

## **Apparatus and Method for Reproducing a Spatially Extended Sound Source or Apparatus and Method for Generating a Bitstream from a Spatially Extended Sound Source**

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### Specification

The present invention relates to audio signal processing and particularly to the encoding or decoding or reproducing of a spatially extended sound source.

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The reproduction of sound sources over several loudspeakers or headphones has been long investigated. The simplest way of reproducing sound sources over such setups is to render them as point sources, i.e. very (ideally: infinitely) small sound sources. This theoretic concept, however, is hardly able to model existing physical sound sources in a realistic way. For instance, a grand piano has a large vibrating wooden closure with many spatially distributed strings inside and thus appears much larger in auditory perception than a point source (especially when the listener (and the microphones) are close to the grand piano. Many real-world sound sources have a considerable size ("spatial extent") like musical instruments, machines, an orchestra or choir or ambient sounds (sound of a waterfall).

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Correct / realistic reproduction of such sound sources has become the target of many sound reproduction methods, be it binaural (i.e. using so-called Head-Related Transfer Functions HRTFs or Binaural Room Impulse Responses BRIRs) using headphones or conventionally using loudspeaker setups ranging from 2 speakers ("stereo") to many speakers arranged in a horizontal plane ("Surround Sound") and many speakers surrounding the listener in all three dimensions ("3D Audio").

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It is an object of the present invention to provide a concept for encoding or reproducing a Spatially Extended Sound Sources with a possibly complex geometric shape.

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### 2D Source Width

This section describes methods that pertain to rendering extended sound sources on a 2D surface faced from the point of view of a listener, e.g. in a certain azimuth range at zero degrees of elevation (like is the case in conventional stereo / surround sound) or certain ranges of azimuth and elevation (like is the case in 3D Audio or virtual real-

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ity with 3 degrees of freedom ["3DoF"] of the user movement, i.e. head rotation in pitch/yaw/roll axes).

Increasing the apparent width of an audio object which is panned between two or more loudspeakers (generating a so-called phantom image or phantom source) can be achieved by decreasing the correlation of the participating channel signals (Blauert, 2001, S. 241-257). With decreasing correlation, the phantom source's spread increases until, for correlation values close to zero (and not too wide opening angles), it covers the whole range between the loudspeakers.

Decorrelated versions of a source signal are obtained by deriving and applying suitable decorrelation filters. Lauridsen (Lauridsen, 1954) proposed to add/subtract a time delayed and scaled version of the source signal to itself in order to obtain two decorrelated versions of the signal. More complex approaches were for example proposed by Kendall (Kendall, 1995). He iteratively derived paired decorrelation all-pass filters based on combinations of random number sequences. Faller et al. propose suitable decorrelation filters ("diffusers") in (Baumgarte & Faller, 2003) (Faller & Baumgarte, 2003). Also Zotter et al. derived filter pairs in which frequency-dependent phase or amplitude differences were used to achieve widening of a phantom source (Zotter & Frank, 2013). Furthermore, (Alary, Politis, & Välimäki, 2017) proposed decorrelation filters based on velvet noise which were further optimized by (Schlecht, Alary, Välimäki, & Habets, 2018).

Besides reducing correlation of the phantom source's corresponding channel signals, source width can also be increased by increasing the number of phantom sources attributed to an audio object. In (Pulkki, 1999), the source width is controlled by panning the same source signal to (slightly) different directions. The method was originally proposed to stabilize the perceived phantom source spread of VBAP-panned (Pulkki, 1997) source signals when they are moved in the sound scene. This is advantageous since dependent on a source's direction, a rendered source is reproduced by two or more speakers which can result in undesired alterations of perceived source width.

Virtual world DirAC (Pulkki, Laitinen, & Erkut, 2009) is an extension of the traditional Directional Audio Coding (DirAC) (Pulkki, 2007) approach for sound synthesis in virtual worlds. For rendering spatial extent, directional sound components of a source are randomly panned within a certain range around the source's original direction, where panning directions vary with time and frequency.

A similar approach is pursued in (Pihlajamäki, Santala, & Pulkki, 2014), where spatial extent is achieved by randomly distributing frequency bands of a source signal into different spatial directions. This is a method aiming at producing a spatially distributed and enveloping sound coming equally from all directions rather than controlling an exact degree of extent.

Verron et al. achieved spatial extent of a source by not using panned correlated signals, but by synthesizing multiple incoherent versions of the source signal, distributing them uniformly on a circle around the listener, and mixing between them (Verron, Aramaki, Kronland-Martinet, & Pallone, 2010). The number and gain of simultaneously active sources determine the intensity of the widening effect. This method was implemented as a spatial extension to a synthesizer for environmental sounds.

### **3D Source Width**

This section describes methods that pertain to rendering extended sound sources in 3D space, i.e. in a volumetric way as it is required for virtual reality with 6 degrees of freedom ("6DoF"). This means 6 degrees of freedom of the user movement, i.e. head rotation in pitch/yaw/roll axes) plus 3 translational movement directions x/y/z.

Potard et al. extended the notion of source extent as a one-dimensional parameter of the source (i.e., its width between two loudspeakers) by studying the perception of source shapes (Potard, 2003). They generated multiple incoherent point sources by applying (time-varying) decorrelation techniques to the original source signal and then placing the incoherent sources to different spatial locations and by this giving them three-dimensional extent (Potard & Burnett, 2004).

In MPEG-4 Advanced AudioBIFS (Schmidt & Schröder, 2004), volumetric objects/shapes (shuck, box, ellipsoid and cylinder) can be filled with several equally distributed and decorrelated sound sources to evoke three-dimensional source extent.

In order to increase and control source extent using Ambisonics, Schmele et al. (Schmele & Sayin, 2018) proposed a mixture of reducing the Ambisonics order of an input signal, which inherently increases the apparent source width, and distributing decorrelated copies of the source signal around the listening space.

Another approach was introduced by Zotter et al., where they adopted the principle proposed in (Zotter & Frank, 2013) (i.e., deriving filter pairs that introduce frequency-dependent phase and magnitude differences to achieve source extent in stereo reproduction setups) for Ambisonics (Zotter F. , Frank, Kronlachner, & Choi, 2014).

A common disadvantage of panning-based approaches (e.g., (Pulkki, 1997) (Pulkki, 1999) (Pulkki, 2007) (Pulkki, Laitinen, & Erkut, 2009)) is their dependency on the listener's position. Even a small deviation from the sweet spot causes the spatial image to collapse into the loudspeaker closest to the listener. This drastically limits their application in the context of virtual reality and augmented reality with 6degrees-of-freedom (6DoF) where the listener is supposed to freely move around. Additionally, distributing time-frequency bins in DirAC-based approaches (e.g., (Pulkki, 2007) (Pulkki, Laitinen, & Erkut, 2009)) not always guarantees the proper rendering of the spatial extent of phantom sources. Moreover, it typically significantly degrades the source signal's timbre.

Decorrelation of source signals is usually achieved by one of the following methods: i) deriving filter pairs with complementary magnitude (e.g. (Lauridsen, 1954)), ii) using all-pass filters with constant magnitude but (randomly) scrambled phase (e.g., (Kendall, 1995) (Potard & Burnett, 2004)), or iii) spatially randomly distributing time-frequency bins of the source signal (e.g., (Pihlajamäki, Santala, & Pulkki, 2014)).

All approaches come with their own implications: Complementary filtering a source signal according to i) typically leads to an altered perceived timbre of the decorrelated signals. While all-pass filtering as in ii) preserves the source signal's timbre, the scrambled phase disrupts the original phase relations and especially for transient signals causes severe temporal dispersion and smearing artifacts. Spatially distributing time-frequency bins proved to be effective for some signals, but also alters the signal's perceived timbre. Furthermore, it showed to be highly signal dependent and introduces severe artifacts for impulsive signals.

Populating volumetric shapes with multiple decorrelated versions of a source signal as proposed in Advanced AudioBIFS ((Schmidt & Schröder, 2004) (Potard, 2003) (Potard & Burnett, 2004)) assumes availability of a large number of filters that produce mutually decorrelated output signals (typically, more than ten point sources per volumetric shape are used). However, finding such filters is not a trivial task and becomes more difficult the more such filters are needed. Furthermore, if the source

signals are not fully decorrelated and a listener moves around such a shape, e.g., in a (virtual reality) scenario, the individual source distances to the listener correspond to different delays of the source signals and their superposition at the listener's ears result in position dependent comb-filtering potentially introducing annoying unsteady coloration of the source signal.

