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INSTRUMENT POSITION IN IMMERSIVE AUDIO: A STUDY ON GOOD PRACTICES AND COMPARISON WITH STEREO APPROACHES

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Instrument position in immersive audio: a study on good practices and comparison with stereo approaches

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Abstract

Spatial audio has long been a focus in music production, driving creative strategies in post-production. Immersive sound technologies have expanded composition possibilities and attracted mainstream interest. However, there is a lack of defined procedures and critical thinking regarding audio mixing guidelines for surround sound in popular music.

An empirical study was conducted to address this, analyzing award-winning songs in the Grammy category of Best Immersive Album from 2005 to the present. The aim was to identify trends in mixing approaches. Position, trajectory, and dynamics were considered variables. The study employed a multi-speaker array and Ambisonics encoding. Sections of songs were analyzed individually using a proposed radial annotation diagram to collect instrument positions, trajectories, and dynamics. Seven songs were selected and analyzed in their 5.1 surround sound mix version and stereo mix version for comparison.

Results showed consistent instrument positioning across songs in each format. Rhythmic instruments and the bass were placed in the center. Lead vocals had a wider spread across the front channels. Harmonic instruments, excluding the bass, were positioned in wider positions, often spreading from their perceived positions. Solo instruments occupied the left, right, and center channels. Dynamics emphasized important elements, with high dynamics for main vocals and solo instruments and lower dynamics for harmony and ambiance layers. Trajectories were rarely used.

The findings indicate a prevailing channel-based thinking in immersive popular music practices. Instrument positions clustered around specific angles, suggesting a bias influenced by the channel-based system. Limited adoption of immersive audio dimensions and reliance on stereo techniques were observed. A high degree of similarity between the two formats was recognized, with no notable differences found. The symmetry between audio sources is ubiquitous. Trajectories and wider adoption of spatial dimensions offered by immersive audio technologies were limited.

Techniques employed for surround audio mixing are highly derivative of stereo approaches. Outliers and secondary approaches observed in the mixing present avenues for future exploration.

Resumo

O áudio espacial tem sido há muito tempo um foco na produção musical, impulsionando estratégias criativas na pós-produção. As tecnologias de som imersivo expandiram as possibilidades de composição e despertaram interesse geral. No entanto, há falta de procedimentos definidos e pensamento crítico em relação às diretrizes de *mixing* de áudio para som *surround* na música popular.

Foi realizado um estudo empírico para abordar essa questão, analisando músicas premiadas na categoria de Melhor Álbum Imersivo dos Grammys desde 2005 até ao presente. O objetivo foi identificar tendências nas abordagens de *mixing*. Posição, trajetória e dinâmicas foram consideradas variáveis. O estudo utilizou uma matriz de alti-falantes múltiplos e codificação Ambisonics. As secções das músicas foram analisadas individualmente, usando um diagrama de anotação radial proposto para recolher posições de instrumentos, trajetórias e dinâmicas. Sete músicas foram selecionadas e analisadas nas suas versões de *mixing* de som *surround* 5.1 e versão *stereo* para comparação.

Os resultados mostraram posições consistentes dos instrumentos em todas as músicas em cada formato. Instrumentos rítmicos e baixo foram colocados no centro. Os vocais principais tiveram uma distribuição mais ampla nos canais frontais. Instrumentos harmónicos, excluindo o baixo, foram colocados em posições mais amplas, muitas vezes espalhando-se das suas posições percebidas. Instrumentos de solo ocuparam os canais esquerdo, direito e central. As dinâmicas enfatizaram elementos importantes, com dinâmicas altas para vocais principais e instrumentos com papel de solo, e dinâmicas mais baixas para camadas de harmonia e ambiência. As trajetórias foram raramente utilizadas.

Os resultados indicam um pensamento predominante *channel-based* nas práticas de música popular imersiva. As posições dos instrumentos agruparam-se em ângulos específicos, sugerindo um viés influenciado pelo sistema *channel-based*. Foi observada uma adoção limitada das dimensões de áudio imersivo e dependência de técnicas *stereo*. Reconheceu-se um alto grau de similaridade entre os dois formatos, sem diferenças significativas. A simetria entre as fontes de áudio é ubíqua. O recurso a trajetórias e a adoção mais ampla das dimensões espaciais oferecidas pelas tecnologias de áudio imersivo foram limitados.

As técnicas utilizadas para *mixing* de áudio *surround* são altamente derivadas de abordagens *stereo*. Exceções e abordagens secundárias observadas no *mixing* apresentam oportunidades para exploração futura.

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Afonso Breda Lopes

"Without music, life would be a mistake."

Friedrich Nietzsche

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Chapter 1

Introduction

Audio mixing is one of the artistic and technical factors shaping popular music[1], a dynamic and always-changing art form. The process of combining many audio sources to produce a finished mix that is seamless and professional is known as audio mixing [Izhaki, 2018, Owsinski, 2013, Savage, 2014]. A composition and it's perception are greatly influenced by the panning and placement of audio sources inside a mix, which significantly impacts the overall soundscape and ambiance of a song.

Furthermore, since the earliest stereophonic recordings, spatial audio has been a topic of fascination in music creation. It encourages a sense of depth and space inside a musical composition, bringing up fresh possibilities for artistic experimentation and cutting-edge audio post-production methods [Rumsey, 2001, Roginska and Geluso, 2017, AES, nd]. Immersive sound technologies' development opened up more options for adjusting instrument placement and applying spatial audio effects. In the mainstream music industry, it also sparked an increase in attention from professionals and enthusiasts [Fonseca, 2020, Barboza et al., 2021, Hamandi, 2022, Lowe, 2021, Cohrs et al., 2022].

Even though immersive audio is becoming more popular and widely used, there are still very few clear protocols and standards that audio producers and engineers may adhere to. The lack of standards or in-depth analysis for employing spatial dimensions in audio mixing, particularly in the context of immersive sound for popular music, is a major difficulty. The capacity of music professionals to properly utilize spatial audio is hampered by this knowledge gap. The shift to surround sound offers extra channels and positions for instruments inside the sound field, perhaps necessitating alternative procedures, despite the fact that there are established practices for stereo audio mixing [Izhaki, 2018, Owsinski, 2013, Savage, 2014, White, 2000].

Achieving a balanced and cohesive sound that works well across various playback platforms and contexts is one of the main problems in spatial audio mixing. The position of each sound source becomes a crucial aspect as a result of the spatial dimensions, which complicates the mixing process. In order to provide an immersive experience without sacrificing the overall balance

[1]Popular music refers to commercially successful and widely appealing music that resonates with a large audience, therefore excluding orchestral/classical music, electroacoustic music and jazz.

and clarity of the mix, proper localization of the instruments and voices inside the soundstage is crucial [Roginska and Geluso, 2017, Owsinski, 2013, Pulkki et al., 2010].

The comparison of stereo and spatial audio mixes is a key emphasis of this dissertation's analysis of the art and science of audio mixing in popular music. The study's objectives include identifying the developments and difficulties in spatial audio mixing as well as the methods and trends employed in audio mixing in popular music.

The research is carried out by thoroughly investigating popular music songs, which includes an evaluation of the audio mixing methods applied, the positioning, dynamics, and trajectories of each audio source, and the overall soundscape and atmosphere produced by each mix. The study also assesses how spatial audio technology affects the listening experience and whether it has the potential to improve the listening experience of popular music.

The process of audio mixing in popular music is explored in this dissertation, and it also furthers our knowledge of how spatial audio technology influences popular music. The study provides a foundation for future research in this area and provides insights into the possibility of more advancement and innovation in the fields of audio mixing and spatial audio.

1.1 Framework

The development of digital audio technology and the growth of spatial audio have had a huge impact on audio mixing in popular music. The composition and perception of the elements of a song are greatly influenced by the panning and placement of audio sources inside a mix, which profoundly affects the listening experience.

This dissertation compares stereo and spatial audio mixes in order to investigate the methods and current developments in audio mixing in popular music. The study aims to comprehend the developments and difficulties in spatial audio mixing of music and to spot any patterns or trends in audio mixing methods.

This thesis is framed within the masters degree in Multimedia, with a specialization in Sound Design and Interactive Music.

A significant portion of the research conducted for this dissertation was submitted as an article to the I3DA 2023 conference which will be held in Bologna, Italy, from 5-7 of September 2023.

1.2 Objectives and Research Questions

The objectives of this dissertation are to examine the importance of instrumentation positioning in popular music, investigate the implementation of immersive audio mixing techniques by specialists, and explore the relationship between stereo panning and instrumentation positioning in 3D audio. The research questions guiding this study are as follows: (1) What is the significance of positioning instruments effectively in popular music to create a cohesive and immersive listening experience? (2) How have specialists in the field of audio mixing utilized immersive audio techniques to enhance spatialization and immersion in music production? (3) How does the traditional practice of stereo panning translate and adapt to the spatial dimensions and positioning possibilities offered by immersive audio technologies? By addressing these research questions, this dissertation aims to contribute to the understanding of audio mixing practices in popular music and provide insights into the creative application of immersive audio techniques for enhancing spatialization and immersion in music production.

And this dissertation also hopes to be helpful in collecting more information regarding the topic of spatial positioning in popular music and understanding how the mixing engineers of immersive audio albums proceed when transforming a stereo mix into a spatial audio mix, how these stereo practices of panning applied to spatial audio, or if they even are at all.

1.3 Project

This project involves a comparative study of the Grammy award-winning albums for the Best Immersive Audio Album category from 2005 to 2023. The study involves a comparison of the stereo version of the single for each selected album, with the surround sound version of the mix, registering all the relevant data like position, movement, and dynamics of instruments and their audio sources. This data is analyzed to identify trends and patterns in instrumentation panning and positioning in popular music and spatial audio.

1.4 Motivations

The main motivation for this research is to investigate the transition from stereo to spatial audio mixing in popular music, which is composed of modern instrumentation, and to understand the good practices when recreating a stereo mix for a spatial audio environment. By excluding orchestral pieces and other genres that would harm the study's uniformity by adding different instrumentation elements, the study aims to provide a deeper understanding of the technical and creative considerations involved in positioning instrumentation elements in a spatial audio mix in popular music.

The focus on popular music holds significant relevance due to its widespread consumption, and interestingly, the transition to spatial audio has been comparatively slower in this genre compared to others like classical or film music. This choice is deeply rooted in the objectives of this thesis, which aim to comprehend the process of spatial audio post-production. Unlike pre-production or recording stages, the genres of music selected for examination possess a crucial characteristic for post-production, namely, the prominent role of the mixing engineer as a creative influence. Documenting these implicit and often unspoken techniques and norms developed throughout the evolution of music production, characterized by a high degree of subjectivity and creative decision-making, can yield valuable insights. By capturing these trends and patterns and presenting them in a concise manner, they can serve as guidelines for promoting good practices when crafting spatial audio mixes for popular music.

1.5 Structure of the Dissertation

Beyond the introduction, this dissertation contains another 5 chapters.

In chapter 2, the state of the art is described and related works are presented and subdivided into 4 sections related to the most important topics being discussed: 2.1, 2.2, 2.3, and 2.4, tying together all these topics in the context of the dissertation.

In chapter 3, the project and methodology employed in this dissertation's practical endeavors are laid out and explained.

In chapter 4, the results for the studies conducted are presented in two sections, 4.1 and 4.2 where both variants of the study are addressed.

In chapter 5, in the form of a discussion of the results reached, a set of reviewed practices and guidelines are explored. These norms are present in section 5.1 with six subsections, 5.1.1, 5.1.2, 5.1.3, 5.1.4, 5.1.5 and 5.1.6, one for each guideline suggested.

In chapter 6, section 6.1 presents macro conclusions that resulted from the whole process of this project, section 6.2 present limitations and remarks that are considered of importance for the context and overall appreciation of this work and, finally, section 6.3 presents considerations for future work.

This dissertation also includes 4 appendices. Appendix A contains all the data compiled into tables that were used for calculations and analysis in this study, appendix B presents all the diagrams created for the analysis of individual songs in the surround sound study, which includes all sections of all songs, appendix C includes the same diagrams created but for the stereo analysis, and appendix D contains a logbook style list of observations collected during the analysis of the songs in their surround sound versions.

Chapter 2

Bibliographic Review

Related Work

This chapter approaches music production, especially audio mixing, from a historical all the way to a technical perspective with an emphasis on three-dimensional audio and audio source positioning in popular music. This section clarifies these topics to establish a solid baseline upon which this dissertation will be built, with these key concepts as clear foundations. The subjects tackled are:

- Audio Mixing; Traditional Audio Mixing Techniques for Stereo; Spatial Audio

2.1 Audio Mixing

Music creation dramatically evolved towards the digital medium in the late 20^{th} century and into the 21^{st} century. Since the recording medium was monophonic in the early days of recording in the 1950s, there truly was not any mixing at all [Owsinski, 2013]. Due to the requirement for processing power, the technologies that gave rise to the process of audio mixing, such as overdubs, grew in a direct relationship to computing capabilities. As a result, audio mixing climbed to a position of prominence in music production. The many stages of music production — from its conception through the finished master, ready for distribution — have altered due to this progression. New technologies have opened up new possibilities for music and improved its quality and reach. Wax cylinders, radio transmission, cassettes, CDs, software plugins, iTunes, smartphones, and Spotify have all made it simpler to make, distribute, and listen to music [Izhaki, 2018].

Audio mixing is what one would consider a technically driven step in the process of music production, but with these developments in the mechanics of audio engineering especially related to the modern genres of music, the role of the mixing engineer has assumed pivotal creative importance [Tingen, 2007], and that's a characteristic of interest to this dissertation, and one that is explored through the musical composition styles picked for scrutiny steering away from classical compositions and heavily recording based pieces of music.

A basic definition of audio mixing is: a process in which multitrack material - whether recorded, sampled, or synthesized - is balanced, treated, and combined into a multichannel format (most commonly, two-channel stereo). But a less technical definition would be: a sonic presentation of emotions, creative ideas, performance, and musicianship [Izhaki, 2018]. If it were needed to summarize sound mixing in a single word, it would be "balance." Mixing entails the integration of all the sounds captured in a multitrack recording and adjusting their levels to achieve a balanced blend, where some sounds are louder than others. Additionally, a mixing engineer balances the spatial placement of the sounds within the stereo field, ranging from left to center to right or anywhere in between. Frequencies are also balanced by brightening or darkening certain sounds, removing or emphasizing specific frequencies. Depth is utilized as another balancing tool to create a sense of proximity or distance for each sound within the listening space [Mendelson, 2020]. And this process, although it can be overshadowed by the final product, with the common listener not realizing its relevance, the consequences of mixing are extremely valued as sonic quality. Sonic quality is also a powerful selling point. It was a major contributor to the rise of the CD and the fall of compact cassettes. Novice classical music listeners often favor new recordings over older, monophonic ones, regardless of how acclaimed the performance on these early recordings is. Record companies issue digitally remastered versions of classic albums that allegedly sound better than the originals [Izhaki, 2018].

One song can be composed of many varieties of instrumentation. A Rock song can be traditionally formed by two guitars, one bass guitar, lead vocals, drums, and keyboard, for example, and these instruments can stand alone as elements of a mix or be grouped into a single element given the right characteristics. Most well-conceived arrangements are limited in the number of elements that occur simultaneously. An element can be a single instrument like a lead guitar or a vocal, or it can be a group of instruments like the bass and drums, a doubled guitar line, a group of backing vocals, etc. Generally, a group of instruments playing exactly the same rhythm is considered an element. Examples: a doubled lead guitar or doubled vocal is a single element, as is a lead vocal with two additional harmonies. Two lead guitars playing different parts are two elements, however. A lead and a rhythm guitar are two separate elements as well [Owsinski, 2013].

In audio production, instrumentation mixing refers to the process of adjusting and balancing the levels, EQ (equalization), panning, and other characteristics of individual musical instruments or groups of instruments in a recorded mix. Instrumentation mixing aims to produce a seamless and harmonious mix that successfully highlights the various musical elements while advancing the project's overall aesthetic concept. Adjusting the levels of each instrument or set of instruments in the mix often marks the beginning of the instrumentation mixing process. Setting the relative loudness of each component in the mix is necessary to ensure that all components can be heard clearly and harmoniously. The mixer can then modify the frequency balance to produce a more polished and unified sound by using EQ, which is used to shape the tonal qualities of each instrument or group of instruments. In order to give the mix a sense of space and movement, the instruments are placed inside the stereo field via panning.

It is critical to recognize the various instrument types that are blended. Space is a crucial mix resource, and when many instruments are blended, they compete for it, mostly due to masking, the phenomena of one sound covering over or obscuring another in a mix, and this can happen when two sounds have similar frequency ranges and interfere with one another, making it challenging to tell one sound from the other. The sounds of percussion instruments come and go; a kick, for instance, makes little or no sound in between strokes. During brief, unsuccessful battles for space, percussion instruments compete. Contrarily, instruments with greater sustain perform for longer periods of time and are, therefore, always competing for space. If we take, for example, a synthesized pad that is created using sawtooth waves incorporates unison, and is played legato (long notes). Such a pad would cover the stereo panorama and the frequency spectrum due to its sonic characteristics that occupy such a large spectrum of frequencies in a way that would likely obscure a lot of other components in the mix. Practically speaking, sustained instruments demand a little more care. Whether it be establishing levels, adjusting them, or panning them, the results of our activities will be felt over a longer time frame than if we are dealing with non-sustaining instruments. Boosting a thick pad's level is more likely to result in masking issues than raising a kick's level. If the kick obscures the pad, it will only do so briefly; thus, it might not be a significant concern. However, if the pad hides the kick, it will do it continuously, which is of great importance [Izhaki, 2018].

During instrument or track mixing (considering that a track can contain any audio source, not necessarily an instrument), additional effects and processing methods, including compression, reverb, and delay, can be employed to sculpt the sound further and achieve the desired aesthetic. Reverb, for instance, can be used to give a mix a sense of depth and distance, while delay, on the other hand, can be utilized to emphasize certain elements or to provide the impression of movement. Dynamic range can be managed, and punch can be added to a mix via compression [Savage, 2014, Izhaki, 2018]. In conclusion, instrumental mixing is essential for producing a finished sound that is well-balanced and aesthetically pleasant. To produce a seamless and polished final mix that successfully highlights the various musical elements and supports the project's overall artistic vision, it takes knowledge of how various sounds interact with one another as well as the ability to use tools like equalization, panning, and effects processing.

Depending on the musical genre and the function of each instrument, different audio mixing components have varying degrees of relevance in a mix. For instance, the beat and vocals are frequently the most crucial components in hip-hop music, yet the snare may be more crucial than the kick in jazz. Spatial effects are significant in ambient music, but club music centers on a pronounced kick, which is less significant in most folk music. Additionally, the importance of each element influences how it is mixed, including levels, frequencies, panning, and depth. By understanding the significance of each element, the mixing process can be made more efficient, and the possibility of wasting time on unimportant or unnecessary tasks is reduced. For example, if a pad only plays for a short period of time at a low level, it may not require as much attention during the mixing process. Identifying the importance of each element is crucial in making the mixing process efficient and effective [Izhaki, 2018]. If determined that the vocals and the bass are the most crucial elements of the song, they will most likely be positioned in the center of the stereo image, and placing another instrument in the same space will make the mix very busy in that particular spot and more susceptible to masking. Panning is a solution to this problem,

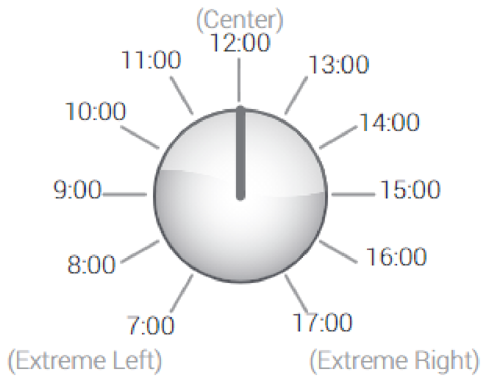

Figure 2.1: Illustration of a pan clock [Izhaki, 2018].

organizing the elements of the mix by order of importance and other characteristics, and this order of importance can be organized through panning as it is more comprehensively explained further in the bibliographic review.

Panning refers to the deliberate placement or movement of a sound within the stereo field of a stereo playback system. Using panning techniques, sound sources can be positioned to create the perception of originating from the left, right, or anywhere in between. This expansive range of sound placement, spanning from left to right, is commonly referred to as the stereo field [Wainwright, 2022].

Within a Digital Audio Workstation (DAW), a control known as a pan pot, derived from the term panoramic potentiometer, or a pan clock (2.1), is employed to position or shift (pan) a sound within the stereo field. By adjusting this knob to the left, the level of sound in the right speaker decreases while the level in the left speaker increases. Conversely, turning the knob to the right amplifies the sound in the right speaker while attenuating the level in the left speaker [Wainwright, 2022].

