visually render the features in a meaningful way, each of these points is located at a certain distance relative to the position of the interest from which the features are viewed. As a result, features that appear in the foreground and, thus, in front of other features, and are associated with a particular composition, are associated with a shorter distance relative to the position of interest so that foreground features are rendered in front of background features. In addition, each of the features is associated with a composition type, or texture, so that the features will be rendered in an appropriate shade or color, and will reflect or indicate shadows appropriate to the albedo of the material of which the feature is comprised. In visually rendering such features, a distance from the position of interest to the point is read into a depth buffer for the point, while the reflectance is read into a stencil buffer. These buffers often are joined and make up different portions of a single buffer.

Embodiments of the present invention use the distance to these points and the composition of these points to determine the reverberation characteristics attributable to each. In one embodiment of the present invention, for selected faces of a cubemap, distances to points within a certain lateral range on the cubemap face are determined, and a compositional hardness of each point is also determined. From the distances to the points, the hardness of the points, and the proportion of the surveyed area populated by these points, suitable environmental parameters can be automatically derived. Thus, without an operator manually setting the reverb properties for a myriad of points, an embodiment of the present invention can automatically derive the parameters for one or more positions of interest. Environmental parameters for a plurality of positions of interest, such as along a spline following an expected path through the computer-generated environment, can be derived and stored. Ultimately, upon rendering of the computer-generated environment, reverberation property set val-

ues, such as I3DL2 values, can be calculated from these environmental parameters or otherwise retrieved and applied to sounds generated within the computer-generated environment to provide desirable sound reverberation.

Deriving Environmental Parameters Affecting Reverberation of Sound

FIGS. **6**A and **6**B illustrate left faces **480** and **580** of cubemaps **400** and **500**, respectively, from which subsets of points have been sampled to determine distances and compositions of features that are represented. More specifically, in FIG. **6**A, an array **610***a* represents a subset of points in a plane of left face **480**. It will be appreciated that sectors **612** as large as the sectors of array **610***a* each would actually span numerous points, but for purposes of this illustration, it will be assumed that each sector **612** covers only a single pixel or point of face **480**. For visual simplicity, array **610***a* is depicted as a four-by-four pixel array; however, in one embodiment of the invention, the array is a 128-by-128 pixel array. It should also be appreciated that an embodiment of the present invention need not visually render graphics data to derive reverberation data from the graphics data. However, for the sake of clarity, face **480** is depicted visually.

Enlarged array **610***b* shows information derived from points in array **610***a*. Specifically, from each sector **612**, two figures are derived. A distance **614** indicates the distance from the position of interest to the point. A hardness **616** represents a relative hardness of the material of which the point is composed. Distance **614** actually is a value associated with each point on face **480**, whereas hardness value **616** is derived from a texture associated with the point. From the texture associated with each point, a hardness value representative of the material represented by the texture can be substituted. A hardness, in one embodiment of the invention, is an eight-bit value assigned to represent the relative hardness of various compositions. A look-up table may be used that lists hardness values associated with various compositions or textures, as shown in exemplary Table 1, below.

TABLE 1

TEXTURE/COMPOSITION	HARDNESS
Leaf	0F
Bush	0F
ChainLink	2F
Tire	4F
Concrete	FF
Grass	4F
Dirt	5F
Wood	7F
Tree	7F
Wall	FF
PVC	7F
Gravel	FF
Window	FF
Crowds	5F
Canvas	0F
Rail	FF
Rock	FF

The hardness values are eight-bit binary values represented as two-digit hexadecimal values. The hardness values, as shown in Table 1, range from a softest value having the least unit reverberation, or 0F (16), to a hardest value having the greatest unit reverberation, or FF (255). In one embodiment of the present invention, the hardness values are scaled to a decimal value in the range between 0.0 and 1.0, where 0.0 represents the softest, least reverberant materials, and 1.0 represents the hardest, most reverberant materials.

Referring back to FIG. **6**A, enlarged array **610***b* includes a distance **614** and a hardness **616** for each of the points included in array **610***a*. Enlarged array **610***b* thus represents a sampling of the values associated with features on left face **480** that might affect reverberation of sound. In the sampled area, five pixels include a trunk **486** of a tree **482** at a distance of 75 units and having a hardness of 7F or 127. Six pixels include leafy branches **484** extending outwardly from trees **482** at a distance of 70 units and having a hardness of 0F or 15. The remaining five pixels of array **610***a* include grass in an open terrain **488** behind tree **482** at a distance of 95 units and having a hardness of 4F or 79. The distances and hardness values are read into the depth and stencil buffers.

Referring to FIG. **6**B, an array **650***a* spans a four-by-four pixel portion of right face **580**, which includes concrete walls **582** supported by wooden beams **584**. Array **650***a* spans a portion of right face **580** including points much closer to the position of interest and comprising much harder materials. As shown in an enlarged array **650***b*, 12 of the points covered by array **650***a* include concrete walls at a distance of six units. From Table 1, concrete has a maximum hardness value of FF or 255. Wooden support beams **584** supporting concrete walls **582** are at a distance of five units and have a hardness value of 7F or 127. Again, these distances and hardness values are read into the depth and stencil buffers.

In one embodiment of the present invention, a distance range and a lateral range relative to the position of interest are set to determine the portion of each face that is evaluated. Thus, in order to reduce processing demands, not every point of each face is evaluated, and points at a distance considered too far to affect reverberation are preferably ignored. It is assumed for the sake of the examples shown in FIGS. **6**A and **6**B that all of the points spanned by arrays **610***a* and **650***a* and which are considered are in a reverberant range, both laterally and in distance.

From the data read into the depth and stencil buffers, intermediate values representing the environment portrayed on the sampled portions of the faces are calculated. In one embodiment of the present invention, these intermediate vales include a mean distance, a mode distance, a median distance, and a mean hardness for each face. The mean distances and mean hardness can be mathematically determined by totaling the values for these parameters that are stored in the depth and stencil buffers, respectively, and dividing by the number of points sampled. For example, the mean distance for points included in array **610***b* is approximately 81 units, and the mean hardness is approximately 92. The mean distance for points included in array **650***b* is 5.75 feet and the mean hardness is 223.