Controlling source width with the Ambisonics-based technique in (Schmele & Sayin, 2018) by lowering Ambisonics order showed to have an audible effect only for transitions from 2nd to 1st or to 0th order. Furthermore, these transitions are not only perceived as a source widening but also frequently as a movement of the phantom source. While adding decorrelated versions of the source signal could help stabilizing the perception of apparent source width, it also introduces comb-filter effects that alter the phantom source's timbre.

It is an object of the present invention to provide an improved concept of reproducing a spatially extended sound source or generating a bitstream from a spatially extended sound source.

This object is achieved by an apparatus for reproducing a spatially extended sound source of claim 1, an apparatus for generating a bitstream of claim 27, a method for reproducing a spatially extended sound source of claim 35, a method for generating a bitstream of claim 36, a bitstream of claim 41, or a computer program of claim 47.

The present invention is based on the finding that a reproduction of a spatially extended sound source can be achieved and, particularly, even rendered possible by means of calculating a projection of a two-dimensional or a three-dimensional hull associated with a spatially extended sound source onto a projection plane using a listener position. This projection is used for calculating positions of at least two sound sources for the spatially extended sound source and, the at least two sound sources are rendered at the positions to obtain a reproduction of the spatially extended sound source, where the rendering results in two or more output signals, and where different sound signals for the different positions are used, but the different sound signals are all associated with one and the same spatially extended sound source.

A high-quality two-dimensional or three-dimensional audio reproduction is obtained, since, on the one hand, a time-varying relative position between the spatially extended sound source and the (virtual) listener position is accounted for. On the other hand, the spatially extended sound source is efficiently represented by geometry

information on the perceived sound source extent and by a number of at least two sound sources such as peripheral point sources that can be easily processed by renderers well-known in the art. Particularly, straightforward renderers in the art are always in the position to render sound sources at certain positions with respect to a certain output format or loudspeaker setup. For example, two sound sources calculated by the sound position calculator at certain positions can be rendered at these positions by amplitude panning, for example.

When, for example, the sound positions are between left and left surround in a 5.1 output format, and when the other sound sources are between right and right surround in the output format, the amplitude panning procedure performed by the renderer would result in quite similar signals for the left and the left surround channel for one sound source and in correspondingly quite similar signals for right and right surround for the other sound source so that the user perceives the sound sources as coming from the positions calculated by the sound position calculator. However, due to the fact that all four signals are, in the end, associated and related to the spatially extended sound source, the user does not simply perceive two phantom sources associated with the positions calculated by the sound position calculator, but the listener perceives a single spatially extended sound source.

An apparatus for reproducing a spatially extended sound source having a defined position in geometry in a space comprises an interface, a projector, a sound position calculator and a renderer. The present invention allows to account for an enhanced sound situation that occurs, for example, within a piano. A piano is a large device and, up to now, the piano sound may have been rendered as coming from a single point source. This, however, does not fully represent the piano's true sound characteristics. In accordance with the present invention, the piano as an example for a spatially extended sound source is reflected by at least two sound signals, where one sound signal could be recorded by a microphone positioned close to the left portion of the piano, i.e., close to the bass strings, while the other sound source could be recorded by a different second microphone positioned close to the right portion of the piano, i.e., near the treble strings generating high tones. Naturally, both microphones will record sounds that are different from each other due to the reflection situation within the piano and, of course, also due to the fact that a bass string is closer to the left microphone than to the right microphone and vice versa. On the other hand, however, both microphone signals will have a considerable amount of similar sound components that, in the end, make up the unique sound of a piano.

In accordance with the present invention, a bitstream representing the spatially extended sound source such as the piano is generated by recording the signals by also recording the geometry information of the spatially extended sound source and, optionally, by also either recording location information related to different microphone positions (or, generally to the two different positions associated with the two different sound sources) or providing a description of the perceived geometric shape of the (piano's) sound. In order to reflect a listener position with respect to the sound sources, i.e., that the listener can "walk around" in a virtual reality or an augmented reality, or any other sound scene, a projection of a hull associated with the spatially extended sound source such as the piano is calculated using the listener position and, positions of the at least two sound sources are calculated using the projection plane, where, particularly, preferred embodiments relate to the positioning of the sound sources at peripheral points of the projection plane.

It is made possible with reduced calculation overhead and reduced rendering overhead to actually represent the exemplary piano sound in a two-dimensional or three-dimensional situation so that, when the listener, for example, is closer to the left part of the sound source such as the piano, the sound that the listener perceives is different from the sound occurring when the user is located close to the right part of the sound source such as the piano or even behind the sound source such as the piano.

In view of the above, the inventive concept is unique in that, on the encoder-side, a way of characterizing a spatially extended sound source is provided that allows the usage of the spatially extended sound source within a sound reproduction situation for a true two-dimensional or three-dimensional setup. Furthermore, usage of the listener position within the highly flexible description of the spatially extended sound source is made possible in an efficient way by calculating a projection of a two-dimensional or three-dimensional hull onto a projection plane using the listener position. Sound positions of at least two sound sources for the spatially extended sound source are calculated using the projection plane and, the at least two sound sources are rendered at the positions calculated by the sound position calculator to obtain a reproduction of the spatially extended sound source having two or more output signals for a headphone or multichannel output signals for two or more channels in a stereo reproduction setup or a reproduction setup having more than two channels such as five, seven or even more channels.

Compared to the prior art method of filling a 3D volume with sound by placing many different point sources in all parts of the volume to be filled, the projection avoids hav-

ing to model many sound sources and reduces the number of employed point sources dramatically by requiring to fill only the projection of the hull, i.e. a 2D space. Furthermore, the number of required point sources is reduced even more by modeling preferably only sources on the hull of the projection which could – in extreme cases – be simply one sound source at the left border of the spatially extended sound source and one sound source at the right border of the spatially extended sound source. Both reduction steps are based on two psychoacoustic observations:

1. In contrast to the azimuth (and elevation) of a sound source, its distance cannot be perceived very reliably. Thus, a projection of the original volume onto a plane perpendicular to the listener, does not alter perception significantly (but can help to reduce the number of point sources needed for rendering).
2. Two decorrelated sounds which are distributed as point sources to the left and the right, respectively, tend to perceptually fill the space between them with sound.

Furthermore, the encoder-side not only allows the characterization of a single spatially extended sound source but is flexible in that the bitstream generated as the representation can include all data for two or more spatially extended sound sources that are preferably related, with respect to their geometry information and location to a single coordinate system. On the decoder-side, the reproduction cannot only be done for a single spatially extended sound source but can be done for several spatially extended sound sources, where the projector calculates a projection for each sound source using the (virtual) listener position. Additionally, the sound position calculator calculates positions of the at least two sound sources for each spatially extended sound source, and the renderer renders all the calculated sound sources for each spatially extended sound source, for example, by adding the two or more output signals from each spatially extended sound source in a signal-by-signal way or a channel-by-channel way and by providing the added channels to the corresponding headphones for a binaural reproduction or to the corresponding loudspeakers in a loudspeaker-related reproduction setup or, alternatively, to a storage for storing the (combined) two or more output signals for later use or transmission.

On the generator- or encoder-side, a bitstream is generated using an apparatus for generating the bitstream representing a compressed description for a spatially extended sound source where the apparatus comprises a sound provider for providing one or more different sound signals for the spatially extended sound source, and an

output data former generates the bitstream representing the compressed sound scene, the bitstream comprising the one or more different sound signals preferably in a compressed way such as compressed by a bitrate compressing encoder, for example an MP3, an AAC, a USAC or an MPEG-H encoder. The output data former is furthermore configured to introduce into the bitstream, in case of two or more different sound signals, an optional individual location information for each sound signal of the two or more different sound signals indicating a location of the corresponding sound signal preferably with respect to the information on the geometry of the spatially extended sound source, i.e., that the first signal is the signal recorded at the left part of a piano in the above example, and a signal recorded at the right side of the piano.

However, alternatively, the location information does not necessarily have to be related to the geometry of the spatially extended sound source but can also be related to a general coordinate origin, although the relation to the geometry of the spatially extended sound source is preferred.