Panning is often overlooked or not fully utilized in many mixes. The term derives from "panorama," which signifies a clear and expansive view. This definition offers insights into understanding and employing the panning function. Panning is a valuable technique to prevent elements from obstructing each other in a mix. By assigning an element a position on the panning spectrum where it encounters the fewest elements with similar frequencies, the mixer enables that element to be heard distinctly. Achieving a broad audio perspective also heavily relies on skillfully utilizing the entire panning spectrum, commonly known as the "stereo image." A strong panning strategy is a crucial component of any mix, and the extensive panning spectrum presents abundant opportunities for creative approaches and applications. The primary guideline in panning is to utilize the entire stereo image, covering the full span from the hard left to the hard right. The practical interpretation of this principle can vary significantly based on the specific project and your creative preferences. However, it generally entails considering the complete range of the stereo field. Panning mono tracks (with a single channel) allow precise control over panning placement, enabling elements to be positioned anywhere on the panning spectrum, ranging from the extreme left to the extreme right [Savage, 2014, White, 2000].

In this dissertation, the emphasis is given to the use of panning in instrumentation mixing and how that comes through when dealing with spatial audio as we ad an additional axis of space or just by adding additional speakers in the same horizontal plane.

2.2 Traditional Audio Mixing Techniques in Stereo

Now to expand upon the topic touched before regarding instrumentation elements mixing.

In the audio production process, traditional techniques have been consolidated through time as somewhat tacit standards. These traditional instrumentation mixing techniques refer to the methods and techniques used in music production to balance and mix together the various elements of an audio recording, such as vocals, drums, guitars, and keyboards. These techniques have been developed over time through a combination of trial and error and experimentation, and they are widely used in music production today.

One important technique in traditional mixing is EQ or equalization. EQ is used to adjust the balance of different frequency ranges within a sound source, allowing the mix engineer to bring out certain elements of the mix and reduce others. For example, EQ can be used to reduce the low-frequency rumble of the bass guitar so that it does not interfere with the kick drum and other low-frequency elements in the mix. The equalizers used in mixing nowadays are used to modify the frequency content of different mix elements rather than to make one sound equal to another. A crucial component of mixing is the frequency quality of each individual instrument and how it fits into the mix's broader frequency spectrum [Izhaki, 2018].

The usage of Compression is also fundamental in traditional instrumentation mixing, it can be used to even out the levels of different sound sources, making sure that they are all heard at roughly the same level. This is especially important for elements such as drums or vocals, which can have wide variations in level throughout the recording. Compressors can make sounds louder, bigger, punchier, richer, or more powerful, but if used incorrectly or superfluously, compressors suppress dynamics, and dynamics are an essential component of a piece of music and a primary means of conveying musical expression [Izhaki, 2018].

Other techniques that are widely used in traditional instrumentation mixing include reverb and delay. These effects can be used to create a sense of space and depth in the mix and can also be used to create a sense of movement and interest within the mix.

Positioning, or panning, is a fundamental traditional mixing technique and refers to the process of adjusting the stereo or surround sound position of a sound source within a mix. Panning is used to create a sense of width and depth in the mix, and it can be used to direct the listener's attention to specific elements of the mix.

It is also important to explain what is mixing in stereo.

Regarding stereo mixing, the fundamental goal is to cater to the human brain and its physiological processes. The essence of "true" stereo mixing lies in crafting a sonic image that emulates sound's natural perception and decoding by our two ears. For instance, our brains determine the location of a sound by analyzing the time and tonal disparities between its arrival at each ear. Ideally, a genuine stereo mix would recreate a sound closely resembling an authentic, live performance. However, the reality of stereo mixing deviates significantly from the organic and natural aspects. Practical considerations contribute to this divergence. During a live performance, the venue's acoustics play a crucial role in blending sound sources and masking the specific localization of each instrument. In contrast, in a studio environment, tracks are often recorded separately with minimal ambient characteristics, allowing for precise control of perceived spatial qualities using technological aids. In practice, modern stereo mixing is less focused on replicating real-world conditions and more concerned with achieving a well-balanced and pleasing blend of musical elements in a recording. It is safe to assume that most contemporary recordings only loosely resemble the sound of a live band performing directly in front of the listener [Keller, 2021].

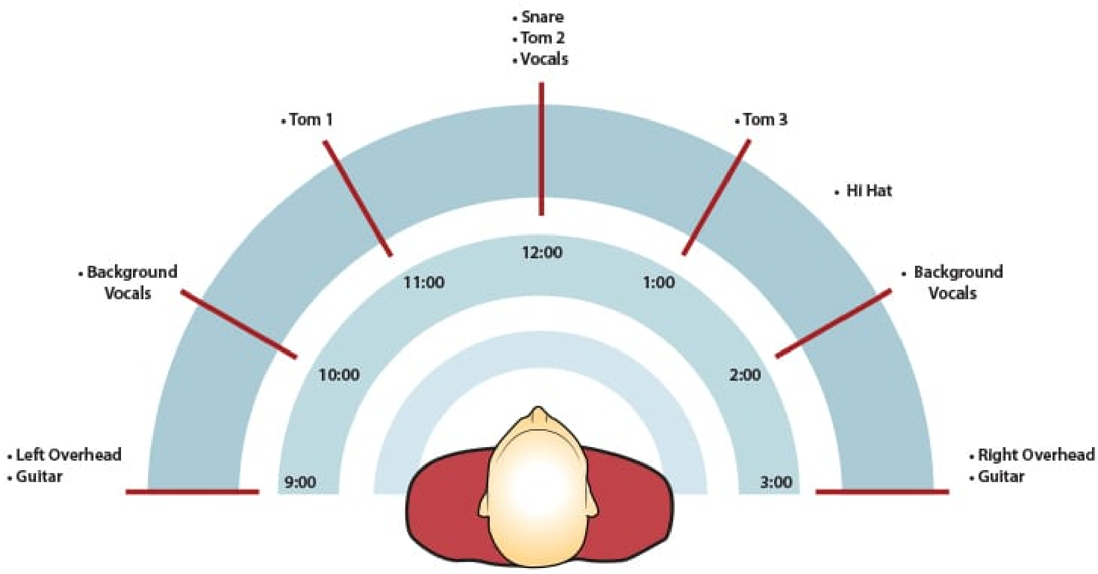

Figure 2.2: Example of visualization of instrument placement in stereo. [Keller, 2021]

In audio mixing, positioning is typically used to separate the various elements of the mix, allowing them to each occupy their own space in the stereo field, as shown in Figure 2.2. This can be achieved by adjusting the level of the left and right channels of a sound source, known as stereo panning. The traditional panning position for instruments varies depending on the style of music and the desired outcome, but there are some standard conventions.

One of the typical panning positions is to place the kick and snare drums in the center of the stereo field because they are considered the foundation of the rhythm section and should be clearly audible to the listener. Low-frequency sounds often perform best when panned dead center. It is ideal to keep these sounds in the center of your mix due to their lack of directionality and the fact that they hold most of the energy in a standard mix [Keller, 2021]. Similarly, the lead vocal is typically panned to the center, as it is the song's main focus, and it should be clearly audible and easy for the listener to understand. Other elements like background vocals, lead guitar, or keyboard parts are often panned to the left and right of the stereo field, creating a sense of separation and movement within the mix.

In popular music mixes, it is common for prominent elements like the lead vocal, bass, snare drum, and kick drum to be centered. Center panning in a stereo system creates a "phantom center" effect, where equal volume in both the left and right speakers tricks our ears into perceiving the sound as emanating from the space between the two speakers. This phenomenon becomes particularly apparent when a sound originates from a center speaker in a surround sound environment. It highlights the aptness of the term "phantom center" to describe our experience of center panning in a stereo setup. From the phantom center position, monophonic elements can be placed anywhere on the panning spectrum, ranging from very soft left or right to hard left or right [Savage, 2014].

The procedures for positioning may be the most well-defined in audio mixing practices, even if in an implied way. It appears commonplace that the main track and low-frequency information are both centered. The backbone, a set of four exactly centered pieces, is the usual outcome of this. These are the snare drum, kick drum, bass guitar, vocals, due to their significance, and bass. All other components should be kept from the center in any song with enough tracks. Even while sound engineers rank masking issues as only the third most significant reason to pan, this is probably connected to optimal practices in releasing from masking [Pestana and Reiss, 2014].

Additionally, stereo panning can be used to create the illusion of a sound source moving in the stereo field. This technique is known as Auto-Panning and can add interest and movement to the mix. It can be used to simulate a sound moving around the listener in a circular motion or to create a sense of depth in the mix by making a sound source appear to move closer or farther away [Savage, 2014].

Another aspect that demands attention is the integration of spatial audio effects. Techniques such as panning, reverberation, and delay can enhance the spatial characteristics of a mix, but their implementation requires careful consideration. In traditional stereo mixing, these effects are typically applied to create width and depth [Izhaki, 2018, Savage, 2014, White, 2000].

2.3 Spatial Audio

There are many three-dimensional sound experiences in daily life. Humans' capacity to understand and interact with their surroundings heavily relies on their spatial awareness and hearing is a crucial component of this process. Natural noises are heard according to their location and, sometimes subconsciously, according to their magnitude (most people rely more strongly on their visual sense for this information). Most of the time, natural sound settings provide indications for all three dimensions (width, height, depth), and people are accustomed to hearing noises from all directions without any specific precedence. Listeners often rely more on vision to detect the situation in front of them and more on sound to deal with things above and behind them since they lack eyes on the back or top of their heads [Rumsey, 2001].

Arriving in the 19^{th} century, the history of spatial sound started to become more and more intertwined with the advancement of contemporary science and technology. Although acoustic study has existed since antiquity, a formal theory of sound localization in 2D was not proposed until the late 19^{th} century. It was then steadily improved for another century to account for spatial localization. However, advancements in the technology for generating spatial audio effects often outpaced the full understanding of the underlying scientific principles [Roginska and Geluso, 2017].

With the aid of a more accurate and natural depiction of sound sources in the three-dimensional environment surrounding the listener, spatial audio, sometimes referred to as immersive audio, strives to improve the immersive experience of audio content [Roginska and Geluso, 2017].

Since the invention of stereo audio and binaural recording, the idea of spatial audio has been around. To produce a more immersive listening experience, researchers started experimenting with stereo sound recordings and binaural recording techniques in the 1950s and 1960s. Although the technology at the time limited these early efforts, they set the stage for further advancements in spatial audio. New spatial audio algorithms and software tools for producing and manipulating spatial audio were developed in the 1990s and 2000s due to digital signal processing and computer technology developments. As spatial audio is a crucial part of immersive media experiences, the development of virtual reality and augmented reality technology in the 2010s have sparked increased interest in spatial audio [Roginska and Geluso, 2017, Rumsey, 2001].

Gaming and Virtual Reality are some of the key industries where spatial audio is important. By enabling the user to locate sound sources in relation to their position in the game environment, spatial audio can significantly enhance the immersion and realism of video games. This can improve the user's experience and increase the game's interest. In first-person shooter games, for instance, detecting the sound of an enemy approaching from a certain angle might provide the player with a crucial tactical edge [Kern and Ellermeier, 2020, Stango, 2021].

Spatial audio has been employed in the entertainment sector to improve the listening experience as a whole. A more immersive and natural listening experience can be created through spatial audio-produced movies, music, and other audio content, which enables the listener to hear sound sources in relation to their position in the virtual environment. The listening experience may become more realistic and engaging as a result [Fonseca, 2020, Rumsey, 2001].

Using spatial audio technology in music can improve the overall listening experience by giving the sound source a more accurate and natural representation in three dimensions. The experience may become more realistic and immersive for the listener as a result [Rumsey, 2001, Bresler, 2021]. Binaural recording methods are one way that spatial audio is utilized in music. In binaural recordings, two microphones are placed at a dummy head's ears to record the sound from several perspectives, simulating how we naturally perceive sound. These recordings can produce a lifelike and immersive listening experience when played back over headphones since the listener hears the sound sources as if they were in the same room as the performers [Fonseca, 2020].

Spatial audio technology is also used in music production and post-production to provide the listener with a more realistic and immersive soundscape. For instance, spatial audio can be utilized in music creation to place and pan sounds in the stereo or surround area, giving the listener a sense of depth and realism [Roginska and Geluso, 2017].

For the employment of spatial audio, many different technologies are widely used, and those technologies can be grouped into categories: channel-based audio, object-based audio, and full-sphere, concretely Ambisonics.

Notable and historically significant channel-based technologies include 5.1 surround (Figure 2.3); 6.1 surround; 7.1 surround; Sony SDDS; Dolby Digital EX [Fonseca, 2020].

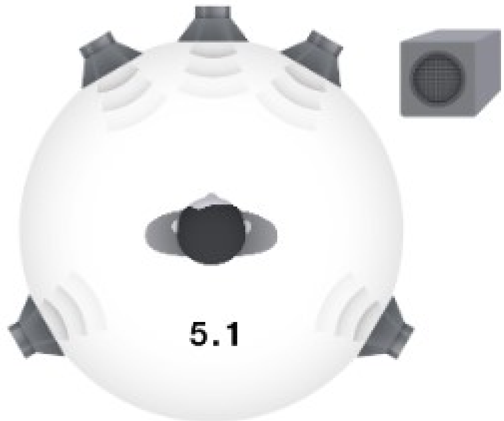

Figure 2.3: Example of 5.1 surround sound setup [Fonseca, 2020].

However, the previously mentioned technologies can not allow for the perception of sound coming from other directions besides the horizontal plane. Therefore, other technologies that place speakers that explore the height component, for example, on the floor or the ceiling, need to be discussed. Some very prominent object-based technologies that allow for this perception are Dolby Atmos [DOLBY, nd]; Auro-spatial [AURO, nd]; DTS:X [DTS, nd]; SONY 360 RA [SONY, nd]; AMBEO [AMBEO, nd]. There are also full sphere technologies and techniques (as exemplified in Figure 2.4) like Ambisonics; Wave Field Synthesis; Vector Base Amplitude Panning; Binaural audio.

A pre-determined speaker configuration, such as stereo or 5.1, is the foundation of channel-based audio, meaning how the mix will be rendered is already known. As a result, a mix for those channels is produced, which is subsequently broadcast. It merely requires transmitting each audio signal to the appropriate speaker during reproduction. Every sound in the studio is processed by a panner, which determines how much sound should be sent to each output channel. Additionally, before being distributed, the output from all panners is mixed (using a bus): the left output from all panners is combined and placed on the left channel, the same for the right channel, and so on. The output signal is eventually disseminated and afterward duplicated [Fonseca, 2020].

The concept behind object-based audio is a little distinct. Object-based audio takes a distinct method by distributing individual sounds independently, with the final mix being mixed only during reproduction, instead of mixing all sounds in the studio and distributing it [Fonseca, 2020].

Ambisonics is a spatial recording and playback technique based on the idea that the sound field's excitation may be represented as a decomposition into spherical harmonics. This format

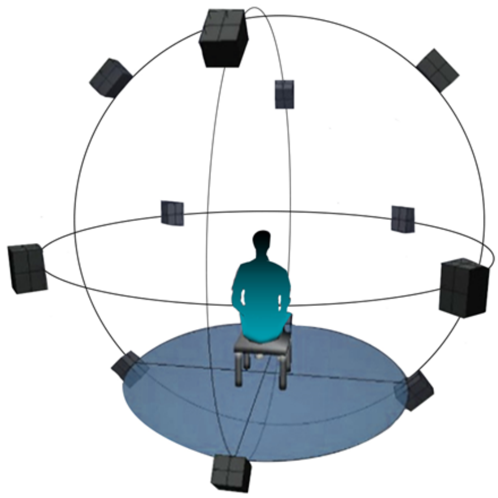

Figure 2.4: Example of a full sphere speaker setup [Belakhindi, 2017].

makes it easier to produce spatial sounds without relying on a playback mechanism. An appropriate decoder accomplishes the adaption to a certain playback system (loudspeakers or motion-tracked headphones) [Zotter and Frank, 2019]. The major objective of Ambisonics was to develop an audio format independent of the output reproduction arrangement. If you record something in Ambisonics, it will not matter how many speakers are present during playback or where they are located since Ambisonics can adapt to it [Fonseca, 2020].

According to Fonseca [Fonseca, 2020], the main advantage of channel-based audio is that it is the ideal solution if we already know exactly what speaker layout will be used to reproduce the music. For instance, it is fantastic if there is knowledge in advance that the mix will be played back on a 5.1 system with the speakers positioned in those predetermined locations. Since channel-based audio is confined to a certain speaker configuration and any changes to the output speaker arrangement call for a new mix, its biggest drawback is its lack of flexibility. A movie could need five distinct mixes, one for each format, if it is released in Stereo, 5.1, 7.1, 11.1, and 22.2, for instance.

The biggest advantage of object-based audio is the capacity to adapt to any speaker layout; additionally, this approach can increase the reproduction's spatial accuracy by using additional speakers to extract the system's full potential for spatial resolution. But there are also disadvantages; firstly, there is a necessity to distribute a considerably greater number of audio channels. Dolby Atmos may employ up to 128 audio channels in movie theaters. However, if we switch to other delivery methods, those 128 audio channels are just too numerous, requiring us to reduce the number of objects, which necessitates rendering many things as beds and eliminating their benefits. Second, there is a limit to the number of objects [Fonseca, 2020].

The main advantage of Ambisonics is its capacity to adjust to any speaker layout. Second, it can recreate a spatial audio scenario with a minimal amount of audio channels (starting with only four channels). Thirdly, Ambisonics can expand to more channels to enhance spatial resolution [Fonseca, 2020]. It offers a high degree of flexibility in terms of positioning sounds in spatial space, compatibility with a wide range of playback systems, and open technology, which allows for greater accessibility and freedom in terms of development and implementation. The drawback of Ambisonics is that if you want a decent spatial resolution, it takes a lot of channels.

Ambisonics recording and playback as a method for spatial audio is utilized in music. When played back through a multi-speaker system, this can be used to produce more immersive and realistic listening experiences.

Overall, spatial audio technology can enhance the overall listening experience for music by providing a more realistic and natural representation of the sound source in the three-dimensional space, creating a sense of immersion for the listener and making the experience more engaging and realistic.

One of the primary challenges in spatial audio mixing is achieving a balanced and coherent sound that translates effectively across different playback systems and environments. The spatial dimensions add complexity to the mixing process, as the position of each sound source becomes a critical factor. Proper localization of instruments and vocals within the soundstage is essential to create an immersive experience without compromising the overall balance and clarity of the mix [Roginska and Geluso, 2017, Owsinski, 2013, Pulkki et al., 2010].

2.4 Conclusions

In summary, the method of making music has undergone a substantial transformation as a result of the progression of music creation towards digital media in the late 20th and early 21st centuries. Audio mixing is an essential step in the production process, which entails balancing, processing, and integrating multitrack recordings into a multichannel format. Particularly in contemporary musical genres like popular music, the mixing engineer's job has expanded to become a creative force. This characteristic is a point of focus since post-production is where lies a big motivation for this dissertation. Audio mixing's goal is to create a harmonic, well-balanced mix that brings out the musical parts and promotes the overall aesthetic idea. Levels, EQ, positioning, and other aspects of specific musical instruments or groups of instruments are adjusted and balanced during the process. Awareness of the various instruments in a mix is critical since they may fight for space and cause masking problems.

A more realistic and immersive depiction of sound sources in a three-dimensional environment is the goal of the technology known as spatial audio. Spatial audio is crucial in fields like gaming, entertainment, and music, where it improves the listener's immersive experience. Channel-based audio, object-based audio, and full-sphere audio are only a few of the methods utilized for spatial audio. Each of these technologies uses unique techniques and features to provide listeners with a more authentic and interesting experience. The technology used in this dissertation will be Ambisonics because it offers a high degree of flexibility in terms of positioning sounds in spatial space, compatibility with a wide range of playback systems, and an open technology, which allows for greater accessibility and freedom in terms of development and implementation. All these features make it a suitable choice for the project of this dissertation.

It is important to keep in mind that audio mixing and these techniques are tightly related to the problem of audio masking. The conventional advice is to use equalization or panning to move objects out of each other's way when the time-frequency content becomes congested [Pestana and Reiss, 2014]. And for audio mixing, positioning is a fundamental technique in mixing instruments and elements of a composition, and it is used to separate these elements of the mix and to create a sense of width and depth in the stereo field. It can also be used to create the illusion of movement and interest within the mix. In regards to popular music production, there are not many studies or references for positioning practices, especially when the conversation is positioning in a spatial environment.