To determine the most represented or mode distance and the median distance, histograms **700** and **760** shown in FIGS. **7**A and **7**B, respectively, are created to derive intermediate values for each face of the cubemap. Histogram **700** charts values collected from array **610***a* (FIG. **6**A), and for each unit distance **710**, plots the number of instances **720** of points located at that distance. Histogram **700** shows five instances **730** of points at a distance of 70 units, five additional instances **740** of points at a distance of 75 units, and six instances **750** of points at a distance of 95 units. Thus, the median distance is 75 units and the mode distance is 95 units. Distances analyzed in the histogram may include a plurality of discrete distances, such as 75 units, or distance ranges, such as between 70 and 79 units. Histogram **760** charts values collected from array **650***a* (FIG. **6**B), and for each unit distance **770**, plots a number of instances **780** of points located at that distance. Histogram **760** shows four instances **790** of

points at a distance of five units and 12 instances **795** of points at a distance of six units. The median distance and mode distances are each six units.

Embodiments of the present invention may use histogram analysis to further refine analysis of the computer-generated environment. For example, using information derived from histograms about the computer-generated environment, multiple mode distances may be used to determine distance to multiple features of the computer-generated environment in order to derive reverberation characteristics associated with those multiple features. Thus, as shown in FIG. **7**B for example, reverberation characteristics may be derived from features at a first mode distance, where there are 12 instances **795** of points at a distance of six units and from features at a second mode distance where there are four instances **790** of points at a distance of five units. For the points identified at each of those mode distances, hardness histograms may be generated to determine a mode hardness of points at each distance, or multiple mode hardnesses at each distances. Using the relative hardness of the materials, the distance to the points, and/or the proportion of points at each distance, associated with the points, reverberation can be attributed to each of the features identified.

For example, in evaluating the graphics data, it may be determined that a first mode distance range 10-15 meters away from the position of interest, and points at the first mode distance includes 40% of the points being evaluated. A second mode distance may be at a distance range 20-25 meters away from the position of interest, and points at the second mode distance includes 36% of the points being evaluated. For points at the first mode distance, a first composition histogram may indicate that a first mode hardness having a maximum hardness of FF, while at the second mode distance, a second composition histogram may indicate a first mode hardness having a lesser hardness value of CF. From these environmental aspects, reverberation attributable to the points having a first mode hardness at the first mode distance and second mode distance can be determined and used to simulate the reverberation. Alternatively, any desired number of mode distances and/or mode hardnesses at each of these distances, or any desired number of mode hardnesses and/or mode distances for each of these hardnesses, can be used to derive a plurality delay lines to create a more detailed reverberation profile for the computer-generated environment.

In sum, by identifying multiple features in the graphics data and analyzing the composition of and distance to the features, embodiments of the present invention may more closely approximate the manner in which reverberation of sound occurs in the physical world. Thus, although additional processing resources are required in deriving environmental parameters associated with multiple features and/or multiple distances in either preprocessing or real-time processing of the computer-generated environment, a more realistic set of assessment reverberation characteristics may result.

Furthermore, in another embodiment of the present invention, a plurality of reverberation characteristics may be derived for each position of interest. The plurality of reverberation characteristics may correspond to a plurality of aspects of the position of interest, such as left and right sides of the position of interest or forward and rearward faces of the position of interest. As a result, if separate left and right and/or forward and rear audio channels are available, reverberation characteristics can be applied to each of those channels to provide a more vivid or realistic multi-dimensional experience. Thus, for example, if in the computer generated environment, the position of interest includes a wide open space to a left side and a confined space of hard surfaces to the right side, reverberation will be applied to more accurately apply reverberation such that a user will experience more reverberation from a right audio channel than a left audio channel.

To derive the multiple sets of reverberation characteristics corresponding to the different aspects of the position of interest, secondary positions of interest actually may be derived from each position of interest, with reverberation characteristics derived for each of the secondary positions of interest. Thus, using the previous example where the position of interest includes a wide open space to a left side and a confined space of hard surfaces to the right side, a secondary left position of interest may be defined as offset to the left of the position of interest by a predetermined amount, while a secondary right position of interest may be defined as offset to the right of the position of interest by a predetermined amount. By determining the reverberation characteristics for both the secondary left position of interest and secondary right position of interest, appropriate reverberation characteristics may be derived to apply to separate left and right audio channels.

Adjustment of Values Affecting Reverberation

In one embodiment of the present invention, these values are then combined to derive an overall value for selected faces of the cubemap in reaching an overall environmental assessment used in determining the reverberation for the position of interest. In combining selected faces, a total number of points sampled and a total number of points within a prescribed range of distances are counted, as further described below. In one embodiment of the invention, the mean distances and mean hardness determined for each face may be weighted rather than simply based upon an average. For example, in the example of an automobile racing environment, it may be desirable to attribute more reverberation to features looming ahead to allow and enable a user to more realistically sense the effect on sound caused by such features before the features pass from view. Accordingly, features positioned forward toward the direction of expected motion may be assigned a higher weight than those in the other directions, i.e., on the other faces of the cubemap. Similarly, when values from the faces are combined to represent an overall value surrounding the position of interest, values of particular faces may be weighted more heavily. Thus, in the example of the automobile racing game, if it is desirable for dramatic effect (or to provide greater realism) to attribute more reverb to overpasses, overhead signs, and tunnels, the overhead face may be assigned greater weight.

In one embodiment of the present invention, weights assigned, ranges used in sampling features, and various other variables affecting reverberation may be adjusted by an operator via a user interface. FIGS. **8**A-**8**D show a series of exemplary interface screens listing adjustments an operator might make. More specifically, FIG. **8**A shows a "CUBEMAP PREPROCESSING PARAMETERS" screen **800** that represents a top-level menu of options an operator may adjust. A cursor **802***a* identifies an operator selection. Thus, for example, from screen **800**, an operator can select options "MINDISTANCE" **804** or "MAXDISTANCE" **806** to adjust a minimum and maximum unit distance from the position of interest, respectively, delineating limits on a scale used in interpolating values, as described below.

Moving the cursor to some options invokes a submenu enabling values related to the option to be adjusted, as shown in FIG. **8**B. A screen **820** is a "CUBEMAP PREPROCESSING FACEWEIGHT/FOCUSING" screen enabling an operator to adjust weights assigned to a particular face and/or portions of that face. Screen **820** is invoked by the operator

positioning a cursor **802***b* over a selection **822** representing "FACEUP," which represents the overhead face of the cubemap. Choosing "FACEUP" **822** invokes a submenu **824** listing a number of values the operator can adjust to vary reverberation derived from the overhead face of the cubemap. From submenu **824**, the operator can adjust, for example, a weight **826** assigned to the overhead face in computing overall values for the cubemap surrounding the current position of interest. In the example of FIG. **8**B, the operator assigns a weight **826** of "10" to provide maximum emphasis on overhead structures in generating reverberation. From submenu **824**, a number of other values may also be set, for example, a "ZFOCUSCENTER" **828** and a "ZFOCUSWIDTH" **830** can be set by the operator to indicate where the selected face will be sampled in deriving environmental parameters from the face.