Furthermore, the apparatus for generating the compressed bitstream also comprises a geometry provider for calculating information on the geometry of the spatially extended sound source and the output data former is configured for introducing, into the bitstream, the information on the geometry, the information on the individual location information for each sound signal, in addition to the at least two sound signals, such as the sound signals as recorded by microphones. However, the sound provider does not necessarily have to actually pick up microphone signals, but the sound signals can also be generated, on the encoder-side using decorrelation processing as the case may be. At the same time, only a small number of sound signals or even a single sound signal can be transmitted for the spatially extended sound signal and the remaining sound signals are generated on the reproduction side using decorrelation processing. This is preferably signaled by a bitstream element in the bitstream so that the sound reproducer always knows how many sound signals are included per spatially extended sound source so that the reproducer can decide, particularly within the sound position calculator, how many sound signals are available and how many sound signals should be derived on the decoder side, such as by signal synthesis or correlation processing.

In this embodiment, the regenerator writes a bitstream element into the bitstream indicating the number of sound signals included for a spatially extended sound source, and, on the decoder-side, the sound reproducer leads the bitstream element

from the bitstream, reads the bitstream element and, decides, based on the bitstream element, how many signals for the preferably peripheral point sources or the auxiliary sources placed in between the peripheral sound sources have to be calculated based on the at least one received sound signal in the bitstream.

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Subsequently, preferred embodiments of the present invention are discussed with respect to the accompanying drawings, in which:

- 10 Fig. 1 is an overview of a block diagram of a preferred embodiment of the reproduction side;
- Fig. 2 illustrates a spherical spatially extended sound source with a different number of peripheral point sources;
- 15 Fig. 3 illustrates an ellipsoid spatially extended sound source with several peripheral point sources;
- Fig. 4 illustrates a line spatially extended sound source with different methods to distribute the location of the peripheral point sources;
- 20 Fig. 5 illustrates a cuboid spatially extended sound source with different procedures to distribute the peripheral point sources;
- Fig. 6 illustrates a spherical spatially extended sound source at different distances;
- 25 Fig. 7 illustrates a piano-shaped spatially extended sound source within approximately parametric ellipsoid shape;
- 30 Fig. 8 illustrates a piano-shaped spatially extended sound source with three peripheral point sources distributed on extreme points of the projected convex hull;
- 35 Fig. 9 illustrates a preferred implementation of the apparatus or method for reproducing a spatially extended sound source;

Fig. 10 illustrates a preferred implementation of the apparatus or method for generating a bitstream representing a compressed description for a spatially extended sound source; and

5 Fig. 11 illustrates a preferred implementation of the bitstream generated by the apparatus or method illustrated in Fig. 10.

Fig. 9 illustrates a preferred implementation of an apparatus for reproducing a spatially extended sound source having a defined position and geometry in a space. The apparatus comprises an interface 100, a projector 120, a sound position calculator 140 and a renderer 160. The interface is configured for receiving a listener position. Furthermore, the projector 120 is configured for calculating a projection of a two-dimensional or three-dimensional hull associated with the spatially extended sound source onto a projection plane using the listener position as received by the interface 100 and using, additionally, information on the geometry of the spatially extended sound source and, additionally, using an information on the position of the spatially extended sound source in the space. Preferably, the defined position of the spatially extended sound source in the space and, additionally, the geometry of the spatially extended sound source in the space is received for reproducing a spatially extended sound source via a bitstream arriving at a bitstream demultiplexer or scene parser 180. The bitstream demultiplexer 180 extracts, from the bitstream, the information of the geometry of the spatially extended sound source and provides this information to the projector. Furthermore, the bitstream demultiplexer also extracts the position of the spatially extended sound source from the bitstream and forwards this information to the projector. Preferably, the bitstream also comprises location information for the at least two different sound sources and, preferably, the bitstream demultiplexer also extracts, from the bitstream, a compressed representation of the at least two sound sources, and the at least two sound sources are decompressed/decoded by a decoder as an audio decoder 190. The decoded at least two sound sources are finally forwarded to the renderer 160, and the renderer renders the at least two sound sources at the positions as provided by the sound position calculator 140 to the renderer 160.

Although Fig. 9 illustrates a bitstream-related reproduction apparatus having a bitstream demultiplexer 180 and an audio decoder 190, the reproduction can also take place in a situation different from an encoder/decoder scenario. For example, the defined position and geometry in space can already exist at the reproduction apparatus such as in a virtual reality or augmented reality scene, where the data is gener-

ated on site and is consumed on the same site. The bitstream demultiplexer 180 and the audio decoder 190 are not actually necessary, and the information of the geometry of the spatially extended sound source and the position of the spatially extended sound source are available without any extraction from a bitstream. Furthermore, the location information relating the location of the at least two sound sources to the geometry information of the spatially extended sound source can also be fixedly negotiated in advance and, therefore, do not have to be transmitted from an encoder to a decoder or, alternatively, this data is generated, again, on site.

Hence, it is to be noted that the location information is only provided in embodiments and there is no need to transmit this information even in case of two or more sound source signals. The decoder or reproducer, for example, can always take the first sound source signal in the bitstream as a sound source on the projection being placed more to the left. Similarly, the second sound source signal in the bitstream can be taken as a sound source on the projection being placed more to the right.

Furthermore, although the sound position calculator calculates positions of at least two sound sources for the spatially extended sound source using the projection plane, the at least two sound sources do not necessarily have to be received from a bitstream. Instead, only a single sound source of the at least two sound sources can be received via the bitstream and the other sound source and, therefore, also the other position or location information can be actually generated on the reproduction side only without the need to transmitting such information from a bitstream generator to the reproducer. However, in other embodiments, all this information can be transmitted and, additionally, a higher number than one or two sound signals can be transmitted in the bitstream, when the bitrate requirements are not tight, and, the audio decoder 190 would decode two, three, or even more sound signals representing the at least two sound sources whose positions are calculated by the sound position calculator 140.

Fig. 10 illustrates the encoder-side of this scenario, when the reproduction is applied within an encoder/decoder application. Fig. 10 illustrates an apparatus for generating a bitstream representing a compressed description for a spatially extended sound source. Particularly, a sound provider 200 and an output data former 240 are provided. In this implementation, the spatially extended sound source is represented by a compressed description having one or more different sound signals, and the output data former generates the bitstream representing the compressed sound scene, where the bitstream comprises at least the one or more different sound signals and

geometry information related to the spatially extended sound source. This represents the situation illustrated with respect to Fig. 9, where all the other information such as the position of the spatially extended sound source (see the dotted arrow in block 120 of Fig. 9) is freely selectable by a user on the reproduction side. Thus, a unique  
5 description of the spatially extended sound source with at least one or more different sound signals for this spatially extended sound source, where these sound signals are merely point source signals, is provided.

The apparatus for generating additionally comprises the geometry provider 220 for  
10 providing such as calculating information on the geometry for the spatially extended sound source. Other ways of providing the geometry information different from calculating comprise receiving a user input such as a figure manually drafted by the user or any other information provided by the user for example by speech, tones, gestures or any other user action. In addition to the one or more different sound signals, also  
15 the information on the geometry is introduced into the bitstream.

Optionally, the information on the individual location information for each sound signal of the one or more different sound signals is also introduced into the bitstream, and/or the position information for the spatially extended sound source is also introduced into the bitstream. The position information for the sound source can be separate from the geometry information or can be included in the geometry information. In the first case, the geometry information can be given relative to the position information. In the second case, the geometry information can comprise, for example for a sphere, the center point in coordinates and the radius or diameter. For a box-like  
20 spatially extended sound source, the eight or at least one of the corner points can be given in absolute coordinates.

The location information for each of the one or more different sound signals is preferably related to the geometry information of the spatially extended sound source. Alternatively, however, absolute location information related to the same coordinate system, in which the position or geometry information of the spatially extended sound source is given is also useful and, alternatively, the geometry information can also be given within an absolute coordinate system with absolute coordinates rather than in a relative way. However, providing this data in a relative way not related to a general  
30 coordinate system allows the user to position the spatially extended sound source in the reproduction setup herself or himself as indicated by the dotted line directed into the projector 120 of Fig. 9.

In a further embodiment, the sound provider 200 of Fig. 10 is configured for providing at least two different sound signals for the spatially extended sound source, and the output data former is configured for generating the bitstream so that the bitstream comprises the at least two different sound signals preferably in an encoded format and optionally the individual location information for each sound signal of the at least two different sound signals either in absolute coordinates or with respect to the geometry of the spatially extended sound source.

In an embodiment, the sound provider is configured to perform a recording of a natural sound source at the individual multiple microphone positions or orientations or to perform to derive a sound signal from a single basis signal or several basis signals by one or more decorrelation filters as, for example, discussed with respect to Fig. 1, item 164 and 166. The basis signals used in the generator can be the same or different from the basis signals provided on the reproduction site or transmitted from the generator to the reproducer.