One of the primary challenges in spatial audio mixing is achieving a balanced and coherent sound that translates effectively across different playback systems and environments. The spatial dimensions add complexity to the mixing process, as the position of each sound source becomes a critical factor. Proper localization of instruments and vocals within the soundstage is essential to create an immersive experience without compromising the overall balance and clarity of the mix.

There are still very few clear methods and standards for audio engineers and producers to adhere to, despite the rising interest in and use of immersive audio. Lack of rules or critical debate on the use of spatial dimensions in audio mixing, particularly in the context of surround sound for popular music, is a major difficulty. Music industry professionals struggle to properly utilize spatial audio because of this knowledge gap. While there are known methods for stereo audio mixing, the switch to surround sound introduces new channels and positions for instruments in the sound field, sometimes necessitating alternative methods.

In conclusion, while spatial audio has gained significant traction in music production, particularly within immersive sound technologies, the lack of well-defined procedures and guidelines for spatial audio mixing in popular music remains a notable challenge.

Chapter 3

Project and Method

In this chapter, a description of the experimental procedure is laid out, and the method for the dissertation project is built.

3.1 Methodology

To tackle the scarcity of available knowledge mentioned in the chapter 2, it was decided to conduct an empirical research to evaluate how professional producers have adapted to the additional spatial dimensions of surround sound technology. In order to do this, a perceptual data-driven study of Grammy-winning songs from the Best Immersive Album category from 2005 to the present was carried out. These songs are frequently from the popular and mainstream music genres[1]. Seven tracks are mixed in 5.1 surround sound. This category of Grammy award is recognized throughout the music business as a level of excellence and applicability for immersive audio. The songs chosen for our study are listed in Table 3.2 and 3.3, with one lead single from each winning album. The full list of Grammy winners for the category in study can be found in Table 3.1.

The genre of the album and the accessibility of the associated surround sound version for procurement or access directly affected the inclusion of particular songs in this research as well as the exclusion of songs from particular years to which the Grammy was awarded. As a result, records that fit into the popular music category were chosen, while works in the symphonic, classical jazz, and electroacoustic genres were excluded.

The omission of these genres stems from the context of popular music, where post-production plays a crucial role in shaping the final sonic outcome. Unlike genres such as classical/orchestral

[1] In the context of this dissertation, "popular music genres" typically include widely recognized and commercially successful styles that have gained broad appeal. Examples of popular music genres often studied include pop, rock, hip-hop, R&B, country, and electronic dance music (EDM). "Mainstream music genres" refer to the dominant and commercially successful styles that tend to shape popular culture. These genres are characterized by their prevalence in the commercial music industry, extensive media exposure, and broad recognition. While specific genres can vary over time, mainstream music genres typically represent the prevailing trends and preferences of the general public.

Year	Work	Performing artist(s)
2005	Genius Loves Company	Ray Charles & Various Artists
2006	Brothers In Arms - 20th Anniversary Edition	Dire Straits
2007	Morph the Cat	Donald Fagen
2008	Love	The Beatles
2009	Mussorgsky: Pictures At An Exhibition; Night On Bald Mountain; Prelude To Khovanshchina	Paavo Järvi & Cincinnati Symphony Orchestra
2010	Transmigration	Robert Spano & The Atlanta Symphony Orchestra & Choruses
2011	Britten's Orchestra	Michael Stern & Kansas City Symphony
2012	Layla and Other Assorted Love Songs (Super Deluxe Edition)	Derek & The Dominos
2013	Modern Cool	Patricia Barber
2014	Live Kisses	Paul McCartney
2015	Beyoncé	Beyoncé
2016	Amused To Death	Roger Waters
2017	Dutilleux: Sur le Même Accord; Les Citations; Mystères de l'Instant & Timbres, Espace, Mouvement	Ludovic Morlot & the Seattle Symphony
2018	Early Americans	Jane Ira Bloom
2019	Eye in the Sky - 35th Anniversary Edition	Alan Parsons Project
2020	Lux	Anita Brevik, the Trondheimsolistene & the Nidarosdomens Jentekor
2021	Soundtrack of the American Soldier	Jim R. Keene & the United States Army Field Band
2022	Alicia	Alicia Keys
2023	Divine Tides	Stewart Copeland & Ricky Kej

Table 3.1: Full list of winners for the Grammy category of best immersive album [WIKI, nd].

ID#	Award year	Title	Author
1	2005	Here We Go Again	Ray Charles & Various Artists
2	2006	Walk of Life	Dire Straits
3	2007	Morph the Cat	Donald Fagen
4	2008	Hey Jude	The Beatles
5	2012	Layla	Derek & The Dominos
6	2016	What God Wants, Pt. I	Roger Waters
7	2019	Eye in the Sky	The Alan Parsons Project

Table 3.2: Seven songs selected from the Grammy-award Best Immersive Album included in the analysis part 1.

music or electroacoustic, the process of post-production in popular music involves distinct considerations. The mix engineer assumes a significant creative role in refining and enhancing the recorded material. Working closely with artists and producers, the mix engineer makes critical de-

ID#	Album
1	Genius Loves Company [Charles and Jones, 2004]
2	Brothers In Arms - 20th Anniversary Edition [Knopfler, 2005]
3	Morph the Cat [Fagen, 2006]
4	Love [McCartney, 2006]
5	Layla And Other Assorted Love Songs (Super Deluxe Edition) [Clapton and Gordon, 2011]
6	Amused To Death [Waters, 1992]
7	Eye in the Sky - 35th Anniversary Edition [Parsons, 2017]

Table 3.3: Seven songs selected from the Grammy-award Best Immersive Album included in the analysis part 2.

cisions regarding the balance, spatial placement, and overall sonic impact of each element within the mix. Popular music post-production embraces a stylized and processed approach, employing various techniques and tools to achieve a polished "commercial" sound.

Additionally, only albums that were available from this preset list were included in the analysis. The selection of songs for the study was determined by a number of factors, such as the importance of the album's lead single or, in situations where one was not available, the appeal of a representative track on streaming platforms.

The selection of these seven songs from the Grammy Awards not only provides insight into the specific mixing strategies employed for each track but also allows for a consideration of time-based trends and technological developments. By examining these award-winning songs, the aim was to identify commonalities, patterns, or potential lack thereof in the mixing approaches used by industry professionals in the realm of immersive audio. The analysis sought to gather valuable information on how mixing techniques have evolved over time and how they are currently being applied in the industry.

To capture and analyze the relevant data, three key variables were considered: position, trajectory, and dynamics. Position refers to the perceived spatial location of audio sources, such as vocals or instruments, within the spatial reproduction field. The trajectory represents the change in position over time, offering insights into how audio sources move within the soundstage. Dynamics, on the other hand, pertain to the apparent loudness and intensity of each individual instrument or vocal component.

The inclusion of these variables allowed for a comprehensive assessment of the spatial mixing strategies employed in these songs. By examining position, trajectory, and dynamics, the study sought to uncover trends, patterns, or deviations that could shed light on the creative decisions made by mix engineers. The analysis aimed to identify any consistent practices, such as specific instrument placements or trajectory patterns, and to determine the degree of emphasis placed on dynamics within the immersive audio mixes.

A system using a multi-speaker array, with 20 speakers, arranged spherically was chosen. This is the multichannel system used for research at the University of Porto's Sound and Music Computing Laboratory in the Faculty of Engineering, and it was chosen due to its availability and viability to be used in the project of this dissertation to decode the analysed songs. Figure 3.4 is

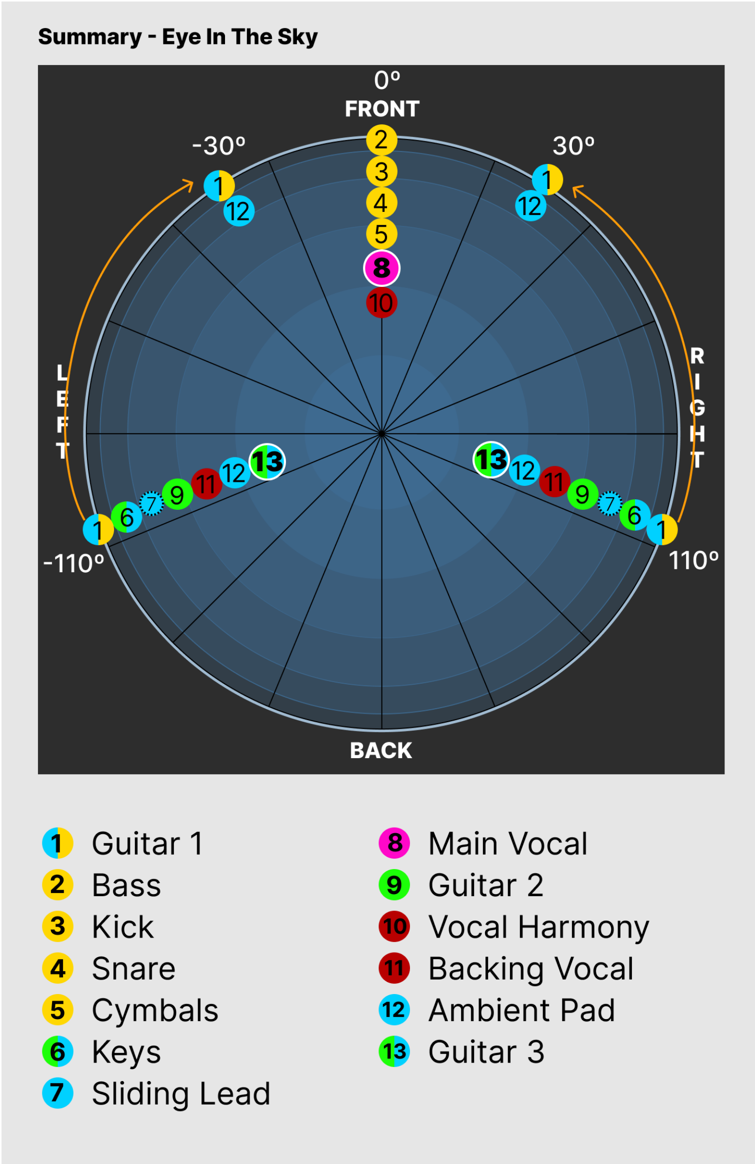

Figure 3.1: This summary graphic is an example for the song "Eye in the Sky." illustrates the nomenclature and methodology for the **immersive** analysis provided in this graphic.

a picture taken during execution of the perceptional analysis in the Laboratory where this system is located. Using Ambisonics, every song was spatially encoded. Stereophonic song tracks were placed with the left and right channels at -30° and 30°, respectively, while surround tracks were placed with the left surround at -110° and the right surround at 110°with LFE directly to the subwoofer. This encoding was made using IEM plugins from the IEM Plug-in Suite, a free and Open-Source audio plugin suite including Ambisonic plug-ins up to 7th order[IEM, nd], to place the 6 tracks of each song being reproduced from their respective position.

To determine a comfortable playing volume and the Ambisonics order to be used across all assessed recordings, a pre-listening testing was undertaken. Each track's gain was modified to a standard level of -12dB, and the subwoofer routing received an extra -12dB. These parameters were

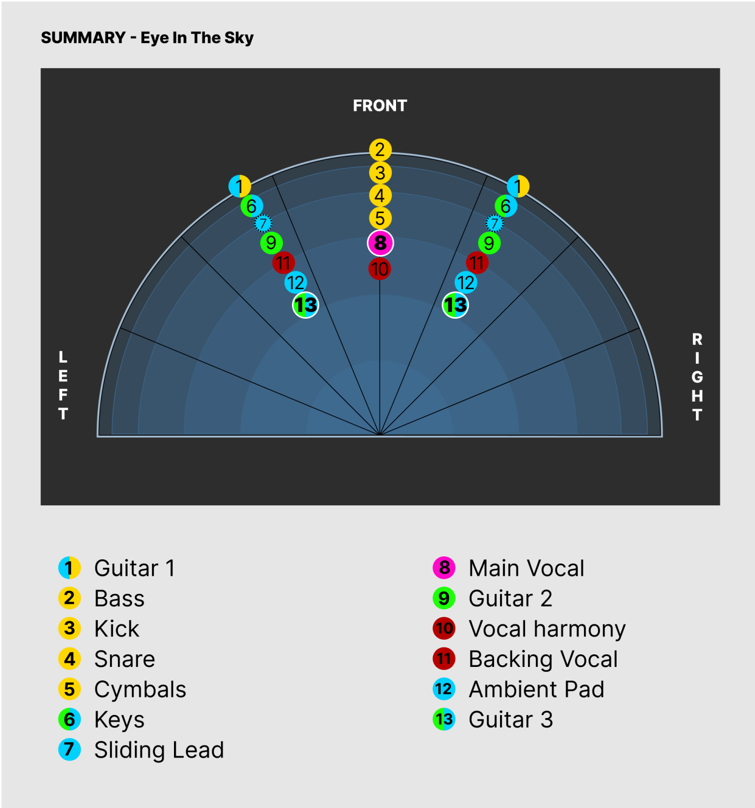

Figure 3.2: This summary graphic is an example for the song "Eye in the Sky." illustrates the nomenclature and methodology for the **stereo** analysis provided in this graphic.

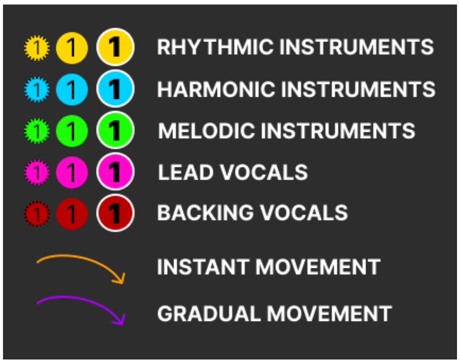

Figure 3.3: Accompanying caption for the diagram. Displays dynamics, trajectory, and instrument identification information, together with numbers and category-specific colors.

changed as necessary for various songs to get the ideal loudness and a comfortable listening volume without distortion. The adoption of an Ambisonics of fifth order was made. No improvements in spatial resolution above the fifth order were registered, despite the fact that higher-order Ambisonics should theoretically result in improved perception [Bertet et al., 2007, Bertet et al., 2013].

The process used the following two steps. The songs were first divided into sections before the perceptual analysis, with sections generally consisting of introductions, verses, choruses, and bridges. A structurally informed study of the instrumentation was possible thanks to the individual

Figure 3.4: Photograph of the multi-speaker array system used in the perceptive analysis.

and sequential investigation of these portions.

Second, the instrument placements and loudness per section in the surround and stereo versions were collected using a radial notation diagram that was created especially for this project, inspired by existing visuals of ambisonics encoding plugins like IEM and tailored to best represent all the data that was to be tackled in this study. These diagrams for both the surround and stereo analysis are represented in Figures 3.1 and 3.2, respectively. The spatial field, which represents the 1) position, 2) trajectories, and 3) dynamics of the instrumental sources and their processing effects, was created as a segmented radial arrangement with 16 equal subdivisions of 22,5°.

A distinctive number identification within colored circles is used in the illustration to identify the instruments. Five instrument types are represented by the colors: rhythmic, harmonic, melodic, lead vocals, and backup vocals. The instruments assessed for each category are listed in Table 3.4. Similar source positions are indicated by stacks of colored circles. Since depth was not taken into account in our investigation, the sequence in which the instruments are placed in the figure is by order of appearence. Please refer to Figure 3.3 for the immediate and gradual movements in

Harmonic	Melodic	Rhythmic	Lead Vocals	Backing Vocals
Piano	Guitar	Kick	Main Vocal	Backing Vocals
Bass	Bass	Snare		
Guitar	Horns	Cymbals		
Keys	Keys	Percussion		
Horns		Bass		
Strings				
Pads				

Table 3.4: Instruments found in the analyzed songs were categorized into harmonic, melodic, rhythmic, lead vocal, and backing vocal groups.

instrument locations indicated by arrows. Instrumental dynamics were coded using a three-level system depending on the size of the circle and variations in design[2] and identification number size, with low, medium, and high degrees of dynamics. Diagrams were annotated according to each split song section.

Multiple listenings of the song portions led to annotations. The 5.1 mix's six channels were heard alone as well as in pairs (for example, front vs. surround channels). To get the greatest possible discrimination of the channels under examination, the listener moved freely inside the sweet spot (for example, facing the rear channels for a clearer sense of the surround channels).

To begin analyzing the findings, the notes for each segment were combined to produce diagrams that summarized the data for complete songs. In addition to two radial histograms per instrument category, surround, and stereo versions, two diagrams were created to display the whole song information for each instrument. Similar design concepts to those seen in the section diagrams above were present in the first diagram. For the instrument category position in the radial diagram, the latter suggests a histogram. The incidence of instrument types is displayed for each radial position in the circle's radius at its center. A greater number of instruments at a specific angle are represented by bigger circles.

Descriptive circular statistics were equally embraced as quantitative findings, even if visual examination and comparison across songs in surround or stereo versions, as well as between versions, provoke many of the qualitative conclusions and debates. More specifically, the mean positions of the instruments and instrument categories, as well as their dispersion, were measured using the corresponding **circular mean $\bar{a}$ circular standard deviations σ**. Both measures can support a framework for scaling up empirical investigation of immersive music and help define recommendations in a more systematic way. The Python `SciPy` [Jones et al., 2001] package is used to construct descriptive circle statistics.

The methodology employed in this study is inherently perceptual and personal, lending itself to a degree of subjectivity. As the analysis delves into the immersive audio experience from a listener's perspective, individual perceptions and preferences play a significant role in shaping the

[2]A stroke was attributed to the high-level dynamics circle in order to create increased legibility. The same was done for low levels of dynamics but with a dashed stroke.

findings. The subjectivity arises from the intricacies of human auditory perception, where individuals may interpret spatial audio cues differently based on their unique listening environments, auditory sensitivities, and personal experiences.

3.1.1 Creation and Evolution of the Proposed Diagram

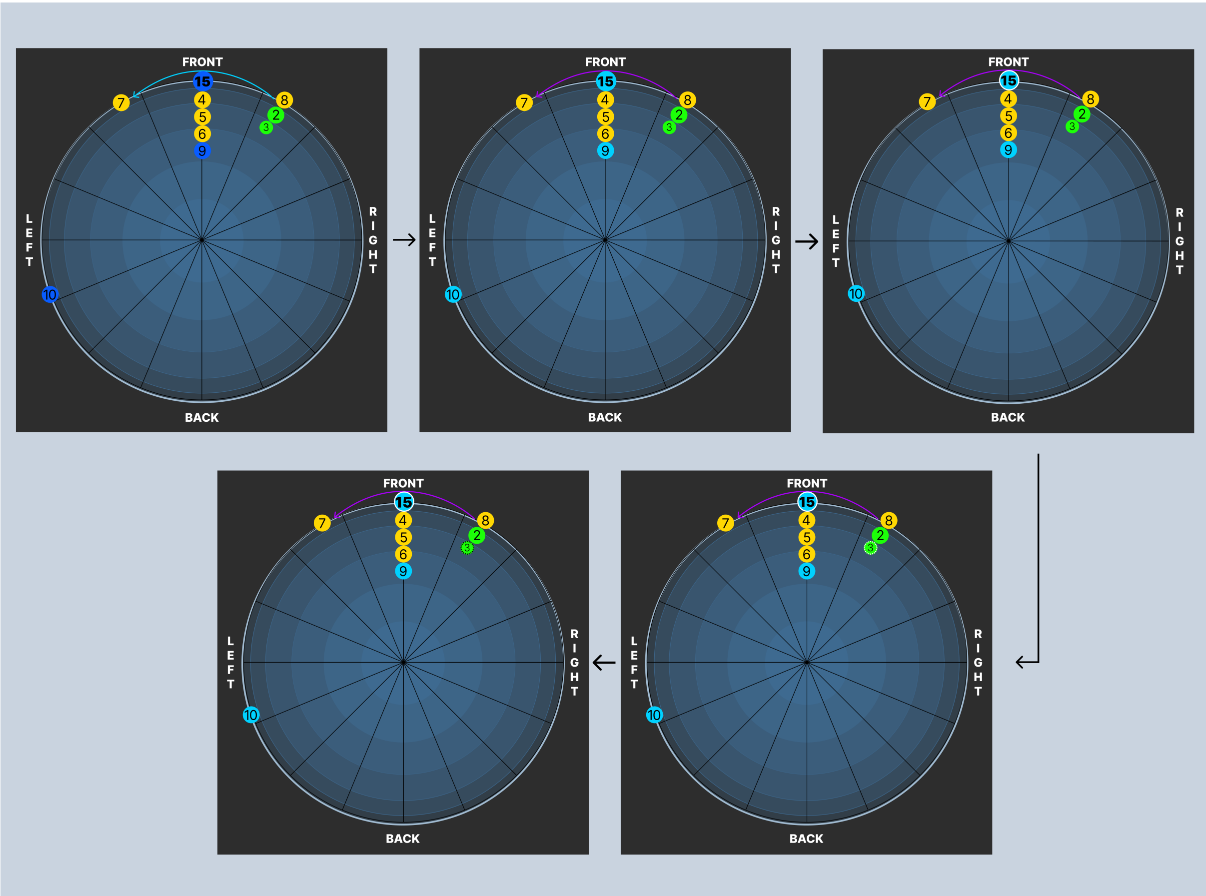

Figure 3.5: Evolution of the proposed radial notation diagram.