In addition to making adjustments that affect how an embodiment of the present invention will derive values from faces of the cube map, an operator also may tune values of the property set that will determine the reverberation at runtime. FIG. **8**C shows a "PROPERTY SCALING FOR RUNTIME DATA" screen **840** enabling the operator to select limits of ranges for various property set values. "REVERBVOLUMENORM" **842** is a value determined in preprocessing that establishes a nominal reverb volume based from the graphics data for a particular preprocessed position. "REVERBVOLUMELERP" **843** is a linear interpolation of "REVERBVOLUMENORM" **842** between "REVERBVOLUMENORMMIN" **844** and "REVERBVOLUMENORMMAX" **846** for each actual position being processed, with "REVERBVOLUMENORMMIN" **842** and "REVERBVOLUMENORMMAX" **844** representing the upper and lower limits, respectively of "REVERBVOLUMELERP" **843**. The operator can adjust "REVERBVOLUMENORMIN" **844**, and "REVERBVOLUMENORMMAX" **846** to ensure a minimum amount of reverberation and limit the maximum degree of reverberation volume, respectively. In FIG. **8**C, "REVERBVOLUMENORMMIN" **844** is set to 0, thus, "REVERBVOLUMELERP" **843** will not yield a value less than 0. "REVERBVOLUMENORMMIN" **844** could be set to any desired level, in one embodiment of the present invention, between 0.0 0.0 and 1.0 that will determine the maximum dryness or maximum wetness, respectively, of the reverb volume attributed to the position being processed. As shown in FIG. **8**D, "REVERBVOLUMENORMMAX" **846** is set to 0.242188, thus, "REVERBVOLUMELERP" **843** will not yield a value in excess of 0.24188 for the position being processed. Using "PROPERTY SCALING FOR RUNTIME DATA" screen **840**, the operator can thus adjust the values that may be interpolated from the preprocessing data derived from the graphics data for preprocessed positions.

Similarly, FIG. **8**D shows an "I3DL2 PARAMETER WET-DRY SCALING" screen **860** that enables the operator to adjust scales of property set values. Values shown on screen **860** generally represent default values. For example, the default for a "DECAYTIME" parameter **862**, which reflects the time passing before a sound's reverberation becomes inaudible in the I3DL2 specification is one second, as shown in FIG. **8**D. However, the operator can adjust this value to cause the reverberations to become inaudible more quickly or more slowly. The operator also can adjust the other property set value defaults to cause the reverberation to be more "wet" or more "dry" and change other affects.

Logical Steps for Automatically Deriving and Applying Reverberation Parameters

In one embodiment of the present invention, environmental characteristics are derived from cubemaps surrounding a plurality of positions of interest throughout the computer-generated environment. These environmental parameters include the mean distances, mean hardness, median distances, mode distances, number of points evaluated, and number of points in range, as described above, in connection with FIGS. **6**A through **7**B. These environmental parameters are reverberation characteristics from which reverberation property set values can be computed at runtime. Thus, in one embodiment of the present invention, these environmental parameters are derived from the graphics data describing the computer-generated environment for each of a plurality of positions of interest and are stored in association with the positions of interest, along with the data describing the computer-generated environment. Then, upon execution of the computer-generated environment during runtime, the environmental parameters are retrieved as the graphics data are rendered. From the environmental parameters, reverberation property set values used by I3DL2 specification or other reverberation parameters are derived at runtime. The number of environmental parameters is less than the number of property set values. Therefore, fewer values need to be derived in preprocessing. Further, fewer values need to be stored along with the rest of the data describing the computer-generated environment. Deriving the property set values from the environmental characteristics is computationally simple, and does not overtax the processing capabilities at runtime.

FIG. **9** is a flow diagram **900** illustrating the logical steps for generating the environmental parameters during preprocessing, and FIG. **10** is a flow diagram **1000** illustrating the logical steps for deriving the property set values from the environmental parameters upon execution (i.e., at runtime). If desired, however, the property set values themselves can be derived in preprocessing and stored in association with the positions of interest.

Flow diagram **900** in FIG. **9** begins at a step **902**. At a step **904**, preprocessing preferences affecting the weighting and tuning of the environmental parameters, are accessed, as described above in connection with FIGS. **8**A-**8**B. At a decision step **906**, it is determined if changes in the preferences are desired. If so, at a step **908**, an operator can change the default preferences or other preferences previously set. If it is determined at decision step **906** that no changes are desired, or once desired changes are made at step **908**, flow diagram **900** proceeds to a step **910**, where graphics data describing the computer-generated environment are accessed.

At a step **912**, flow diagram **900** accesses a next position of interest in the computer-generated environment. The positions of interest for which environmental parameters are derived can be selected in a number of ways. In one embodiment of the present invention, using the example of an automobile racing simulation, the positions of interest might be chosen to represent a plurality of positions at pre-selected intervals around a race course. For example, the positions of interest might be designated as being spaced apart every two meters from a starting point of the course, through its finish line. At a step **914**, data describing a next face of the cubemap for the position of interest are accessed. At a step **916**, as described above in connection with FIGS. **5**A-**7**B, data from the face are rendered to derive the environmental parameters. At a step **918**, for each desired point (including those within a desired distance and lateral range of the position of interest), the distance to the point is stored in a depth buffer. At a step **920**, for each desired point, a hardness value is stored in the

stencil buffer. As described above, in one embodiment of the present invention, a lookup table associates a hardness value with each texture of features that may be included in the computer-generated environment. Upon accessing each point, the hardness value is retrieved for the texture and is stored in the stencil buffer.

Once the face has been rendered to store the distance and hardness in the appropriate buffers, at a step **922**, distance histograms are generated, as described above in connection with FIGS. **7**A and **7**B. At a step **924**, as also described in connection with FIGS. **7**A and **7**B, the median and mode distances are determined from the data retrieved from the cubemap face. At a step **926**, other environmental parameters for the face, including the mean hardness and mean distance, are calculated.

At a decision step **928**, it is determined if all the faces have been processed. If not, flow diagram **900** loops to step **914** to access data for the next face of the cubemap for the current position of interest. On the other hand, if it is determined at decision step **928** that all the cubemap faces for the current position of interest have been processed, at a step **930** the environmental parameters are combined and/or weighted to derive the composite environmental parameters for the current position of interest. At a step **932**, the environmental parameters are associated and/or stored in connection with the current position of interest so that the environmental parameters can be retrieved when the computer-generated environment is rendered upon execution.