In a further embodiment, the geometry provider 220 is configured to derive, from the geometry of the spatially extended sound source, a parametric description or a polygonal description, and the output data former is configured to introduce, into the bitstream, this parametric description or polygonal description.

Furthermore, the output data former is configured to introduce, into the bitstream, a bitstream element, in a preferred embodiment, wherein this bitstream element indicates a number of the at least one different sound signal for the spatially extended sound source included in the bitstream or included in an encoded audio signal associated with the bitstream, where the number is 1 or greater than 1. The bitstream generated by the output data former does not necessarily have to be a full bitstream with audio waveform data on the one hand and metadata on the other hand. Instead, the bitstream can also only be a separate metadata bitstream comprising, for example, the bitstream field for the number of sound signals for each spatially extended sound source, the geometry information for the spatially extended sound source and, in an embodiment, also the position information for the spatially extended sound source and optionally the location information for each sound signal and for each spatially extended sound source, the geometry information for the spatially extended sound source and, in an embodiment, also the position information for the spatially extended sound source. The waveform audio signals typically available in a compressed form are transmitted by a separate data stream or a separate transmission

channel to the reproducer so that the reproducer receives, from one source, the encoded metadata and from a different source the (encoded) waveform signals.

Furthermore, an embodiment of the bitstream generator comprises a controller 250.

5 The controller 250 is configured to control the sound provider 200 with respect to the number of sound signals to be provided by the sound provider. In line with this procedure, the controller 250 also provides the bitstream element information to the output data former 240 indicated by the hatched line signifying an optional feature. The output data former introduces, into the bitstream element, the specific information on  
10 the number of sound signals as controlled controller 250 and provided by the sound provider 200. Preferably, the number of sound signals is controlled so that the output bitstream comprising the encoded audio sound signals fulfills external bitrate requirements. When an allowed bitrate is high, the sound provider will provide more sound signals compared to a situation, when the bitrate allowed is small. In an extreme case, the sound provider will only provide the single sound signal for a spatially  
15 extended sound source when the bitrate requirements are tight.

The reproducer will read the correspondingly set bitstream element and will proceed, within the renderer 160, to synthesize, on the decoder-side and using the transmitted  
20 sounds signal, a corresponding number of further sound signals so that, in the end, a required number of peripheral point sources and, optionally, auxiliary sources have been generated.

When, however, the bitrate requirements are not so tight, the controller 250 will control the sound provider to provide a high number of different sound signals, for example, recorded by a corresponding number of microphones or microphone orientations. Then, on the reproduction side, any decorrelation processing is not necessary at all or is only necessary to a small degree so that, in the end, a better reproduction quality is obtained by the reproducer due to the reduced or not required decorrelation  
30 processing on the reproduction side. A trade-off between bitrate on the one hand and quality on the other hand is preferably obtained via the functionality of the bitstream element indicating the number of sounds signals per spatially extended sound source.

35 Fig. 11 illustrates a preferred embodiment of the bitstream generated by the bitstream generating apparatus illustrated in Fig. 10. The bitstream comprises, for example, a second spatially extended sound source 401 indicated as SESS<sub>2</sub> with the corresponding data.

Furthermore, Fig. 11 illustrates detailed data for each spatially extended sound source in relation to the spatially extended sound source number 1. In the example in Fig. 11, two sound signals are there for the spatially extended sound source that have been generated in the bitstream generator from, for example, microphone output data picked up from microphones placed at two different places of a spatially extended sound source. The first sound signal is sound signal 1 indicated at 301 and the second sound signal is sound signal 2 indicated at 302, and both sound signals are preferably encoded via an audio encoder for bitrate compression. Furthermore, item 311 represents the bitstream element indicating the number of sound signals for the spatially extended sound source 1 as, for example, controlled by the controller 250 of Fig. 10.

A geometry information for the spatially extended sound source is introduced as shown in block 331. Item 301 indicates the optional location information for the sound signals preferably in relation to the geometry information such as, with respect to the piano example, indicating "close to the bass strings" for sound signal 1 and "close to the treble strings" for sound signal 2 indicated at 302. The geometry information may, for example, be a parametric representation or a polygonal representation of a piano model, and this piano model would be different for a grand piano or a (small) piano, for example. Item 341 additionally illustrates the optional data on the position information for the spatially extended sound source within the space. As stated, this position information 341 is not necessary, when the user provides the position information as indicated by the dotted line in Fig. 9 directed into the projector. However, even when the position information 341 is included in the bitstream, the user can nevertheless replace or modify the position information by means of a user interaction.

Subsequently preferred embodiments of the present invention are discussed. Embodiments relate to rendering of Spatially Extended Sound Sources in 6DoF VR/AR (virtual reality/augmented reality).

Preferred Embodiments of the invention are directed to a method, apparatus or computer program being designed to enhance the reproduction of Spatially Extended Sound Sources (SESS). In particular, the embodiments of the inventive method or apparatus consider the time-varying relative position between the spatially extended sound source and the virtual listener position. In other words, the embodiments of the inventive method or apparatus allow the auditory source width to match the spatial

extent of the represented sound object at any relative position to the listener. As such, an embodiment of the inventive method or apparatus applies in particular to 6-degrees-of-freedom (6DoF) virtual, mixed and augmented reality applications where spatially extended sound source complements the traditionally employed point sources.

The embodiment of the inventive method or apparatus renders a spatially extended sound source by using several peripheral point sources which are fed with (preferably significantly) decorrelated signals. In contrast to other methods, the locations of these peripheral point sources depend on the position of the listener relative to the spatially extended sound source. Figure 1 depicts the overview block diagram of a spatially extended sound source renderer according to the embodiment of the inventive method or apparatus.

Key components of the block diagram are:

1. Listener position: This block provides the momentary position of the listener, as e.g. measured by a virtual reality tracking system. The block can be implemented as a detector 100 for detecting or an interface 100 for receiving the listener position.
2. Position and geometry of the spatially extended sound source: This block provides the position and geometry data of the spatially extended sound source to be rendered, e.g. as part of the virtual reality scene representation.
3. Projection and convex hull computation: This block 120 computes the convex hull of the spatially extended sound source geometry and then projects it in the direction towards the listener position (e.g. "image plane", see below). Alternatively, the same function can be achieved by first projecting the geometry towards the listener position and then computing its convex hull.
4. Location of peripheral point sources: This block 140 computes the locations of the used peripheral point sources from the convex hull projection data calculated by the previous block. In this computation, it may also consider the listener position and thus the proximity/distance of the listener (see below). The output are n peripheral point sources locations.

- 5           5.   Renderer core: The renderer core 162 auralizes the  $n$  peripheral point sources by positioning them at the specified target locations. This can be e.g. binaural renderers using head related transfer functions or renderers for loudspeaker reproduction (e.g. vector based amplitude panning). The renderer core produces  $l$  loudspeaker or headphone output signals from  $k$  input audio basis signals (e.g. decorrelated signals of an instrument recording) and  $m \geq (n-k)$  additional decorrelated audio signals.
- 10           6.   Source Basis Signals: This block 164 is the input for  $k$  basis audio signals that are (sufficiently) decorrelated from each other and represent the sound source to be rendered (e.g. a mono –  $k=1$  – or a stereo –  $k=2$  – recording of a music instrument). The  $k$  basis audio signals are for example taken from the bitstream (see e.g. elements 301, 302 of Fig. 11) as received from a decoder side generator or can be provided at the reproduction site from an external
- 15           source.
7.   Decorrelators: This optional block 166 generates additional decorrelated audio signals, as needed for rendering  $n$  peripheral point sources.
- 20           8.   Signal output: The renderer provides  $l$  output signals for loudspeaker (e.g.  $n=5.1$ ) or binaural (typically  $n=2$ ) rendering.

Figure 1 illustrates an overview of the block diagram of an embodiment of the inventive method or apparatus. Dashed lines indicate the transmission of metadata such as geometry and positions. Solid lines indicate transmission of audio, where the  $k$ ,  $l$ , and  $m$  indicate the multitude of the audio channels. The renderer core 162 receives possibly  $k + m$  audio signals and  $n$  ( $\leq k + m$ ) position data. Blocks 162, 164, 166 together form an embodiment of the general renderer 160.

