

Apparatus and Method for Encoding or Decoding of Precomputed Data for Rendering Early Reflections in AR/VR systems

5	<u>Description</u>
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The present invention relates to an apparatus and a method for encoding or decoding, and, in particular, to an apparatus and a method for encoding or decoding of precomputed data for rendering early reflections in augmented reality (AR) or virtual reality (VR) systems.

Further improving and developing audio coding technologies is a continuous task of audio coding research, wherein, it is intended to create a realistic audio experience for a listener, for example in augmented reality or virtual reality scenarios that takes audio effects such as reverberation, e.g., caused by reflections at objects, walls, etc. into account, while, at the same time, it is intended to encode and decode audio information with high efficiency.

One of these new audio technologies that aim to create an improved listening experience for augmented or virtual reality is, for example, MPEG-I. MPEG-I is the new under-development standard for virtual and augmented reality applications. It aims at creating AR or VR experiences that are natural, realistic and deliver an overall convincing experience, not only for the eyes, but also for the ears.

25 For example, using MPEG-I technologies, when hearing a concert in VR, a listener is not
rooted to just one spot, but can move freely around the concert hall. Or, for example,
MPEG-I technologies may be employed for the broadcast of e-sports or sporting events in
which users can move around the stadium while they watch the game.

Previous solutions enable a visual or acoustic experience from one observation point in what are known as the three degrees of freedom (3DoF). By contrast, the upcoming MPEG-I standard supports a full six degrees of freedom (6DoF). With 3DoF, users can move their heads freely and receive input from multiple sides. But with 6DoF, the user is able to move within the virtual space. They can walk around, explore every viewing angle, and even interact with the virtual world. MPEG-I technologies are likewise applicable for augmented reality (AR), in which the user acts within the real world that has been

extended by virtual elements. For example, you could arrange several virtual musicians within your living room and enjoy your own personal concert.

To achieve this goal, MPEG-I provides a sophisticated technology to produce a
5 convincing and highly immersive audio experience, and involves taking into account many aspects of acoustics. One example is sound propagation in rooms and around obstacles. Another is sound sources, which can be either static or in motion, wherein the latter produces the Doppler effect. The sound propagation shall have realistic radiation patterns and size. For example, MPEG-I technologies aim to take diffraction of sound around
10 obstacles or room corners into account and aim to provide an efficient rendering of these effects.

Overall, MPEG-I aims to provide a long-term stable format for rich VR and AR content. Reproduction using MPEG-I shall be possible both with dedicated receiver devices and on
15 everyday smartphones. MPEG-I aims to distribute VR and AR content as a next-generation video service over existing distribution channels, such that providers can offer users truly exciting and immersive experiences with entertainment, documentary, educational or sports content.

20 It is desirable that additional audio information, such as information on a real or virtual acoustic environment and/or their effects, such as reverberation, is provided for a decoder, for example, as additional audio information. Providing such information in an efficient way would be highly appreciated.

25 Summarizing the above, it would be highly appreciated, if improved concepts for audio encoding and audio decoding would be provided.

The object of the present invention is to provide improved concepts for audio encoding and audio decoding. The object of the present invention is solved by the subject-matter of
30 the independent claims. Particular embodiments are provided in the dependent claims.

An apparatus for generating one or more audio output signals from one or more encoded audio signals according to an embodiment is provided. The apparatus comprises at least one entropy decoding module for decoding encoded additional audio information, when
35 the encoded additional audio information is entropy-encoded, to obtain decoded additional audio information. Moreover, the apparatus comprises a signal processor for generating

the one or more audio output signals depending on the one or more encoded audio signals and depending on the decoded additional audio information.

Moreover, an apparatus for encoding one or more audio signals and additional audio information according to an embodiment is provided. The apparatus comprises an audio signal encoder for encoding the one or more audio signals to obtain one or more encoded audio signals. Furthermore, the apparatus comprises at least one entropy encoding module for encoding the additional audio information using entropy encoding to obtain encoded additional audio information.

Furthermore, an apparatus for generating one or more audio output signals from one or more encoded audio signals according to an embodiment is provided. The apparatus comprises an input interface for receiving the one or more encoded audio signals and for receiving additional audio information data. Furthermore, the apparatus comprises a signal generator for generating the one or more audio output signals depending on the encoded audio signals and depending on second additional audio information. The signal generator is configured to obtain the second additional audio information using the additional audio information data and using first additional audio information, if the additional audio information data exhibits a redundancy state. Moreover, the signal generator is configured to obtain the second additional audio information using the additional audio information data without using the first additional audio information, if the additional audio information data exhibits a non-redundancy state.

Moreover, an apparatus for encoding one or more audio signals and for generating additional audio information data according to an embodiment is provided. The apparatus comprises an audio signal encoder for encoding the one or more audio signals to obtain one or more encoded audio signals. Furthermore, the apparatus comprises a additional audio information generator for generating the additional audio information data, wherein the additional audio information generator exhibits a non-redundancy operation mode and a redundancy operation mode. The additional audio information generator is configured to generate the additional audio information data, if the additional audio information generator exhibits the non-redundancy operation mode, such that the additional audio information data comprises the second additional audio information. Moreover, the additional audio information generator is configured to generate the additional audio information data, if the additional audio information generator exhibits the non-redundancy operation mode, such that the additional audio information data does not comprise the second additional audio information or does only comprise a portion of the second additional audio information, such that the second additional audio information is

obtainable using the additional audio information data together with first additional audio information.

Furthermore, a method for generating one or more audio output signals from one or more encoded audio signals according to an embodiment is provided. The method comprises:

- Decoding encoded additional audio information, when the encoded additional audio information is entropy-encoded, to obtain decoded additional audio information. And:
- Generating the one or more audio output signals depending on the one or more encoded audio signals and depending on the decoded additional audio information.

Moreover, a method for encoding one or more audio signals and additional audio information according to an embodiment is provided. The method comprises:

- Encoding the one or more audio signals to one or more encoded audio signals. And:
- Encoding the additional audio information using entropy encoding to obtain encoded additional audio information.

Furthermore, a method for generating one or more audio output signals from one or more encoded audio signals according to another embodiment is provided. The method comprises:

- Receiving the one or more encoded audio signals and receiving additional audio information data. And:
- Generating the one or more audio output signals depending on the encoded audio signals and depending on second additional audio information.

The method comprises obtaining the second additional audio information using the additional audio information data and using first additional audio information, if the additional audio information data exhibits a redundancy state. Moreover, the method comprises obtaining the second additional audio information using the additional audio

information data without using the first additional audio information, if the additional audio information data exhibits a non-redundancy state.

Furthermore, a method for encoding one or more audio signals and for generating
5 additional audio information data according to an embodiment is provided. The method comprises:

- Encoding the one or more audio signals to obtain one or more encoded audio
10 signals. And:
- Generating the additional audio information data.

In a non-redundancy operation mode, generating the additional audio information data is
conducted, such that the additional audio information data comprises the second
15 additional audio information. In a redundancy operation mode, generating the additional
audio information data is conducted, such that the additional audio information data does
not comprise the second additional audio information or does only comprise a portion of
the second additional audio information, such that the second additional audio information
is obtainable using the additional audio information data together with first additional audio
20 information.

Furthermore, computer programs are provided, wherein each of the computer programs is
configured to implement one of the above-described methods when being executed on a
computer or signal processor.

25 In the following, embodiments of the present invention are described in more detail with
reference to the figures, in which:

Fig. 1 illustrates an apparatus for generating one or more audio output signals
30 from one or more encoded audio signals according to an embodiment.

Fig. 2 illustrates an apparatus for generating one or more audio output signals
according to another embodiment, which further comprises at least one
non-entropy decoding module and a selector.

35 Fig. 3 illustrates an apparatus for generating one or more audio output signals
according to a further embodiment, wherein the apparatus comprises a

non-entropy decoding module, a Huffman decoding module and an arithmetic decoding module.

Fig. 4 illustrates an apparatus for encoding one or more audio signals and additional audio information according to an embodiment.

Fig. 5 illustrates an apparatus for encoding one or more audio signals and additional audio information according to another embodiment, which comprises at least one non-entropy encoding module and a selector.

Fig. 6 illustrates an apparatus for generating one or more audio output signals according to a further embodiment, wherein the apparatus comprises a non-entropy encoding module, a Huffman encoding module and an arithmetic encoding module.

Fig. 7 illustrates a system according to an embodiment.

Fig. 8 illustrates a particular embodiment which depicts encoding of the additional audio data and decoding of the encoded additional audio data.

Fig. 9 illustrates an apparatus for generating one or more audio output signals from one or more encoded audio signals according to another embodiment.

Fig. 10 illustrates an apparatus for encoding one or more audio signals and for generating additional audio information data according to an embodiment.

Fig. 11 illustrates a system according to another embodiment.

Fig. 1 illustrates an apparatus 100 for generating one or more audio output signals from one or more encoded audio signals according to an embodiment.

The apparatus 100 comprises at least one entropy decoding module 110 for decoding encoded additional audio information, when the encoded additional audio information is entropy-encoded, to obtain decoded additional audio information.

Moreover, the apparatus 100 comprises a signal processor 120 for generating the one or more audio output signals depending on the one or more encoded audio signals and depending on the decoded additional audio information.

5 Fig. 2 illustrates an apparatus 100 for generating one or more audio output signals according to another embodiment, wherein, compared to the apparatus 100 of Fig. 1, the apparatus 100 of Fig. 2 further comprises at least one non-entropy decoding module 111 and a selector 115.

10 The at least one non-entropy decoding module 111 may, e.g., be configured to decode the encoded additional audio information, when the encoded additional audio information is not entropy-encoded, to obtain the decoded additional audio information.

The selector 115 may, e.g., be configured to select one of the at least one entropy
15 decoding module 110 and of the at least one non-entropy decoding module 111 for decoding the encoded additional audio information depending on whether or not the encoded additional audio information is entropy-encoded.

According to an embodiment, the encoded additional audio information may, e.g.,
20 comprise augmented reality data or virtual reality data.

In an embodiment, the encoded additional audio information depends on a real listening environment or depends on a virtual listening environment or depends on an augmented listening environment.

25 In a typical application scenario, a listening environment shall be modelled and encoded on an encoder side and the modelling of the listening environment shall be received on a decoder side.

30 Typical additional audio information relating to a listening environment may, e.g., be information on a plurality of reflection objects, where sound waves may, e.g., be reflected. In general, reflection objects that are relevant for reflections are those that have an extension which is (significantly) greater than the wavelength of audible sound. Thus, when considering reflections, walls or other large reflection objects are of particular
35 importance. Such reflection objects may, e.g., be suitably represented by surfaces, on which sounds are reflected.

In a three-dimensional environment, a surface may, for example, be characterized by three points in a three-dimensional coordinate system, where each of these three points may, e.g., be defined by its x-coordinate value, its y-coordinate value and its z-coordinate value. Thus, for each of the three points, three x-, y-, z- values would be needed, and
 5 thus, in total, nine coordinate values would be needed to define a surface.

A more efficient representation of a surface may, e.g., be achieved by defining the surface by using its normal vector $\vec{n}_0$ and by using a scalar distance value d which defines the distance from a defined origin to the surface. If the normal vector $\vec{n}_0$ of the surface is
 10 defined by an azimuth angle and an elevation angle (the length of the normal vector is 1 and thus does not have to be encoded), a surface can thus be defined by only three values, namely the scalar distance value d of the surface, and by the azimuth angle and elevation angle of the normal vector $\vec{n}_0$ of the surface.

15 Usually, for efficient encoding, the azimuth angle and the elevation angle may, e.g., be suitably quantized. For example, each azimuth angle may have one out of 2^n different azimuth values and the elevation angles may, for example, be encoded such that each elevation angle may have one out of 2^{n-1} different elevation values.

20 As outlined above, when defining a listening environment focusing on reflections, the representation of walls plays an important role. This is true for indoor scenarios where indoor walls play highly significant role for, e.g., early reflections. This is, however, also true for outdoor scenarios, where walls of buildings represent a major portion of relevant reflection objects.

25 It is observed that in usual environments, a lot of walls stand with an about 90° degree angle on each other. For example, in an indoor scenario, a lot of horizontal and vertical walls are present. While it has been found that due to construction deviations the relationship between the walls is not always exactly 90° , but, may, e.g., be 89.8° , 89.6° ,
 30 90.3° or similar, there is still a significant rate of walls that have a relationship with respect to each other around 90° and around 0° .

For example, an elevation angle of a wall may, e.g., be defined to be 0° , if the wall is a horizontal wall and may, e.g., be defined to be 90° , if the surface of the wall is a vertical
 35 wall. Then, in real-world examples there will be a significant rate of walls that have an elevation angle of about 90° (e.g., 89.8° , 89.7° , 90.2°) and a significant rate of walls that have an elevation angle of about 0° (e.g., 0.3° , -0.2° , 0.4°).

The same observation for elevation angles applies often for azimuth angles, as often, rooms have a rectangular shape.

Returning to the example of elevation angles, it should be noted that, however, if the 0°
5 value of the elevation angle is defined differently than above, other values result that usual walls exhibit. For example, if a surface is defined to have a 0° elevation angle, if is inclined by 20° with respect to a horizontal plane, then a lot of real-world walls may, e.g., have an elevation angle of about -20° (e.g., -19.8°, -20.0°, -20.2°) and a lot of real-world walls may, e.g., have an elevation angle of about 70° (e.g., 69.8°, 70.0°, 70.2°). Still, a significant rate
10 have walls will have same elevation angles at certain elevation angles (in this example at around -20° and at around 70°). The same applies for azimuth angles.

Moreover, some other walls will have other certain typical elevation angles. For example, roofs are typically inclined by 45° or by 35° or by 30°. A certain frequentness of these
15 values will also occur in real world-examples.

It is moreover noted that not all real-world rooms have a rectangular ground shape but may, for example, exhibit other regular shapes. For example, consider a room that has an octagonal ground shape. Although there, it may be assumed that some azimuth angles,
20 for example, azimuth angles of about 0°, 45°, 90° and 135° occur more frequently than other azimuth angles.