At a decision step **934**, it is determined if preprocessing has been completed for all the positions of interest. If not, flow diagram loops to step **912** where the data for the next position of interest is accessed, and the successive steps are performed for that position of interest, as described above. On the other hand, if it is determined at decision step **934** that preprocessing is complete for all positions of interest, the reverberation preprocessing ends at a step **936**.

It should be appreciated that the process described by flow diagram **900** is largely automatic. Environmental parameters from which the property set values can be derived are determined from the graphics data. Operators and designers are enabled to adjust values and repeat preprocessing until they are satisfied with the results. However, operator intervention is not required. The option that enables an operator to selectively modify the automatically selected values is thus very different from conventional methods that require reverberation property set values to be assigned manually throughout the computer-generated environment.

Derivation of environmental parameters as described in connection with FIGS. **6**A-**6**B, **7**A-**7**B, and **9** is computationally straightforward. As described above, values are derived for each desired cube face for a position of interest:

```
struct REVERB_CUBE_FACE
{
   float m_fMeanDistance;
   float m_fModeDistance;
   float m_fMedianDistance;
   float m_fMeanHardness;
};
```

From the data for each cube face, the values are combined to determine overall environmental parameters:

```
struct REVERB_COMBINED_DATA
{
   float m_fMeanDistance;
   float m_fModeDistance;
   float m_fTopModeDistance;
   float m_fMeanHardness;
   int  m_nTotalSamples;      // 128×128×6 possible pixels
   int  m_nInRangeSamples;    // 128×128×6 possible pixels
how many are in range
};
```

It will be appreciated that, in one embodiment of the invention, it may be desirable to emphasize reverberation for overhead structures appearing on overhead cubemap faces for dramatic effect. Accordingly, a mode distance for the overhead face, "TopModeDistance" may be included in the overall derivation to ensure emphasis to be attributed to a most-commonly occurring distance of features appearing overhead. As described above, data for each face is partially derived using straightforward histogramatic analysis:

```
struct PER_FACE_DATA
{
   float m_fFaceWeight;
   int  m_nCarZFocusCenter; // pixel along car Z that is Most important
   to reverb
   int   m_nCarZFocusWidth; // pixels along car Z that is are used
for reverb; outside of width from center pixels are ignored
   bool m_bSpewNextHistogram;
   CDepthHistogram m_DepthHistogram;
   CDepthHistogram m_HardnessHistogram;
   int m_nDepthMode;
   float m_fDepthModeNormInv; // 0.0 = far; 1.0 = near
   // do frequency analysis on depth histogram
   CDepthHistogram m_freqhist;
   int m_nMode0Class;
   float m_fMode0Frequency; // the frequency that occurs most often
   in depth
   int m_nMode1Class;
   float m_fMode1Frequency;
   REVERB_CUBE_FACE m_Results;
};
```

With the reverberation characteristics being derivable from the environmental parameters that were automatically determined and stored according to flow diagram **900**, reverberation property set values are readily generated at runtime according to the logical steps illustrated in flow diagram **1000** of FIG. **10**. Flow diagram **1000** begins at a step **1002**. At a step **1004**, the location of the current position within the computer-generated environment is determined. At a step **1006**, environmental parameters stored in association with preprocessed positions of interest are accessed. At a decision step **1008**, it is determined if environmental parameters were preprocessed and stored for the current position. If so, at a step **1010**, the environmental parameters are retrieved. On the other hand, if it is determined at decision step **1008** that environmental parameters were not preprocessed and stored for the current position, at a step **1012**, the two closest positions for which environmental parameters were preprocessed are identified. At a step **1014**, environmental parameters for each of the two closest positions are then retrieved. At a step **1016**, the retrieved environmental parameters are interpolated to derive environmental parameters for the current position. In one embodiment of the present invention, the environmental parameters retrieved are interpolated linearly as a function

of a relative distance from the current position of interest to each of the closest positions for which environmental values are available.

Regardless of whether the environmental parameters were preprocessed and simply retrieved for the position of interest at step **1010** or were determined by interpolation at step **1016**, at a step **1018**, the reverberation property set values are calculated. In one embodiment of the present invention, the reverberation property set values are derived by linear interpolation. As described in connection with FIGS. **8A-8D**, an operator can set reverberation values to range from the values for an idealized large open space, where no surfaces exist that will cause reverberation of sound, to the values for a small closed space where sound readily reverberates. By setting the limits as described above for maximum reverberation, maximum distances, and similar values, reverberation property set values can thus be calculated by interpolating the property set values according to environmental parameters with which the property set values are associated.

In one embodiment of the present invention, interpolation is performed using a conventional linear interpolation. For example, a "LerpClamp" routine may be invoked to determine linear interpolation, based on provided values between a predetermined minimum and maximum:

```
//Linearly interpolates and clamps an f32 value such that:
//if(inVal < inMin) return outMin
//else if(inVal > inMax) return outMax
//else interpolate the value
f32 LerpClampF32(f32 inVal, f32 inMin, f32 inMax, f32 outMin, f32
outMax)
{
    //Validate data
    CheckMinMaxF32( inMin, inMax);
    //MAssert(inMin <= inMax);
    //If we should clamp low
    if(inVal <= inMin)
    {
      return outMin;
    }
    else if(inVal >= inMax) //If we should clamp high
    {
      return outMax;
    }
    else //We should interpolate
    {
      return LerpF32(outMin, outMax, (inVal - inMin) / (inMax -
      inMin));
    }
}
//Returns the linear interpolation of two f32 values, based on the
interpolant f32 LerpF32(f32 val0, f32 val1, f32 interpolant)
{
  return val0 + (interpolant * (val1 - val0));
}
```

Using LerpClamp or a similar routine and the appropriate arithmetic calculations, reverberation property set values are derived from environmental parameters determined by pre-processing (as shown in FIG. 9):

```
void CAudioReverb::UpdateReverbFromSplinePoint( REVERB_
COMBINED_DATA & reverbpoint)
{
  ////////////////////////////////////////////////////////////////////////
  // compute lerps from big open(0.0) space to small closed space(1.0)
  m_Cubemap.m_CombinedData = reverbpoint;
    // decay time longer for more pixels in audible range
    m_fDecayTimeNorm=reverbpoint.m_nInRangeSamples
  /float(reverbpoint.m_nTotalSamples);
    // reverb louder for more pixels in predetermined audible range or
    m_fReverbVolumeNorm=reverbpoint.m_nInRangeSamples
/float(reverbpoint.m_nTotalSamples);
      // reverb delay longer for further mean distance
      m_fReverbDistance = reverbpoint.m_fMeanDistance;
      // rever HF ratios so harder surfaces reflect HF more
```