Figure 3.5 illustrates the several steps that were taken to better the initial proposition of a radial notation diagram. The genesis of this notation system as already been explained previously in this section, this subsection delves into the necessary evolution the diagrams add to undertake in order to better be understood. These changes were necessary due to demands that came into existence during the execution of the analysis. This evolution was mostly related to problems with readability, especially regarding the system adopted to represent the different dynamics levels.

In the initial proposition, it was defined that each dynamics level was to be represented by a circle with distinct dimensions, namely:

- Low (diameter = 24 px);
- Medium (diameter = 30px);

- High (diameter = 36 px).

In the first draft (that is not represented in Figure 3.5) font size was not considered as a visibility-facilitating asset. It was then also decided in the first proposition represented in Figure 3.5, that specific weights and sizes for the instrument identification number would be associated with each dynamics level, from the same font family (Inter), namely:

- Low (weight = Light, size = 18px);
- Medium (weight = Regular , size = 24px);
- High (weight = Black , size = 26px).

The changes represented in the second image of Figure 3.5 were to change the color of the harmonic instruments to a lighter blue, a shade with greater contrast with the background and the identification number inside the circles, in order to allow greater visibility and easier reading. It was also decided that the blue arrow would change to purple, so as not to be confused with the new shade of blue chosen for the harmonic instruments.

In the third image, high dynamics circles are highlighted by a white stroke (2px), to more easily be distinguished from other dynamics levels.

In the fourth diagram, another alteration was made: circles with low dynamics levels are highlighted by a white dashed stroke (2px) to be more easily distinguished from other dynamics levels.

In the final proposition, in order to increase the contrast and increase visibility, the dashed stroke of the "circles" with low dynamics level is changed to black.

Chapter 4

Results and Findings

The analysis of immersive and stereo versions of the dataset of songs is addressed in this chapter. For each format, **position**, **dynamics**, and **trajectory** are tackled. The dataset analysis has yielded significant results regarding the positioning of instrument audio sources. Two key aspects emerged from the analysis: global patterns and trends per instrument across all songs and outliers that foster different creative and technical solutions. The subsequent sections provide a comprehensive exposition of these findings, shedding light on the spatial characteristics of instrument placement in the context of immersive audio mixes.

For this study, it is also noteworthy to mention that considering more than one audio source does not necessarily mean that the number of instruments is the same as audio sources. One instrument can have 2 or more perceived audio sources from different angles.

The instrument category location and dynamics descriptive circular statistics are shown in Tables 4.1 and 4.2 for both the surround and stereo versions. Each instrument and instrument category's overall patterns and trends are examined in the sections that follow, with a focus on the variables of location, dynamics, and trajectory. The stereo versions are then compared after that. The results' implications for the formulation of recommendations are then examined.

All the data compiled in tables is available in appendix A. And the diagrams for the full section analysis of all songs in their surround sound and stereo versions are available in appendices B and C, respectively. Also, a logbook-style list of observations written during the surround sound versions analysis can be found in appendix D.

Instrument Category	**surround**	**stereo**
Harmonic	44 ± 77	3 ± 5
Melodic	31 ± 104	-4 ± 21
Rhythmic	14 ± 23	-2 ± 14
Lead vocals	12 ± 35	-6 ± 12
Backing vocals	0 ± 91	-2 ± 24

Table 4.1: Mean angles of instrument category positions $\bar{a}$ and their standard deviations σ for surround and stereo versions of the songs.

Instrument Category	surround	stereo
Harmonic	$1,9 \pm 0,4$	$1,9 \pm 0,4$
Melodic	$2,4 \pm 0,5$	$2,2 \pm 0,6$
Rhythmic	$2 \pm 0,4$	$1.9 \pm 0,4$
Lead Vocals	$2,9 \pm 0,3$	$2,9 \pm 0,3$
Backing Vocals	2 ± 0	$2,1 \pm 0,3$

Table 4.2: Mean dynamics of each instrument category and their standard deviations for both surround and stereo studies. Three levels of dynamics are considered, each represented by an integer value in the [1,3] range.

4.1 Surround Sound Versions

This section tackles the results related to the three variables analyzed for the Immersive study in surround sound. Each variable will be addressed in a subsection, Position in 4.1.1, dynamics in 4.1.2, and Trajectory in 4.1.3.

4.1.1 Position

Figure 4.1 shows the instrument position for all instrument categories in the surround songs. The size of the circles corresponds to the occurrence of that instrument group in a particular location.

One of the sound reproduction field's greatest degrees of dispersion ($\sigma = 77$) is found in the *harmonic instrument category*. These instruments are mostly distributed in angles of -30°, 30°, 110°, and -110°, with symmetrical places about 0° being held by comparable instruments in 80% of the cases. Furthermore, the harmonic instruments are largely removed from this position, with the noticeable exception of the bass instrument, which regularly occupies the front center position at 0°. The songs "Walk of Life" (Figure 4.2) and "Layla" (Figure 4.3), which display the guitars at 0°, are an exception to this norm. Given that guitars typically adopt an audio source position at 30°, -30°, 110°, and -110°, this guitar positioning is out of the ordinary.

Melodic instruments are usually placed at -30°, 30°, and 0° in the front of the spatial reproduction field. The audio source is positioned inside these frontal angles 71% of the time when a melodic instrument, like a solo, takes over the function of the main melody in a certain segment. The songs "Eye in the Sky" (Figure 4.4) and "Walk of Life" (Figure 4.2) are two prominent outliers since the key melodies, aside from the main voice, are placed at 110° or 110°, respectively, as illustrated in Figure 4.1. It is vital to note that not all melodic instruments play the primary melody in a certain segment of the song; instead, they frequently play complementing melodies. This category has the largest amount of dispersion in the sphere of sound reproduction ($\sigma = 104$) due to these two prominent roles played by its instruments.

In 86% of the songs under consideration, the *Rhythmic instruments* are positioned at 0°. Detail-wise, "Hey Jude" (Figure 4.5) is the lone exception, with the kick and the snare appearing in the center front position 87% of the time otherwise. In this particular exception, the drum set is heard at a -30°angle. There are a few small exceptions to this rule as well, mostly found in cymbals. It

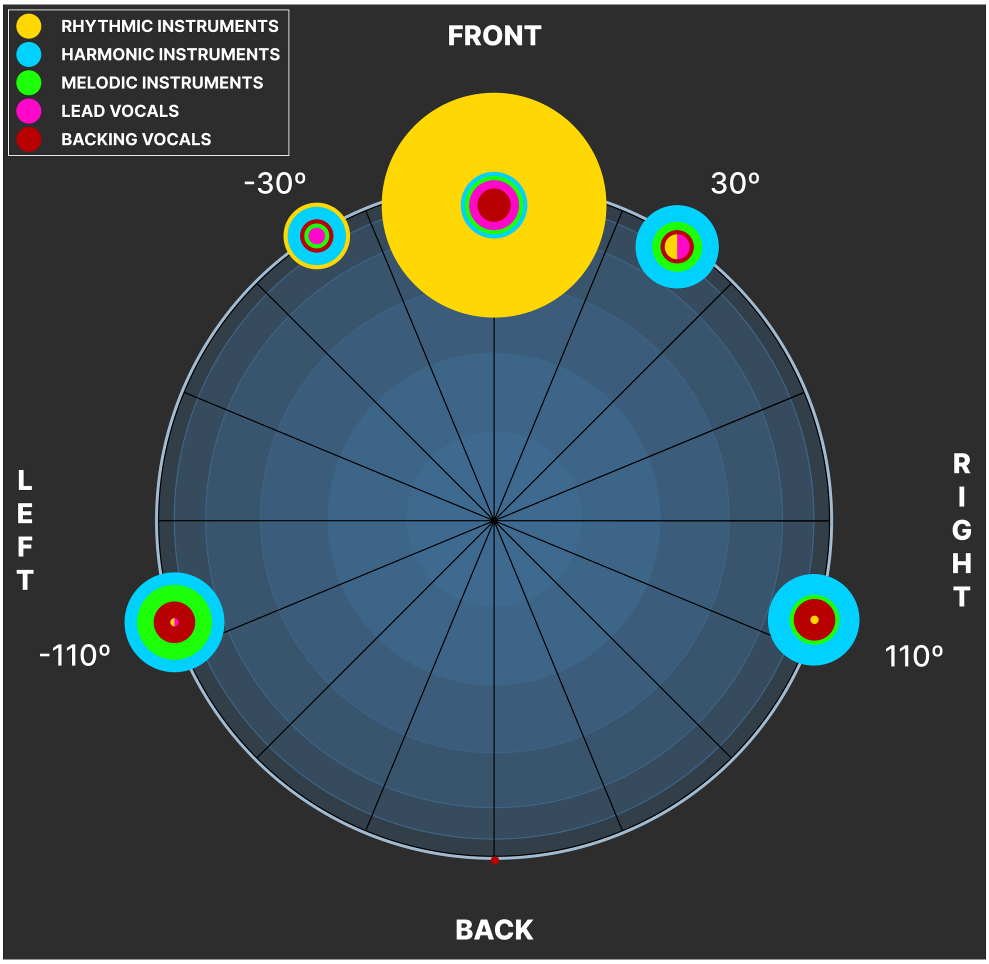

Figure 4.1: A diagram showing the incidence of each category of instrument (rhythmic, harmonic, melodic, lead, and backing vocals) in the **surround** study. The diameter of the circles represents the occurrence of a certain category in a specific position. The presence of colored half circles indicates that instruments appearing at that angle occur equally frequently in the second category (color) as the specified category.

is important to note that this remark is supported by the bass, which, together with the drum kit, is seen as being a crucial element in building the rhythmic basis of the ensemble. Please note that although playing different roles in different songs, the bass was not always regarded as a rhythmic instrument in the study.

The *lead vocals* are predominantly located at the 0° angle. However, an exception to this pattern is observed in the song "Here We Go Again" (Figure 4.6), which features a duet with two lead vocals. The lead vocals are placed separately at the -30° and 30° angles, as illustrated in Figure 4.1.

Regarding the *lead vocals*, it is observed that the main vocal in a song is consistently positioned within the three front angles, namely -30°, 0°, and 30°. Furthermore, it is noteworthy that the majority of lead vocals are predominantly located at the 0° angle. However, an exception to this pattern is observed in the song "Here We Go Again", which features a duet with two lead vocals.

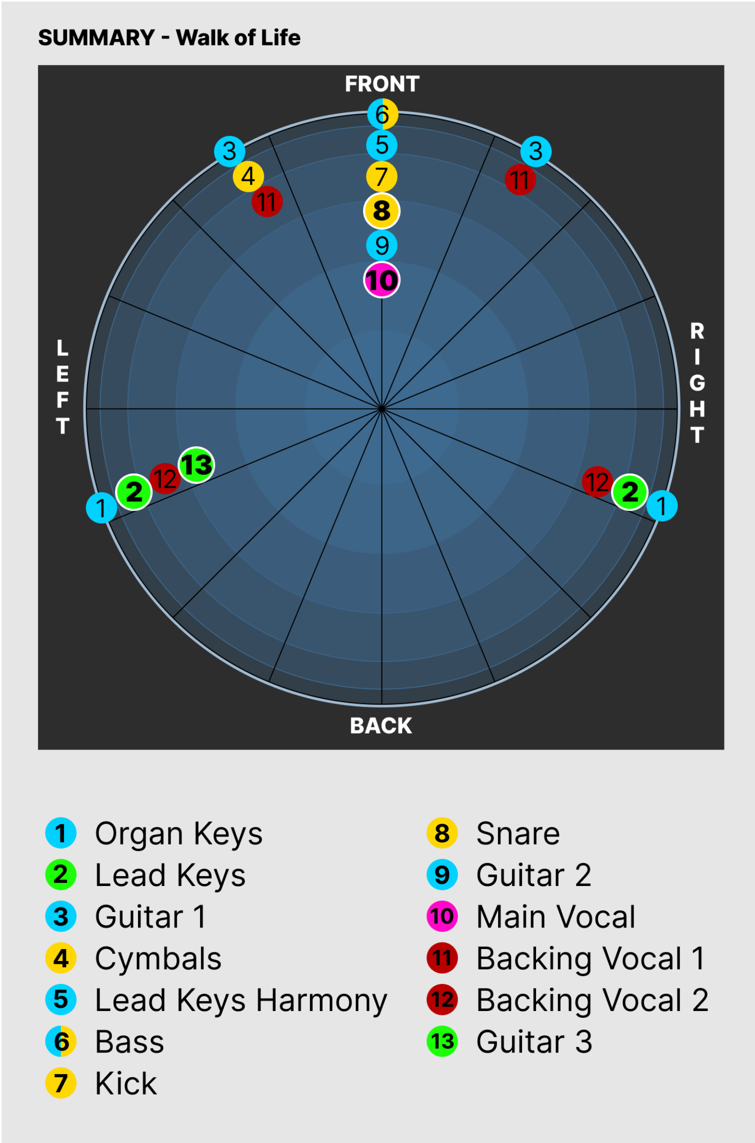

Figure 4.2: Summary diagram for the analysis of the song "Walk of Life"

In this case, the lead vocals are placed separately at the -30° and 30° angles, as illustrated in Figure 4.6.

Maintaining symmetry between audio sources is seen as having a strong propensity in the *backing vocal category*. A second audio source for the same voice is always placed in a symmetrical location when a backup vocal is first introduced in a song with an audio source that is not in the center of the sound field. For instance, if one audio source is at 110°, the symmetrical source at -110° may be detected[1]. In this category, the habit of preserving symmetrical placement of audio sources is constantly seen and occurs with 100% of the audio sources that are not situated at 0° or 180°. In the song "Morph The Cat" (Figure 4.7), one of the audio sources for a backup vocal is

[1]This situation also illustrates the aforementioned observation that considering more than one audio source does not necessarily mean that the number of instruments is the same as audio sources.

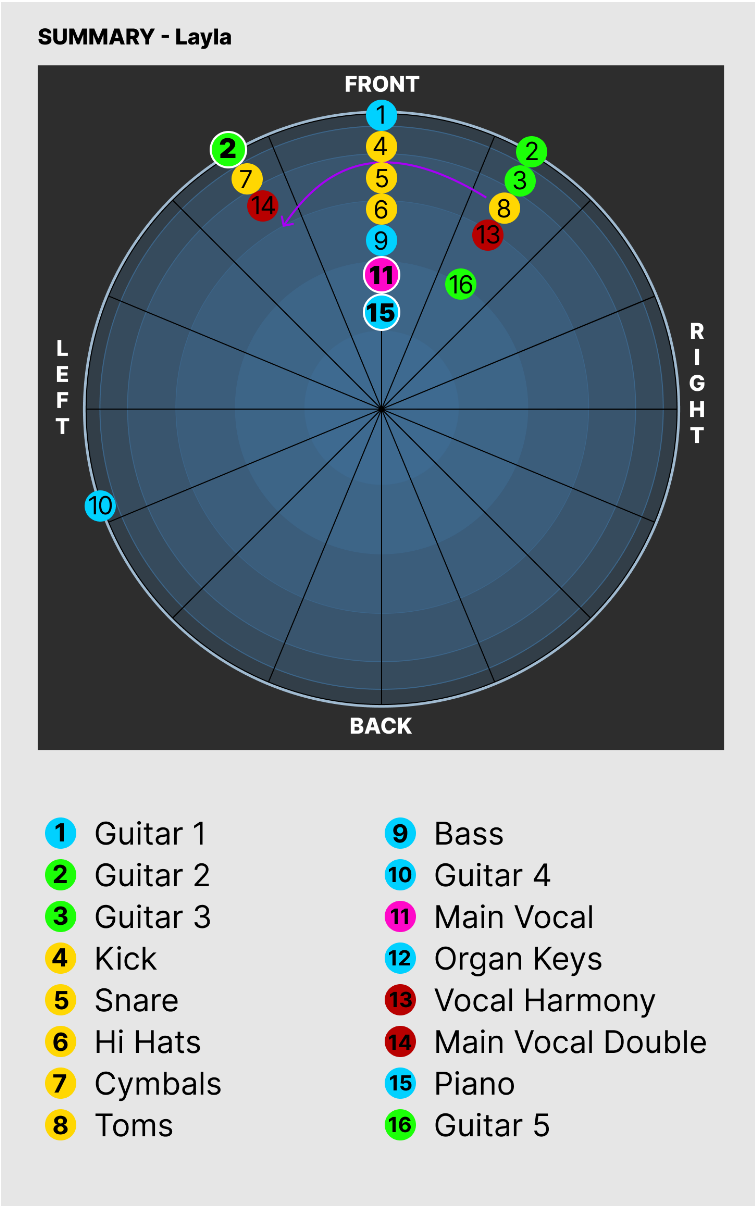

Figure 4.3: Summary diagram for the analysis of the song "Layla".

seen to be at 180°, which is a notable departure from this norm.

A distinct inclination towards achieving symmetry in the placement of instruments within the sound reproduction field is observed. The analysis of instrument data, categorized by instrument types, reveals a prevalent occurrence of mean positions at 0° and 180°, accounting for 72.5% of all instruments that compose any of the 7 songs analyzed. This is verified for the instruments denominated as keys, where, throughout the study, in the songs they are present, in 90% of instances their mean value is either 0° or 180°. Additionally, a mere 8.8% of instruments exhibit a deviation of 16° or less from these symmetrical values, which can be considered an insignificant deviation. Consequently, a total of 81.3% of instruments comply with the principle of symmetry. However, it is worth noting two exceptions to this general tendency: the songs "What God Wants, Pt. I"

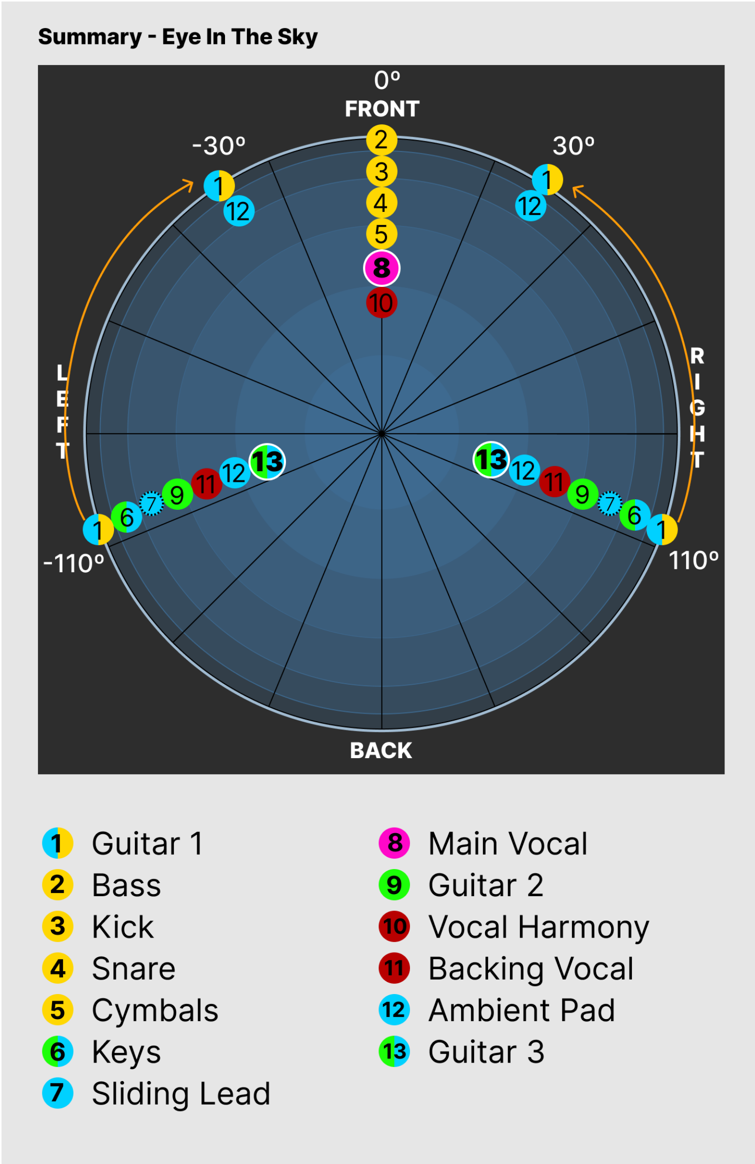

Figure 4.4: Summary diagram for the analysis of the song "Eye in the Sky"

and "Hey Jude". This symmetry is achieved either through mirroring audio sources from within a certain instrument category or even by using audio sources from different instrument categories to achieve this balance.