Moreover, in outdoor examples, walls will often exhibit similar azimuth angles. For example, two parallel walls of one house will exhibit similar azimuth angles, but this may,
25 e.g., also relate to walls of neighbouring houses that are often build in a row with a regular, similar ground shape with respect to each other. There also, walls of neighbouring houses will exhibit similar azimuth values, and thus have similarly oriented reflective walls/surfaces,

30 From the above-observation, it has been found that it is often particularly suitable to encode and decode additional audio information using entropy encoding. This applies particular for scenarios, where an occurrence of particular values out of all possible values occurs (significantly) more often than for other values.

35 In a particular embodiment, the values of elevation angles of surfaces (for example, representing reflection objects) may, e.g., be encoded and decoded using entropy coding, for example, using Huffman coding or using arithmetic coding.

Likewise, in a particular embodiment, the values of azimuth angles of surfaces (for example, representing reflection objects) may, e.g., be encoded and decoded using entropy coding, for example, using Huffman coding or using arithmetic coding.

- 5 The above considerations also apply for other application scenarios. For example, for a given audio source position s and, e.g., for a given listener position l , a reflection sequence may, e.g., define a number of one or more surfaces identified by a number of one or more surface indexes, wherein the one or more surface indexes define the surfaces where a sound wave originating from the audio source on a certain propagation path is reflected until it arrives (audible) at a listener position.

For example, for a source at position s and a listener at position l , the reflection sequence [5, 18] defines that on a particular propagation path, a sound wave from a source at position s is first reflected at the surface with surface index 5 and then at the surface with surface index 18 until it finally arrives at the position l of the listener (audible, such that the listener can still perceive it). A second reflection sequence may, e.g., be reflection sequence [3, 12]. A third reflection sequence that only comprises [5], indicating that on a particular propagation path, a sound wave from sound source s is only reflected by surface 5 and then arrives audible at the position l of the listener. A fourth reflection sequence [3, 7] defines that on a particular propagation path, a sound wave from source s is first reflected at the surface with surface index 3 and then at the surface with surface index 7 until it finally arrives audibly at the listener. All reflection sequences for the listener at position l and for the source at position s together define a set of reflection sequences for the listener at position l and for the source at position s .

25 However, there may, e.g., also be other surfaces defined, for example surfaces with surface indexes 6, 8, 9, 10, 11, or 15 that may, e.g., be located far away from the position l of the listener and far away from the position s of the source. These surfaces will occur less often or not at all in the set of reflection sequences for the listener at the position l and for the source at position s . From this observation it has been found that often, it is advisable to code a set of reflection sequences using entropy coding.

Moreover, even if a plurality of sets of reflection sequences are jointly encoded for a plurality of different listener positions and/or a plurality of different source positions, it may still be advisable to employ entropy coding. For example, in certain listening environments, a user-reachable region may, e.g., be defined, wherein, e.g., the user may, e.g., be assumed to never move through dense bushes or other regions that are not accessible. In some application scenarios, sets of reflection sequences for user positions

within these non-accessible regions are not provided. It follows that walls within these regions will usually appear less often in the plurality of sets of reflection sequences, as they are located far away from all defined possible user positions. This results in different occurrences of surface indexes in the plurality of sets of reflection sequences, and thus, entropy encoding these surface indexes in the reflection sets is proposed.

In an embodiment, the actual occurrences of the different values of the additional audio information may, e.g., be observed, and, e.g., based on this observation, either entropy encoding or non-entropy encoding may, e.g., be employed. Using non-entropy encoding when the occurrences of the different values appear with a same or at least roughly similar frequency has inter alia the advantage, that a predefined codeword to symbol relationship may, e.g., be employed that does not have to be transmitted from an encoder to a decoder.

Returning again to more general examples that may also be applied for other application examples than the just described ones:

According to an embodiment, the encoded additional audio information may, e.g., comprise propagation information depending on one or more propagations of one or more sound waves along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

In an embodiment, the propagation information may, e.g., be reflection information depending on one or more reflections at one or more reflection objects of one or more sound waves propagating along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

According to an embodiment, the propagation information may, e.g., be diffraction information depending on one or more diffractions at one or more diffraction objects of one or more sound waves propagating along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

According to an embodiment, the encoded additional audio information may, e.g., comprise data for rendering early reflections. The signal processor 120 may, e.g., be configured to generate the one or more audio output signals depending on the data for rendering early reflections.

In an embodiment, the signal processor 120 may, e.g., be configured to generate a binaural signal comprising two binaural channels as the one or more audio output signals.

- 5 According to an embodiment, the at least one entropy decoding module 110 may, e.g., comprise a Huffman decoding module 116 for decoding the encoded additional audio information, when the encoded additional audio information is Huffman-encoded.

- 10 In an embodiment, the at least one entropy decoding module 110 may, e.g., comprise an arithmetic decoding module 118 for decoding the encoded additional audio information, when the encoded additional audio information is arithmetically-encoded.

- Fig. 3 illustrates an apparatus 100 for generating one or more audio output signals according to another embodiment, wherein the apparatus 100 comprises a non-entropy
15 decoding module 111, a Huffman decoding module 116 and an arithmetic decoding module 118.

- The selector 115 may, e.g., be configured to select one of the at least one non-entropy decoding module 111 and of the Huffman decoding module 116 and of the arithmetic
20 decoding module 118 for decoding the encoded additional audio information.

- According to an embodiment, the at least one non-entropy decoding module 111 may, e.g., comprise a fixed-length decoding module for decoding the encoded additional audio information, when the encoded additional audio information is fixed-length-encoded.

- 25 In an embodiment, the apparatus 100 may, e.g., be configured to receive selection information. The selector 115 may, e.g., be configured to select one of the at least one entropy decoding module 110 and of the at least one non-entropy decoding module 111 depending on the selection information.

- 30 According to an embodiment, the apparatus 100 may, e.g., be configured to receive a codebook or a coding tree on which the encoded additional audio information depends. The at least entropy decoding module 110 may, e.g., be configured to decode the encoded additional audio information using the codebook or using the coding tree.

- 35 In an embodiment, the apparatus 100 may, e.g., be configured to receive an encoding of a structure of the coding tree on which the encoded additional audio information depends. The at least entropy decoding module 110 may, e.g., be configured to reconstruct a

plurality of codewords of the coding tree depending on the structure of the coding tree. Moreover, the at least entropy decoding module 110 may, e.g., be configured to decode the encoded additional audio information using the codewords of the coding tree.

- 5
- For example, typical coding information that may, e.g., be transmitted from an encoder to a decoder may, e.g., be a codeword list of N elements that comprises all N codewords of the code and a symbol list that comprises all N symbols that are encoded by the N codewords of the code. It may be defined that a codeword at position p with $1 \leq p \leq N$ of the codeword list encodes the symbol at position p of the symbol list.

- 10
- For example, content of the following two lists may, e.g., be transmitted, wherein each of the symbols may, for example, represent an surface index identifying a particular surface:

codeword	00	01	10	110	1110	1111
symbol	18	23	15	3	7	9

- 15
- Instead of transmitting the codeword list, however, according to an embodiment, a representation of the coding tree may, e.g., be transmitted from an encoder, which may, e.g., be received by a decoder. The decoder may, e.g., be configured to construct the codeword list from the received representation of the coding tree.
- 20
- For example, each inner node (e.g., except the root node of the coding tree) may, e.g., be represented by a first bit value (e.g., 0) and each leaf node of the coding tree may, e.g., be represented by a second bit value (e.g., 1).

Considering the above codeword list,

- 25
- | | | | | | | |
|----------|----|----|----|-----|------|------|
| codeword | 00 | 01 | 10 | 110 | 1110 | 1111 |
|----------|----|----|----|-----|------|------|

traversing the coding tree from the leftmost branches to the rightmost branches, encoding all new inner nodes when traversing the coding tree with 0, and all leaf nodes when traversing the coding tree with 1, leads to an encoding of a coding tree with the above

- 30
- codewords being represented as:

to reach leaf node with codeword	00	01	10	110	1110	1111
Bits	01	1	01	01	01	1

The resulting representation of the coding tree is: 01 1 01 01 01 1.

5 On the decoder side, the representation of the coding tree can be resolved into a list of codewords:

Codeword 1: First leaf node comes at second node: codeword 1 with bits 00.

10 Codeword 2: Next, another leaf node follows: codeword 2 with bits: 01.

Codeword 3: All nodes on the left side of the root node have been found, continue with the right branch of the root node: the first leaf on the right side of the root node is at the second node: codeword 3 with bits "10"

15 Codeword 4: Ascend one node upwards (under first branch 1). Descend into the right branch (second branch 1), an inner node (0); move into the left branch (branch 0), a leaf node (1): codeword 4: "110". (leaf node under branches 1 – 1 – 0)

20 Codeword 5: Ascend one node upwards (under second branch 1). Descend into the right branch (third branch 1), an inner node (0); move into the left branch (branch 0), a leaf node (1): codeword 5: "1110" (leaf node under branches 1 – 1 – 1 – 0)

25 Codeword 6: Ascend one node upwards Descend into the right branch (fourth branch 1), this is a leaf node (1): codeword 6: "1111" (leaf node under branches 1 – 1 – 1 – 1).

30 By coding the coding tree structure instead of the codewords, coding efficiency is increased.

In an embodiment, the apparatus 100 may, e.g., further comprise a memory having stored thereon a codebook or a coding tree. The at least entropy decoding module 110 may, e.g., be configured to decode the encoded additional audio information using the
35 codebook or using the coding tree.

According to an embodiment, the apparatus 100 may, e.g., be configured to receive the encoded additional audio information comprising a plurality of transmitted symbols and an

offset value. The at least one non-entropy decoding module 111 may, e.g., be configured to decode the encoded additional audio information using the plurality of transmitted symbols and using the offset value.

- 5 In an embodiment, the data for rendering early reflections may, e.g., comprise information on a location of one or more walls, being one or more real walls or virtual walls in an environment. The signal processor 120 may, e.g., be configured to generate the one or more audio output signals depending on the information on the location of one or more walls.

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According to an embodiment, the information on each wall of the one or more walls may, e.g., comprise information on a azimuth angle and/or an elevation angle of said wall, wherein the azimuth angle of said wall may, e.g., be entropy-encoded and/or the elevation angle of said wall may, e.g., be entropy-encoded. One or more entropy decoding modules of the at least one entropy decoding module 110 are configured to decode an entropy-encoded azimuth angle of said wall and/or an entropy-encoded elevation angle of said wall.

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- In an embodiment, said one or more of the at least one entropy decoding module 110 are configured to decode the entropy-encoded azimuth angle of said wall and/or the entropy-encoded elevation angle of said wall using the codebook or the coding tree.

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- According to an embodiment, the encoded additional audio information may, e.g., comprise voxel position information, wherein the position information may, e.g., comprise information on one or more positions of one or more voxels out of a plurality of voxels within a three-dimensional coordinate system. The signal processor 120 may, e.g., be configured to generate the one or more audio output signals depending on the voxel position information.

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- 30 In an embodiment, the at least one entropy decoding module 110 may, e.g., be configured to decode encoded additional audio information being entropy-encoded, wherein the encoded additional audio information being entropy-encoded may, e.g., comprise at least one of the following:

35

- a list of triangle indexes, for example, **earlySurfaceFacelidx**,
- an array length of a list of triangle indexes, for example, an array length of **earlySurfaceFacelidx**, for example, **earlySurfaceLengthFacelidx**,

- an array with azimuth angles specifying surface normals in spherical coordinates (for example, in Hesse normal form), for example, **earlySurfaceAzi**,
5
- an array with elevation angles specifying surface normals in spherical coordinates (for example, in Hesse normal form), for example, **earlySurfaceEle**,
- 10 - an array with distance values (for example, in Hesse normal form), for example, **earlySurfaceDist**,
- an array with positions of a listener, for example, an array with listener voxel indices, for example, **earlyVoxelL**,
15
- an array with positions of one or more sound sources, for example, an array with source voxel indices, for example, **earlyVoxelS**,
- 20 - a removal list or a removal set, for example, a differentially encoded removal list or a differentially encoded removal set, specifying indices of reflection sequences of a set of reflection sequences that shall be removed or a reference reflection sequence list that shall be removed, for example, **earlyVoxelIndicesRemovedDiff**,
- 25 - a number of reflection sequences or a number of reflection paths, for example, **earlyVoxelNumPaths**
- an array, for example, a two-dimensional array, specifying a reflection order, for example, **earlyVoxelOrder**
30
- reflection sequences, for example, **earlyVoxelSurf**.

Fig. 4 illustrates an apparatus 200 for encoding one or more audio signals and additional audio information according to an embodiment.

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The apparatus 200 comprises an audio signal encoder 210 for encoding the one or more audio signals to obtain one or more encoded audio signals.

Furthermore, the apparatus 200 comprises at least one entropy encoding module 220 for encoding the additional audio information using entropy encoding to obtain encoded additional audio information.

5 Fig. 5 illustrates an apparatus 200 for encoding one or more audio signals and additional audio information according to another embodiment. Compared to the apparatus 200 of Fig. 4, the apparatus 200 of Fig. 4 further comprises at least one non-entropy encoding module 221 and a selector 215.

10 The at least one non-entropy encoding module 221 may, e.g., be configured to encode the additional audio information to obtain the encoded additional audio information, and

The selector 215 may, e.g., be configured to select one of the at least one entropy encoding module 220 and of the at least one non-entropy encoding module 221 for
15 encoding the additional audio information depending on a symbol distribution within the additional audio information that is to be encoded.

According to an embodiment, the encoded additional audio information may, e.g.,
20 comprise augmented reality data or virtual reality data.

In an embodiment, the encoded additional audio information depends on a real listening environment or depends on a virtual listening environment or depends on an augmented listening environment.

25 According to an embodiment, the additional audio information may, e.g., comprise propagation information depending on one or more propagations of one or more sound waves along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

30 In an embodiment, the propagation information may, e.g., be reflection information depending on one or more reflections at one or more reflection objects of one or more sound waves propagating along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

35 According to an embodiment, the propagation information may, e.g., be diffraction information depending on one or more diffractions at one or more diffraction objects of one or more sound waves propagating along one or more propagation paths in the real

listening environment or in the virtual listening environment or in the augmented listening environment.

According to an embodiment, the encoded additional audio information may, e.g.,
5 comprise data for rendering early reflections.