-continued

```
      m_fRoomHFHardness = reverbpoint.m_fMeanHardness;
      // rever HF ratios so harder surfaces reflect HF more
      m_fDecayHFHardness = reverbpoint.m_fMeanHardness;
        m_fDecayTimeLerp=LerpClampF32(m_fDecayTimeNorm,
m_fDecayTimeNormMin, m_fDecayTimeNormMax, 0.0f, 1.0f);
      m_fReverbVolumeLerp=LerpClampF32(m_fReverbVolumeNorm,
m_fReverbVolumeNormMin, m_fReverbVolumeNormMax, 0.0f, 1.0f);
        m_fReverbDelayLerp=1.0f - LerpClampF32(m_fReverbDistance,
m_fReverbDistanceMin, m_fReverbDistanceMax, 0.0f, 1.0f);
      m_fRoomHFHardnessLerp=LerpClampF32(m_fRoomHFHardness,
m_fRoomHFHardnessMin, m_fRoomHFHardnessMax, 0.0f, 1.0f);
        m_fDecayHFHardnessLerp=LerpClampF32(m_
fDecayHFHardness, m_fDecayHFHardnessMin, m_
fDecayHFHardnessMax, 0.0f, 1.0f);
  // start with current reverb settings
    DSI3DL2LISTENER environment = g_AudioCore.m_Reverb.m_
    dl2Current;
    // adjust delays and decay based on distance info
    environment.flDecayTime=LerpF32(m_dl2DrySpace.flDecayTime,
m_dl2WetSpace.flDecayTime, m_fDecayTimeLerp);
    environment.lReflections=LerpF32(m_dl2DrySpace.lReflections,
m_dl2WetSpace.lReflections, m_fReverbVolumeLerp);
    environment.flReflectionsDelay=LerpF32(m_
dl2DrySpace.flReflectionsDelay, m_dl2WetSpace.flReflectionsDelay,
m_fReverbDelayLerp);
    environment.lReverb=LerpF32(m_dl2DrySpace.lReverb,          m_
dl2WetSpace.lReverb, m_fReverbVolumeLerp);
    environment.flReverbDelay=LerpF32(m_
dl2DrySpace.flReverbDelay, m_dl2WetSpace.flReverbDelay, m_
fReverbDelayLerp);
    // adjust HF ratios based on hardness info
    environment.lRoomHF=LerpF32(m_dl2DrySpace.lRoomHF,
m_dl2WetSpace.lRoomHF, m_fRoomHFHardnessLerp);
    environment.flDecayHFRatio=LerpF32(m_
dl2DrySpace.flDecayHFRatio, m_dl2WetSpace.flDecayHFRatio, m_
fDecayHFHardnessLerp);
    g_AudioCore.m_Reverb.SetEnvironment( environment );
  }
```

The reverberation for each position of interest can thus readily be determined at runtime as the user moves about in the computer-generated environment. The results are consistent and realistic, and more importantly, are determined without requiring manual setting of parameters for each potential position of interest in the environment. Accordingly, a substantial savings in labor is achieved, and the resulting reverberation effects heard at runtime are typically much more realistic.

Exemplary Computing System for Implementing Present Invention

With reference to FIG. **11**, an exemplary system suitable for implementing various portions of the present invention is shown. The system includes a general purpose computing device in the form of a conventional PC **1120**, provided with a processing unit **1121**, a system memory **1122**, and a system bus **1123**. The system bus couples various system components including the system memory to processing unit **1121** and 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. The system memory includes read only memory (ROM) **1124** and random access memory (RAM) **1125**. A basic input/output system (BIOS) **1126**, containing the basic routines that help to transfer information between elements within the PC **1120**, such as during start up, is stored in ROM **1124**. PC **1120** further includes a hard disk drive **1127** for reading from and writing to a hard disk (not shown), a magnetic disk drive **1128** for reading from or writing to a removable magnetic disk **1129**, and an optical disk drive **1130** for reading from or writing to a removable optical disk **1131**, such as a compact disk-read only memory (CD-ROM) or other optical media.

Hard disk drive **1127**, magnetic disk drive **1128**, and optical disk drive **1130** are connected to system bus **1123** by a hard disk drive interface **1132**, a magnetic disk drive interface **1133**, and an optical disk drive interface **1134**, respectively. The drives and their associated computer readable media provide nonvolatile storage of computer readable machine instructions, data structures, program modules, and other data for PC **1120**. Although the exemplary environment described herein employs a hard disk, removable magnetic disk **1129**, and removable optical disk **1131**, it will be appreciated by those skilled in the art that other types of computer readable media, which can store data and machine instructions that are accessible by a computer, such as magnetic cassettes, flash memory cards, digital video disks (DVDs), Bernoulli cartridges, RAMs, ROMs, and the like, may also be used in the exemplary operating environment.

A number of program modules may be stored on the hard disk, magnetic disk **1129**, optical disk **1131**, ROM **1124**, or RAM **1125**, including an operating system **1135**, one or more application programs **1136**, other program modules **1137**, and program data **1138**. A user may enter commands and information in PC **1120** and provide control input through input devices, such as a keyboard **1140** and a pointing device **1142**. Pointing device **1142** may include a mouse, stylus, wireless remote control, or other pointer. Other input devices (not shown) may include a microphone, joystick, haptic joystick, yoke, foot pedals, game pad, satellite dish, scanner, camera, or the like. These and other input/output (I/O) devices are often connected to processing unit **1121** through an I/O device interface **1146** that is coupled to the system bus **1123**. The term I/O interface is intended to encompass each interface specifically used for a serial port, a parallel port, a game port, a keyboard port, a Firewire (IEEE 1394) port, and/or a universal serial bus (USB) interface. A display **1147** can be connected to system bus **1123** via an appropriate interface, such as a video graphics adapter **1148**. It will be appreciated that PCs are often coupled to other peripheral output devices (not shown), such as speakers (through a sound card or other audio interface—not shown) and printers.