In the song "Hey Jude", the diagram in Figure 4.5 illustrates that the primary rhythmic elements, specifically the drum kit, are positioned in the left front channel at -30°. The mean value for the kick and snare in the overview of the whole study is -4° and not 0° due to this outlier. On the other hand, in the song "What God Wants, Pt. I"(Figure 4.8), while maintaining symmetry with the central axis, an additional axis of symmetry becomes apparent splitting the diagram between -110° and 30°. This is evident in the placement of certain instruments with multiple audio sources, such as instrument number 5, choir vocal, and instrument number 8, guitar 2, which are situated at these angles. It should be noted that some songs exhibit minor asymmetries; however,

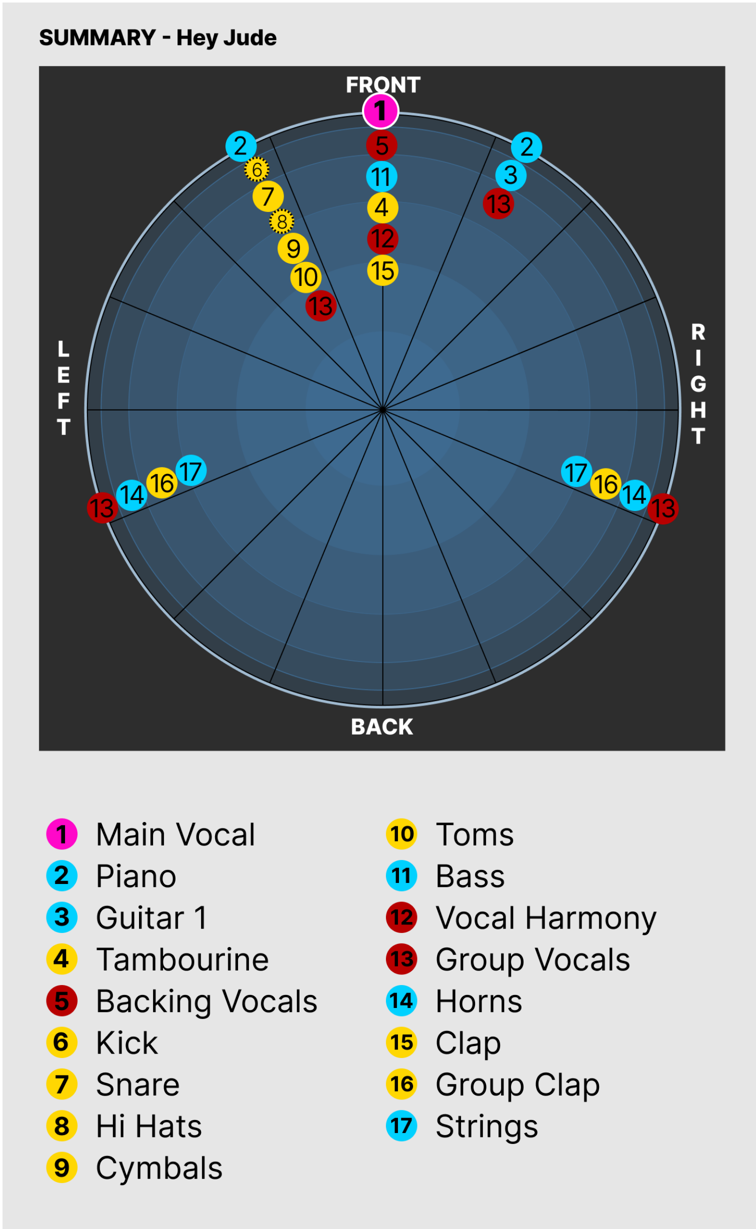

Figure 4.5: Summary diagram for the analysis of the song "Hey Jude"

these deviations do not appear to be particularly significant and other factors, such as dynamics, may influence these choices during the mixing process, and their implications will be discussed in the subsequent chapter.

4.1.2 Dynamics

Without any significant outliers, the dynamics data analysis for each song revealed similar trends and patterns. The threefold-level dynamics in the [1, 3] range for the instrument categories are presented in Table 4.2 together with their means and standard deviations.

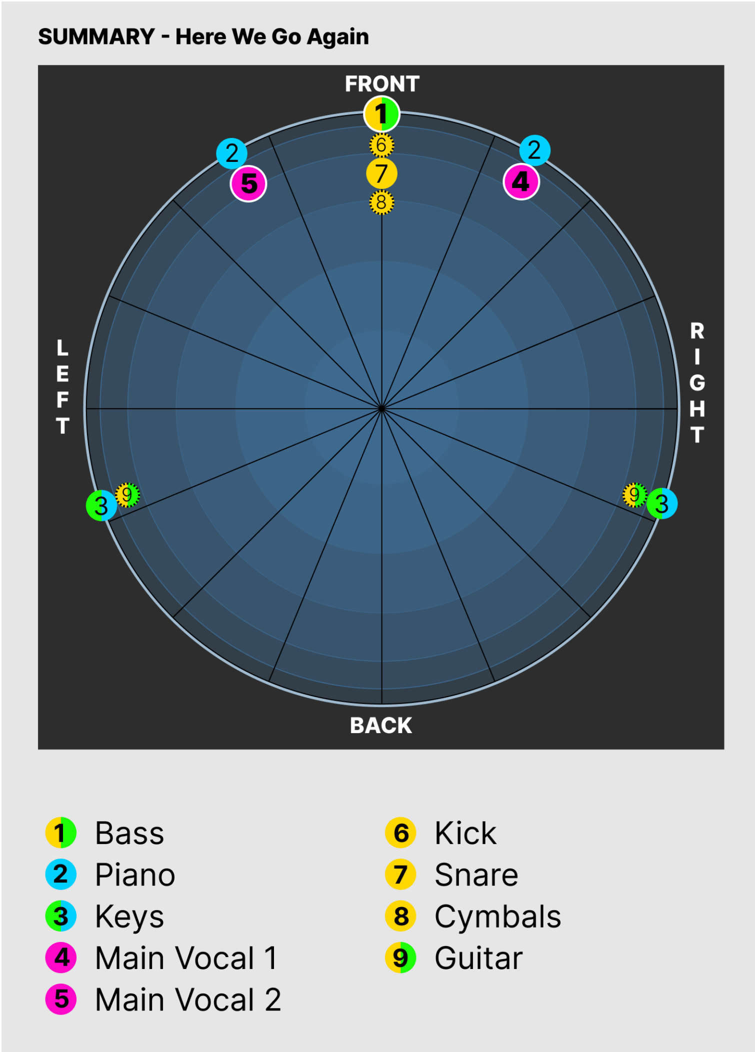

Figure 4.6: Summary diagram for the analysis of the song “Here We Go Again”.

The majority of instruments (66%) showed a medium dynamic level. More instruments fell into the harmonic group and had the lowest dynamic level. Aside from the main vocal instruments, melodic instruments showed the highest dynamic level. A great degree of homogeneity was present in the rhythmic instruments, with a mean value that was precisely 2 (mid-level dynamic value). Above all other areas, the dynamic range of lead voices is clearly emphasized. Finally, the perceived mean dynamic level of the background singers was 2 ± 0, indicating consistency throughout the songs under analysis.

4.1.3 Trajectory

Due to their dearth, trajectory data produced the least in the entire analysis. Nonetheless “What God Wants, Pt. I” (Figure 4.8), “Eye in the Sky” (Figure 4.4), and “Layla” (Figure 4.3) all had identifiable trajectories.

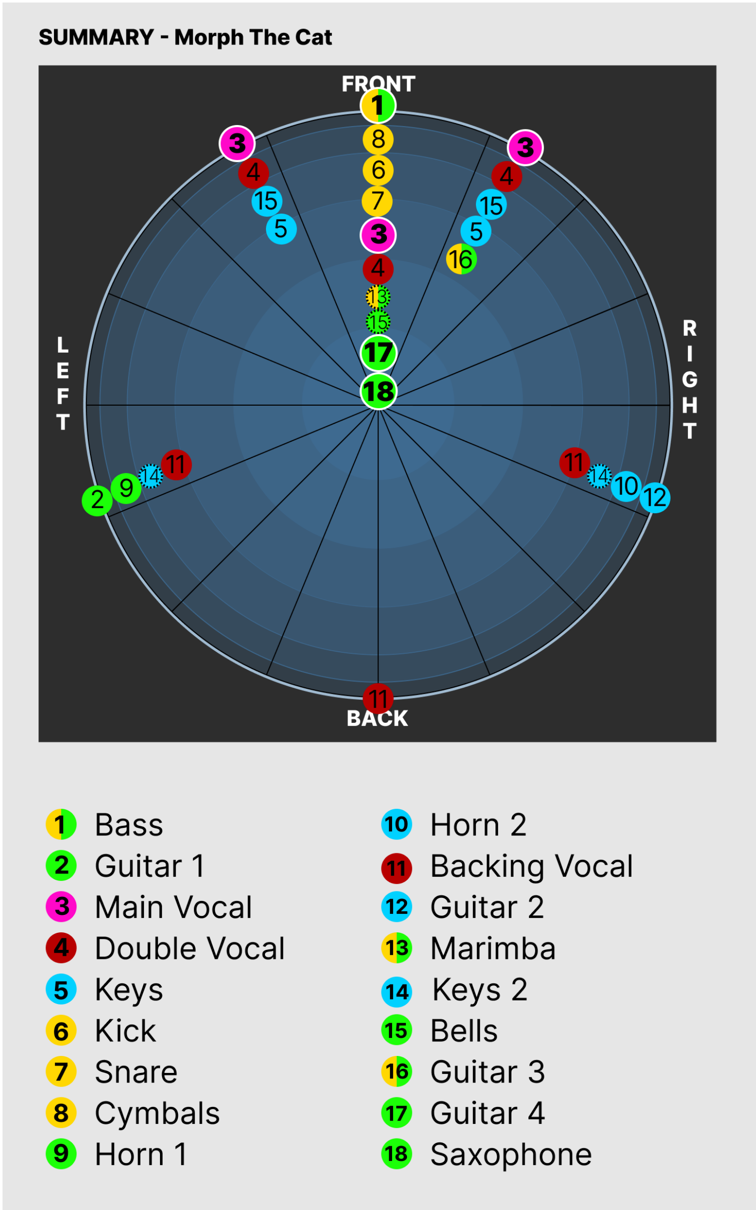

Figure 4.7: Summary diagram for the analysis of the song “Morph the Cat”.

Throughout the whole song “Eye in the Sky”, just one instantaneous trajectory could be seen. A guitar that was first heard at -110° and 110° immediately moved to the front counterparts at -30° and 30°, where it stayed for the duration of the song.

Two gradual trajectories for the song “What God Wants, Pt. I” were noticed. Both were used on sound effects as opposed to musical instruments. It happened during the song’s entrance part, following a trajectory that passed across the front of the audio space between -110° and 110° and was accompanied by sound effects that furthered the narrative of the song. The second trajectory was heard in the song’s final sections, where a sound effect added to the lead vocal caused it to travel in a 360° circle around the listener.

A repeated gradual trajectory in the percussion of the song “Layla” was also noticed. The drum

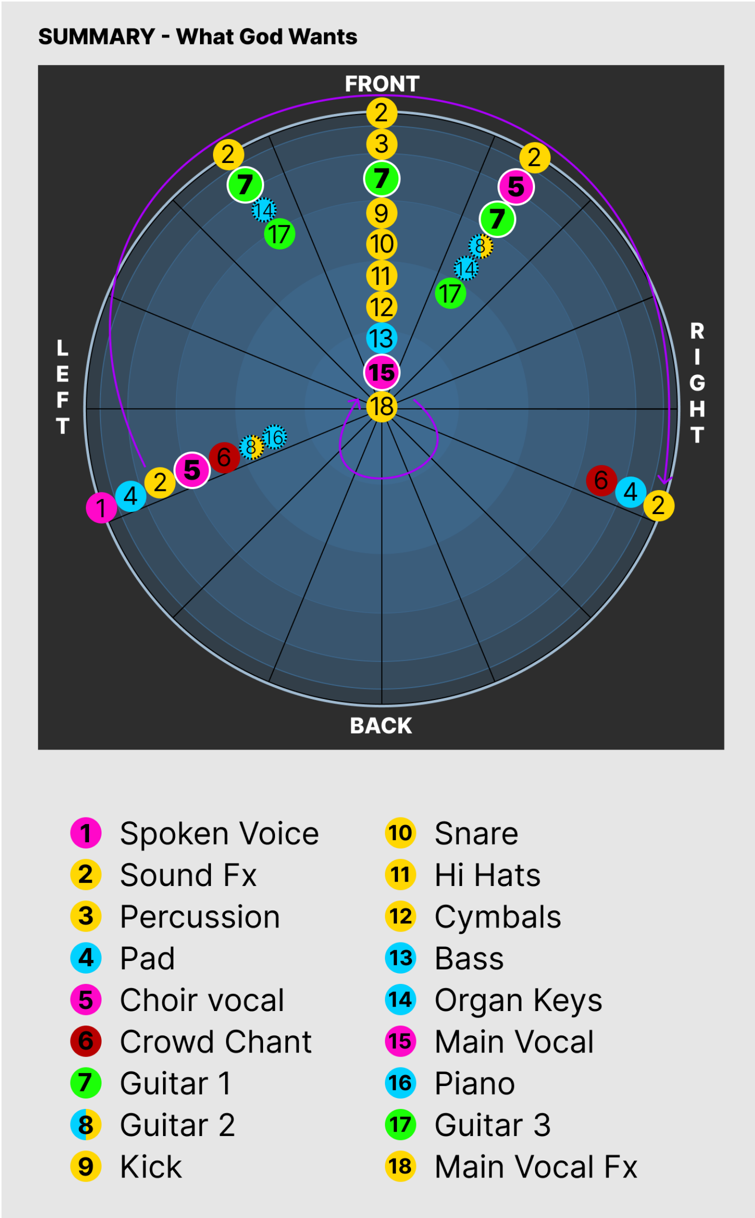

Figure 4.8: Summary diagram for the analysis of the song "What God Wants, Pt. I".

kit's toms were subjected to a slow movement in this trajectory that began at 30° and gradually decreased to -30° degrees during the course of the song.

4.2 Stereo Study

This section tackles the results related to the three variables analyzed for the Stereo analysis. Each variable will be addressed in a subsection, Position in 4.2.1, Dynamics in 4.2.2, and Trajectory in 4.2.3.

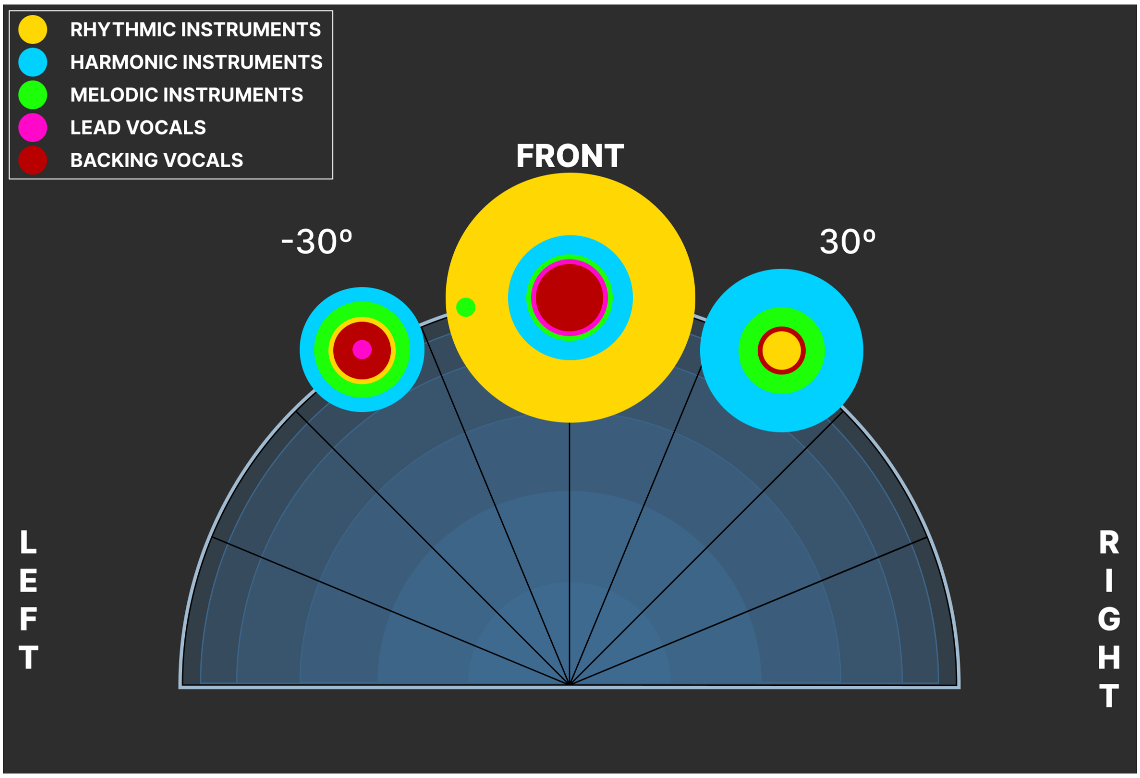

Figure 4.9: A diagram showing the incidence of each category of instrument (rhythmic, harmonic, melodic, lead, and backing vocals) in the **stereo** study. The diameter of the circle represents the occurrence of a certain category in a specific position. The presence of colored half circles indicates that instruments appearing at that angle occur equally frequently in the second category (color) as the specified category.

4.2.1 Position

With the overview provided by Table 4.1 and Figure 4.9 conclusions for the variant of the study relating to the stereo versions, and comparisons with the surround analysis can be drawn.

In the *harmonic category* of instruments, when excluding the bass which consistently occupies the 0° position, a significant proportion of audio sources (79%) are positioned at either -30° or 30°. In surround sound mixes, this pattern has not changed. For instance, in the stereo study, guitars are only placed at 0° in two songs, accounting for 18% of guitars in the harmonic instrument category. It is worth noting that, similar to the surround versions, almost every instrument that has one audio source at -30° or 30° also has another instrument or audio source of the same instrument placed at the opposite angle. In other words, an instrument positioned at 30° has a counterpart at -30°, and vice versa[2]. This symmetrical placement occurs 80% of the time, serving as a strong indicator for the maintenance of audio source symmetry. Additionally, the mean value for the harmonic instrument category is approximately 3°.

[2]This situation also illustrates the aforementioned observation that considering more than one audio source does not necessarily mean that the number of instruments is the same as audio sources.

Melodic instruments are mostly found in the three most often utilized positions: -30°, 30°, and 0°. Of note are two songs, “Layla” (Figure Figure 4.10) and “What God Wants, Pt. I” (Figure 4.11) that unusually position two lead instruments at about -15°. Additionally, the melodic instrument category’s mean value is around -4°, offering more support for the idea of symmetry-based sound reproduction field balance.

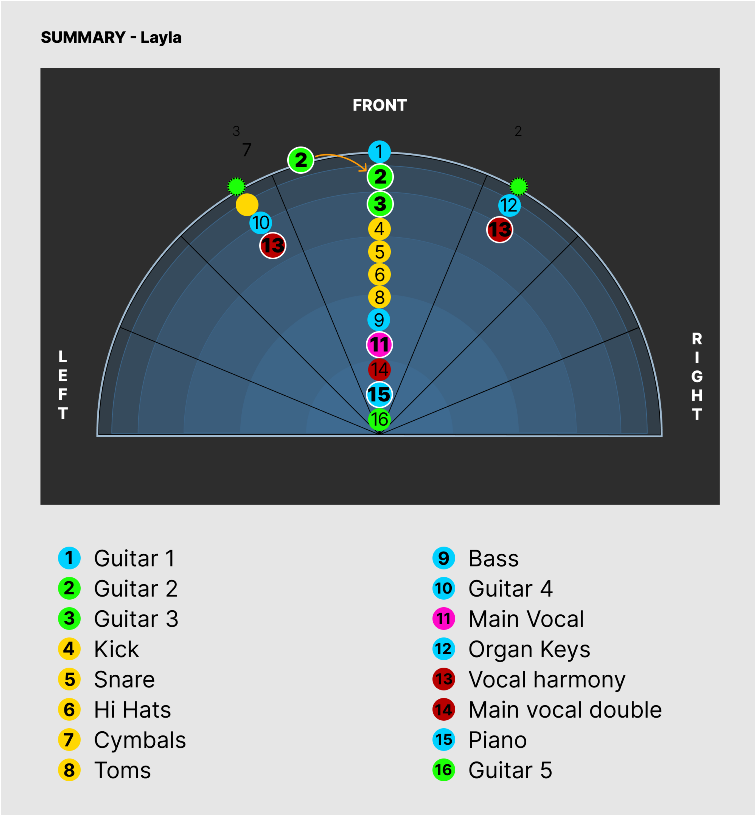

Figure 4.10: Summary diagram for the analysis of the song “Layla”

The “groove anchors”– *rhythmic instruments* – are usually placed in the exact middle. 91% of the time, the bass, kick, and snare are at 0°. By placing the drum set at -30°, the song “Hey Jude” (Figure 4.12) stands out as a distinct exception. A similar location was also seen in the surround version[3]. The placement of cymbals and other percussion instruments varies slightly, with the exception of the drums, which are more uniformly distributed among the three most common angles, -30°, 30°, and 0°.