In an embodiment, the at least one entropy encoding module 220 may, e.g., comprise a Huffman encoding module 226 for encoding the additional audio information using Huffman encoding.
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According to an embodiment, the at least one entropy encoding module 220 may, e.g., comprise an arithmetic encoding module 228 for encoding the additional audio information using arithmetic encoding.

15 Fig. 6 illustrates an apparatus 200 for generating one or more audio output signals according to another embodiment, wherein the apparatus 200 comprises a non-entropy encoding module 221, a Huffman encoding module 226 and an arithmetic encoding module 228.

20 The selector 215 may, e.g., be configured to select one of the at least one non-entropy encoding module 221 and of the Huffman encoding module 226 and of the arithmetic encoding module 228 for encoding the additional audio information.

In an embodiment, the at least one non-entropy encoding module 221 may, e.g., comprise
25 a fixed-length encoding module for encoding the additional audio information.

According to an embodiment, the apparatus 200 may, e.g., be configured to generate selection information indicating one of the at least one entropy encoding module 220 and of the at least one non-entropy encoding module 221 which has been employed for
30 encoding the additional audio information.

In an embodiment, the apparatus 200 may, e.g., be configured to transmit a codebook or a coding tree which has been employed to encode the additional audio information.

35 In an embodiment, the apparatus 200 may, e.g., be configured to transmit an encoding of a structure of the coding tree on which the encoded additional audio information depends.

According to an embodiment, the apparatus 200 may, e.g., further comprise a memory having stored thereon a codebook or a coding tree. The at least entropy encoding module 220 may, e.g., be configured to encode the additional audio information using the codebook or using the coding tree.

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In an embodiment, the at least one entropy encoding module 220 may, e.g., be configured to encode the additional audio information such that the encoded additional audio information may, e.g., comprise a plurality of transmitted symbols and an offset value.

10 According to an embodiment, the data for rendering early reflections may, e.g., comprise information on a location of one or more walls, being one or more real walls or virtual walls in an environment.

In an embodiment, the information on each wall of the one or more walls may, e.g.,
15 comprise information on a azimuth angle and/or an elevation angle of said wall, wherein the azimuth angle of said wall may, e.g., be entropy-encoded and/or the elevation angle of said wall may, e.g., be entropy-encoded. One or more entropy encoding modules of the at least one entropy encoding module 220 are configured to encode the additional audio information such that the encoded additional audio information may, e.g., comprise an
20 entropy-encoded azimuth angle of said wall and/or an entropy-encoded elevation angle of said wall.

According to an embodiment, said one or more entropy encoding modules are configured to encode the entropy-encoded azimuth angle of said wall and/or the entropy-encoded
25 elevation angle of said wall using the codebook or the coding tree.

In an embodiment, the encoded additional audio information may, e.g., comprise voxel position information, wherein the position information may, e.g., comprise information on one or more positions of one or more voxels out of a plurality of voxels within a three-
30 dimensional coordinate system.

According to an embodiment, the at least one entropy encoding module 220 may, e.g., be configured to encode the additional audio information using entropy encoding, wherein the encoded additional audio information may, e.g., comprise at least one of the following:

35

- a list of triangle indexes, for example, **earlySurfaceFaceIdx**,

- an array length of a list of triangle indexes, for example, an array length of **earlySurfaceFacelIdx**, for example, **earlySurfaceLengthFacelIdx**,
- 5 - an array with azimuth angles specifying surface normals in spherical coordinates (for example, in Hesse normal form), for example, **earlySurfaceAzi**,
- 10 - an array with elevation angles specifying surface normals in spherical coordinates (for example, in Hesse normal form), for example, **earlySurfaceEle**,
- 15 - an array with distance values (for example, in Hesse normal form), for example, **earlySurfaceDist**,
- 20 - an array with positions of a listener, for example, an array with listener voxel indices, for example, **earlyVoxelL**,
- an array with positions of one or more sound sources, for example, an array with source voxel indices, for example, **earlyVoxelS**,
- 25 - a removal list or a removal set, for example, a differentially encoded removal list or a differentially encoded removal set, specifying indices of reflection sequences of a set of reflection sequences that shall be removed or a reference reflection sequence list that shall be removed, for example, **earlyVoxelIndicesRemovedDiff**,
- a number of reflection sequences or a number of reflection paths, for example, **earlyVoxelNumPaths**
- 30 - an array, for example, a two-dimensional array, specifying a reflection order, for example, **earlyVoxelOrder**
- reflection sequences, for example, **earlyVoxelSurf**.

35 Fig. 7 illustrates a system according to an embodiment. The system comprises the apparatus 200 of Fig. 4 for encoding one or more audio signals and additional audio information to obtain one or more encoded audio signals and encoded additional audio information. Moreover, the system comprises the apparatus 100 of Fig. 1 for generating

one or more audio output signals from the one or more encoded audio signals depending on the encoded additional audio information.

Fig. 8 illustrates a particular embodiment which depicts encoding of the additional audio data and decoding of the encoded additional audio data. In Fig. 8 the additional audio data is AR data or VR data, which is encoded on an encoder side to obtain encoded AR data or VR data. Metadata may also be encoded. The encoded AR data or the encoded VR data is then decoder on the decoder side to obtain decoded AR data or decoded VR data. On the encoder side, a selector steers an encoder switch to select one of N different encoder modules for encoding the AR data or VR data. In Fig. 8, the selector provides information to the decoder side such that the corresponding decoding module out of N decoding modules is selected for decoding the encoded AR data or the encoded VR data.

In the following, further embodiments are provided.

According to an embodiment, a system for encoding and decoding data series having an encoder sub-system and a decoder sub-system is provided. The encoder sub-system may, e.g., comprise at least two different encoding methods, an encoder selector, and an encoder switch which chooses one of the encoding methods. The encoder sub-system may, e.g., transmit the chosen selection, encoding parameters of the chosen encoder, and data encoded by the chosen encoder. The decoder sub-system may, e.g., comprise the corresponding decoders and a decoder switch which selects one of the decoding methods.

In an embodiment, the data series may, e.g., comprise AR/VR data.

According to an embodiment, the data series may, e.g., comprise metadata for rendering early reflections.

In an embodiment, at least one fixed length encoder/decoder may, e.g., be used and at least one variable length encoder/decoder may, e.g., be used.

According to an embodiment, one of the variable length encoders/decoders is a Huffman encoder/decoder.

In an embodiment, the encoding parameters may, e.g., include a codebook or a decoding tree.

According an embodiment, the encoding parameters may, e.g., include an offset value and where a combination of this offset value and the transmitted symbols yields the decoded data series.

- 5 Fig. 9 illustrates an apparatus 300 for generating one or more audio output signals from one or more encoded audio signals according to another embodiment.

The apparatus 300 comprises an input interface 310 for receiving the one or more encoded audio signals and for receiving additional audio information data.

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Furthermore, the apparatus 300 comprises a signal generator 320 for generating the one or more audio output signals depending on the encoded audio signals and depending on second additional audio information.

- 15 The signal generator 320 is configured to obtain the second additional audio information using the additional audio information data and using first additional audio information, if the additional audio information data exhibits a redundancy state.

- Moreover, the signal generator 320 is configured to obtain the second additional audio
20 information using the additional audio information data without using the first additional audio information, if the additional audio information data exhibits a non-redundancy state.

- According to an embodiment, the input interface 310 may, e.g., be configured to receive propagation information data as the additional audio information data. The signal
25 generator 320 may, e.g., be configured to generate the one or more audio output signals depending on the second additional audio information, being second propagation information. Moreover, the signal generator 320 may, e.g., be configured to obtain the second propagation information using the propagation information data and using the first additional audio information, being first propagation information, if the propagation
30 information data exhibits a redundancy state. Furthermore, the signal generator 320 may, e.g., be configured to obtain the second propagation information using the propagation information data without using the first propagation information, if the propagation information data exhibits a non-redundancy state.

- 35 According to an embodiment, the first propagation information and/or the second propagation information may, e.g., depend on one or more propagations of one or more sound waves along one or more propagation paths in a real listening environment or in a virtual listening environment or in an augmented listening environment.

In an embodiment, the propagation information data may, e.g., comprise reflection information data and/or diffraction information data. The first propagation information may, e.g., comprise first reflection information and/or first diffraction information. Moreover, the
5 second propagation information may, e.g., comprise second reflection information and/or second diffraction information.

According to an embodiment, the input interface 310 may, e.g., be configured to receive reflection information data as the propagation information data. The signal generator 320
10 may, e.g., be configured to generate the one or more audio output signals depending on the second propagation information, being second reflection information. Moreover, the signal generator 320 may, e.g., be configured to obtain the second reflection information using the reflection information data and using the first propagation information, being first reflection information, if the reflection information data exhibits a redundancy state.
15 Furthermore, the signal generator 320 may, e.g., be configured to obtain the second reflection information using the reflection information data without using the first reflection information, if the reflection information data exhibits a non-redundancy state.

In an embodiment, the first reflection information and/or the second reflection information
20 may, e.g., depend on one or more reflections at one or more reflection objects of one or more sound waves propagating along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

25 The first and the second reflection information may, e.g., comprise the sets of reflection sequences described above. As already outlined, example, for a given audio source position s and, e.g., for a given listener position l , a reflection sequence may, e.g., define a number of one or more surfaces identified by a number of one or more surface indexes defines the surfaces where a sound wave originating from the audio source on a certain
30 propagation path is reflected until it arrives (audible) at a listener position.

All these reflection sequences defined for a listener at position l and for a source at position s form a set of reflection sequences.

35 It has been found that, for example, for neighbouring listener positions, the sets of reflection sequences are quite similar. It is thus proposed that an encoder encodes only those reflection sequences (e.g., in reflection information data) that are not comprised by a similar set of reflection sequences (e.g., in the first reflection information) and only

indicates those reflection sequences of the similar set of reflection sequences of the similar set of reflection sequences that are not valid for the current set of reflection sequences. Likewise, the respective decoder obtains the current set of reflection sequences (e.g., the second reflection information) from the similar set of reflection sequences (e.g., the first reflection information) using the received reduced information (e.g., the reflection information data).

In an embodiment, the input interface 310 may, e.g., be configured to receive diffraction information data as the propagation information data. The signal generator 320 may, e.g., be configured to generate the one or more audio output signals depending on the second propagation information, being second diffraction information. Moreover, the signal generator 320 may, e.g., be configured to obtain the second diffraction information using the diffraction information data and using the first propagation information, being first diffraction information, if the diffraction information data exhibits a redundancy state. Furthermore, the signal generator 320 may, e.g., be configured to obtain the second diffraction information using the diffraction information data without using the first diffraction information, if the diffraction information data exhibits a non-redundancy state.

According to an embodiment, the first diffraction information and/or the second diffraction information may, e.g., depend on one or more diffractions at one or more diffraction objects of one or more sound waves propagating along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

For example, the first and the second diffraction information may, e.g., comprise a set of diffraction sequences for a listener at position l and for a source at position s . A set of diffraction sequences may, e.g., be defined analogously as the set of reflection sequences but relates to diffraction objects (e.g., objects that cause diffraction) rather than to reflection objects. Often, the diffraction objects and the reflection objects may, e.g., be the same objects. When these objects are considered as reflection objects, the surfaces of these objects are considered, while, when these objects are considered as diffraction objects, the edges of these objects are considered for diffraction.

According to an embodiment, if the propagation information data exhibits the redundancy state, the propagation information data may, e.g., indicate one or more propagation sequences that are to be removed from the first propagation information, being a first set of propagation sequences, and/or may, e.g., indicate one or more propagation sequences that are to be added to the first set of propagation sequences to obtain the second

propagation information, being a second set of propagation sequences. The signal generator 320 may, e.g., be configured to update the first set of propagation sequences using the propagation information data to obtain the second set of propagation sequences.

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In an embodiment, each reflection sequence of the first set of reflection sequences and of the second set of reflection sequences may, e.g., indicate a group of one or more reflection objects or a group of one or more diffraction objects.

10 In an embodiment, if the propagation information data exhibits the non-redundancy state, the propagation information data may, e.g., comprise the second set of propagation sequences, and the signal generator 320 may, e.g., be configured to determine the second set of propagation sequences from the propagation information data.

15 According to an embodiment, the first set of propagation sequences may, e.g., be associated with a first listener position and with a first source position. The second set of propagation sequences may, e.g., be associated with a second listener position and with a second source position. The first listener position may, e.g., be different from the second listener position, and/or wherein the first source position may, e.g., be different from the
20 second source position.

In an embodiment, the first set of propagation sequences may, e.g., be a first set of reflection sequences. The second set of propagation sequences may, e.g., be a second set of reflection sequences. Each reflection sequence of the first set of reflection
25 sequences may, e.g., comprise information on the group of one or more reflection objects of the reflection sequence, where sound waves emitted by an audio source at the first source position and perceivable by a listener at the first listener position are reflected on their way to the current listener location. Each reflection sequence of the second set of reflection sequences may, e.g., comprise information on the group of one or more
30 reflection objects of the reflection sequence, where sound waves emitted by an audio source at the second source position and perceivable by a listener at the second listener position are reflected on their way to the current listener location.

According to an embodiment, the one or more encoded audio signals are associated with
35 the audio source being located at the source position of the second set of reflection sequences. The signal generator 320 may, e.g., be configured to generate the one or more audio output signals using the one or more encoded audio signals and using the second set of reflection sequences such that the one or more audio output signals may,

e.g., comprise early reflections of the sound waves emitted by the audio source at the source position of the second set of reflection sequences.

5 In an embodiment, the input interface 310 may, e.g., be configured to receive reflection information data as the propagation information data. The signal generator 320 may, e.g., be configured to obtain a plurality of sets of reflection sequences, wherein each of the plurality of sets of reflection sequences may, e.g., be associated with a listener position and with a source position. The input interface 310 may, e.g., be configured to receive an indication. For determining the second set of reflection sequences, the signal generator
10 320 may, e.g., be configured, if the reflection information data exhibits the redundancy state, to determine the first listener position and the first source position using the indication, and to choose that one of the plurality of sets of reflection sequences as the first set of reflection sequences which is associated with the first listener position and with the first source position.

15 For example, each reflection sequence of each set of reflection sequences of the plurality of sets of reflection sequences may, e.g., comprise information on the group of one or more reflection objects of the reflection sequence, where sound waves emitted by an audio source at the source position of said set of reflection sequences and perceivable by
20 a listener at the listener position of the said set of reflection sequences are reflected on their way to the current listener location.