The present invention may be practiced on a single machine, although PC **1120** can also operate in a networked environment using logical connections to one or more remote computers, such as a remote computer **1149**. Remote computer **1149** may be another PC, a server (which is typically generally configured much like PC **1120**), a router, a network PC, a peer device, or a satellite or other common network node, and typically includes many or all of the elements described above in connection with PC **1120**, although only an external memory storage device **1150** has been illustrated in FIG. **11**. The logical connections depicted in FIG. **11** include a local area network (LAN) **1151** and a wide area network (WAN) **1152**. Such networking environments are common in offices, enterprise wide computer networks, intranets, and the Internet.

When used in a LAN networking environment, PC **1120** is connected to LAN **1151** through a network interface or adapter **1153**. When used in a WAN networking environment, PC **1120** typically includes a modem **1154**, or other means such as a cable modem, Digital Subscriber Line (DSL) interface, or an Integrated Service Digital Network (ISDN) interface for establishing communications over WAN **1152**, such as the Internet. Modem **1154**, which may be internal or external, is connected to the system bus **1123** or coupled to the bus via I/O device interface **1146**, i.e., through a serial port. In a networked environment, program modules, or portions thereof, used by PC **1120** may be stored in the external memory storage device **1150**. It will be appreciated that the network connections shown are exemplary and other means of establishing a communications link between the computers may be used, such as wireless communication and wide band network links.

Although the present invention has been described in connection with the preferred form of practicing it and modifications thereto, those of ordinary skill in the art will understand that many other modifications can be made to the present invention within the scope of the claims that follow. Accordingly, it is not intended that the scope of the invention in any way be limited by the above description, but instead be determined entirely by reference to the claims that follow.

The invention in which an exclusive right is claimed is defined by the following:

1. A computer implemented method for deriving reverberation characteristics for a computer-generated environment from graphics data that are used by a computing system having a processor and reverberation engine for visually displaying contents of the computer-generated environment, comprising the computing system performing steps of:

(a) selecting a position of interest in the computer-generated environment;

(b) accessing the graphics data that are used for displaying at least a portion of the computer-generated environment viewable from the position of interest when the computer-generated environment is rendered; and

(c) automatically deriving reverberation characteristics for the position of interest from the graphics data for each of a plurality of points in the portion of the computer-generated environment,

the reverberation characteristics being derived at least in part from:

(i) a distance of the point from the position of interest; and

(ii) a hardness value associated with the point, the hardness value indicating a relative level of acoustic reflectance that is associated with the point~wherein the reverberation characteristics include a plurality of environmental parameters from which the property set values are calculable when the computer-generated environment is rendered, and wherein the environmental parameters for the points include at least two of:

a mean distance to the points from the position of interest;

a mode distance to the points from the position of interest;

a median distance to the points from the position of interest;

a mean hardness value associated with the points; and

a total number of points in the portion of the computer-generated environment.

2. The method of claim **1**, wherein the property set values are configured to be supplied to a reverberation engine that conforms to at least one of:

(a) a IA3DL2 specification; and

(b) a EAX specification.

3. The method of claim **1**, further comprising the step of identifying a subset of the points describing the portion of the computer-generated environment viewable from the position of interest, the subset including points within at least one of:

(a) a predefined distance range from the position of interest; and

(b) a lateral range relative to the position of interest.

4. The method of claim **1**, further comprising the step of identifying a plurality of subsets of points describing the portion of the computer-generated environment, each of the plurality of subsets of points including points at:

(a) a plurality of mode distances from the position of interest; and

(b) a plurality of mode hardnesses of points at a particular distance.

5. The method of claim **4**, wherein separate delay lines relating to each of the plurality of subsets of points are used in developing the reverberation characteristics for the position of interest.

6. The method of claim **3**, wherein the environmental parameters further include a total number of points within the subset.

7. The method of claim **6**, further comprising the step of deriving, in proportion to the total number of points within the subset to the total number of points, a portion of the property set values that includes at least one of:

(a) a reverb decay time; and

(b) a reverb volume.

8. The method of claim **1**, further comprising the step of deriving, in proportion to the mean hardness value associated with the points, a portion of the property set values that includes at least one of:

(a) a decay high frequency ratio;

(b) a room high frequency attenuation; and

(c) a reflection delay time.

9. The method of claim **1**, further comprising the step of deriving, in proportion to distances from the position of interest to the points, a portion of the property set values that includes at least one of:

(a) a decay time;

(b) a reflection intensity;

(c) a reflection delay time; and

(d) a reverb intensity.

10. The method of claim **1**, wherein the graphics data include a cubemap describing the visually displayable contents of the computer-generated environment that are viewable from the position of interest, and wherein the reverberation characteristics for the position of interest are based on points representable on at least one of the faces of the cubemap.

11. The method of claim **10**, wherein the reverberation characteristics derived from any face of the cubemap are weighted according to at least one of:

(a) a face of the cubemap with which a point is associated; and

(b) a position within the face with which the point is associated.

12. The method of claim **1**, wherein the hardness value is derivable from a feature in the computer-generated environment with which the point is associated.

13. The method of claim **1**, wherein the hardness value is retrieved from a hardness value table listing hardness values associated with materials comprising features potentially included in the computer-generated environment.

14. The method of claim **1**, further comprising the step of automatically deriving a plurality of reverberation characteristics for the position of interest from the graphics data corresponding to a plurality of aspects of the position of interest and applying each of the plurality of reverberation characteristics to audio channels presented upon execution of the computer-generated environment corresponding to the aspects of the position of interest.

15. The method of claim **14**, wherein the plurality of reverberation characteristics for the position of interest are determined by identifying a plurality of secondary positions of interest corresponding to the aspects of the position of interest and determining the reverberation characteristics for each of the secondary positions of interest.

16. The method of claim **14**, wherein the aspects of the position of interest correspond to at least one of:

(a) lateral sides of the position of interest; and

(b) forward and rearward faces of the position of interest.

17. The method of claim **1**, further comprising the step of deriving the reverberation characteristics in a pre-processing step performed before the computer-generated environment is visually rendered.

18. The method of claim **17**, wherein the distance from the position of interest to each of the plurality of points is stored in a depth buffer and the hardness of each of the plurality of points is stored in a stencil buffer.

19. The method of claim **17**, further comprising the step of storing the reverberation characteristics with the position of interest such that the reverberation characteristics associated with the position of interest are retrievable when the computer-generated environment is visually rendered upon execution.

20. The method of claim **17**, further comprising the step of calculating a series of reverberation characteristics for a plurality of positions of interest within the computer-generated environment, the plurality of positions including at least one of:

(a) a plurality of positions selected by an operator; and

(b) a plurality of positions at predetermined intervals along an exemplary path through the computer-generated environment.