Both studies treat *lead vocals* in a similar fashion with a mean angle of -6° for stereo versions. The song “What God Wants, Pt. I” (Figure 4.11) is an exception, as the beginning, which includes spoken word and a lead vocal, is positioned at -30°. In the subsequent songs, the lead vocal is

[3]The location of the drum set at -30° in the stereo version of “Hey Jude” can be ascribed to the constraints of recording technology at the time [Everest and Ron, 1998] since mono mixes were common and the number of tracks available for recording was constrained. Later, experimental approaches were employed, and the decision was made to pan the drums to the left. This same positioning was kept in later remixes of the song, and it was carried over to the surround sound mix in the version included in the Grammy-winning compilation album “Love” (which was utilized in this study).

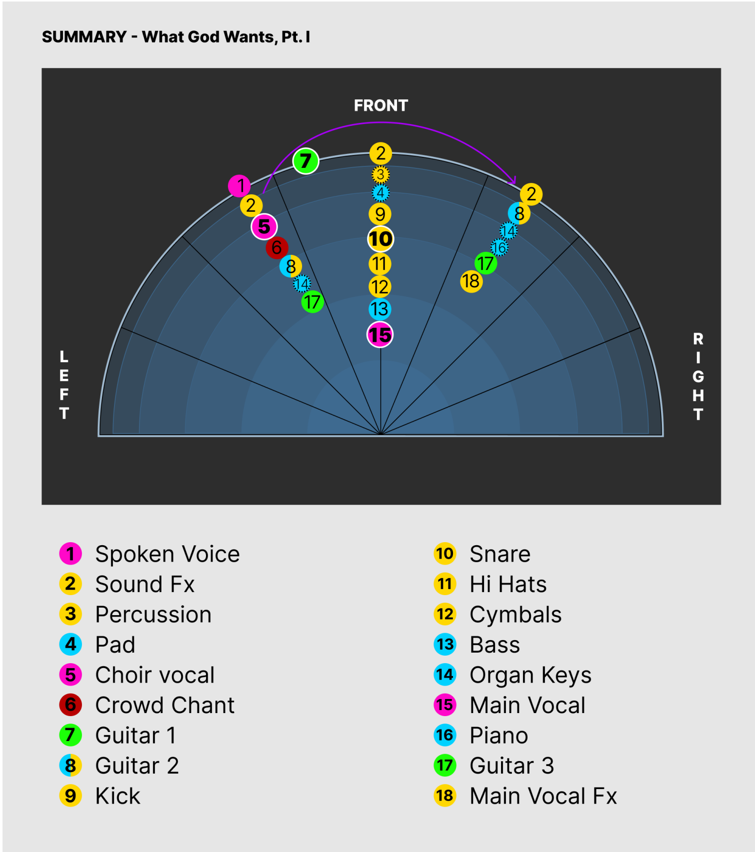

Figure 4.11: Summary diagram for the analysis of the song "What God Wants, Pt. I"

positioned at 0°. Even "Here We Go Again" (Figure 4.13), the outlier for the surround sound study, places its two primary singers in the middle.

Backing vocals follow a symmetrical arrangement similar to the surround versions, with 94% of the audio sources either situated at 0° or having symmetric audio sources at -30° and 30°. With "What God Wants, Pt. I" (Figure 4.11) being the sole exception, the background voice is positioned at -30°.

The illustrations show how songs achieve full audio source symmetry, partial symmetry, or an asymmetrical approach from a visual perspective. It becomes clear that the songs either adhere to this notion in its entirety or only slightly stray from it. "Eye in the Sky" (Figure 4.14) serves as an illustration of full symmetry. The songs "Walk of Life" (Figure 4.15) and "Here We Go Again" (Figure 4.13), which together with "Eye in the Sky", make up approximately 43% of the examined songs, also exhibit this symmetrical arrangement. One exception to this pattern is the song "Layla" (Figure 4.10), where 95% of the audio sources work together to create a symmetrical balance, just shy of 100%. Similar to "Layla," are "Morph the Cat" (Figure 4.16), and "What God Wants" (Figure 4.11). Only "Hey Jude" (Figure 4.12), takes a novel method by panning the drum set to -30°, which deviates significantly from symmetry. These discoveries draw attention to the common practice of aiming for symmetry in post-production audio mixing, much to the methods used in surround sound versions.

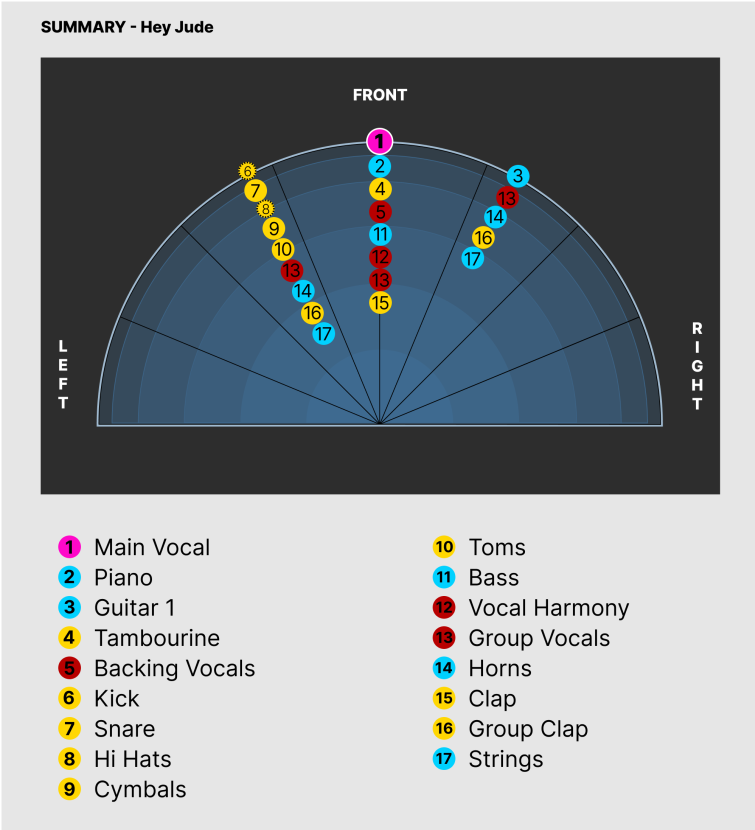

Figure 4.12: Summary diagram for the analysis of the song "Hey Jude".

4.2.2 Dynamics

Dynamics for surround and stereo versions have comparable descriptive statistics, as seen in Table 4.2. Mean dynamic levels are either same or varied somewhat. There are two songs where one instrument that was audible during the surround sound study was not audible in the stereo version, despite the minor statistical changes not being particularly noticeable. This is the case for "Morph the Cat" (Figure 4.16) where a keyboard instrument offered a value of one for dynamics in the immersive version and a backup vocal in the song "Walk of Life" (Figure 4.15), respectively. Since these instruments in the stereo versions with less gain in the mix are discovered to be eclipsed by the overlapping audio sources coming from the same place, this suggests that masking is more common with lower dynamic levels.

4.2.3 Trajectory

Trajectories were hardly ever employed in stereo versions, with just two occurrences perceptible, similar to the surround sound audio mixes. One is for a sound effect in the song "What God Wants, Pt. I" (Figure 4.11) that works on the same principles as the surround sound version, and the other is for the song "Layla" (Figure 4.10) that uses the lead guitar's immediate trajectory from -15° to 0° between song parts.

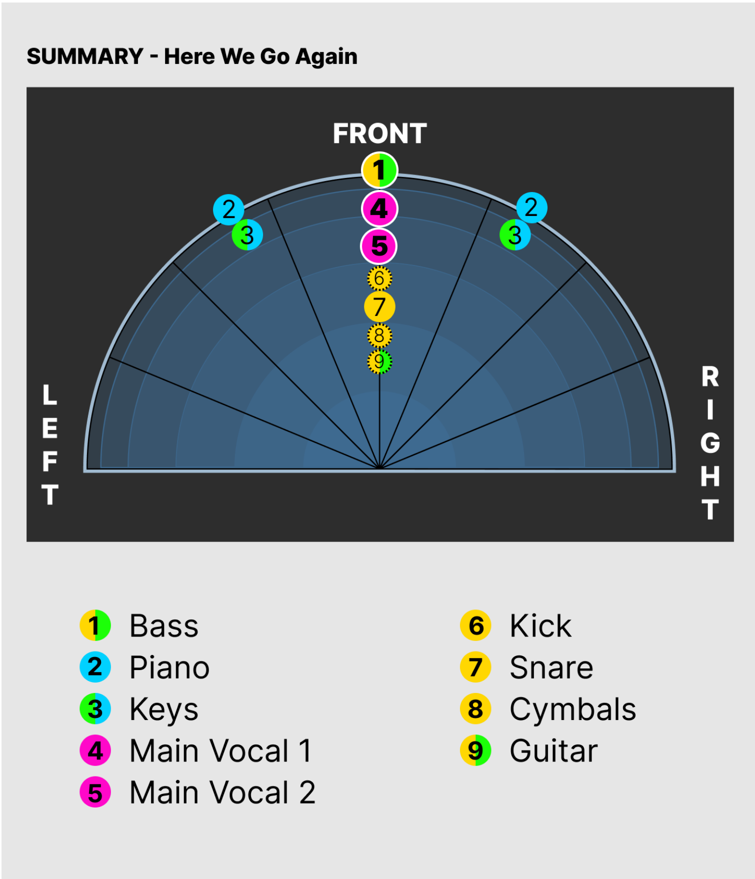

Figure 4.13: Summary diagram for the analysis of the song “Here We Go Again”.

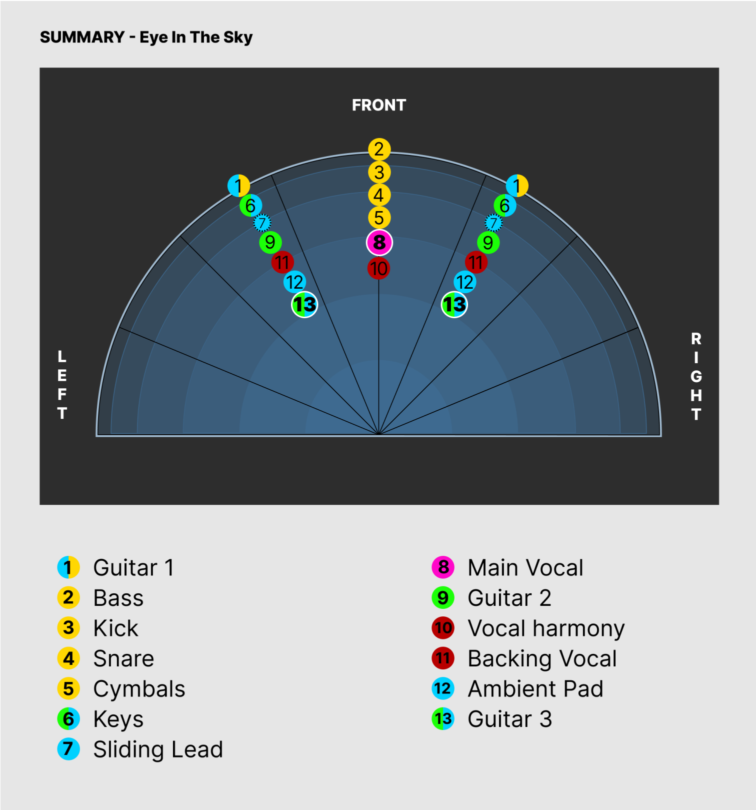

Figure 4.14: Summary diagram for the analysis of the song “Eye In The Sky”.

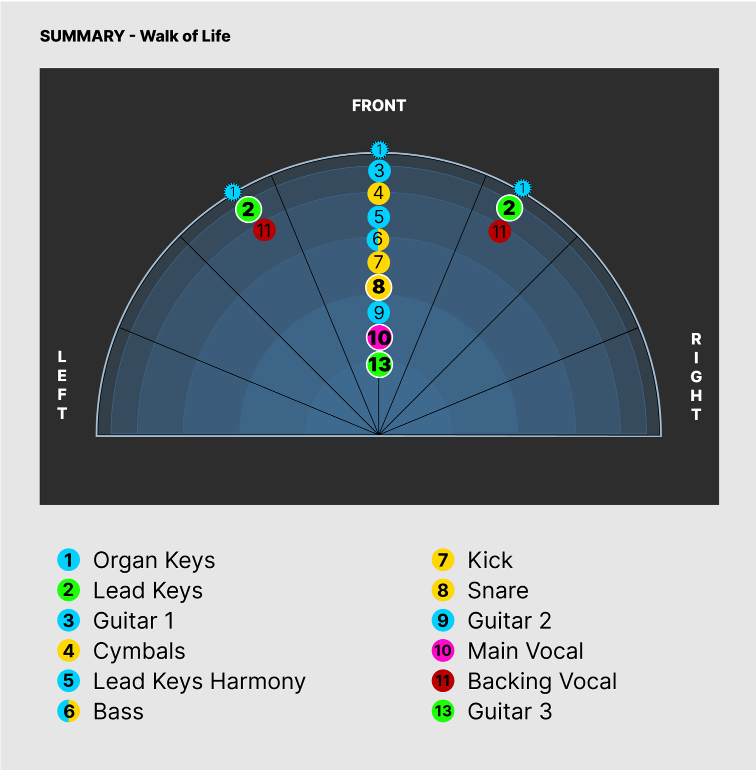

Figure 4.15: Summary diagram for the analysis of the song “Walk of Life”.

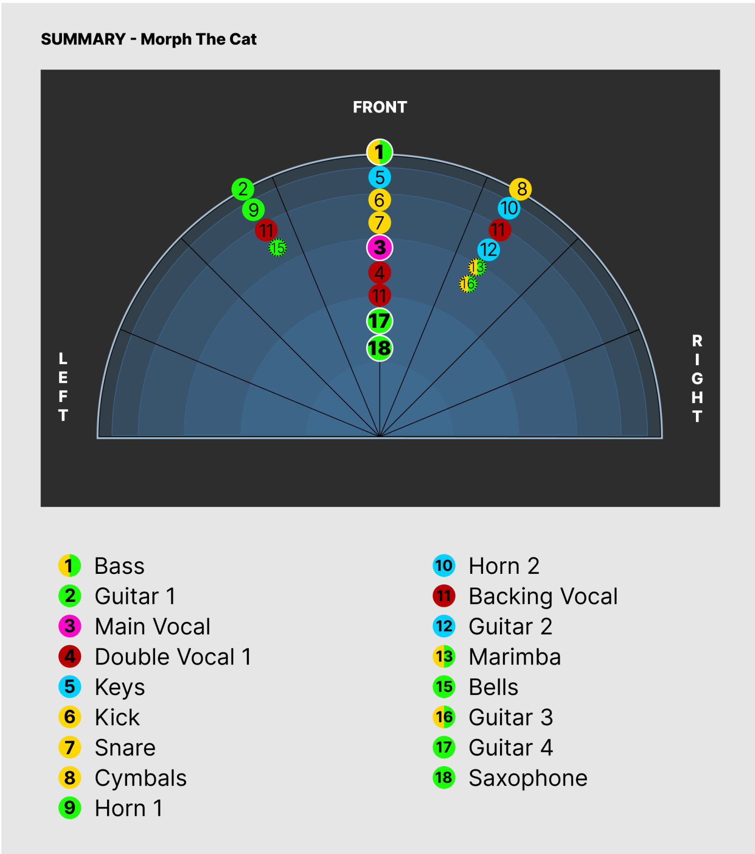

Figure 4.16: Summary diagram for the analysis of the song “Morph The Cat”.

Chapter 5

Discussion of Results

5.1 Reviewed practices for surround instrument position

In this section, six recommendations are presented, derived from the extensive analysis of songs featured in the Immersive Awards, which were produced by highly skilled engineers with extensive know-how in immersive audio. These recommendations are influenced by the observed characteristics and trends identified during the analysis process. It is important to note that these recommendations serve as valuable insights and guidelines, rather than strict formulas to be followed by those seeking to produce music in a surround sound format. By exploring the positioning and handling of each instrument category, the first five recommendations provide specific guidance for achieving optimal results. Additionally, a general principle of symmetry emerged from the analysis, which is discussed as the final recommendation. These recommendations aim to inform and inspire creative decisions in immersive audio mixing while recognizing the importance of individual artistic expression and experimentation within the surround sound context.

5.1.1 *1) Harmonic instruments placed in wide positions avoiding the 0° position to create a harmonic background*

A close examination of ***harmonic instruments category*** within songs in surround mixes demonstrates a significant match with observed stereo approaches. As a complimentary expansion of these stereo approaches, surround mixes include extra locations at -110° and 110°. The expansive instrument placement and purposeful avoidance of the 0° position point to a conscious strategy for constructing a harmonically rich backdrop with layered instrumentation that should improve the overall enveloping sound in both stereo and surround versions. This goal is achieved via the surround sound format, which surrounds the listener with harmonic information.

Illustrated in Figure 5.1

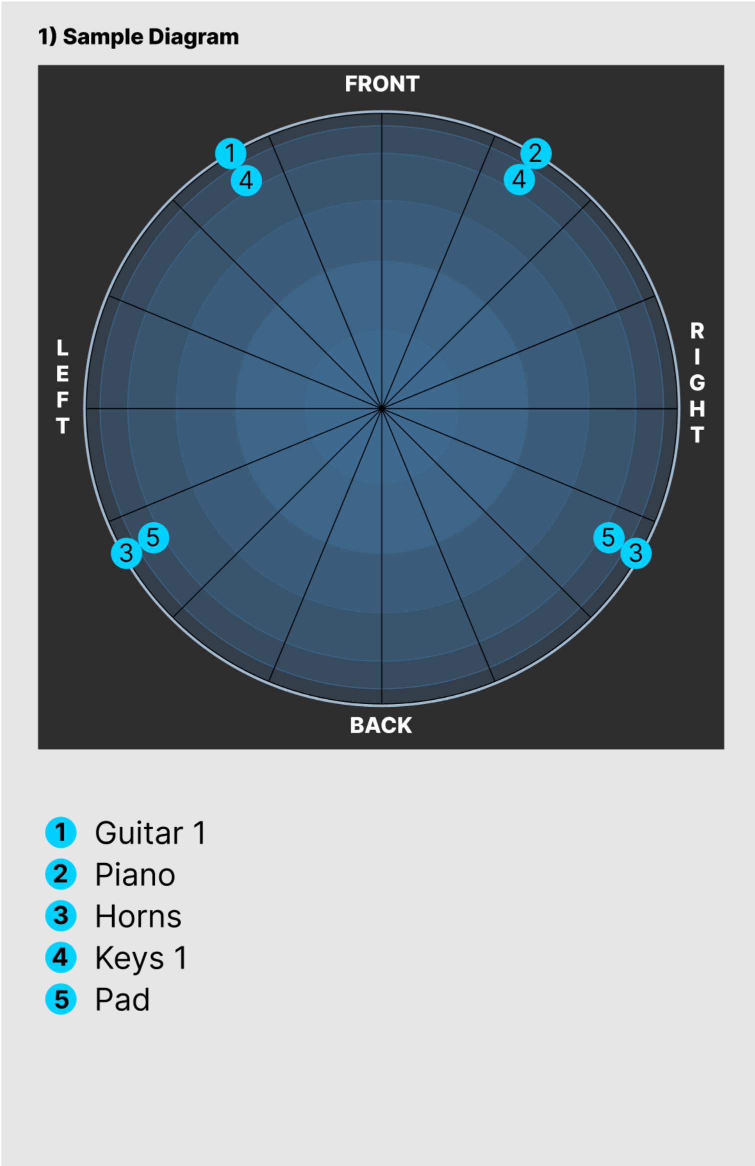

Figure 5.1: Sample diagram illustrating the trend registered in subsection 5.1.1

5.1.2 *2) Melodic instruments with lead roles placed at the "main stage" of the sound reproduction field (between -30° and 30°)*

The findings for the ***melodic instruments category*** reveal a preference for placing lead melody instruments at -30°, 0°, and 30° in the surround mixes. Stereo versions of these findings cannot be meaningfully compared because they only have front channels as an option. It presupposes that the listener's attention will be focused on the front of the surround sound reproduction area, which is nevertheless closely related to and even a derivation of stereo thinking. The importance of the front stage is emphasized, and the principal melodic instruments are brought into sharper focus by using these angles in surround sound.