According to an embodiment, if the reflection information data exhibits a redundancy state, the indication may, e.g., indicate to choose the first listener position and the first
25 source position, such that the first listener position is neighboured to the second listener position and/or such that the first source position is neighboured to the second listener position. If the reflection information data exhibits a redundancy state, the signal generator 320 may, e.g., be configured to determine the first listener position and/or the first source position according to the indication.

30 In an embodiment, if the reflection information data exhibits a redundancy state, the indication may, e.g., indicate to choose the first listener position and the first source position, such that the first listener position is neighboured to the second listener position and such that the first source position is identical with the second listener position. The
35 signal generator 320 is configured to determine the first listener position and the first source position according to the indication.

Or, in an embodiment, if the reflection information data exhibits a redundancy state, the indication may, e.g., indicate to choose the first listener position and the first source position, such that the first listener position is identical with the second listener position and such that the first source position is neighboured to the second listener position. The
5 signal generator 320 may, e.g., be configured to determine the first listener position and the first source position according to the indication.

According to an embodiment, in a coordinate system, a first position and a second position are neighboured, if in each coordinate direction of the coordinate system, the first
10 position immediately precedes or immediately succeeds the second position or is identical to the second position, and if in at least one coordinate direction of the coordinate system, the first position and the second position are different from each other.

In an embodiment, the indication may, e.g., indicate one of the following:

15

- that the reflection information data exhibits the non-redundancy state,
- that the reflection information data exhibits a first redundancy state, so that the first listener position and the first source position shall be chosen, such that the first
20 source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in a first coordinate direction of a coordinate system, the first listener position immediately precedes the second listener position, and wherein in a second coordinate direction and in a third coordinate direction of the coordinate system, the first
25 listener position is identical with the second listener position,
- that the reflection information data exhibits a second redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the
30 first listener position is neighboured to the second listener position, wherein in the second coordinate direction of the coordinate system, the first listener position immediately precedes the second listener position, and wherein in the first coordinate direction and in the third coordinate direction of the coordinate system, the first listener position is identical with the second listener position,
35
- that the reflection information data exhibits a third redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the

first listener position is neighboured to the second listener position, wherein in the third coordinate direction of the coordinate system, the first listener position immediately precedes the second listener position, and wherein in the first coordinate direction and in the second coordinate direction of the coordinate system, the first listener position is identical with the second listener position.

If the indication indicates the first redundancy state or the second redundancy state or the first redundancy state, the signal generator 320 may, e.g., be configured to determine the first listener position and the first source position according to the indication.

According to an embodiment, each of the first listener position, the first source position, the second listener position and the second source position may, e.g., defines a position of a voxel out of a plurality of voxels within a three-dimensional coordinate system.

For example, each of the listener position and the source position of each of the plurality of sets of reflection sequences may, e.g., define a position of a voxel out of a plurality of voxels within a three-dimensional coordinate system.

In an embodiment, the signal generator 320 may, e.g., be configured to generate a binaural signal comprising two binaural channels as the one or more audio output signals.

Fig. 10 illustrates an apparatus 400 for encoding one or more audio signals and for generating additional audio information data according to an embodiment.

The apparatus 400 comprises an audio signal encoder 410 for encoding the one or more audio signals to obtain one or more encoded audio signals.

Furthermore, the apparatus 400 comprises an additional audio information generator 420 for generating the additional audio information data, wherein the additional audio information generator 420 exhibits a non-redundancy operation mode and a redundancy operation mode.

The additional audio information generator 420 is configured to generate the additional audio information data, if the additional audio information generator 420 exhibits the non-redundancy operation mode, such that the additional audio information data comprises the second additional audio information.

Moreover, the additional audio information generator 420 is configured to generate the additional audio information data, if the additional audio information generator 420 exhibits the non-redundancy operation mode, such that the additional audio information data does not comprise the second additional audio information or does only comprise a portion of the second additional audio information, such that the second additional audio information is obtainable using the additional audio information data together with first additional audio information.

According to an embodiment, the additional audio information generator 420 may, e.g., be a propagation information generator for generating propagation information data as the additional audio information data. The propagation information generator may, e.g., be configured to generate the propagation information data, if the propagation information generator exhibits the non-redundancy operation mode, such that the propagation information data comprises the second additional audio information being second propagation information. Moreover, the propagation information generator may, e.g., be configured to generate the propagation information data, if the propagation information generator exhibits the non-redundancy operation mode, such that the propagation information data does not comprise the second propagation information or does only comprise a portion of the second propagation information, such that the second propagation information is obtainable using the propagation information data together with first propagation information.

According to an embodiment, the first propagation information and/or the second propagation information may, e.g., depend on one or more propagations of one or more sound waves along one or more propagation paths in a real listening environment or in a virtual listening environment or in an augmented listening environment.

In an embodiment, the propagation information data may, e.g., comprise reflection information data and/or diffraction information data. The first propagation information may, e.g., comprise first reflection information and/or first diffraction information. The second propagation information may, e.g., comprise second reflection information and/or second diffraction information.

According to an embodiment, the propagation information generator may, e.g., be a reflection information generator for generating reflection information data as the propagation information data. The reflection information generator may, e.g., be configured to generate the reflection information data, if the reflection information generator exhibits the non-redundancy operation mode, such that the reflection

information data comprises second reflection information as the second propagation information. Moreover, the reflection information generator may, e.g., be configured to generate the reflection information data, if the reflection information generator exhibits the non-redundancy operation mode, such that the reflection information data does not
5 comprise the second reflection information or does only comprise a portion of the second reflection information, such that the second reflection information is obtainable using the reflection information data together with the first propagation information being first reflection information.

10 In an embodiment, the first reflection information and/or the second reflection information may, e.g., depend on one or more reflections at one or more reflection objects of one or more sound waves propagating along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

15 According to an embodiment, the propagation information generator may, e.g., be a diffraction information generator for generating diffraction information data as the propagation information data. The diffraction information generator may, e.g., be configured to generate the diffraction information data, if the diffraction information
20 generator exhibits the non-redundancy operation mode, such that the diffraction information data comprises second diffraction information as the second propagation information. Moreover, the diffraction information generator may, e.g., be configured to generate the diffraction information data, if the diffraction information generator exhibits the non-redundancy operation mode, such that the diffraction information data does not
25 comprise the second diffraction information or does only comprise a portion of the second diffraction information, such that the second diffraction information is obtainable using the diffraction information data together with the first propagation information being first diffraction information.

30 In an embodiment, the first diffraction information and/or the second diffraction information may, e.g., depend on one or more diffractions at one or more diffraction objects of one or more sound waves propagating along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

35 According to an embodiment, the propagation information generator may, e.g., be configured in the redundancy operation mode to generate the propagation information data such that the propagation information data may, e.g., indicate one or more

propagation sequences that are to be removed from the first propagation information, being a first set of propagation sequences, and/or may, e.g., indicate one or more propagation sequences that are to be added to the first set of propagation sequences to obtain the second propagation information, being a second set of propagation sequences.

5

In an embodiment, each propagation sequence of the first set of propagation sequences and of the second set of propagation sequences may, e.g., indicate a group of one or more reflection objects or a group of one or more diffraction objects.

10 In an embodiment, the propagation information generator may, e.g., be configured in the non-redundancy operation mode to generate the propagation information data such that the propagation information data may, e.g., comprise the second set of propagation sequences.

15 According to an embodiment, the first set of propagation sequences may, e.g., be associated with a first listener position and with a first source position. The second set of propagation sequences may, e.g., be associated with a second listener position and with a second source position. The first listener position may, e.g., be different from the second listener position, and/or wherein the first source position may, e.g., be different from the
20 second source position.

In an embodiment, the first set of propagation sequences may, e.g., be a first set of reflection sequences. The propagation information generator may, e.g., be a reflection information generator. The second set of propagation sequences may, e.g., be a second
25 set of reflection sequences. The propagation information data may, e.g., be reflection information data. Each reflection sequence of the first set of reflection sequences may, e.g., comprise information on the group of one or more reflection objects of the reflection sequence, where sound waves emitted by an audio source at the first source position and perceivable by a listener at the first listener position are reflected on their way to the
30 current listener location. The reflection information generator may, e.g., be configured to generate the reflection information data such that each reflection sequence of the second set of reflection sequences may, e.g., comprise information on the group of one or more reflection objects of the reflection sequence, where sound waves emitted by an audio source at the second source position and perceivable by a listener at the second listener
35 position are reflected on their way to the current listener location.

According to an embodiment, the one or more encoded audio signals are associated with the audio source being located at the source position of the second set of reflection sequences.

- 5 In an embodiment, the reflection information generator may, e.g., be configured in the redundancy operation mode to generate an indication suitable for determining the first listener position and the first source position of the first set of reflection sequences.

- 10 According to an embodiment, the reflection information generator may, e.g., be configured in the redundancy operation mode to generate the indication such that the indication may, e.g., indicate to choose the first listener position and the first source position, such that the first listener position is neighboured to the second listener position and/or such that the first source position is neighboured to the second listener position.

- 15 In an embodiment, the reflection information generator may, e.g., be configured in the redundancy operation mode to generate the indication such that the indication may, e.g., indicate to choose the first listener position and the first source position, such that the first listener position is neighboured to the second listener position and such that the first source position is identical with the second listener position.

- 20 Or, in an embodiment, the reflection information generator may, e.g., be configured in the redundancy operation mode to generate the indication such that the indication may, e.g., indicate to choose the first listener position and the first source position, such that the first listener position is identical with the second listener position and such that the first source position is neighboured to the second listener position.
- 25

- According to an embodiment, in a coordinate system, a first position and a second position are neighboured, if in each coordinate direction of the coordinate system, the first position immediately precedes or immediately succeeds the second position or is identical to the second position, and if in at least one coordinate direction of the coordinate system, the first position and the second position are different from each other.
- 30

- In an embodiment, the reflection information generator may, e.g., be configured in the redundancy operation mode to generate the indication such that the indication may, e.g., indicate one of the following:
- 35

- that the reflection information data exhibits the non-redundancy state,

- that the reflection information data exhibits a first redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in a first coordinate direction of a coordinate system, the first listener position immediately precedes the second listener position, and wherein in a second coordinate direction and in a third coordinate direction of the coordinate system, the first listener position is identical with the second listener position,
- that the reflection information data exhibits a second redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in the second coordinate direction of the coordinate system, the first listener position immediately precedes the second listener position, and wherein in the first coordinate direction and in the third coordinate direction of the coordinate system, the first listener position is identical with the second listener position,
- that the reflection information data exhibits a third redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in the third coordinate direction of the coordinate system, the first listener position immediately precedes the second listener position, and wherein in the first coordinate direction and in the second coordinate direction of the coordinate system, the first listener position is identical with the second listener position.

According to an embodiment, each of the first listener position, the first source position, the second listener position and the second source position may, e.g., define a position of a voxel out of a plurality of voxels within a three-dimensional coordinate system.

Fig. 11 illustrates a system according to another embodiment. The system comprises the apparatus 400 of Fig. 10 for encoding one or more audio signals to obtain one or more encoded audio signals and for generating additional audio information data. Moreover, the system comprises the apparatus 300 of Fig. 9 for generating one or more audio output signals from the one or more encoded audio signals depending on the additional audio information data.

In the following, further particular embodiments are provided.

More particularly, binary encoding and decoding of metadata is considered.

- 5 The current working draft for the MPEG-I 6DoF Audio specification ("first draft version of RM0") states that **earlySurfaceDataJSON**, **earlySurfaceConnectedDataJSON**, and **earlyVoxelDataJSON** are represented as a "zero terminated character string in ASCII encoding. This string contains a JSON formatted document as provisional data format". In this input document we are proposing to replace this provisional data format by a binary data format using an encoding method which results in significantly smaller bitstream sizes.

This Core Experiment is based on the first draft version of RM0. It aims at replacing the JSON formatted early reflection metadata by a binary encoding format. By applying particular techniques, substantial reductions of the size of the early reflection payload achieved while introducing insignificant quantization errors.

The techniques applied to reduce the payload size comprise:

- 20 1. **Data consolidation:** Variables which are no longer used by the RefSoft renderer (**earlySurfaceConnectedData**) are removed.
2. **Coordinate system:** The unit normal vector of the reflection planes are transmitted in spherical coordinates instead of Cartesian coordinates to reduce the number of coefficients from 3 to 2.
- 25 3. **Quantization:** The coefficients which define the reflection planes are quantized with high resolution (quasi lossless coding).
4. **Entropy encoding:** A codebook based general purpose encoding schema is used for entropy coding of the transmitted symbols. The applied method is beneficial specially for data series with a very large number of symbols while also being suitable for a small number of symbols.
- 30 5. **Inter-voxel redundancy reduction:** The similarity of voxel data of voxel neighbors is exploited to further reduce the bitstream size. A differential approach is used where the differences between the current voxel data set and a neighbor voxel data set is encoded.

35

The decoder is simplified since a parsing step of the JSON data is no longer needed while the runtime complexity of the renderer is not affected by the proposed changes.

Furthermore, the proposed replacement also reduces the library dependencies of the renderer as well as the library dependencies of the encoder since generating and parsing JSON documents is no longer needed.

- 5
- For all “test 1” and “test 2” scenes, the proposed encoding method provides on average a reduction of 21.33% in overall bitstream size over P13. Considering only scenes with reflecting mesh data, the proposed encoding method provides on average a reduction of 28.91% in overall bitstream size over P13.
- 10
- In the following, information on Addition/Replacement is considered.

The encoding method presented in this Core Experiment is meant as a replacement for major parts of payloadEarlyReflections(). The corresponding payload handler in the reference software for packets of type PLD_EARLY_REFLECTIONS is meant to be replaced accordingly.

In the following, further technical information is provided.