21. The method of claim **20**, further comprising the step of deriving reverberation characteristics for an additional position for which the reverberation characteristics were not previously calculated, by interpolating the reverberation characteristics for at least two other positions of interest that are proximate to the additional position.

22. The method of claim **1**, further comprising the step of enabling an operator to selectively adjust at least one of:

(a) allowable ranges of the property set values; and

(b) operands used in deriving the property set values from the reverberation characteristics.

23. The method of claim **1**, further comprising the step of adjusting reverberation for the position of interest to provide a desired effect, by using reverberation characteristics for an alternate position of interest that is one of:

(a) ahead of the position of interest in the computer-generated environment; and

(b) behind the position of interest in the computer-generated environment.

24. A memory medium having machine executable instructions stored for carrying out the steps of claim **1**.

25. A computer-implemented method for deriving reverberation characteristics from data used by a computing system having a processor and reverberation engine for visually displaying a computer-generated environment, comprising the computing system performing steps of:

(a) identifying a plurality of positions of interest within the computer-generated environment;

(b) preprocessing the computer-generated environment before the computer-generated environment is visually rendered, to access cubemaps from the data used for visually displaying at least a portion of the computer-generated environment viewable from each of the positions of interest when the computer-generated environment is rendered, a plurality of cubemaps being used for the plurality of positions of interest;

(c) deriving reverberation characteristics for each position of interest from each of a plurality of points in the cubemap for the position of interest, the reverberation characteristics being derived at least in part from:

(i) a distance from the position of interest; and

(ii) a hardness value associated with the point, said hardness value being indicative of an acoustic reflectivity at the point; and

(d) storing the reverberation characteristics in association with each position of interest such that the reverberation characteristics are retrievable when the computer-generated environment is visually rendered upon execution; and

wherein the reverberation characteristics include a plurality of environmental parameters from which the property set values are calculable when the computer-generated environment is rendered, and

wherein the environmental parameters for the points include at least two of:

a mean distance to the points from the position of interest;

a mode distance to the points from the position of interest;

a median distance to the points from the position of interest;

a mean hardness value associated with the points; and

a total number of points in the portion of the computer-generated environment.

26. The method of claim **25**, wherein the reverberation characteristics include at least one of:

(a) property set values usable by a reverberation engine; and

(b) a plurality of environmental parameters from which the property set values are calculable when the computer-generated environment is rendered.

27. The method of claim **26**, wherein the property set values are configured to be supplied to a reverberation engine that conforms to at least one of:

(a) an IA3DL2 specification; and

(b) an EAX specification.

28. The method of claim **26**, wherein the environmental parameters for the points include at least one of:

(a) a mean distance from the position of interest to the points;

(b) a mode distance from the position of interest to the points;

(c) a median distance from the position of interest to the points;

(d) a mean hardness associated with the points; and

(e) a total number of points in the portion of the computer-generated environment.

29. The method of claim **28**, further comprising the step of identifying a subset of the points describing the portion of the computer-generated environment viewable from the position of interest, the subset including points within at least one of:

(a) a distance range from the position of interest; and

(b) a lateral range relative to the position of interest.

30. The method of claim **28**, further comprising the step of identifying a plurality of subsets of points describing the portion of the computer-generated environment, each of the plurality of subsets of points including points at:

(c) a plurality of mode distances from the position of interest; and

(d) a plurality of mode hardnesses of points at a particular distance.

31. The method of claim **30**, wherein separate delay lines relating to each of the plurality of subsets of points are used in developing the reverberation characteristics for the position of interest.

32. The method of claim **29**, wherein the environmental parameters further include a total number of points within the subset.

33. The method of claim **32**, further comprising the step of deriving, in proportion to the total number of points within the subset to the total number of points, a portion of the property set values that includes at least one of:

(a) a reverb decay time; and

(b) a reverb volume.

34. The method of claim **28**, further comprising the step of deriving, in proportion to the mean hardness of the points, a portion of the property set values that includes at least one of:

(a) a decay high frequency ratio;

(b) a room high frequency attenuation; and

(c) a reflections delay time.

35. The method of claim **28**, further comprising the step of deriving, in proportion to distances from the position of interest to the points, a portion of the property set values that includes at least one of:

(a) a decay time;

(b) a reflection intensity;

(c) a reflection delay time; and

(d) a reverb intensity.

36. The method of claim **25**, wherein the reverberation characteristics derived from each of a plurality of faces within a cubemap is weighted according to at least one of:

(a) a face of the cubemap with which the point is associated; and

(b) a position within the face of the cubemap with which the point is associated.

37. The method of claim **25**, wherein the hardness value is derivable from a feature with which the point is associated.

38. The method of claim **25**, wherein the hardness value is retrieved from a hardness value table listing hardness values associated with materials comprising features potentially included in the computer-generated environment.

39. The method of claim **25**, further comprising the step of automatically deriving a plurality of reverberation characteristics for the position of interest from the graphics data corresponding to a plurality of aspects of the position of interest and applying each of the plurality of reverberation characteristics to audio channels presented upon execution of the computer-generated environment corresponding to the aspects of the position of interest.

40. The method of claim **39**, wherein the plurality of reverberation characteristics for the position of interest are determined by identifying a plurality of secondary positions of interest corresponding to the aspects of the position of interest and determining the reverberation characteristics for each of the secondary positions of interest.

41. The method of claim **39**, wherein the aspects of the position of interest correspond to at least one of:

(c) lateral sides of the position of interest; and

(d) forward and rearward faces of the position of interest.

42. The method of claim **25**, wherein the distance from the position of interest to each of the plurality of points is stored in a depth buffer, and wherein the hardness of each of the plurality of points is stored in a stencil buffer.

43. The method of claim **25**, wherein the plurality of positions of interest are identified according to at least one of:

(a) an operator selection; and

(b) a predetermined interval along an exemplary path through the computer-generated environment.

44. The method of claim **25**, further comprising the step of deriving reverberation characteristics for an additional position for which the reverberation characteristics were not previously calculated, by interpolating the reverberation characteristics for at least two other positions of interest that are proximate to the additional position.

45. The method of claim **26**, further comprising the step of enabling an operator to selectively adjust at least one of:

(a) allowable ranges of the property set values; and

(b) operands used in deriving the property set values from the reverberation characteristics.

46. The method of claim **25**, further comprising the step of adjusting reverberation for the position of interest to achieve a desired effect, by using reverberation characteristics for an alternate position of interest that is one of:

(a) ahead of the position of interest in the computer-generated environment; and

(b) behind the position of interest in the computer-generated environment.