- 30           The locations of the peripheral point sources depend on the geometry, in particular spatial extent, of the spatially extended sound source and the relative position of the listener with respect to the spatially extended sound source. In particular, the peripheral point sources may be located on the projection of the convex hull of the spatially extended sound source onto a projection plane. The projection plane may be either a
- 35           picture plane, i.e., a plane perpendicular to the sightline from the listener to the spatially extended sound source or a spherical surface around the listener's head. The projection plane is located at an arbitrary small distance from the center of the listener's head. Alternatively, the projection convex hull of the spatially extended sound

source may be computed from the azimuth and elevation angles which are a subset of the spherical coordinates relative from the listener head's perspective. In the illustrative examples below, the projection plane is preferred due to its more intuitive character. In the implementation of the computation of the projected convex hull, the angular representation is preferred due to simpler formalization and lower computational complexity. Please note that both the projection of the spatially extended sound source's convex hull is identical to the convex hull of the projected spatially extended sound source geometry, i.e. the convex hull computation and the projection onto a picture plane can be used in either order.

The peripheral point source locations may be distributed on the projection of the convex hull of the spatially extended sound source in various ways, including:

- They could be distributed uniformly around the hull projection
- They could be distributed at extremal points of the hull projection
- They could be located at the horizontal and/or vertical extremal points of the hull projection (see figures in the Section Practical Examples).

In addition to peripheral point sources, also other auxiliary point sources may be used to produce an enhanced sense of acoustic filling at the expense of additional computational complexity. Further, the projected convex hull may be modified before positioning the peripheral point sources. For instance, the projected convex hull can be shrunk towards the center of gravity of the projected convex hull. Such a shrunk projected convex hull may account for the additional spatial spread of the individual peripheral point sources introduced by the rendering method. The modification of the convex hull may further differentiate between the scaling of the horizontal and vertical directions.

When the listener position relative to the spatially extended sound source changes, then the projection of the spatially extended sound source onto the projection plane changes accordingly. In turn, the locations of the peripheral point sources change accordingly. The peripheral point source locations shall be preferably chosen such that they change smoothly for continuous movement of the spatially extended sound source and the listener. Further, the projected convex hull is changed when the geometry of the spatially extended sound source is changed. This includes rotation of the spatially extended sound source geometry in 3D space which alters the projected convex hull. Rotation of the geometry is equal to an angular displacement of the listener position relative to the spatially extended sound source and is such as referred

to in an inclusive manner as the relative position of the listener and the spatially extended sound source. For instance, a circular motion of the listener around a spherical spatially extended sound source is represented by rotating the peripheral point sources around the center of gravity. Equally, rotation of the spatially extended sound source with a stationary listener results in the same change of the peripheral point source locations.

The spatial extent as it is generated by the embodiment of the inventive method or apparatus is inherently reproduced correctly for any distance between the spatially extended sound source and the listener. Naturally, when the user approaches the spatially extended sound source, the opening angle between the peripheral point source increases as it is appropriate for modeling physical reality.

Whereas the angular placement of the peripheral point sources is uniquely determined by the location on the projected convex hull on the projection plane, the distances of the peripheral point sources may be further chosen in various ways, including

- All peripheral point sources have the same distance equal to the distance of the entire spatially extended sound source, e.g., defined through the center of gravity of the spatially extended sound source relative to the head of the listener.
- The distance of each peripheral point source is determined by the back projection of the locations on projected convex hull onto the geometry of the spatially extended sound source such as the peripheral point sources projection onto the projection plane results in the same point. The back projection of the peripheral point sources from the projected convex hull onto the spatially extended sound source may not always be uniquely determined such that additional projection rules have to be applied (see Section Practical Examples).
- The distance of the peripheral point sources may not be determined at all if the rendering of the peripheral point sources does not require the distance property, but only the relative angular placement in azimuth and elevation.

To specify the geometric shape / convex hull of the spatially extended sound source, an approximation is used (and, possibly, transmitted to the renderer or renderer core) including a simplified 1D, e.g., line, curve; 2D, e.g., ellipse, rectangle, polygons; or 3D shape, e.g., ellipsoid, cuboid and polyhedra. The geometry of the spatially ex-

tended sound source or the corresponding approximative shape, respectively, may be described in various ways, including:

- 5       • Parametric description, i.e., a formalization of the geometry via a mathematical expression which accepts additional parameters. For instance, an ellipsoid shape in 3D may be described by an implicit function on the Cartesian coordinate system and the additional parameters are the extend of the principal axes in all three directions. Further parameters may include 3D rotation, deformation functions of the ellipsoid surface.
- 10      • Polygonal description, i.e., a collection of primitive geometric shapes such as lines, triangles, square, tetrahedron, and cuboids. The primate polygons and polyhedral may be concatenated to larger more complex geometries.

15       The peripheral point source signals are derived from the basis signals of the spatially extended sound source. The basis signals can be acquired in various ways such as:  
1) Recording of a natural sound source at a single or multiple microphone positions and orientations (Example: recording of a piano sound as seen in the practical examples); 2) Synthesis of an artificial sound source (Example: sound synthesis with varying parameters); 3) Combination of any audio signals (Example: various mechanical sounds of a car such as engine, tires, door, etc.).  
20       Further, additional peripheral point source signals may be generated artificially from the basis signals by multiple decorrelation filters (see earlier section).

25       In certain application scenarios, the focus is on compact and interoperable storage/transmission of 6DoF VR/AR content. In this case, the entire chain consists of three steps:

1. Authoring/encoding of the desired spatially extended sound sources into a bitstream
- 30    2. Transmission/storage of the generated bitstream. In accordance with the presented invention, the bitstream contains, besides other elements, the description of the spatially extended sound source geometries (parametric or polygons) and the associated source basis signal(s), such like a monophonic or a stereophonic piano recording. The waveforms may be compressed (see item  
35    260 in Fig. 10) using perceptual audio coding algorithms, such as mp3 or MPEG-2/4 Advanced Audio Coding (AAC).
3. Decoding/rendering of the spatially extended sound sources based on the transmitted bitstream as described previously.

In addition to the core method described previously, several options for further processing exist:

5     Option 1 – Dynamic Choice of peripheral point source Number and Location

Depending on the distance of the listener to the spatially extended sound source, the number of peripheral point sources can be varied. As an example, when the spatially extended sound source and the listener are far away from each other, the opening  
10    angle (aperture) of the projected convex hull becomes small and thus fewer peripheral point sources can be chosen advantageously, thus saving on computational and memory complexity. In the extreme case, all peripheral point sources are reduced into a single remaining point source. Appropriate downmixing techniques may be  
15    applied to ensure that interference between the basis and derived signals does not degrade the audio quality of the resulting peripheral point source signals. Similar techniques may apply also in close distance of the spatially extended sound source to the listener position if the geometry of the spatially extended sound source is highly irregular depending on the relative viewpoint of the listener. For instance, a spatially extended sound source geometry which is a line of finite lengths may degenerate  
20    on the projection plane towards a single point. In general, if the angular extent of the peripheral point sources on the projected convex hull is low, the spatially extended sound source may be represented by fewer peripheral point sources. In the extreme case, all peripheral point sources are reduced into a single remaining point source.

25    Option 2 – Spreading Compensation

Since each peripheral point source also exhibits a spatial spread toward the outside of the convex hull projection, the perceived auditory image width of the rendered spatially extended sound source is somewhat larger than the convex hull used for rendering. In order to align this with a desired target geometry, there are two possibilities:  
30    ties:

1. Compensation during authoring: The additional spread of the rendering procedure is considered during content authoring. Specifically, a somewhat  
35    smaller spatially extended sound source geometry is chosen during content authoring such that the actually rendered size is as desired. This can be checked by monitoring the effect of the renderer or renderer core in the authoring environment (e.g. a production studio). In this case, the transmitted

bitstream and renderer or renderer core use a reduced target geometry as compared to the target size.

2. Compensation during rendering: The spatially extended sound source renderer or renderer core can be made aware of the additional perceptual spread by the rendering procedure and thus can be enabled to compensate for this effect. As a simple example, the geometry used for rendering could be

- reduced by a constant factor  $a < 1.0$  (e.g.  $a = 0.9$ ), or
- reduced by a constant opening angle  $\alpha = 5$  degrees

before it is applied to place peripheral point sources. In this case, the transmitted bitstream contains the eventual target size of the spatially extended sound source geometry.

Also, a combination of these approaches is feasible.

#### Option 3 – Generation of peripheral point source Waveforms

Further, the actual signals for feeding the peripheral point sources can be generated from recorded audio signals by considering the user position relative to the spatially extended sound source in order to model spatially extended sound sources with geometry dependent sound contributions such as a piano with sounds of low notes on the left side and vice versa.