In particular, it is proposed to remove of Unused Variables

- 20
- The RM0 bitstream parser generates the data structures *earlySurfaceData* and *earlySurfaceConnectedData* from the bitstream variables **earlySurfaceDataJSON** and **earlySurfaceConnectedDataJSON**. This data defines the reflection planes of static scene geometries and triangles which belong to connected surface areas. The motivation for splitting the set of all triangles that belong to a reflection plane into several groups of connected areas was to allow the renderer to only check a sub set during the visibility test. However, the reference software implementation no longer utilizes this distinctive information. Internally, the Intel Embree library is used for fast ray tracing with its own acceleration method (bounding volume hierarchy data structures).
- 25
-
- 30
- It is therefore proposed to simplify these data structures by combining them into a single data structure without the connected surface information:

Table - earlySurfaceData() data structure

Array variables	Variable Type
earlySurfaceData()	
{	

Array variables	Variable Type
earlySurfaceData_surfaceIdx[s];	int
earlySurfaceData_faceIdx[s][f];	int
earlySurfaceData_N0[s];	[float, float, float]
earlySurfaceData_d[s];	float
}	

In the following, quantization is considered.

Instead of transmitting Cartesian coordinates for the unit normal vectors N_o , it is more
 5 efficient to transmit spherical coordinates as one of the values, the distance, is a constant
 and does not need to be transmitted:

$$\begin{aligned}\varphi_{azi} &= \text{atan2}(-x, -z) \\ \theta_{ele} &= \text{atan2}(y, \sqrt{x^2 + z^2}) \\ 10 \quad r_{dist} &= 1\end{aligned}$$

It is proposed to quantize the azimuth angle φ_{azi} with 12 bits and the elevation angle θ_{ele}
 with 11 bits as follows:

$$\begin{aligned}15 \quad N_{azi} &= 144 \cdot \text{floor}\left(\frac{2^{12}}{144}\right) \\ azi_quant &= \text{round}\left(\varphi_{azi} \frac{N_{azi}}{2\pi}\right)\end{aligned}$$

and elevation angle of the surface normal N_o as follows:

$$\begin{aligned}20 \quad N_{ele} &= 72 \cdot \text{floor}\left(\frac{2^{11}}{72}\right) \\ ele_quant &= \text{round}\left(\theta_{ele} \frac{N_{ele}}{\pi} + \frac{N_{ele}}{2}\right)\end{aligned}$$

This quantization scheme ensures that integer multiples of 5° as well as various dividers
 of 360° which are power of 2 are directly on the quantization grid. The resulting 4032
 25 quantization steps for the azimuth angle and 2017 quantization steps for the elevation
 angle can be regarded as quasi-lossless due to the high resolution.

For the quantization of the surface distance d we propose a 1mm resolution. This is the
 same resolution which is also used for transmitting scene geometry data.

The actual number of bits that is used to transmit these values depends on the entropy coding scheme described in the following section.

In the following, entropy coding according to particular embodiments is considered.

5

If the symbol distribution is not uniform, entropy encoding can be used to reduce the amount of bits needed for transmitting the data. A widely used method for entropy coding is Huffman coding which uses smaller code words for more frequent symbols and longer code words for less frequent symbols, resulting in a smaller mean word size. Lately arithmetic coding gained popularity, where the complete message text is encoded at once. For the encoding of directivity data for example, an adaptive arithmetic encoding mechanism is used. This adaptive method is especially advantageous if the symbol distribution is steadily changing over time.

10

15

In the case of the early reflection metadata, we cannot make any assumption about the temporal behavior of the symbol distribution (like certain symbols occur more frequently at the beginning of the transmission while others occur more frequently at the end of the transmission). It is more reasonable to assume that the symbol distribution is fixed and can be determined during initialization of the encoder. Furthermore, adjusting the symbol distribution at runtime and using a symbol distribution which deviates from the a priori known symbol distribution actually voids the theoretical benefit of the adaptive arithmetic coding method.

20

25

For this reason it is proposed to use a classic Huffman code for entropy coding of early reflection metadata. This requires that either a pre-defined codebook is used, that the used codebook, or that the binary decoding tree together with a list of corresponding symbols is transmitted. The latter can be efficiently generated by a recursive algorithm: it traverses the decoding tree and encodes a leaf, i.e. a valid code word, by a '1' and encodes a branching by a '0'. If the current word is not a valid code word, i.e. the algorithm is at a branching of the decoding tree, 2 recursions are performed: one for the left side where the current word is extended by a '0' and one for the right side where the current word is extended by a '1'. The following pseudo code illustrates the encoding algorithm for the decoding tree:

30

35

Using a predefined codebook is actually one of three options, namely, using a pre-defined codebook, or using a codebook comprising a code word list and a symbol list, or using a decoding tree and a symbol list.

```
function traverseTreeEncode(Bitstream reference bs,  
                           List<int> reference symbol_list,  
                           List<bool> code)  
{  
5     if (code in codebookInverse) {  
        bs.append(1);  
        symbol = codebookInverse[code];  
        symbol_list.append(symbol);  
    } else {  
10     bs.append(0);  
        traverseTreeEncode(bs, symbol_list, code + 0);  
        traverseTreeEncode(bs, symbol_list, code + 1);  
    }  
}
```

15

This algorithm also generates a list of all symbols in tree traversal order. The same mechanism can be used on the decoder side to extract the decoding tree topology as well as the valid code words:

```
20 function traverseTreeDecode(Bitstream reference bs,  
                             List<int> reference code_list,  
                             List<bool> code)  
{  
    bool isLeaf = bs.readBool();  
25    if (isLeaf) {  
        code_list.append(code);  
    } else {  
        traverseTreeDecode(bs, code_list, code + 0);  
        traverseTreeDecode(bs, code_list, code + 1);  
30    }  
}
```

35

Since only a single bit is spent for each code word and for each branching, this results in a very efficient encoding of the decoding tree.

In addition to the topology of the decoding tree, the symbol list needs to be transmitted in tree traversal order for a complete transmission of the codebook.

In some cases transmitting the codebook in addition to the symbols might result in a bitstream which is even larger than a simple fixed length encoding. We therefore introduce a new generic purpose method for transmitting data using codebooks. Our proposed method utilizes either variable length encoding using the encoding scheme described above or a fixed length encoding. In the latter case only the word size, i.e. the number of bits for each code word, must be transmitted instead of a complete codebook. Optionally, a common offset for the integer values of the symbols may be given in the bitstream, if the difference to the offset results in a smaller word size. The following function parses such a generic codebook and returns a data structure for the current codebook instance:

10

Syntax	No. of bits	Mnemonic
<code>genericCodebook() {</code>		

this.flagFixedLength;	1	uimbsbf
this.flagOffset	1	
if (this.flagOffset) {		uimbsbf
wordSizeOffset;	6	
this.offset;	wordSizeOffset	uimbsbf
}		uimbsbf
else {		
this.offset = 0;		
}		
this.wordSize;	6	uimbsbf
if (this.flagFixedLength) {		
numCodes = 1 << this.wordSize;		
for (unsigned int n = 0; n <		
numCodes; n++) {		
// initialize bool array of		
given length		
this.codeList[n] = Bitarray(n,		
this.wordSize);		
this.symbolList[n] = n +		
this.offset;		
}		
}		
else {	this.wordSize	uimbsbf
Bitarray code = [];		
this.codeList =		
traverseTreeDecode(code);		
for (int n = 0; n <		
this.codeList.size(); n++) {		
rawList[n];		
this.symbolList[n] =		
rawList[n] + this.offset;		
}		
}		
return this;		
}		

In this implementation the keyword “Bitarray” is used as an alias for a bit sequence of a certain length. Furthermore, the keyword “append()” denotes a method which extends the length of the array by one or more elements, that are added at the end.

5

The recursively executed tree traversal function is defined as follows:

Syntax	No. of bits	Mnemonic
<pre>traverseTreeDecode(Bitarray code) { Bitarray codeList[]; isLeaf; if (isLeaf) { codeList.append(code); } else { Bitarray codeLeft = code; Bitarray codeRight = code; codeLeft.append(0); codeRight.append(1); codeList.append(traverseTreeDecode(codeLeft)); codeList.append(traverseTreeDecode(codeRight)); } return codeList; }</pre>		
	1	uimsbf

10

As they have different symbol distributions, we propose to use individual codebooks for the following arrays:

15

- **earlySurfaceLengthFacIdx**
- **earlySurfaceFacIdx**
- **earlySurfaceAzi**
- **earlySurfaceEle**
- **earlySurfaceDist**
- **earlyVoxell** (see next section)

- **earlyVoxelS** (see next section)
- **earlyVoxelIndicesRemovedDiff** (see next section)
- **earlyVoxelNumPaths** (see next section)
- **earlyVoxelOrder** (see next section)
- 5 • **earlyVoxelSurf** (see next section)

In the following, Inter-Voxel Redundancy Reduction according to particular embodiments is described.

- 10 The early reflection voxel database **earlyVoxelDatabase[l][s]** stores a list of reflection sequences which are potentially visible for a source within the voxel with index *s* and a listener within the voxel with index *l*. In many cases this list of reflection sequences will be very similar for neighbor voxels. By reducing this inter-voxel redundancy, the bitstream size can be significantly reduced.

- 15 The proposed inter-voxel redundancy reduction uses 4 operating modes signaled by the bitstream variable **earlyVoxelMode[v]**. In mode 0 (“no reference”) the list of reflection sequences for source voxel **earlyVoxelS[v]** and listener voxel **earlyVoxelL[v]** is transmitted as an array with path index *p* and order index *o* using generic codebooks for the variables **earlyVoxelNumPaths[v]**, **earlyVoxelOrder[v][p]**, and **earlyVoxelSurf[v][p][o]**. In the other operating modes, the difference between a reference and the current list of reflection sequences is transmitted.

- 25 In mode 1 (“x-axis reference”) the list of reflection sequences for the current source voxel and the listener voxel neighbor in the negative x-axis direction is used as reference. A list of indices is transmitted, which specify the entries of the reference list, that need to be removed, together with a list of additional reflection sequences.

- 30 Mode 2 (“y-axis reference”) differs from mode 1 by using the listener voxel neighbor in the negative y-axis direction.

Mode 3 (“z-axis reference”) differs from mode 1 by using the listener voxel neighbor in the negative z-axis direction.

- 35 The index list **earlyVoxelIndicesRemoved[v]** which specifies the entries of the reference list that need to be removed can be encoded more efficiently, if a zero terminated list **earlyVoxelIndicesRemovedDiff[v]** of differences is transmitted instead. This reduces the entropy since smaller values become more likely and larger values


```

        this.codeList[n] = Bitarray(n,
this.wordSize);
        this.symbolList[n] = n + this.offset;
    }
}
else {
    Bitarray code = [];
    this.codeList = traverseTreeDecode( code );
    for (int n = 0; n < this.codeList.size(); n++) {
        rawList[n];                this.wordSize    uimsbf
        this.symbolList[n] = rawList[n] +
this.offset;
    }
}
return this;
}
}
```

The code word list “codeList” is transmitted using the following recursive tree traversal algorithm where the keyword “Bitarray” is used as an alias for a bit sequence of a certain length. Furthermore, the keyword “append()” denotes a method which extends the length of the array by one or more elements, that are added at the end:

5

Table — Syntax of traverseTreeDecode()

Syntax	No. of bits	Mnemonic
traverseTreeDecode(Bitarray code) { Bitarray codeList[]; isLeaf ; if (isLeaf) { codeList.append(code); } else { Bitarray codeLeft = code; Bitarray codeRight = code; codeLeft.append(0); codeLeft.append(1); codeList.append(traverseTreeDecode(codeLeft)); codeList.append(traverseTreeDecode(codeRight)); } return codeList; }	1	uimsbf

An instance “exampleCodebook” of such a codebook is created as follows:

5 exampleCodebook = genericCodebook();

In addition to the data fields of the returned data structure, generic codebooks have a method “get_symbol()” which reads in a valid code word from the bitstream, i.e. the nth element of codeList[], and returns the corresponding symbol, i.e. symbolList[n]. The usage of this method is indicated as follows:

10 **exampleVariable** = exampleCodebook.get_symbol();

In the following, a proposed syntax for early reflection payload is presented

15 **Table — Syntax of payloadEarlyReflections()**

Syntax	No. of bits	Mnemonic
payloadEarlyReflections() {		
earlyTriangleCullingDistanceOrder1;	8	uimsbf
earlyTriangleCullingDistanceOrder2;	8	uimsbf
earlyTriangleSourceDistanceOrder1;	8	uimsbf
earlyTriangleSourceDistanceOrder2;	8	uimsbf
 earlyVoxelGridOriginX;	32	float
earlyVoxelGridOriginY;	32	float
earlyVoxelGridOriginZ;	32	float
 earlyVoxelGridPitchX;	32	float
earlyVoxelGridPitchY;	32	float
earlyVoxelGridPitchZ;	32	float
 earlyVoxelGridShapeX;	32	uimsbf
earlyVoxelGridShapeY;	32	uimsbf
earlyVoxelGridShapeZ;	32	uimsbf
 earlyHasSurfaceData;	1	uimsbf
if (earlyHasSurfaceData) {		
earlySurfaceDataLength;	32	uimsbf

Syntax	No. of bits	Mnemonic
earlySurfaceData(); }	earlySurfaceDataLength * 8	
earlyHasVoxelData; if (earlyHasVoxelData) { earlyVoxelDataLength; earlyVoxelData(); }	1 32 earlyVoxelDataLength * 8	uimsbf uimsbf

Table — Syntax of earlySurfaceData()

Syntax	No. of bits	Mnemonic
earlySurfaceData() { codebookLengthFaceIdx = genericCodebook(); codebookFaceIdx = genericCodebook(); codebookAzi = genericCodebook(); codebookEle = genericCodebook(); codebookDist = genericCodebook(); earlySurfaceDistOffset; numberOfSurfaces; for (int s = 0; s < numberOfSurfaces; s++) { earlySurfaceLengthFaceIdx[s] = codebookLengthFaceIdx.get_symbol(); for (int f = 0; f < earlySurfaceLengthFaceIdx[s]; f++) { earlySurfaceFaceIdx[s][f] = codebookFaceIdx.get_symbol(); } earlySurfaceAzi[s] = codebookAzi.get_symbol(); earlySurfaceEle[s] = codebookEle.get_symbol(); earlySurfaceDist[s] = codebookDist.get_symbol(); } }	22 16	tcimsbf uimsbf vlclbf vlclbf vlclbf

Syntax	No. of bits	Mnemonic
<pre> earlyVoxelData() { codebookL = genericCodebook(); codebookS = genericCodebook(); codebookIndicesRemoved = genericCodebook(); codebookNumPaths = genericCodebook(); codebookOrder = genericCodebook(); codebookSurf = genericCodebook(); numberOfVoxelPairs; for (int v = 0; v < numberOfVoxelPairs; v++) { earlyVoxelL[v] = codebookL.get_symbol(); earlyVoxelS[v] = codebookS.get_symbol(); earlyVoxelMode[v]; bool remove_loop = earlyVoxelMode[v] != 0; int k = 0; while (remove_loop) { earlyVoxelIndicesRemovedDiff[v][k] = codebookIndicesRemoved.get_symbol(); remove_loop = earlyVoxelIndicesRemovedDiff[v][k] != 0; k += 1; } earlyVoxelNumPaths[v] = codebookNumPaths.get_symbol(); for (int p = 0; p < earlyVoxelNumPaths[v]; p++) { earlyVoxelOrder[v][p] = codebookOrder.get_symbol(); for (int o = 0; o < earlyVoxelOrder[v][p]; o++) { earlyVoxelSurf[v][p][o] = codebookSurf.get_symbol(); } } } } </pre>	32 2	uimbsbf vlclbf vlclbf uimbsbf vlclbf vlclbf vlclbf

```

    }
}
}
```

In the following, a proposed data structure, namely an early reflection payload data structure is presented.