Illustrated in Figure 5.2

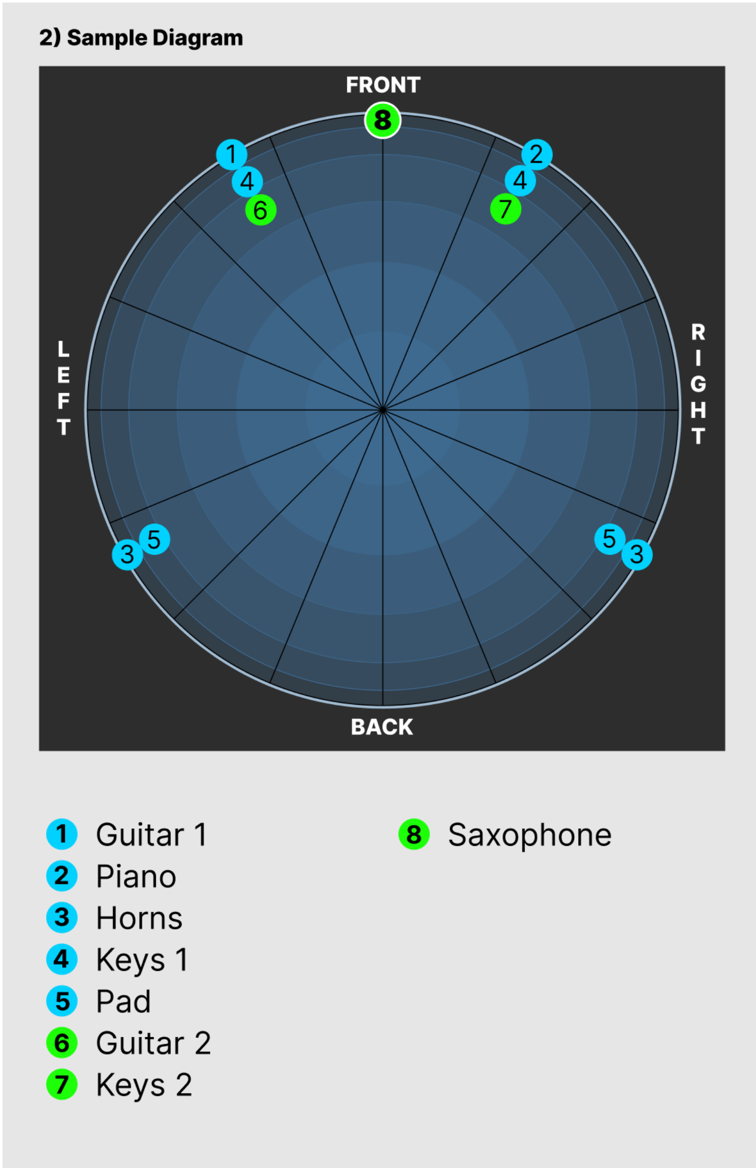

Figure 5.2: Sample diagram illustrating the trend registered in subsection 5.1.2

5.1.3 *3) Rhythmic instruments and bass, "groove anchors", placed in a fixed position at the center of the sound reproduction field (0°)*

An anticipated pattern for constructing the song's groove is produced by positioning the ***rhythmic instruments*** at a constant center point (at 0°). The goal of this position is to ground the listener and enable a more effective awareness of other parts within the song, resulting in a concentrated listening experience. This technique enables producers to experiment with various aspects without degrading the listener's overall experience in the context of popular music [Izhaki, 2018, Keller, 2021].

Illustrated in Figure 5.3

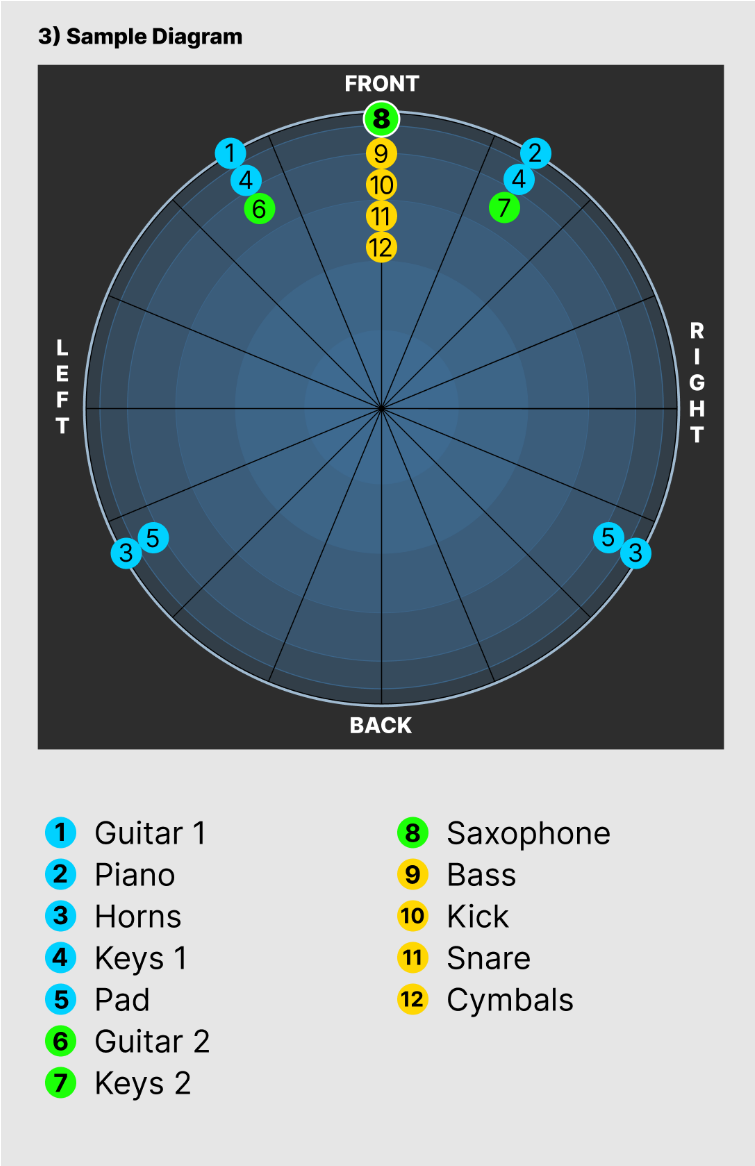

Figure 5.3: Sample diagram illustrating the trend registered in subsection 5.1.3

5.1.4 *4) To underline their significance, position Lead Vocals in the foreground of the sound reproduction field, ideally at 0°and with strong dynamics.*

The ***lead vocal***, which serves as the main instrument in the song, is consistently positioned at 0°. This location may be heard in both stereo and surround mixes, with the three frontal angles (-30°, 0°, and 30°) acting as a cohesive space in tracks like "Morph the Cat" (Figure 4.7). In these situations, the vocals are dispersed from different directions, resulting in a sensation of immersion with audio sources heard from various perspectives. While still retaining the listener's focus on the vocals, this is a distinctive method for immersive audio mixing.

Illustrated in Figure 5.4

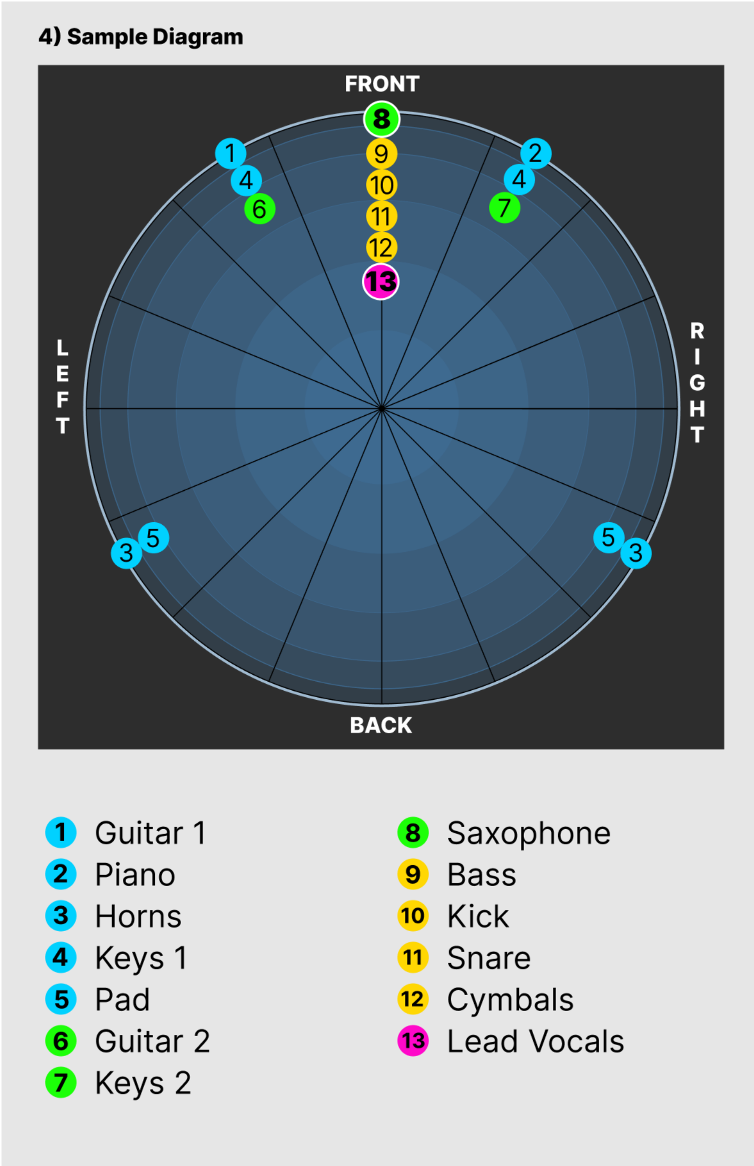

Figure 5.4: Sample diagram illustrating the trend registered in subsection 5.1.4

5.1.5 *5) Using symmetric Backing Vocals audio sources to create an enveloping harmony.*

As it crosses all instrument categories, a noticeable trend in the ***backing vocals category*** offers insightful data that will be further studied in guideline 6). This category specifically serves as an illustration of the audio source symmetry theory. A surprising amount of symmetry is maintained while utilizing many audio sources to produce a lush and encompassing voice layer with backing vocals. Its importance and prevalence across many audio mixing techniques are highlighted by the symmetrical arrangement that holds for surround and stereo song analysis.

Illustrated in Figure 5.5

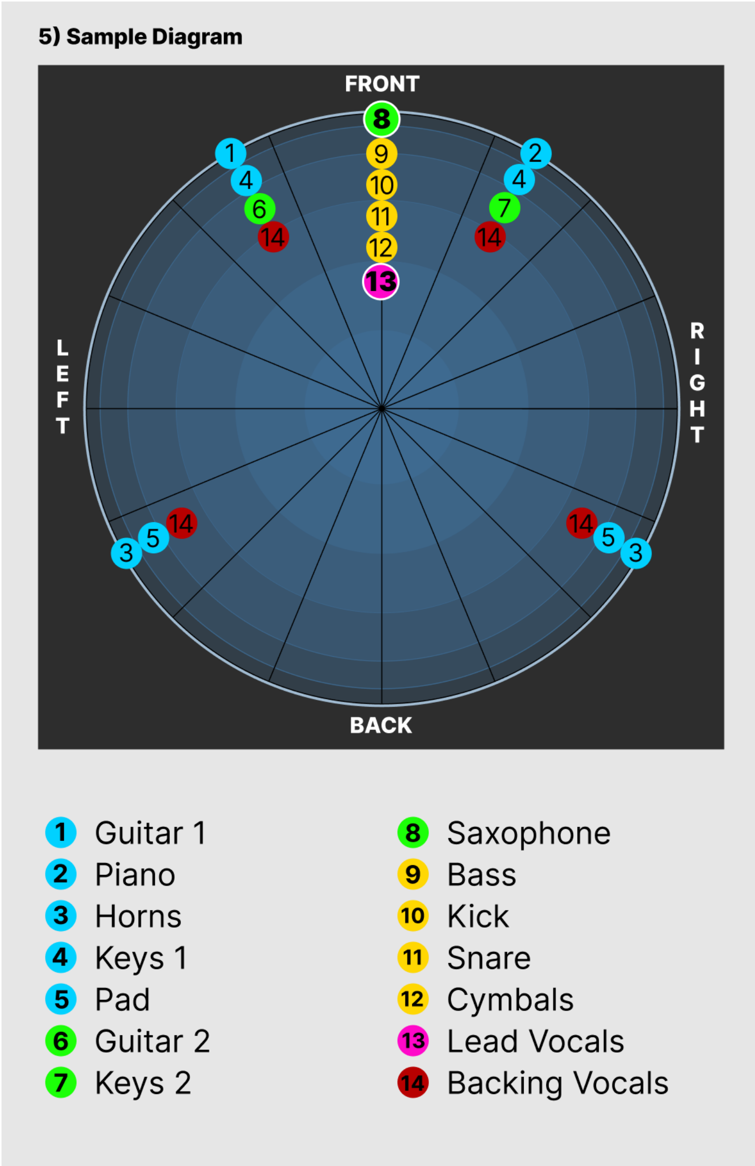

Figure 5.5: Sample diagram illustrating the trend registered in subsection 5.1.5

5.1.6 *6) Create a balanced mix through the symmetry of audio sources, placing the instruments evenly across the sound field.*

The symmetry between audio sources emerges as a consistent and prominent trend across the analyzed songs, showcasing a deliberate approach to spatial placement. This symmetrical arrangement is particularly noticeable within specific instrument categories, such as harmonic instruments and backing vocals, where a balanced distribution of sound sources is often employed. Additionally, this symmetry extends beyond instrument categories, with similar patterns observed between different instruments across various categories. Even in instances where songs deviate from the symmetrical norm, the departures are relatively subtle, indicating a preference for maintaining overall equilibrium and spatial coherence in the mix. This adherence to symmetry reflects a deliberate artistic choice and suggests a conscious effort to create a sense of harmony and balance within the immersive audio experience.

Chapter 6

Conclusions and Future Work

This chapter presents the conclusions and future work resulting from the research on audio source positioning in popular music, encompassing stereo and immersive audio mixes. By analyzing trends in Grammy winners for Best Immersive Audio Album, this study aimed to provide insights into current audio mixing practices. The findings offer valuable implications for the industry and lay the groundwork for future advancements in immersive audio mixing strategies.

6.1 Conclusions

The predominance of a channel-based thinking[1] is demonstrated by the examination of instrument position and traits inside immersive mixes, specifically surround 5.1 mixes on a set of seven Grammy Award-winning tracks, i.e. in popular music practices. The bulk of audio sources are placed at the typical speaker positions in a 5.1 channel-based systems, which are at angles of -110°, -30°, 0°, 30°, and 110°. It is interesting to note that the audio source placements between the surround sound and stereo analysis vary. While the stereo versions occasionally include instruments at -15°, the surround sound versions do not use this technique. Expanding the use of atypical placements throughout the spatial reproduction field may present exciting opportunities and depart from the study's channel-based reasoning.

A squandered opportunity to develop more immersive and experimental experiences is the restricted use of the remaining sound reproduction field. Notable issues include the infrequent use of moving audio sources and the disregard for trajectories. It seems sensible that popular music tries to steer clear of dangers that may jeopardize the composition given its widespread appeal. In the case of immersive audio, some of these issues can be alleviated, allowing for more inventive methods of creating engrossing listening experiences.

[1] refers to a way of thinking or doing audio production that focuses largely on the separate audio tracks or channels within a multichannel system, such as stereo or surround sound.

In stereo audio mixing, the symmetry of the audio sources is frequently used to produce a balanced mix and a harmonious stereo picture. The listening experience can be hampered by imbalances when one side conveys more information than the other, producing a left or right channel that is disproportionately louder [Izhaki, 2018]. According to the study's findings, this strategy translates into immersive audio mixing. When you consider the purpose of these surround sound mixes for well-known songs, it seems understandable that symmetry is stressed.

However, there can be circumstances in which an asymmetrical approach might be valuable, especially if the producer is attempting to replicate a real-life experience. It makes sense to favour symmetry in immersive forms like the one this study looked at in order to strike a balance between retaining the composition and generating a novel and immersive listening experience. This study found no evidence of the use of dynamics to achieve auditory balance between instruments through loudness equilibrium, or, to put it another way, placing an audio source with higher gain in opposition to two instruments with lower dynamic levels in the symmetric position, i.e., -30°and 30°, which was the expectation going into the study.

The benefit of using surround sound instead of stereo for improved awareness of distinct audio sources is another interesting discovery. A more effective separation of instruments may be achieved by adding two more positions for audio sources. The current study shows that, in comparison to their stereo counterparts, the surround sound versions make it easier to perceive specific audio sources. When instruments can be perceived from more than just three angles (i.e. from more positions than stereo allows), the problem of masking, when the presence of one instrument interferes with the perception of another, is lessened. Notably, in the immersive audio mix of two tracks, an instrument that was undetectable in the stereo version became audible. This noteworthy remark relates to the songs "Walk of Life"[Knopfler, 2005] and "Morph the Cat"[Fagen, 2006]. With positions other than those notably used for the songs in this study's channel-based approach, this improved perception may be even more effective, meaning that by positioning audio sources from a greater variety of angles, more auditory separation can be achieved and thus better instrument perception in the mix.

The development of the radial notation diagram for data collection and visualization in this study has proven to be a valuable and serendipitous contribution to the field of spatial audio analysis. While not originally a planned objective, its emergence during the research process has provided a powerful tool for representing and understanding the spatial positioning of audio sources. The radial notation diagram offers a clear and intuitive visual representation of instrument positions, trajectories, and dynamics within the immersive audio mix. Its simplicity and effectiveness make it accessible to researchers, engineers, and musicians working in the field of spatial audio. Moreover, this diagram holds the potential for further refinement and improvement by future researchers, allowing for continued advancements in the analysis and interpretation of spatial audio data. The unexpected inclusion of the radial notation diagram in this study exemplifies the importance of remaining open to new ideas and exploring unanticipated avenues, as it can lead to significant contributions that enhance the overall understanding and practice of immersive audio mixing.

It is important to acknowledge that the findings and observations presented in this study cannot be regarded as definitive norms or absolute guidelines for spatial audio mixing in popular music. The analysis conducted provides a valuable starting point and a snapshot of the prevalent trends and patterns observed within the selected songs. However, the field of immersive audio is dynamic and ever-evolving, with new technologies, artistic approaches, and creative possibilities continuously emerging. Therefore, it is crucial to view these findings as a foundation for further exploration and experimentation rather than definitive rules. Future studies should continue to push the boundaries, expand the scope of analysis, and explore alternative techniques to deepen our understanding of spatial audio mixing in popular music. Embracing a spirit of ongoing experimentation and open-mindedness is essential to foster innovation and drive the evolution of immersive audio practices in the ever-changing landscape of music production.

6.2 Limitations and Observations

During the listening analysis conducted in this study, it is important to acknowledge the potential for perceptual errors arising from the nature of the research and the human component involved. One such potential error is the presence of a visual bias resulting from the arrangement of speakers in the spherical array when determining instrument positions. While efforts were made to minimize this bias through careful listening and annotation, the visual cues provided by the speaker arrangement may have influenced the perception of instrument placement to some extent.

The examination of the song "Layla" revealed another flaw in the research since it was clearly divided into two sections, each with distinctly different instrument dynamics. The song contains contrasting passages that are dynamically quite different from one another. The suggested technique fails to fully capture all the intricacies of the data for this song when looking at the data as a whole, integrating both portions and summarizing them as a whole. While automating procedures and distilling the complexity of musical structure into quantitative indicators can be useful approaches for large-scale analysis, taking into account finer perceptual complexities in the study of audio mixing is essential.