Example: The sound of an upright piano is characterized by its acoustic behavior. This is modeled by (at least) two audio basis signals, one near the lower end of the piano keyboard ("low notes") and one near the upper end of the keyboard ("high notes"). These basis signals can be obtained by appropriate microphone use when recording the piano sound and transmitted to the 6DoF renderer or renderer core, ensuring that there is sufficient decorrelation between them.

The peripheral point source signals are then derived from these basis signals by considering the position of the user relative to the spatially extended sound source:

- When the user faces the piano from the front (keyboard) side, the two peripheral point sources are wide apart from each other near the left and the right end of the piano keyboard, respectively. In this case, the basis signal for the low keys can be directly fed into the left peripheral point source and the basis signal for the high keys can be directly used to drive the right peripheral point source.

- As the listener walks around the piano by around 90 degrees to the right, the two peripheral point sources are panned very close to each other since the projection of the piano volume model (e.g. an ellipse) is small when looking at it from the side. If the basis signals would be continued to be used to directly drive the peripheral point source signals, one the peripheral point sources would contain predominantly high notes whereas the other one would carry mostly low notes. As this is undesired from a physical point of view, rendering can be improved by rotating the two basis signals to form the peripheral point source signals by a Givens rotation by the same angle as the user movement relative to the piano center of gravity. In this way, both signals contain signals of similar spectral content while still being decorrelated (assuming that the basis signals have been decorrelated).

#### Option 4 – Postprocessing of Rendered spatially extended sound source

The actual signals can be pre- or post-processed to account for position- and direction-dependent effect, e.g. directivity pattern of the spatially extended sound source. In other words, the whole sound emitted from the spatially extended sound source, as described previously, can be modified to exhibit, e.g., a direction-dependent sound radiation pattern. In the case of the piano signal, this could mean that the radiation towards the back of the piano has less high frequency content than to the front of it. Further, the pre- and post-processing of the peripheral point source signals may be adjusted individually for each of the peripheral point sources. For instance, the directivity pattern may be chosen differently for each of the peripheral point sources. In the given example of a spatially extended sound source representing a piano, the directivity patterns of the low and high key range may be similar as described above, however additional signals such as pedaling noises have a more omnidirectional directivity pattern.

Subsequently, several advantages of preferred embodiments are summarized

Lower computational complexity compared to a full filling of the spatially extended sound source interior with point sources (e.g., as used in Advanced AudioBIFS)

- Less potential for destructive interference between point source signals
- Compact size of bitstream information (geometric shape approximations, one or more waveforms)

- Enables use of legacy recordings (e.g. stereo recording of piano) that have been produced for music consumption for the purpose of VR/AR rendering

Subsequently, various practical implementation examples are presented:

- 5      • Spherical spatially extended sound source
- Ellipsoid spatially extended sound source
- Line spatially extended sound source
- Cuboid spatially extended sound source
- Distance-dependent peripheral point sources
- 10     • Piano-shaped spatially extended sound source

As described in embodiments of the inventive method or apparatus above various methods for determining the location of the peripheral point sources may be applied. The following practical examples demonstrate some isolated methods in specific cases. In a complete implementation of the embodiment of the inventive method or apparatus, the various methods may be combined as appropriate considering computational complexity, application purpose, audio quality and ease of implementation.

The spatially extended sound source geometry is indicated as a green surface mesh. Note that the mesh visualization does not imply that the spatially extended sound source geometry is described by a polygonal method as in fact the spatially extended sound source geometry might be generated from a parametric specification. The listener position is indicated by a blue triangle. In the following examples the picture plane is chosen as the projection plane and depicted as a transparent gray plane which indicates a finite subset of the projection plane. Projected geometry of the spatially extended sound source onto the projection plane is depicted with the same surface mesh in green. The peripheral point sources on the projected convex hull are depicted as red crosses on the projection plane. The back projected peripheral point sources onto the spatially extended sound source geometry are depicted as red dots. The corresponding peripheral point sources on the projected convex hull and the back projected peripheral point sources on the spatially extended sound source geometry are connected by red lines to assist to identify the visual correspondence. The positions of all objects involved are depicted in a Cartesian coordinate system with units in meters. The choice of the depicted coordinate system does not imply that the computations involved are performed with Cartesian coordinates.

The first example in Figure 2 considers a spherical spatially extended sound source. The spherical spatially extended sound source has a fixed size and fixed position relative to the listener. Three different set of three, five and eight peripheral point sources are chosen on the projected convex hull. All three sets of peripheral point sources are chosen with uniform distance on the convex hull curve. The offset positions of the peripheral point sources on the convex hull curve are deliberately chosen such that the horizontal extent of the spatially extended sound source geometry is well represented.

Figure 2 illustrates spherical spatially extended sound source with different numbers (i.e., 3 (top), 5 (middle), and 8 (bottom)) of peripheral point sources uniformly distributed on the convex hull.

The next example in Figure 3 considers an ellipsoid spatially extended sound source. The ellipsoid spatially extended sound source has a fixed shape, position and rotation in 3D space. Four peripheral point sources are chosen in this example. Three different methods of determining the location of the peripheral point sources are exemplified:

a) two peripheral point sources are placed at the two horizontal extremal points and two peripheral point sources are placed at the two vertical extremal points. Whereas, the extremal point positioning is simple and often appropriate. This example shows that this method might yield peripheral point source locations which are relatively close to each other.

b) All four peripheral point sources are distributed uniformly on the projected convex hull. The offset of the peripheral point sources location is chosen such that topmost peripheral point source location coincides with the topmost peripheral point source location in a). It can be seen that the choice of the peripheral point source location offset has a considerable influence on the representation of the geometric shape via the peripheral point sources.

c) All four peripheral point sources are distributed uniformly on a shrunk projected convex hull. The offset location of the peripheral point source locations is equal to the offset location chosen in b). The shrink operation of the projected convex hull is performed towards the center of gravity of the projected convex hull with a direction independent stretch factor.

Figure 3 illustrates an ellipsoid spatially extended sound source with four peripheral point sources under three different methods of determining the location of the peripheral point sources: a/top) horizontal and vertical extremal points, b/middle) uniformly distributed points on the convex hull, c/bottom) uniformly distributed points on a shrunk convex hull.

The next example in Figure 4 considers a line spatially extended sound source. Whereas the previous examples considered volumetric spatially extended sound source geometry, this example demonstrates that the spatially extended sound source geometry may well be chosen as a single dimensional object within 3D space. Subfigure a) depicts two peripheral point sources placed on the extremal points of the finite line spatially extended sound source geometry. b) Two peripheral point sources are placed at the extremal points of the finite line spatially extended sound source geometry and one additional point source is placed in the middle of the line. As described in embodiments of the inventive method or apparatus, placing additional point sources within the spatially extended sound source geometry may help to fill large gaps in large spatially extended sound source geometries. c) The same line spatially extended sound source geometry as in a) and b) is considered, however the relative angle towards the listener altered such that projected length of the line geometry is considerably smaller. As described in embodiments of the inventive method or apparatus above, the reduced size of the projected convex hull may be represented by a reduced number of peripheral point sources, in this particular example, by a single peripheral point source located in the center of the line geometry.

Figure 4 illustrates a Line spatially extended sound source with three different methods to distribute the location of the peripheral point sources: a/top) two extremal points on the projected convex hull; b/middle) two extremal points on the projected convex hull with an additional point source in the center of the line; c/bottom) one peripheral point sources in the center of the convex as the projected convex hull of the rotated line is too small to allow more than one peripheral point sources.

The next example in Figure 5 considers a cuboid spatially extended sound source. The cuboid spatially extended sound source has fixed size and fixed location, however the relative position of the listener changes. Subfigures a) and b) depicts differing methods of placing four peripheral point sources on the projected convex hull. The back projected peripheral point source locations are uniquely determined by the choice on the projected convex hull. c) depicts four peripheral point sources which do

not have well-separated back projection locations. Instead the distances of the peripheral point source locations are chosen equal to the distance of the center of gravity of the spatially extended sound source geometry.

- 5 Figure 5 illustrates a cuboid spatially extended sound source with three different methods to distribute the peripheral point sources: a/top) two peripheral point sources on the horizontal axis and two peripheral point sources on the vertical axis; b/middle) two peripheral point sources on the horizontal extremal points of the projected convex hull and two peripheral point sources on the vertical extremal points of the projected convex hull; c/bottom) back projected peripheral point source distances are chosen to be equal to the distance of the center of gravity of the spatially extended sound source geometry.