5	earlyTriangleCullingDistanceOrder1	Triangle culling distance for 1st order reflections.
	earlyTriangleCullingDistanceOrder2	Triangle culling distance for 2nd order reflections.
	earlySourceCullingDistanceOrder1	Source culling distance for 1st order reflections.
	earlySourceCullingDistanceOrder2	Source culling distance for 2nd order reflections.
10	earlyVoxelGridOriginX	x-component of the Cartesian coordinate of the voxel grid origin [0,0,0].
	earlyVoxelGridOriginY	y-component of the Cartesian coordinate of the voxel grid origin [0,0,0].
15	earlyVoxelGridOriginZ	z-component of the Cartesian coordinate of the voxel grid origin [0,0,0].
	earlyVoxelGridPitchX	Voxel grid spacing along the x-axis (voxel width).
	earlyVoxelGridPitchY	Voxel grid spacing along the y-axis (voxel length).
20	earlyVoxelGridPitchZ	Voxel grid spacing along the z-axis (voxel height).
	earlyVoxelGridShapeX	Number of voxels along the x-axis.
	earlyVoxelGridShapeY	Number of voxels along the y-axis.
	earlyVoxelGridShapeZ	Number of voxels along the z-axis.
25	earlyHasSurfaceData	Flag indicating the presence of earlySurfaceData.
	earlySurfaceDataLength	Length of the earlySurfaceData block in bytes.
	earlyHasVoxelData	Flag indicating the presence of earlyVoxelData.
30	earlyVoxelDataLength	Length of the earlySurfaceData block in bytes.
	earlySurfaceDistOffset	Offset in mm for earlySurfaceDist.
	numberOfSurfaces	Number of surfaces.
	earlySurfaceLengthFacelIdx	Array length of earlySurfaceFacelIdx.

	earlySurfaceFaceIdx	List of triangle IDs.
	earlySurfaceAzi	Array with azimuth angles specifying the surface normals in spherical coordinates (Hesse normal form).
5	earlySurfaceEle	Array with elevation angles specifying the surface normals in spherical coordinates (Hesse normal form).
	earlySurfaceDist	Array with distance values (Hesse normal form).
10	numberOfVoxelPairs	Number of source & listener voxel pairs with available voxel data.
	earlyVoxelL	Array with listener voxel indices.
	earlyVoxelS	Array with source voxel indices.
15	earlyVoxelMode	Array specifying the encoding mode of the voxel data.
	earlyVoxelIndicesRemovedDiff	Differentially encoded removal list specifying the indices of the reference reflection sequence list that shall be removed.
	earlyVoxelNumPaths	Number of reflection paths.
20	earlyVoxelOrder	2D Array specifying the reflection order.
	earlyVoxelSurf	Reflection sequences given as 3D array of surface indices.

25 In the following, renderer stages considering early reflections are proposed and and terms and definitions are provided.

Voxel grid:

30 The renderer uses voxel data to speed up the computational complex visibility check of reflected sound propagation paths. The scene is rasterized into a regular grid with a grid spacing that can be defined individually for each dimension. Each voxel is identified by a unique voxel ID and a sparse database is used to store pre-computed data for a given source/listener voxel pair. The relevant variables and data structures are:

- 35 • **earlyVoxelGridOriginX**
- **earlyVoxelGridOriginY**
- **earlyVoxelGridOriginZ**
- **earlyVoxelGridPitchX**
- **earlyVoxelGridPitchY**
- 40 • **earlyVoxelGridPitchZ**
- **earlyVoxelGridShapeX**
- **earlyVoxelGridShapeY**

- **earlyVoxelGridShapeZ**

These variables are the basis for voxel coordinates $\mathbf{V} = [v_x, v_y, v_z]^T$ with 3 integer numbers as components. For any point $\mathbf{P} = [p_x, p_y, p_z]^T$ located in the scene, the corresponding voxel coordinate is computed by the following rounding operations to the nearest integer number:

$$v_x = \text{round}((p_x - \text{earlyVoxelGridOriginX}) / \text{earlyVoxelGridPitchX}) \quad (1)$$

$$v_y = \text{round}((p_y - \text{earlyVoxelGridOriginY}) / \text{earlyVoxelGridPitchY}) \quad (2)$$

$$v_z = \text{round}((p_z - \text{earlyVoxelGridOriginZ}) / \text{earlyVoxelGridPitchZ}) \quad (3)$$

A voxel coordinate can be converted into a voxel index:

10

$$n = v_x + \text{earlyVoxelGridShapeX} * (v_y + \text{earlyVoxelGridShapeY} * v_z) \quad (4)$$

This representation is for example used in the sparse voxel database **earlyVoxelDatabase**[l][s][p] for the listener voxel ID l and the source voxel ID s .

15 **Culling distances:**

The encoder can use source and/or triangle distance culling to speed up the pre-computation of voxel data. The culling distances are encoded in the bitstream to allow the renderer to smoothly fade-out reflections that reach the used culling thresholds. The relevant variables and data structures are:

20

- **earlyTriangleCullingDistanceOrder1**
- **earlyTriangleCullingDistanceOrder2**
- **earlySourceCullingDistanceOrder1**
- **earlySourceCullingDistanceOrder2**

25

Surface data:

Surface data is geometrical data which defines the reflection planes on which sound is reflected. The relevant variables and data structures are:

30

- **earlySurfaceIdx[s];**
- **earlySurfaceFaceIdx[s][f];**
- **earlySurface_N0[s]**
- **earlySurface_d[s]**

35

The surface index **earlySurfaceIdx[s]** identifies the surface and is referenced by the sparse voxel database **earlyVoxelDatabase[l][s][p]**. The triangle ID list **earlySurfaceFaceIdx[s][f]** defines the triangles of the static mesh which belong to this surface. One of these triangles must be hit for a successful visibility test of a specular planar reflection. The reflection plane of each surface is given in Hesse normal form using the surface normal N_0 and the surface distance d which are converted as follows:

```

10  int max_steps_azi = 1 << 12;
    int max_steps_ele = 1 << 11;
    int num_steps_azi = 144 * (max_steps_azi / 144);
    int num_steps_ele = 72 * (max_steps_ele / 72);
    int shift_ele = num_steps_ele / 2;
    float quant2azi = double(2.0 * M_PI) / double(num_steps_azi);
15  float quant2ele = double(M_PI) / double(num_steps_ele);
    float quant2dist = 0.001f;

    for (int s = 0; s < numberOfSurfaces; s++) {
20      earlySurfaceIdx[s] = s;
        float azi = earlySurfaceAzi[s] * quant2azi;
        float ele = (earlySurfaceEle[s] - shift_ele) * quant2ele;
        earlySurface_N0[s][0] = -1.0 * sin(azi) * cos(ele);
        earlySurface_N0[s][1] = sin(ele);
        earlySurface_N0[s][2] = -1.0 * cos(azi) * cos(ele);
25      earlySurface_d[s] = (earlySurfaceDist[s] + dist_offset) *
        quant2dist;
    }

```

30 Voxel data

Early Reflection Voxel Data is a sparse voxel database containing lists of reflection sequences of potentially visible image sources for given pairs of source and listener voxels. The entries of the database can either be undefined for the case that the given pair of source and listener voxel is not specified in the bitstream, they can be an empty list, or they can contain a list of *surface connected IDs*. The relevant variables and data structures are:

- **numberOfVoxelPairs**
- 40 • **earlyVoxelL[v]**
- **earlyVoxelS[v]**
- **earlyVoxelMode[v]**
- **earlyVoxelIndicesRemovedDiff[v][k]**
- **earlyVoxelNumPaths[v]**
- 45 • **earlyVoxelOrder[v][p]**

- **earlyVoxelSurf[v][p][o]**

The sparse voxel database **earlyVoxelDatabase[l][s][p]** is derived from these variables by the following algorithm:

```

5  int delta_x = voxelCoordinateToVoxelIndex( {1, 0, 0} );
   int delta_y = voxelCoordinateToVoxelIndex( {0, 1, 0} );
   int delta_z = voxelCoordinateToVoxelIndex( {0, 0, 1} );
   int delta_list[4] = { 0, -delta_x, -delta_y, -delta_z };
10  for (int v = 0; v < numberOfVoxelPairs; v++) {
       PathList path_list;
       int l = earlyVoxelL[v];
       int s = earlyVoxelS[v];
15      int mode = earlyVoxelMode[v];

       if (mode != 0) {
           int l_ref = l + delta_list[mode];
           path_list = earlyVoxelDatabase[l_ref][s];
20
           // generate list with removed items in reverse order
           int numberOfIndicesRemoved =
               length(earlyVoxelIndicesRemovedDiff[v]) - 1;
           int listIndicesRemoved[numberOfIndicesRemoved];
25           int val = -1;
           for (int k = 0; k < numberOfIndicesRemoved; k++) {
               val += earlyVoxelIndicesRemovedDiff[v][k];
               listIndicesRemoved[numberOfIndicesRemoved - 1 - k] =
30           val;
           }

           // remove reflection sequences
           for (int k = 0; k < numberOfIndicesRemoved; k++) {
35               path_list.erase(listIndicesRemoved[k]);
           }

           // add reflection sequences
           for (int p = 0; p < earlyVoxelNumPaths[v]; p++) {
40               path_list.append(earlyVoxelSurf[v][p]);
           }

           // add sorted path list to sparse voxel database
           path_list = shortlex_sort(path_list);
45           int num_paths = length(path_list);
           for (int p = 0; p < num_paths; p++) {
               earlyVoxelDatabase[l][s][p] = path_list[p];
           }
50     }

```

In this algorithm, the function `voxelCoordinateToVoxelIndex()` denotes the voxel coordinate to voxel index conversion. The keyword `PathList` denotes a list of integer

arrays which can be modified by the method `append()`, that adds an element at the end of the list, and the method `erase()`, that removes a list element at a given position. Furthermore, the function `shortlex_sort()` denotes a sorting function which sorts the given list of reflection sequences in shortlex order.

5

Complexity Evaluation

The decoder is simplified since a parsing step of the JSON data is no longer needed while the runtime complexity of the renderer is not affected by the proposed changes.

10

Evidence for the Merit

In order to verify that the proposed method works correctly and to prove its technical merit, we encoded all “test 1” and “test 2” scenes and compared the size of the early reflection metadata with the encoding result of the P13 encoder.

15

Data Compression

Table lists the size of payloadEarlyReflections for the P13 encoder (“old size / bytes”) and a variant of the P13 encoder with the proposed encoding method (“new size / bytes”). The last column lists the achieved compression ratio, i.e. the ratio of the old and the new payload size.

20

In all cases the proposed method results in smaller payload sizes. For all scenes with reflecting scene objects, i.e. scenes with mesh data, a compression ratio greater than 10 was achieved. For some scenes (“SingerInTheLab” and “VirtualBasketball”) a compression ratio close to or even greater than 100 was achieved.

25

Table – size comparison of payloadEarlyReflections

Scene	old size / bytes	new size / bytes	compression ratio
ARBmw	49	41	1.20
ARHomeConcert_Test1	49	41	1.20
ARPortal	3635	208	17.48
Battle	71474	3794	18.84
Beach	49	41	1.20
Canyon	442297	20591	21.48

Cathedral	4476209	122576	36.52
DowntownDrummer	170140	6745	25.22
GigAdvertisement	49	41	1.20
Hospital	85350	4673	18.26
OutsideHOA	44289	3185	13.91
Park	4002785	162528	24.63
ParkingLot	948184	53121	17.85
Recreation	6690228	372541	17.96
SimpleMaze	15866	975	16.27
SingerInTheLab	85016	714	119.07
SingerInYourLab_small	49	41	1.20
VirtualBasketball	478238	4853	98.54
VirtualPartition	301	65	4.63

In the following, the total bitstream saving is considered.

- 5 The following table lists the saving of total bitstream size in percent. On average, the total bitstream size was reduced by 21.33%. Considering only scenes with mesh data, the total bitstream sizes were reduced by 28.91% on average.

Table – saving of total bitstream size

Scene			old total size / bytes	new total size / bytes	saving / %
ARBmw			7827	7819	0.10
ARHomeConcert_Test 1			5963	5955	0.13
ARPortal	40745	37318	8.41		
Battle			285137	217457	23.74
Beach			6248	6240	0.13
Canyon			1421293	999587	29.67
Cathedral			11110385	6756752	39.19
DowntownDrummer			440299	276904	37.11
GigAdvertisement			6553	6545	0.12
Hospital			3649408	356873	2.21

		1	
OutsideHOA	118206	77102	34.77
Park	19027460	15187203	20.18
ParkingLot	1973557	1078494	45.35
Recreation	30335390	24017703	20.83
SimpleMaze	840490	825599	1.77
SingerInTheLab	99631	15329	84.61
SingerInYourLab_small	9726	9718	0.08
VirtualBasketball	871379	397994	54.33
VirtualPartition	9295	9059	2.54

Data Validation and Quantization Errors

5 The following table lists the result of our data validation test for an extended test set, which additionally includes all “test 4” scenes plus further scenes that did not make it into the official test repository, where we compared the decoded metadata, e.g., earlySurfaceData and earlyVoxelData, with the output of the P13 decoder. For the P13 payload, the connected surface data and the surface data was combined in order to be able to compare it to the new encoding method. The validation result “identical structure”
10 means that both payloads had the same reflecting surfaces and that the data only differed by the expected quantization errors.