47. A memory medium having machine executable instructions stored for carrying out the steps of claim **25**.

48. A system for deriving reverberation characteristics for a computer-generated environment from graphics data used for visually displaying the computer-generated environment, comprising:

(a) at least one user input device;

(b) a display screen;

(c) a processor in communication with the input device and the display screen; and

(d) a memory in communication with the processor, the memory storing data and machine instructions that cause the processor to carry out a plurality of functions, including:

(i) selecting a position of interest in the computer-generated environment;

(ii) accessing the graphics data used for displaying at least a portion of the computer-generated environment viewable from the position of interest when the computer-generated environment is rendered; and

(iii) deriving reverberation characteristics for the position of interest from the graphics data describing each of a plurality of points in the portion of the computer-generated environment, the reverberation characteristics being derived at least in part from:

(A) a distance from plurality of points to the position of interest; and

(B) a hardness value associated with the point, said hardness value being indicative of an acoustic reflectivity at the point

wherein the reverberation characteristics include at least one of:

(a) property set values usable by a reverberation engine; and

(b) a plurality of environmental parameters from which the property set values are calculable when the computer-generated environment is rendered, and

wherein the environmental parameters for the points include at least two of:

a mean distance to the points from the position of interest; a mode distance to the points from the position of interest; a median distance to the points from the position of interest; a mean hardness value associated with the points; and a total number of points in the portion of the computer-generated environment.

49. The system of claim **48**, wherein the property set values are configured to be supplied to a reverberation engine conforming to at least one of:

(a) an IA3DL2 specification; and

(b) an EAX specification.

50. The system of claim **48**, wherein the machine instructions stored in the memory further cause the processor to identify a subset of the points for the portion of the computer-generated environment viewable from the position of interest, the subset including points within at least one of:

(a) a distance range from the position of interest; and

(b) a lateral range relative to the position of interest.

51. The system of claim **50**, wherein the machine instructions stored in the memory further cause the processor to identify a plurality of subsets of points describing the portion of the computer-generated, each of the plurality of subsets of points including points at:

(a) a plurality of mode distances from the position of interest; and

(b) a plurality of mode hardnesses of points at a particular distance.

52. The system of claim **51**, wherein separate delay lines relating to each of the plurality of subsets of points are used in developing the reverberation characteristics for the position of interest.

53. The system of claim **50**, wherein the environmental parameters further include a total number of points within the subset.

54. The system of claim **53**, wherein the machine instructions stored in the memory further cause the processor to derive, in proportion to the total number of points within the subset to the total number of points, a portion of the property set values that includes at least one of:

(a) a reverb decay time; and

(b) a reverb volume.

55. The system of claim **48**, wherein the machine instructions stored in the memory further cause the processor to derive, in proportion to the mean hardness of the points, a portion of the property set values that include at least one of:

(a) a decay high frequency ratio;

(b) a room high frequency attenuation; and

(c) a reflections delay time.

56. The system of claim **48**, wherein the machine instructions stored in the memory further cause the processor to derive, in proportion to distances to the points from the position of interest, a portion of the property set values that includes at least one of:

(a) a decay time;

(b) a reflection intensity;

(c) a reflection delay time; and

(d) a reverb intensity.

57. The system of claim **48**, wherein the graphics data includes a cubemap for the visually displayable contents of the computer-generated environment viewable from the position of interest, and wherein the reverberation characteristics for the position of interest are based on points representable on a plurality of faces of the cubemap.

58. The system of claim **57**, wherein the machine instructions stored in the memory further cause the processor to weight the reverberation characteristics derived from each of the plurality of faces according to at least one of:

(a) a face of the cubemap with which the point is associated; and

(b) a position within the face of the cubemap with which the point is associated.

59. The system of claim **48**, wherein the machine instructions stored in the memory further cause the processor to derive the hardness value from a feature with which the point is associated.

60. The system of claim **48**, wherein the machine instructions stored in the memory further cause the processor to retrieve the hardness value from a table listing hardness values associated with materials comprising features potentially included in the computer-generated environment.

61. The system of claim **48**, wherein the machine instructions stored in the memory further cause the processor to derive a plurality of reverberation characteristics for the position of interest from the graphics data corresponding to a plurality of aspects of the position of interest and applying each of the plurality of reverberation characteristics to audio channels presented upon execution of the computer-generated environment corresponding to the aspects of the position of interest.

62. The system of claim **61**, wherein the machine instructions stored in the memory further cause the processor to determine the plurality of reverberation characteristics for the position of interest by identifying a plurality of secondary positions of interest corresponding to the aspects of the position of interest and determining the reverberation characteristics for each of the secondary positions of interest.

63. The system of claim **61**, wherein the aspects of the position of interest correspond to at least one of:

(a) lateral sides of the position of interest; and

(b) forward and rearward faces of the position of interest.

64. The system of claim **48**, wherein the machine instructions stored in the memory further cause the processor to derive the reverberation characteristics in a pre-processing step performed before the computer-generated environment is visually rendered.

65. The system of claim **64**, wherein the machine instructions stored in the memory further cause the processor to store distances from the position of interest to each of the plurality of points in a depth buffer, and to store the hardness of each of the plurality of points in a stencil buffer.

66. The system of claim **64**, wherein the machine instructions stored in the memory further cause the processor to store the reverberation characteristics with the position of interest such that the reverberation characteristics are retrievable when the computer-generated environment is visually rendered upon execution.

67. The system of claim **64**, wherein the machine instructions stored in the memory further cause the processor to calculate a series of reverberation characteristics for a plurality of positions of interest within the computer-generated environment, the plurality of positions including at least one of:

(a) a plurality of positions selected by an operator; and

(b) a plurality of positions at predetermined intervals along an exemplary path through the computer-generated environment.

68. The system of claim **67**, wherein the machine instructions stored in the memory further cause the processor to derive reverberation characteristics for an additional position for which the reverberation characteristics were not previously calculated by interpolating the reverberation characteristics for at least two other positions of interest that are proximate to the additional position.

69. The system of claim **48**, wherein the machine instructions stored in the memory further cause the processor to enable an operator to selectively adjust at least one of:

(a) allowable ranges of the property set values; and

(b) operands used in deriving the property set values from the reverberation characteristics.

70. The system of claim **48**, wherein the machine instructions stored in the memory further cause the processor to adjust reverberation for the position of interest by using reverberation characteristics for an alternate position of interest that is one of:

(a) ahead of the position of interest in the computer-generated environment; and

(b) behind the position of interest in the computer-generated environment.

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