- 15 The next example in Figure 6 considers a spherical spatially extended sound source of fixed size and shape, but at three different distances relative to the listener position. The peripheral point sources are distributed uniformly on the convex hull curve. The number of peripheral point sources is dynamically determined from the length of the convex hull curve and the minimum distance between the possible peripheral point source locations. a) The spherical spatially extended sound source is at close distance such that four peripheral point sources are chosen on the projected convex hull. b) The spherical spatially extended sound source is at medium distance such that three peripheral point sources are chosen on the projected convex hull. a) The spherical spatially extended sound source is at far distance such that only two peripheral point sources are chosen on the projected convex hull. As described in embodiments of the inventive method or apparatus above, the number of peripheral point sources may also be determined from the extent represented in spherical angular coordinates.

- 30 Figure 6 illustrates a spherical spatially extended sound source of equal size but at different distances: a/top) close distance with four peripheral point sources distributed uniformly on the projected convex hull; b/middle) middle distance with three peripheral point sources distributed uniformly on the projected convex hull; c/bottom) far distance with two peripheral point sources distributed uniformly on the projected convex hull.

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The last example in Figure 7 and 8 considers a piano-shaped spatially extended sound source placed within a virtual world. The user wears a head-mounted display (HMD) and headphones. A virtual reality scene is presented to the user consisting of

an open world canvas and a 3D upright piano model standing on the floor within the free movement area (see Figure 7). The open world canvas is a spherical static image projected onto a sphere surrounding the user. In this particular case, the open world canvas depicts a blue sky with white clouds. The user is able to walk around and watch and listen to the piano from various angles. In this scene the piano is rendered as either a single point source placed in the center of gravity or as a spatially extended sound source with three peripheral point sources on the projected convex hull (see Figure 8). Rendering experiments show the vastly superior realism of the peripheral point source rendering method over a rendering as a single point source.

To simplify the computation of the peripheral point source locations, the piano geometry is abstracted to an ellipsoid shape with similar dimensions, see Figure 7. Further, two substitute point sources are placed on left and right extremal points on the equatorial line, whereas the third substitute point remains at the north pole, see Figure 8. This arrangement guarantees the appropriate horizontal source width from all angles at a highly reduced computational cost.

Figure 7 illustrates a piano-shaped spatially extended sound source (depicted in green) with an approximative parametric ellipsoid shape (indicated as a red mesh).

Figure 8 illustrates a piano-shaped spatially extended sound source with three peripheral point sources distributed on the vertical extremal points of the projected convex hull and the vertical top position of the projected convex hull. Note that for better visualization, the peripheral point sources are placed on a stretched projected convex hull.

Subsequently, specific features of embodiments of the invention are provided. The characteristics of the presented embodiments are the following:

- To fill the perceived acoustic space of the spatially extended sound source, preferably not its entire interior is filled with decorrelated point sources (peripheral point sources), but only its periphery as it is facing the listener (e.g., "the projection of the spatially extended sound source's convex hull towards the listener"). Specifically, this means that the peripheral point source locations are not attached to the spatially extended sound source geometry but are computed dynamically taking into account the relative position of the spatially extended sound source with respect to the listener position.

- Dynamic computation of peripheral point sources (number and location)
- An approximation of the spatially extended sound source shape is used (for a scenario using a compressed representation: transmitted as part of the bit-stream).

The application of the described technology may be as a part of an Audio 6DoF VR/AR standard. In this context, one has the classic encoding/bitstream/decoder(+renderer) scenario:

- In the encoder, the shape of the spatially extended sound source would be encoded as side information together with the 'basis' waveforms of the spatially extended sound source which may be either
  - a mono signal, or
  - a stereo signal (preferably sufficiently decorrelated), or
  - even more recorded signals (also preferably sufficiently decorrelated) characterizing the spatially extended sound source. These waveforms could be low bitrate coded.
- In the decoder/renderer, the spatially extended sound source shape and the corresponding waveforms are retrieved from the bitstream and used for rendering the spatially extended sound source as described previously.

Depending on the used embodiments and as alternatives to the described embodiments, it is to be noted that the interface can be implemented as an actual tracker or detector for detecting a listener position. However, the listening position will typically be received from an external tracker device and fed into the reproduction apparatus via the interface. However, the interface can represent just a data input for output data from an external tracker or can also represent the tracker itself.

Furthermore, as outlined, additional auxiliary audio sources between the peripheral sound source may be required.

Furthermore, it has been found that left/right peripheral sources and optionally horizontally (with respect to the listener) spaced auxiliary sources are more important for the perceptual impression than vertically spaced peripheral sound sources, i.e., peripheral sound source on top and at the bottom of the spatially extended sound source. When, for example, resources are scarce, it is preferred to use at least horizontally spaced peripheral (and optionally auxiliary) sound sources while vertically

spaced peripheral sound sources can be omitted in the interest of saving processing resources.

Furthermore, as outlined, the bitstream generator can be implemented to generate a  
5 bitstream with only one sound signal for the spatially extended sound source, and, the remaining sound signals are generated on the decoder-side or reproduction side by means of decorrelation. When only a single signal exists, and when the whole space is to be filled up equally with this single signal, any location information is not necessary. However, it can be useful to have, in such a situation, at least additional  
10 information on a geometry of the spatially extended sound source calculated by a geometry information calculator such as the one illustrated at 220 in Fig. 10.

It is to be mentioned here that all alternatives or aspects as discussed before and all aspects as defined by independent claims in the following claims can be used indi-  
15 vidually, i.e., without any other alternative or object than the contemplated alternative, object or independent claim. However, in other embodiments, two or more of the alternatives or the aspects or the independent claims can be combined with each other and, in other embodiments, all aspects, or alternatives and all independent claims can be combined to each other.

20 An inventively encoded sound field description can be stored on a digital storage medium or a non-transitory storage medium or can be transmitted on a transmission medium such as a wireless transmission medium or a wired transmission medium such as the Internet.

25 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 de-  
30 scription of a corresponding block or item or feature of a corresponding apparatus.

Depending on certain implementation requirements, embodiments of the invention can be implemented in hardware or in software. The implementation can be per-  
35 formed using a digital storage medium, for example a floppy disk, a DVD, a CD, a ROM, a PROM, an EPROM, an EEPROM or a FLASH memory, having electronically readable control signals stored thereon, which cooperate (or are capable of cooperat-  
ing) with a programmable computer system such that the respective method is per-  
formed.

Some embodiments according to the invention comprise a data carrier having 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 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 described herein, stored on a machine readable carrier or a non-transitory storage medium.

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.

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.

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.

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.

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

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.

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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.

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### Claims

1. Apparatus for reproducing a spatially extended sound source having a defined position and geometry in a space, the apparatus comprising:

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an interface for receiving a listener position;

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a projector for calculating a projection of a two-dimensional or three-dimensional hull associated with the spatially extended sound source onto a projection plane using the listener position, information on the geometry of the spatially extended sound source, and information on the position of the spatially extended sound source;

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a sound position calculator for calculating positions of at least two sound sources for the spatially extended sound source using the projection plane; and

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a renderer for rendering the at least two sound sources at the positions of the at least two sound sources to obtain a reproduction of the spatially extended sound source having two or more output signals, wherein the renderer is configured to use different sound signals for the different positions of the at least two sound sources, wherein the different sound signals are associated with the spatially extended sound source.

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2. Apparatus of claim 1,

wherein a detector is configured to detect a momentary listener position in the space using a tracking system, or wherein the interface is configured for using position data input via the interface.

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3. Apparatus of claim 1 or 2, configured for receiving a scene description, the scene description comprising the information on the defined position and the information on the defined geometry of the spatially extended sound source, and at least one basis sound signal associated with the spatially extended sound source,

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wherein the apparatus further comprises a scene description parser for parsing the scene description to retrieve the information on the defined position, the

information on the defined geometry and the at least one basis sound signal,  
or

5 wherein the scene description comprises, for the spatially extended sound  
source, at least two basis sound signals and location information for each basis  
sound signal of the at least two basis sound signals with respect to the infor-  
mation on the geometry of the spatially extended sound source, and wherein  
the sound position calculator is configured to use the location information for  
10 the at least two basis sound signals when calculating the positions of the at  
least two sound sources using the projection plane.

4. Apparatus of one of the preceding claims,

15 wherein the projector is configured to compute the hull of the spatially extended  
sound source using the information on the geometry of the spatially extended  
sound source and to project the hull in a direction towards a listener using the  
listener position to obtain the projection of the two-dimensional or three-dimen-  
sional hull onto the projection plane, or

20 wherein the projector is configured to project a geometry of the spatially ex-  
tended sound source as defined by the information on the geometry of the spa-  
tially extended sound source in a direction towards to the listener position and  
to calculate the hull of a projected geometry to obtain the projection of the two-  
dimensional or three-dimensional hull onto the projection plane.