For all scenes the decoded earlyVoxelData was identical and the decoded earlySurfaceData was either identical or structurally identical.

15 **Table – validation of transmitted data**

Scene	earlySurfaceData	earlyVoxelData
ARBmw	identical	identical
ARHomeConcert_Test1	identical	identical
ARPortal	identical structure	identical
BOrchestra	identical	identical
Battle	identical structure	identical
Beach	identical	identical
Canyon	identical structure	identical

Cathedral	identical structure	identical
DowntownDrummer	identical structure	identical
FountainMusicVR	identical structure	identical
GigAdvertisement	identical	identical
Hospital	identical structure	identical
LivingRoom	identical structure	identical
MultiZoneMusic	identical	identical
MultiZoneMusic_objects	identical structure	identical
Offices	identical structure	identical
Outside	identical structure	identical
OutsideHOA	identical structure	identical
Park	identical structure	identical
ParkingLot	identical structure	identical
Recreation	identical structure	identical
Restaurant	identical	identical
SimpleMaze	identical structure	identical
SingerInTheLab	identical structure	identical
SingerInYourLab	identical	identical
SingerInYourLab_small	identical	identical
VirtualBasketball	identical structure	identical
VirtualPartition	identical structure	identical

The following table lists the minimum, mean, median, and maximum quantization error in mm of the transmitted plane normal N_0 after conversion into Cartesian coordinates. The maximum quantization error of 1.095 mm corresponds to an angular deviation of 0.063° .

- 5 With a resolution of 0.088° per quantization step and hence 0.044° maximum quantization error per axis, the observed results are in good accordance with the theoretical values.

A maximum angular deviation of 0.063° for the surface normal vector N_0 is so small that the transmission can be regarded as quasi lossless.

10

Table – quantization error of the normal unit vector of the surfaces in mm

Scene	min	mean	median	max
ARPortal	0	0.164	6.56e-5	0.728
Battle	0	0.254	0.100	1.035
Canyon	4.37e-5	0.521	0.529	1.066
Cathedral	1.19e-5	0.358	0.349	0.985

DowntownDrummer	0	0.284	0.239	0.917
FountainMusicVR	0	0.063	4.37e-5	0.729
Hospital	0	0.304	0.266	1.003
LivingRoom	0	0.036	4.37e-5	0.650
MultiZoneMusic_ objects	0	0.186	8.51e-3	0.696
Offices	1.19e-5	0.259	0.349	0.803
Outside	0	3.84e-5	4.37e-5	8.74e-5
OutsideHOA	0	0.063	4.37e-5	0.729
Park	0	0.392	0.430	0.828
ParkingLot	1.19e-5	0.569	0.603	1.095
Recreation	0	0.515	0.533	1.087
SimpleMaze	0	3.97e-5	4.37e-5	8.74e-5
SingerInTheLab	1.19e-5	0.249	0.349	0.349
Testroom	0	3.69e-5	4.37e-5	8.74e-5
VirtualBasketball	1.19e-5	0.399	0.349	0.932
VirtualPartition	0	4.37e-5	4.37e-5	8.74e-5

The following table lists the minimum, mean, median, and maximum quantization error in mm of the transmitted plane distance. With a resolution of 1 mm per quantization step, the observed maximum deviation of 0.519 mm is in good accordance with the expected maximum value of 0.5 mm. The overshoot can be explained by the limited precision of the used single precision floating point variables which do not provide sufficient sub-millimeter resolution for large scenes like “Park”, “ParkingLot”, and “Recreation”.

A maximum deviation of 0.519 mm for the surface distance d is so small that the transmission can be regarded as quasi lossless.

Table— quantization error of the surface distances in mm

Scene	min	mean	median	max
ARPortal	0	0.259	0.277	0.500
Battle	0	0.141	0.047	0.495
Canyon	0	0.254	0.250	0.502
Cathedral	0	0.249	0.244	0.504
DowntownDrummer	0	0.223	0.201	0.504
FountainMusicVR	2.38e-4	0.180	0.101	0.423
Hospital	0	0.158	0.087	0.498

LivingRoom	0	0.204	0.200	0.500
MultiZoneMusic_objects	0	0.193	0.103	0.475
Offices	1.91e-3	0.254	0.236	0.500
Outside	0	0.133	0.099	0.299
OutsideHOA	2.38e-4	0.180	0.101	0.423
Park	0	0.251	0.244	0.519
ParkingLot	0	0.247	0.244	0.519
Recreation	0	0.248	0.244	0.519
SimpleMaze	0	2.98e-5	0	2.38e-4
SingerInTheLab	0	0.050	0.050	0.101
Testroom	0	1.12e-4	0	4.77e-4
VirtualBasketball	9.54e-4	0.241	0.248	0.500
VirtualPartition	0	0	0	0

In an embodiment, a binary encoding method for `earlySurfaceData()` and `earlyVoxelData()` as part of the early reflection metadata in `payloadEarlyReflections()` is provided. For the test set comprising 30 AR and VR scenes, we compared the decoded data with the data
5 decoded by the P13 decoder and observed only expected quantization errors. The quantization errors of the surface data was so small that the transmission can be regarded as quasi-lossless. The transmitted voxel data was identical.

In all cases the proposed method results in smaller payload sizes. For all scenes with
10 reflecting scene objects, i.e. scenes with mesh data, a compression ratio greater than 10 was achieved. For some scenes ("SingerInTheLab" and "VirtualBasketball"), a compression ratio close to or even greater than 100 was achieved. For all "test 1" and "test 2" scenes, the proposed encoding method provides on average a reduction of 21.33% in overall bitstream size over P13. Considering only scenes with reflecting mesh
15 data, the proposed encoding method provides on average a reduction of 28.91% in overall bitstream size over P13.

The proposed encoding method does not affect the runtime complexity of the renderer.

20 Moreover, the proposed replacement also reduces the library dependencies of the reference software since generating and parsing JSON documents is no longer needed.

Although some aspects have been described in the context of an apparatus, it is clear that these aspects also represent a description of the corresponding method, where a block or device corresponds to a method step or a feature of a method step. Analogously, aspects described in the context of a method step also represent a description of a corresponding
5 block or item or feature of a corresponding apparatus. Some or all of the method steps may be executed by (or using) a hardware apparatus, like for example, a microprocessor, a programmable computer or an electronic circuit. In some embodiments, one or more of the most important method steps may be executed by such an apparatus.

10 Depending on certain implementation requirements, embodiments of the invention can be implemented in hardware or in software or at least partially in hardware or at least partially in software. The implementation can be performed using a digital storage medium, for example a floppy disk, a DVD, a Blu-Ray, a CD, a ROM, a PROM, an EPROM, an EEPROM or a FLASH memory, having electronically readable control signals stored
15 thereon, which cooperate (or are capable of cooperating) with a programmable computer system such that the respective method is performed. Therefore, the digital storage medium may be computer readable.

Some embodiments according to the invention comprise a data carrier having
20 electronically readable control signals, which are capable of cooperating with a programmable computer system, such that one of the methods described herein is performed.

Generally, embodiments of the present invention can be implemented as a computer
25 program product with a program code, the program code being operative for performing one of the methods when the computer program product runs on a computer. The program code may for example be stored on a machine readable carrier.

Other embodiments comprise the computer program for performing one of the methods
30 described herein, stored on a machine readable carrier.

In other words, an embodiment of the inventive method is, therefore, a computer program having a program code for performing one of the methods described herein, when the computer program runs on a computer.
35

A further embodiment of the inventive methods is, therefore, a data carrier (or a digital storage medium, or a computer-readable medium) comprising, recorded thereon, the computer program for performing one of the methods described herein. The data carrier,

the digital storage medium or the recorded medium are typically tangible and/or non-transitory.

5 A further embodiment of the inventive method is, therefore, a data stream or a sequence of signals representing the computer program for performing one of the methods described herein. The data stream or the sequence of signals may for example be configured to be transferred via a data communication connection, for example via the Internet.

10 A further embodiment comprises a processing means, for example a computer, or a programmable logic device, configured to or adapted to perform one of the methods described herein.

15 A further embodiment comprises a computer having installed thereon the computer program for performing one of the methods described herein.

20 A further embodiment according to the invention comprises an apparatus or a system configured to transfer (for example, electronically or optically) a computer program for performing one of the methods described herein to a receiver. The receiver may, for example, be a computer, a mobile device, a memory device or the like. The apparatus or system may, for example, comprise a file server for transferring the computer program to the receiver.

25 In some embodiments, a programmable logic device (for example a field programmable gate array) may be used to perform some or all of the functionalities of the methods described herein. In some embodiments, a field programmable gate array may cooperate with a microprocessor in order to perform one of the methods described herein. Generally, the methods are preferably performed by any hardware apparatus.

30 The apparatus described herein may be implemented using a hardware apparatus, or using a computer, or using a combination of a hardware apparatus and a computer.

The methods described herein may be performed using a hardware apparatus, or using a computer, or using a combination of a hardware apparatus and a computer.

35

The above described embodiments are merely illustrative for the principles of the present invention. It is understood that modifications and variations of the arrangements and the details described herein will be apparent to others skilled in the art. It is the intent,

therefore, to be limited only by the scope of the impending patent claims and not by the specific details presented by way of description and explanation of the embodiments herein.

Claims

1. An apparatus (300) for generating one or more audio output signals from one or more encoded audio signals, wherein the apparatus (300) comprises:
- 5 an input interface (310) for receiving the one or more encoded audio signals and for receiving additional audio information data, and
- 10 a signal generator (320) for generating the one or more audio output signals depending on the encoded audio signals and depending on second additional audio information,
- 15 wherein the signal generator (320) is configured to obtain the second additional audio information using the additional audio information data and using first additional audio information, if the additional audio information data exhibits a redundancy state, and
- 20 wherein the signal generator (320) is configured to obtain the second additional audio information using the additional audio information data without using the first additional audio information, if the additional audio information data exhibits a non-redundancy state.
2. An apparatus (300) according to claim 1,
- 25 wherein the input interface (310) is configured to receive propagation information data as the additional audio information data,
- 30 wherein the signal generator (320) is configured to generate the one or more audio output signals depending on the second additional audio information, being second propagation information,
- 35 wherein the signal generator (320) is configured to obtain the second propagation information using the propagation information data and using the first additional audio information, being first propagation information, if the propagation information data exhibits a redundancy state, and
- wherein the signal generator (320) is configured to obtain the second propagation information using the propagation information data without using the first

propagation information, if the propagation information data exhibits a non-redundancy state.

3. An apparatus (300) according to claim 2,

5

wherein the propagation information data comprises reflection information data and/or diffraction information data,

10

wherein the first propagation information comprises first reflection information and/or first diffraction information, and

wherein the second propagation information comprises second reflection information and/or second diffraction information.

- 15 4. An apparatus (300) according to claim 2,

wherein the input interface (310) is configured to receive reflection information data as the propagation information data,

20

wherein the signal generator (320) is configured to generate the one or more audio output signals depending on the second propagation information, being second reflection information,

25

wherein the signal generator (320) is configured to obtain the second reflection information using the reflection information data and using the first propagation information, being first reflection information, if the reflection information data exhibits a redundancy state, and

30

wherein the signal generator (320) is configured to obtain the second reflection information using the reflection information data without using the first reflection information, if the reflection information data exhibits a non-redundancy state.

5. An apparatus (300) according to claim 2,

35

wherein the input interface (310) is configured to receive diffraction information data as the propagation information data,

wherein the signal generator (320) is configured to generate the one or more audio output signals depending on the second propagation information, being second diffraction information,

5 wherein the signal generator (320) is configured to obtain the second diffraction information using the diffraction information data and using the first propagation information, being first diffraction information, if the diffraction information data exhibits a redundancy state, and

10 wherein the signal generator (320) is configured to obtain the second diffraction information using the diffraction information data without using the first diffraction information, if the diffraction information data exhibits a non-redundancy state.

6. 15 An apparatus (300) according to one of the preceding claims, further depending on claim 2,

20 wherein the first propagation information and/or the second propagation information depends on one or more propagations of one or more sound waves along one or more propagation paths in a real listening environment or in a virtual listening environment or in an augmented listening environment.

7. An apparatus (300) according to one of the preceding claims, further depending on claim 3 or 4,

25 wherein the first reflection information and/or the second reflection information depends on one or more reflections at one or more reflection objects of one or more sound waves propagating along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

30 8. An apparatus (300) according to one of the preceding claims, further depending on claim 3 or 5,

35 wherein the first diffraction information and/or the second diffraction information depends on one or more diffractions at one or more diffraction objects of one or more sound waves propagating along one or more propagation paths in the real listening environment or in the virtual listening environment or in the augmented listening environment.

9. An apparatus (300) according to one of claims 2 to 8,
- 5 wherein, if the propagation information data exhibits the redundancy state, the propagation information data indicates one or more propagation sequences that are to be removed from the first propagation information, being a first set of propagation sequences, and/or indicates one or more propagation sequences that are to be added to the first set of propagation sequences to obtain the second propagation information, being a second set of propagation sequences, and the
- 10 signal generator (320) is configured to update the first set of propagation sequences using the propagation information data to obtain the second set of propagation sequences.
10. An apparatus (300) according to claim 9,
- 15 wherein each propagation sequence of the first set of propagation sequences and of the second set of propagation sequences indicates a group of one or more reflection objects or a group of one or more diffraction objects.
- 20 11. An apparatus (300) according to claim 9 or 10,
- wherein, if the propagation information data exhibits the non-redundancy state, the propagation information data comprises the second set of propagation sequences, and the signal generator (320) is configured to determine the second set of
- 25 propagation sequences from the propagation information data.
12. An apparatus (300) according to claim 11,
- 30 wherein the first set of propagation sequences is associated with a first listener position and with a first source position,
- wherein the second set of propagation sequences is associated with a second listener position and with a second source position, and
- 35 wherein the first listener position is different from the second listener position, and/or wherein the first source position is different from the second source position.

13. An apparatus (300) according to claim 12, further depending on claim 4,

wherein each reflection sequence of the first set of reflection sequences comprises information on the group of one or more reflection objects of the reflection sequence, where sound waves emitted by an audio source at the first source position and perceivable by a listener at the first listener position are reflected on their way to the current listener location, and

wherein each reflection sequence of the second set of reflection sequences comprises information on the group of one or more reflection objects of the reflection sequence, where sound waves emitted by an audio source at the second source position and perceivable by a listener at the second listener position are reflected on their way to the current listener location.

14. An apparatus (300) according to claim 13,

wherein the one or more encoded audio signals are associated with the audio source being located at the source position of the second set of reflection sequences,

wherein the signal generator (320) is configured to generate the one or more audio output signals using the one or more encoded audio signals and using the second set of reflection sequences such that the one or more audio output signals comprises early reflections of the sound waves emitted by the audio source at the source position of the second set of reflection sequences.

15. An apparatus (300) according to one of claims 12 to 14, further depending on claim 4,

wherein the signal generator (320) is configured to obtain a plurality of sets of reflection sequences, wherein each of the plurality of sets of reflection sequences is associated with a listener position and with a source position,

wherein the input interface (310) is configured to receive an indication,

wherein, for determining the second set of reflection sequences, the signal generator (320) is configured, if the reflection information data exhibits the redundancy state, to determine the first listener position and the first source

position using the indication, and to choose that one of the plurality of sets of reflection sequences as the first set of reflection sequences which is associated with the first listener position and with the first source position.

5 16. An apparatus (300) according to claim 15,

10 wherein, if the reflection information data exhibits a redundancy state, the indication indicates to choose the first listener position and the first source position, such that the first listener position is neighboured to the second listener position and/or such that the first source position is neighboured to the second listener position,

15 wherein, if the reflection information data exhibits a redundancy state, the signal generator (320) is configured to determine the first listener position and/or the first source position according to the indication.

17. An apparatus (300) according to claim 16,

20 wherein, if the reflection information data exhibits a redundancy state, the indication indicates to choose the first listener position and the first source position, such that the first listener position is neighboured to the second listener position and such that the first source position is identical with the second listener position, wherein the signal generator (320) is configured to determine the first listener position and the first source position according to the indication; or

25 wherein, if the reflection information data exhibits a redundancy state, the indication indicates to choose the first listener position and the first source position, such that the first listener position is identical with the second listener position and such that the first source position is neighboured to the second listener position, wherein the signal generator (320) is configured to determine the first listener position and the first source position according to the indication.

18. An apparatus (300) according to claim 16 or 17,

35 wherein, in a coordinate system, a first position and a second position are neighboured, if in each coordinate direction of the coordinate system, the first position immediately precedes or immediately succeeds the second position or is identical to the second position, and if in at least one coordinate direction of the

coordinate system, the first position and the second position are different from each other.

19. An apparatus (300) according to one of claims 16 to 18,

5

wherein the indication indicates one of the following:

that the reflection information data exhibits the non-redundancy state,

10

that the reflection information data exhibits a first redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in a first coordinate direction of a coordinate system, the first listener position immediately precedes the second listener position, and wherein in a second coordinate direction and in a third coordinate direction of the coordinate system, the first listener position is identical with the second listener position,

15

20

that the reflection information data exhibits a second redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in the second coordinate direction of the coordinate system, the first listener position immediately precedes the second listener position, and wherein in the first coordinate direction and in the third coordinate direction of the coordinate system, the first listener position is identical with the second listener position,

25

30

that the reflection information data exhibits a third redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in the third coordinate direction of the coordinate system, the first listener position immediately precedes the second listener position, and wherein in the first coordinate direction and in the second coordinate direction of the coordinate system, the first listener position is identical with the second listener position,

35

- 5 wherein, if the indication indicates the first redundancy state or the second redundancy state or the first redundancy state, the signal generator (320) is configured to determine the first listener position and the first source position according to the indication.
20. An apparatus (300) according to one of claims 12 to 19,
- 10 wherein each of the first listener position, the first source position, the second listener position and the second source position defines a position of a voxel out of a plurality of voxels within a three-dimensional coordinate system.
21. An apparatus (300) according to one of the preceding claims,
- 15 wherein the signal generator (320) is configured to generate a binaural signal comprising two binaural channels as the one or more audio output signals.
22. An apparatus (400) for encoding one or more audio signals and for generating additional audio information data, wherein the apparatus (400) comprises:
- 20 an audio signal encoder (410) for encoding the one or more audio signals to obtain one or more encoded audio signals, and
- 25 an additional audio information generator (420) for generating the additional audio information data, wherein the additional audio information generator (420) exhibits a non-redundancy operation mode and a redundancy operation mode,
- 30 wherein the additional audio information generator (420) is configured to generate the additional audio information data, if the additional audio information generator (420) exhibits the non-redundancy operation mode, such that the additional audio information data comprises the second additional audio information, and
- 35 wherein the additional audio information generator (420) is configured to generate the additional audio information data, if the additional audio information generator (420) exhibits the non-redundancy operation mode, such that the additional audio information data does not comprise the second additional audio information or does only comprise a portion of the second additional audio information, such that

the second additional audio information is obtainable using the additional audio information data together with first additional audio information.

23. An apparatus (400) according to claim 22,

5

wherein the additional audio information generator (420) is a propagation information generator for generating propagation information data as the additional audio information data,

10

wherein the propagation information generator is configured to generate the propagation information data, if the propagation information generator exhibits the non-redundancy operation mode, such that the propagation information data comprises the second additional audio information being second propagation information, and

15

wherein the propagation information generator is configured to generate the propagation information data, if the propagation information generator exhibits the non-redundancy operation mode, such that the propagation information data does not comprise the second propagation information or does only comprise a portion of the second propagation information, such that the second propagation information is obtainable using the propagation information data together with first propagation information.

20

24. An apparatus (400) according to claim 23,

25

wherein the propagation information data comprises reflection information data and/or diffraction information data,

30

wherein the first propagation information comprises first reflection information and/or first diffraction information, and

wherein the second propagation information comprises second reflection information and/or second diffraction information.

35

25. An apparatus (400) according to claim 23,

wherein the propagation information generator is a reflection information generator for generating reflection information data as the propagation information data,

5 wherein the reflection information generator is configured to generate the reflection information data, if the reflection information generator exhibits the non-redundancy operation mode, such that the reflection information data comprises second reflection information as the second propagation information, and

10 wherein the reflection information generator is configured to generate the reflection information data, if the reflection information generator exhibits the non-redundancy operation mode, such that the reflection information data does not comprise the second reflection information or does only comprise a portion of the second reflection information, such that the second reflection information is obtainable using the reflection information data together with the first propagation information being first reflection information.

15 26. An apparatus (400) according to claim 23,

20 wherein the propagation information generator is a diffraction information generator for generating diffraction information data as the propagation information data,

25 wherein the diffraction information generator is configured to generate the diffraction information data, if the diffraction information generator exhibits the non-redundancy operation mode, such that the diffraction information data comprises second diffraction information as the second propagation information, and

30 wherein the diffraction information generator is configured to generate the diffraction information data, if the diffraction information generator exhibits the non-redundancy operation mode, such that the diffraction information data does not comprise the second diffraction information or does only comprise a portion of the second diffraction information, such that the second diffraction information is obtainable using the diffraction information data together with the first propagation information being first diffraction information.

35 27. An apparatus (400) according to one of the preceding claims, further depending on claim 23,

wherein the first propagation information and/or the second propagation information depends on one or more propagations of one or more sound waves

along one or more propagation paths in a real listening environment or in a virtual listening environment or in an augmented listening environment.

28. An apparatus (400) according to one of the preceding claims, further depending on
5 claim 24 or 25,

wherein the first reflection information and/or the second reflection information
depends on one or more reflections at one or more reflection objects of one or
more sound waves propagating along one or more propagation paths in the real
10 listening environment or in the virtual listening environment or in the augmented
listening environment.

29. An apparatus (400) according to one of the preceding claims, further depending on
15 claim 24 or 26,

wherein the first diffraction information and/or the second diffraction information
depends on one or more diffractions at one or more diffraction objects of one or
more sound waves propagating along one or more propagation paths in the real
listening environment or in the virtual listening environment or in the augmented
20 listening environment.

30. An apparatus (400) according to one of claims 23 to 29,
25 wherein the propagation information generator is configured in the redundancy
operation mode to generate the propagation information data such that the
propagation information data indicates one or more propagation sequences that
are to be removed from the first propagation information, being a first set of
propagation sequences, and/or indicates one or more propagation sequences that
are to be added to the first set of propagation sequences to obtain the second
30 propagation information, being a second set of propagation sequences.

31. An apparatus (400) according to claim 30,
35 wherein each propagation sequence of the first set of propagation sequences and
of the second set of propagation sequences indicates a group of one or more
reflection objects or a group of one or more diffraction objects.

32. An apparatus (400) according to claim 30 or 31,

wherein the propagation information generator is configured in the non-redundancy operation mode to generate the propagation information data such that the propagation information data comprises the second set of propagation sequences.

5

33. An apparatus (400) according to claim 32,

wherein the first set of propagation sequences is associated with a first listener position and with a first source position,

10

wherein the second set of propagation sequences is associated with a second listener position and with a second source position, and

wherein the first listener position is different from the second listener position, and/or wherein the first source position is different from the second source position.

15

34. An apparatus (400) according to claim 33, further depending on claim 25,

20

wherein each reflection sequence of the first set of reflection sequences comprises information on the group of one or more reflection objects of the reflection sequence, where sound waves emitted by an audio source at the first source position and perceivable by a listener at the first listener position are reflected on their way to the current listener location, and

25

wherein the reflection information generator is configured to generate the reflection information data such that each reflection sequence of the second set of reflection sequences comprises information on the group of one or more reflection objects of the reflection sequence, where sound waves emitted by an audio source at the second source position and perceivable by a listener at the second listener position are reflected on their way to the current listener location.

30

35. An apparatus (400) according to claim 34,

35

wherein the one or more encoded audio signals are associated with the audio source being located at the source position of the second set of reflection sequences.

36. An apparatus (400) according to one of claims 33 to 35, further depending on claim 25,
- 5 wherein the reflection information generator is configured in the redundancy operation mode to generate an indication suitable for determining the first listener position and the first source position of the first set of reflection sequences.
37. An apparatus (400) according to claim 36,
- 10 wherein the reflection information generator is configured in the redundancy operation mode to generate the indication such that the indication indicates to choose the first listener position and the first source position, such that the first listener position is neighboured to the second listener position and/or such that the first source position is neighboured to the second listener position.
- 15 38. An apparatus (400) according to claim 37,
- 20 wherein the reflection information generator is configured in the redundancy operation mode to generate the indication such that the indication indicates to choose the first listener position and the first source position, such that the first listener position is neighboured to the second listener position and such that the first source position is identical with the second listener position; or
- 25 wherein the reflection information generator is configured in the redundancy operation mode to generate the indication such that the indication indicates to choose the first listener position and the first source position, such that the first listener position is identical with the second listener position and such that the first source position is neighboured to the second listener position.
- 30 39. An apparatus (400) according to claim 37 or 38,
- 35 wherein, in a coordinate system, a first position and a second position are neighboured, if in each coordinate direction of the coordinate system, the first position immediately precedes or immediately succeeds the second position or is identical to the second position, and if in at least one coordinate direction of the coordinate system, the first position and the second position are different from each other.

40. An apparatus (400) according to one of claims 37 to 39,

wherein the reflection information generator is configured in the redundancy operation mode to generate the indication such that the indication indicates one of the following:

that the reflection information data exhibits the non-redundancy state,

that the reflection information data exhibits a first redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in a first coordinate direction of a coordinate system, the first listener position immediately precedes the second listener position, and wherein in a second coordinate direction and in a third coordinate direction of the coordinate system, the first listener position is identical with the second listener position,

that the reflection information data exhibits a second redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in the second coordinate direction of the coordinate system, the first listener position immediately precedes the second listener position, and wherein in the first coordinate direction and in the third coordinate direction of the coordinate system, the first listener position is identical with the second listener position,

that the reflection information data exhibits a third redundancy state, so that the first listener position and the first source position shall be chosen, such that the first source position is identical with the second source position, and such that the first listener position is neighboured to the second listener position, wherein in the third coordinate direction of the coordinate system, the first listener position immediately precedes the second listener position, and wherein in the first coordinate direction and in the second coordinate direction of the coordinate system, the first listener position is identical with the second listener position.

41. An apparatus (400) according to one of claims 33 to 40,
wherein each of the first listener position, the first source position, the second
listener position and the second source position defines a position of a voxel out of
5 a plurality of voxels within a three-dimensional coordinate system.
42. A system comprising:
an apparatus (400) according to one of claims 22 to 41 for encoding one or more
10 audio signals to obtain one or more encoded audio signals and for generating
additional audio information data, and
an apparatus (300) according to one of claims 1 to 21 for generating one or more
15 audio output signals from the one or more encoded audio signals depending on
the additional audio information data.
43. A method for generating one or more audio output signals from one or more
encoded audio signals, wherein the method comprises:
20 receiving the one or more encoded audio signals and receiving additional audio
information data, and
generating the one or more audio output signals depending on the encoded audio
signals and depending on second additional audio information,
25 wherein the method comprises obtaining the second additional audio information
using the additional audio information data and using first additional audio
information, if the additional audio information data exhibits a redundancy state,
and
30 wherein the method comprises obtaining the second additional audio information
using the additional audio information data without using the first additional audio
information, if the additional audio information data exhibits a non-redundancy
state.
35
44. A method for encoding one or more audio signals and for generating additional
audio information data, wherein the method comprises:

encoding the one or more audio signals to obtain one or more encoded audio signals, and

generating the additional audio information data,

5

wherein, in a non-redundancy operation mode, generating the additional audio information data is conducted, such that the additional audio information data comprises the second additional audio information, and

10

wherein, in a redundancy operation mode, generating the additional audio information data is conducted, such that the additional audio information data does not comprise the second additional audio information or does only comprise a portion of the second additional audio information, such that the second additional audio information is obtainable using the additional audio information data together with first additional audio information.

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45. A computer program for implementing the method of claim 43 or 44 when being executed on a computer or signal processor.

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