25 5. Apparatus of one of the preceding claims,

30 wherein the sound position calculator is configured to calculate the positions of  
the at least two sound sources in the space from hull projection data and the  
listener position.

6. Apparatus of one of the preceding claims,

35 wherein the sound position calculator is configured to calculate the position so  
that the at least two sound sources are peripheral sound sources and are lo-  
cated on the projection plane, or

wherein the sound position calculator is configured for calculating such that a position of a peripheral sound source of the peripheral sound sources is located on the right of the projection plane with respect to a listener and/or to the left of the projection plane with respect to the listener, and/or on top of the projection plane with respect to the listener and /or at a bottom of the projection plane with respect to the listener.

7. Apparatus of one of the preceding claims,

wherein the renderer is configured to render the at least two sound sources using

panning operations depending on the positions of the at least two sound sources to obtain loudspeaker signals for a predefined loudspeaker setup, or

binaural rendering operations using head related transfer functions depending on the positions of the at least two sound sources to obtain headphone signals.

8. Apparatus of one of the preceding claims,

wherein a first number of basis sound signals is associated with the spatially extended sound source, the first number being one or greater than one, wherein the first number of basis sound signals is related to the same spatially extended sound source,

wherein the sound position calculator determines a second number of sound sources used for the rendering of the spatially extended sound source, the second number being greater than one, and

wherein the renderer comprises one or more decorrelators for generating a decorrelated signal from one or more basis sound signals of the first number, wherein the second number is greater than the first number.

9. Apparatus of one of the preceding claims,

wherein the interface is configured to receive a time-varying position of a listener in the space,

5 wherein the projector is configured to calculate a time-varying projection in the space,

wherein the sound position calculator is configured to calculate a time-varying number of sound sources or time-varying positions of the at least two sound sources in the space, and  
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wherein the renderer is configured to render the time varying number of sound sources or the at least two sound sources at the time varying positions in the space.

15 10. Apparatus of one of the preceding claims,

wherein the interface is configured to receive the listener position in six degrees of freedom, and

20 wherein the projector is configured to calculate the projection depending on the six degrees of freedom.

11. The apparatus of one of the preceding claims, wherein the projector is configured  
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to calculate the projection as a picture plane such as a plane perpendicular to a sight line of a listener, or

30 to calculate the projection as a spherical surface around a head of the listener, or

to calculate the projection as the projection plane being located at a pre-determined distance from a center of the listener's head, or

35 to calculate the projection of the hull of a spatially extended sound source from an azimuth angle and an elevation angle being derived from spherical coordinates relative to the perspective of a listener's head, the hull being a convex hull.

12. Apparatus of one of the preceding claims,

5 wherein the sound position calculator is configured to calculate the positions of the at least two sound sources so that the positions are uniformly distributed around the projection of the hull, or so that the positions are placed at extremal or peripheral points of the hull projection, or so that the positions are located at horizontal or vertical extremal or peripheral points of the projection of the hull.

- 10 13. Apparatus of one of the preceding claims,

15 wherein the sound position calculator is configured to determine, in addition to positions for peripheral sound sources, positions for auxiliary sound sources located on or before or behind or within the projection of the hull with respect to the listener.

14. Apparatus of one of the preceding claims,

20 wherein the projector is configured to additionally shrink the projection of the hull such as towards a center of gravity of the hull or the projection by a variable or predetermined amount or by different variables or predetermined amounts in different directions such as a horizontal direction and a vertical direction.

- 25 15. Apparatus of one of the preceding claims, wherein the sound position calculator is configured for calculating such that at least one additional auxiliary sound source is located on the projection plane between a left peripheral sound source and a right peripheral sound source with respect to the listener position, or

30 wherein the sound position calculator is configured for calculating such that at least one additional auxiliary sound source is located on the projection plane between a left peripheral sound source and a right peripheral sound source with respect to the listener position, wherein a single additional auxiliary source is placed in the middle between the left peripheral sound source and the right peripheral sound source, or two or more additional auxiliary sources are placed  
35 equidistantly between the left peripheral sound source and the right peripheral sound source.

16. Apparatus of one of the preceding claims,

5 wherein the sound position calculator is configured to perform a rotation of the positions of the at least two sound sources of the spatially extended sound source preferably around a center of gravity of the projection in case of a receipt of a circular motion of the listener around the spatially extended sound source via the interface, or in case of a receipt of a rotation of the spatially extended sound source with respect a stationary listener via the interface.

- 10 17. Apparatus of one of the preceding the claims,

wherein the renderer is configured to receive, for each sound source, an opening angle depending on the distance between the listener and the sound source and to render the sound source depending on the opening angle.

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18. Apparatus of one of the preceding claims,

wherein the renderer is configured to receive a distance information for each sound source, and

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wherein the renderer is configured to render the sound source depending on the distance so that a sound source being placed closer to the listener is rendered with more volume compared to a sound source being placed less close to the listener and having the same volume.

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19. Apparatus of one of the preceding claims, wherein the sound position calculator is configured to

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determine, for each sound source, a distance being equal to the distance of the spatially extended sound source with respect to the listener, or

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determine a distance of each sound source by a back projection of a location of the sound source on the projection onto the geometry of the spatially extended sound source, and

wherein the renderer is configured to render the at least two sound sources using the information on the distance.

20. Apparatus of one of the preceding claims,

5 wherein the information on the geometry is defined as a one-dimensional line or curve, a two-dimensional area such as an ellipse, a rectangle, or a polygon, or a group of polygons, or a three-dimensional body such an ellipsoid, a cuboid or a polyhedral, and/or

10 wherein the information is defined as a parametric description or a polygonal description or a parametric representation of the polygonal description.

21. Apparatus of one of the preceding claims,

15 wherein the sound position calculator is configured to determine a number of sound sources depending on a distance of the listener to the spatially extended sound source, wherein a number of sound sources is higher for a smaller distance compared to a smaller number for a greater distance between the listener and the spatially extended sound source.

20 22. Apparatus of one of the preceding claims, configured for receiving information on a spreading introduced by the spatially extended sound source, and

25 wherein the projector is configured to apply a shrinking operation to the hull or the projection using the information on the spreading for at least partly compensating the spreading.

23. Apparatus of one of the preceding claims,

30 wherein the renderer is configured to render, in case of the positions of the at least two sound sources being identical to each other within a defined tolerance range, the sound sources by combining basis signals associated with the spatially extended sound source to obtain rotated basis signals and to render the rotated basis signals at the positions of the at least two sound sources.

35 24. Apparatus of one of the preceding claims,

wherein the renderer is configured to perform a preprocessing or a post-processing, when generating the at least two sound sources in accordance with a position- or direction-dependent characteristic.

5     25.     Apparatus of one of the preceding claims,

10           wherein the spatially extended sound source has, as the information on the geometry, an information that the spatially extended sound source is a spherical, and ellipsoid, a line, a cuboid or a piano-shape spatially extended sound source.

26.     Apparatus of one of the preceding claims, configured for

15           receiving a bitstream representing a compressed description for the spatially extended sound source, the bitstream comprising a bitstream element indicating a first number of different sound signals for the spatially extended sound source included in the bitstream or an encoded audio signal received by the apparatus, the number being one or greater than one,

20           reading the bitstream element and retrieving the first number of different sound signals for the spatially extended sound source included in the bitstream or in the encoded audio signal, and

25           wherein the sound position calculator determines a second number of sound sources used for the rendering of the spatially extended sound source, the second number being greater than one, and

30           wherein the renderer is configured to generate, depending on the first number extracted from the bitstream, a third number of one or more decorrelated signals, the third number being derived from a difference between the second number and the third number.

27.     Method for reproducing a spatially extended sound source having a defined position and geometry in a space, the method comprising:

35           receiving a listener position;

calculating a projection of a two-dimensional or three-dimensional hull associated with the spatially extended sound source onto a projection plane using the listener position, information on the geometry of the spatially extended sound source, and information on the position of the spatially extended sound source;

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calculating positions of at least two sound sources for the spatially extended sound source using the projection plane; and

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rendering the at least two sound sources at the positions of the at least two sound sources to obtain a reproduction of the spatially extended sound source having two or more output signals, wherein the rendering comprises using different sound signals for the different positions of the at least two sound sources, wherein the different sound signals are associated with the spatially extended sound source.

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28. Computer program for performing, when running on a computer or a processor, the method of claim 27.