In conclusion, the methods and strategies used in immersive audio for popular music continue to be largely based on stereo traditions. This claim is supported by the examination of the songs included in the research since they were already quite well-known when their immersive audio mixes were first imagined. Even in the context of this innovative format and listening experience, it is conceivable that the producers were wary of taking chances that would potentially compromise the songs' integrity. In order to preserve the songs' essential qualities and reduce any disturbances when switching to an immersive audio environment, standard methods have been followed.

Despite being commonly used in immersive audio, surround sound has several limitations when compared to other technologies in terms of fully exploring spatial dimensions. Because it cannot accurately replicate the height axis, it relies on horizontal placement. Since the vertical dimension is essential for generating a genuine feeling of space, this restriction limits the immersive experience. While giving a larger soundstage than stereo, surround sound falls short of creating a genuinely immersive three-dimensional audio experience. It may be thought of as a compromise between stereo and immersive audio.

In addition to offering complete solutions for collecting and reproducing complex sound positions in three-dimensional space, the rise of object-based audio and sophisticated spatial formats also calls for a broader viewpoint on musical post-production. Expanding our ideas of audio creation and taking inspiration from many areas of the audio domain is necessary in order to fully realize the immersiveness' potential. We can push the limits of immersion and open up new creative doors in music production by embracing these possibilities from the beginning of the process. This study can be seen as a step in the right direction because it encourages the exploration and integration of cutting-edge methods and technologies, ensuring that immersive audio experiences are woven into the very fabric of musical composition and production from the very beginning.

6.3 Future Work

It is crucial to emphasize critical thinking and evaluation of spatial audio practices. As technologies evolve, the industry must remain vigilant in assessing various spatial audio techniques, artistic merits and potential drawbacks. This critical approach will ensure that spatial audio is employed thoughtfully and purposefully rather than being seen as a mere novelty or gimmick.

The music industry must foster a community-driven effort that encourages experimentation, research, and sharing of best practices in spatial audio mixing. Collaboration between audio engineers, producers, and artists can facilitate the development of standardized techniques and workflows tailored to surround sound in popular music.

In conclusion, while spatial audio has gained significant traction in music production, particularly within immersive audio technologies, the lack of well-defined procedures and guidelines for spatial audio mixing in popular music remains a notable challenge. And to tackle this scarcity of available knowledge, an empirical study was conducted in this dissertation. Award-winning songs in the Grammy category of Best Immersive Album from 2005 to the present were analyzed, examining the position, trajectory, and dynamics of instruments. With expectations, that were met, of finding recognizable trends and patterns across mixing approaches.

References

[AES, nd] AES (n.d.). An audio timeline. *Audio Engineering Society*. Cited on page 1.

[AMBEO, nd] AMBEO (n.d.). Ambeo immersive audio by sennheiser: End-to-end immersive experience. accessed 12/02/2023. Cited on page 13.

[AURO, nd] AURO (n.d.). Auro-3d. accessed 12/02/2023. Cited on page 13.

[Barboza et al., 2021] Barboza, J. R., Magalhaes, E., and Bernardes, G. (2021). Towards best practices in spatial audio post production: A case study of brazilian popular music. *2021 Immersive and 3D Audio: From Architecture to Automotive, I3DA 2021*. Cited on page 1.

[Belakhindi, 2017] Belakhindi, M. (2017). Introduction to ambisonics — 360 degree audio. Cited on pages xi and 14.

[Bertet et al., 2007] Bertet, S., Daniel, J., Parizet, E., Gros, L., and Warusfel, O. (2007). Investigation of the perceived spatial resolution of higher order ambisonics sound fields: A subjective evaluation involving virtual and real 3d microphones. *Audio Engineering Society*. Cited on page 21.

[Bertet et al., 2013] Bertet, S., Daniel, J., Parizet, E., Warusfel, O., and Warusfel, O. (2013). Investigation on localisation accuracy for first and higher order ambisonics reproduced sound sources. *Audio Engineering Society*. Cited on page 21.

[Bresler, 2021] Bresler, Z. (2021). Immersed in pop. *Journal of Popular Music Studies*, 33:84–103. Cited on page 12.

[Charles and Jones, 2004] Charles, R. and Jones, N. (2004). Here we go again. Cited on page 19.

[Clapton and Gordon, 2011] Clapton, E. and Gordon, J. (2011). Layla. Cited on page 19.

[Cohrs et al., 2022] Cohrs, J., Wood, C., Conquest, J., and Köerner, W. (2022). Key concepts in spatial audio. *New York Times*. Cited on page 1.

[DOLBY, nd] DOLBY (n.d.). Dolby atmos - official site - dolby. accessed 12/02/2023. Cited on page 13.

[DTS, nd] DTS (n.d.). Surround sound experience for your home | dts:x. accessed 12/02/2023. Cited on page 13.

[Everest and Ron, 1998] Everest, F. A. and Ron, S. (1998). *The New Stereo Soundbook*. Audio Engineering Associates, 2nd edition. Cited on page 38.

[Fagen, 2006] Fagen, D. (2006). Morph the cat. Cited on pages 19 and 54.

[Fonseca, 2020] Fonseca, N. (2020). *All You Need to Know About 3D Audio*. Sound Particles, 1st edition. Cited on pages xi, 1, 12, 13, 14, and 15.

[Hamandi, 2022] Hamandi, S. (2022). Apple music and mercedes-benz bring premium immersive spatial audio to drivers worldwide. *Apple Newsroom*. Cited on page 1.

[IEM, nd] IEM (n.d.). Iem plug-in suite. Cited on page 20.

[Izhaki, 2018] Izhaki, R. (2018). *Mixing Audio*. Routledge, 3rd edition. Cited on pages xi, 1, 5, 6, 7, 8, 9, 11, 47, and 54.

[Jones et al., 2001] Jones, E., Oliphant, T., and Peterson, P. (2001). {SciPy}: Open source scientific tools for {Python}. Cited on page 23.

[Keller, 2021] Keller, D. (2021). Mixing in stereo: Adding width and depth to your recordings | universal audio. Cited on pages xi, 10, and 47.

[Kern and Ellermeier, 2020] Kern, A. C. and Ellermeier, W. (2020). Audio in vr: Effects of a soundscape and movement-triggered step sounds on presence. *Frontiers in Robotics and AI*, 7. Cited on page 12.

[Knopfler, 2005] Knopfler, M. (2005). Walk of life. Cited on pages 19 and 54.

[Lowe, 2021] Lowe, Z. (2021). Apple music's zane lowe explains how spatial audio will transform music. *Apple Newsroom*. Cited on page 1.

[McCartney, 2006] McCartney, P. (2006). Hey jude. Cited on page 19.

[Mendelson, 2020] Mendelson, R. (2020). Mixing music: What is sound mixing? Cited on page 6.

[Owsinski, 2013] Owsinski, B. (2013). *The Mixing Engineer's Handbook*. Cengage Learning PTR, 3rd edition. Cited on pages 1, 2, 5, 6, and 15.

[Parsons, 2017] Parsons, A. (2017). Eye in the sky. Cited on page 19.

[Pestana and Reiss, 2014] Pestana, P. and Reiss, J. D. (2014). Intelligent audio production strategies informed by best practices. *Audio Engineering Society*. Cited on pages 11 and 16.

[Pulkki et al., 2010] Pulkki, V., Laitinen, M.-V., Vilkamo, J., Ahonen, J., Lokki, T., and Pihlajamäki, T. (2010). Directional audio coding - perception-based reproduction of spatial sound. pages 1–4. Cited on pages 2 and 15.

[Roginska and Geluso, 2017] Roginska, A. and Geluso, P. (2017). *Immersive Sound*. Routledge, 1st edition. Cited on pages 1, 2, 12, and 15.

[Rumsey, 2001] Rumsey, F. (2001). *Spatial Audio*. Routledge, 1st edition. Cited on pages 1, 11, and 12.

[Savage, 2014] Savage, S. (2014). *Mixing and Mastering In the Box*. Oxford University Press, 1st edition. Cited on pages 1, 7, 9, and 11.

[SONY, nd] SONY (n.d.). 360 reality audio | tão envolvente. tão real. | sony pt. accessed 12/02/2023. Cited on page 13.

[Stango, 2021] Stango, M. (2021). Building worlds: The immersive sounds of gaming. Cited on page 12.

[Tingen, 2007] Tingen, P. (2007). Secrets of the mix engineers: Tom elmhirst. Cited on page 5.

[Wainwright, 2022] Wainwright, C. (2022). What is panning in music? Cited on page 8.

[Waters, 1992] Waters, R. (1992). What god wants, pt. i. Cited on page 19.

[White, 2000] White, P. (2000). Improving your stereo mixing. Cited on pages 1, 9, and 11.

[WIKI, nd] WIKI (n.d.). Grammy award for best immersive audio album - wikipedia. Cited on pages xvii and 18.

[Zotter and Frank, 2019] Zotter, F. and Frank, M. (2019). *Ambisonics: A Practical 3D Audio Theory for Recording, Studio Production, Sound Reinforcement, and Virtual Reality (Springer Topics in Signal Processing, 19)*. Springer, 1st edition. Cited on page 14.

REFERENCES

Appendix A

Data Analysis Contents - Tables

This appendix contains all the tables created for the data analysis of both the surround sound and stereo studies.

Surround Sound Study Position data Overview Table

	Harmonic							Melodic				Rhythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Eye In The Sky			-30	110			30	110			110	0	0	0		0	0	0
			30	-110			-30	-110			-110							110
			110	110				110										-110
			-110	-110				-110										
Walk of Life		0	30	110				-110			-110	0	0	-30		0	0	-30
			-30	-110							110							30
			0	0														110
																		-110
Hey Jude	30	0	30		110	110						-30	-30	0	-110		0	0
	-30				-110	-110							0	-30	110			0
															-30			30
																		-30
																		-110
																		110
What God Wants	-110	0	30	30			110	30				0	0	0	30		0	-110
			-110	-30			-110	-30							-30		30	110
								0							0		-110	
								30							0			
								-30							0			
Layla	0	0	0	30				30				0	0	0	30		0	30
			-110					-30						-30	-30			-30
								30										
								30										
Morph The Cat			110	30	110			-110	0	-110	0	0	0	0	0	0	30	30
				-30	110			30		0	0				30		0	0
					-110			0									-30	-30
																		110
																		-110
																		180
Here We Go Again	30			110				110	0		110	0	0	0		0	30	
	-30			-110				-110			-110						-30	
MEAN	**-13**	**0**	**1**	**11**	**151**	**180**	**0**	**-3**	**0**	**-55**	**180**	**-4**	**-4**	**-10**	**0**	**0**	**-3**	**0**
CATEGORY MEAN	**47**							**31**				**-4**					**-3**	**0**
STANDARD DEVIATION	**48**	**0**	**75**	**105**	**79**	**84**	**94**	**81**	**0**	**60**	**182**	**10**	**10**	**14**	**47**	**0**	**35**	**91**
	77							**104**				**23**					**35**	**91**

Figure A.1: Table with all the Position data relative to the surround sound analysis

"Eye In The Sky" Surround Sound Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Eye In The Sky			-30	110			30	110			110	0	0	0		0	0	0
			30	-110			-30	-110			-110							110
			110	110				110										-110
			-110	-110				-110										
MEAN			**0**	**180**			**0**	**180**			**180**	**0**	**0**	**0**		**0**	**0**	**0**
STANDARD DEVIATION			**94**	**84**			**31**	**84**			**84**	**0**	**0**	**0**		**0**	**0**	**122**

Figure A.2: Table with Position data relative to the song "Eye In The Sky"

"Walk of Life" Surround Sound Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Walk of Life		0	30	110				-110			-110	0	0	-30		0	0	-30
			-30	-110							110							30
			0	0														110
																		-110
MEAN		**0**	**0**	**0**				**-110**			**180**	**0**	**0**	**-30**		**0**	**0**	**0**
STANDARD DEVIATION		**0**	**25**	**122**				**0**			**84**	**0**	**0**	**0**		**0**	**0**	**94**

Figure A.3: Table with Position data relative to the song "Walk of Life"

“Hey Jude” Surround Sound Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Hey Jude	30	0	30		110	110						-30	-30	0	-110		0	0
	-30				-110	-110							0	-30	110			0
															-30			30
																		-30
																		-110
																		110
MEAN	0	0	30		180	180						-30	-15	-15	-70		0	0
STANDARD DEVIATION	31	0	0		84	84						0	15	15	107		0	67

Figure A.4: Table with Position data relative to the song “Hey Jude”

“What God Wants, Pt. I” Surround Sound Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
What God Wants	-110	0	30	30			110	30				0	0	0	30		0	-110
			-110	-30			-110	-30							-30		30	110
								0							0		-110	
								30							0			
								-30							0			
MEAN	-110	0	-40	0			180	0				0	0	0	0		-16	180
STANDARD DEVIATION	0	0	84	31			84	27				0	0	0	19		65	84

Figure A.5: Table with Position data relative to the song “What God Wants, Pt. I”

“Layla” Surround Sound Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Layla	0	0	0	30				30				0	0	0	30		0	30
			-110					-30						-30	-30			-30
								30										
								30										
MEAN	0	0	-55	30				16				0	0	-15	0		0	0
STANDARD DEVIATION	0	0	60	0				26				0	0	15	31		0	31

Figure A.6: Table with Position data relative to the song “Layla”

“Morph The Cat” Surround Sound Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbal	ercussic	Bass	Main Vocal	Backing Vocals
Morph The Cat			110	30	110			-110	0	-110	0	0	0	0	0	0	30	30
				-30	110			30		0	0				30		0	0
					-110			0									-30	-30
																		110
																		-110
																		180
MEAN			110	0	138			-16	0	-55	0	0	0	0	15	0	0	0
STANDARD DEVIATION			0	31	71			65	0	60	0	0	0	0	15	0	25	107

Figure A.7: Table with Position data relative to the song “Morph The Cat”

“Here We Go Again” Surround Sound Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Here We Go Again	30			110				110	0		110	0	0	0		0	30	
	-30			-110				-110			-110						-30	
MEAN	**0**			**180**				**180**	**0**		**180**	**0**	**0**	**0**		**0**	**0**	
STANDARD DEVIATION	**31**			**84**				**84**	**0**		**84**	**0**	**0**	**0**		**0**	**31**	

Figure A.8: Table with Position data relative to the song “Here We Go Again”

Stereo Study Position data Overview Table

	Harmonic							Melodic				Rhythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Eye In The Sky			-30	110			30	110			110	0	0	0		0	0	0
			30	-110			-30	-110			-110							110
			110	110				110										-110
			-110	-110				-110										
Walk of Life		0	30	110				-110			-110	0	0	-30		0	0	-30
			-30	-110							110							30
			0	0														110
																		-110
Hey Jude	30	0	30		110	110						-30	-30	0	-110		0	0
	-30				-110	-110							0	-30	110			0
															-30			30
																		-30
																		-110
																		110
What God Wants	-110	0	30	30			110	30				0	0	0	30		0	-110
			-110	-30			-110	-30							-30		30	110
								0							0		-110	
								30							0			
								-30							0			
Layla	0	0	0	30				30				0	0	0	30		0	30
			-110					-30						-30	-30			-30
								30										
								30										
Morph The Cat			110	30	110			-110	0	-110	0	0	0	0	0	0	30	30
				-30	110			30		0	0				30		0	0
					-110			0									-30	-30
																		110
																		-110
																		180
Here We Go Again	30			110				110	0		110	0	0	0		0	30	
	-30			-110				-110			-110						-30	
MEAN	**-13**	**0**	**1**	**11**	**151**	**180**	**0**	**-3**	**0**	**-55**	**180**	**-4**	**-4**	**-10**	**0**	**0**	**-3**	**0**
CATEGORY MEAN	**47**							**31**				**-4**					**-3**	**0**
STANDARD DEVIATION	**48**	**0**	**75**	**105**	**79**	**84**	**94**	**81**	**0**	**60**	**182**	**10**	**10**	**14**	**47**	**0**	**35**	**91**
	77							**104**				**23**					**35**	**91**

Figure A.9: Table with all the Position data relative to the stereo sound analysis

“Eye In The Sky” Stereo Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Eye In The Sky			-30	-30			-30	-30			-30	0	0	0		0	0	0
			30	30			30	30			30							-30
			-30	-30				-30										30
			30	30				30										
MEAN			**0**	**0**			**0**	**0**			**0**	**0**	**0**	**0**		**0**	**0**	**0**
STANDARD DEVIATION			**31**	**31**			**31**	**31**			**31**	**0**	**0**	**0**		**0**	**0**	**25**

Figure A.10: Table with Position data relative to the song “Eye In The Sky”

"Walk of Life" Stereo Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Walk of Life		0	0	30				0			30	0	0	0		0	0	30
			0	-30							-30							-30
				0														
				0														
MEAN		**0**	**0**	**0**				**0**			**0**	**0**	**0**	**0**		**0**	**0**	**0**
STANDARD DEVIATION		**0**	**0**	**21**				**0**			**31**	**0**	**0**	**0**		**0**	**0**	**31**

Figure A.11: Table with Position data relative to the song "Walk of Life"

"Hey Jude" Stereo Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Hey Jude	0	0	30		30	30						-30	-30	0	-30		0	0
					-30	-30							0	-30	-30			0
															30			-30
																		0
																		30
MEAN	**0**	**0**	**30**		**0**	**0**						**-30**	**-15**	**-15**	**-11**		**0**	**0**
STANDARD DEVIATION	**0**	**0**	**0**		**31**	**31**						**0**	**15**	**15**	**29**		**0**	**19**

Figure A.12: Table with Position data relative to the song "Hey Jude"

"What God Wants, Pt. I" Stereo Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
What God Wants	30	0	30	30			0	-15				0	0	0	0		-30	-30
			-30	-30				30							30		0	
								-30							-30		-30	
															0			
															30			
MEAN	**30**	**0**	**0**	**0**			**0**	**-5**				**0**	**0**	**0**	**6**		**-20**	**-30**
STANDARD DEVIATION	**0**	**0**	**31**	**31**			**0**	**26**				**0**	**0**	**0**	**23**		**14**	**0**

Figure A.13: Table with Position data relative to the song "What God Wants, Pt. I"

"Layla" Stereo Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Layla	0	0	0	30				-30				0	0	0	0		0	-30
			-30					-15						-30				30
								30										0
								0										
								0										
								0										
MEAN	**0**	**0**	**-15**	**30**				**-3**				**0**	**0**	**-15**	**0**		**0**	**0**
STANDARD DEVIATION	**0**	**0**	**15**	**0**				**18**				**0**	**0**	**15**	**0**		**0**	**25**

Figure A.14: Table with Position data relative to the song "Layla"

"Morph The Cat" Stereo Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Morph The Cat			30	0	30			-30	0	-30	30	0	0	30	0		0	0
								30		0	-30							0
								0										-30
																		30
MEAN			30	0	30	0	0	0	0	-15	0	0	0	30	0	0	0	0
STANDARD DEVIATION																		

Figure A.15: Table with Position data relative to the song "Morph The Cat"

"Here We Go Again" Stereo Position data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Here We Go Again	-30			-30				0	0		-30	0	0	0		0	0	
	30			30							30						0	
MEAN	0	0		0				0	0		0	0	0	0		0	0	
STANDARD DEVIATION	31	0		31				0	0		31	0	0	0		0	0	

Figure A.16: Table with Position data relative to the song "Here We Go Again"

Surround Sound Amplitude data

	Harmonic							Melodic				Rhythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Eye In The Sky			2	2			2	2			2	2	2	2		2	3	2
			3	1				3										2
Walk of Life		2	2	2				3			3	2	3	2		2	3	2
			2	2														2
Hey Jude	2	2	2		2	2						1	2	2	2		3	2
													2	2	2			2
																		2
What God Wants	1	2	1	1			2	3				2	2	2	2		2	2
								2							2		3	
															2		3	
Layla	3	2	2	1				3				2	2	2	2		3	2
			2					2						2				2
								2										
Morph The Cat			2	2	2			2	3	2	1	2	2	2	1	3	3	2
				1				2		3	1							2
								3										
Here We Go Again	2			2				1	3		2	1	2	1		3	3	
																	3	
MEAN	2	2	2	1.6	2	2	2	2.3	3	2.5	1.8	1.7	2.1	1.9	1.9	2.5	2.9	2
STANDARD DEVIATION	0.7	0	0.5	0.5	0	0	0	0.6	0	0.5	0.7	0.5	0.3	0.3	0.3	0.5	0.3	0
CATEGORY MEAN	1.9							2.4				2					2.9	2

Figure A.17: Table with amplitude data relative to all songs in the surround sound study

Stereo Amplitude data

	Harmonic							Melodic				Rythmic					Lead Vocals	Backing Vocals
	Piano	Bass	Guitar	Keys	Horns	Strings	Pads	Guitar	Bass	Horns	Keys	Kick	Snare	Cymbals	Percussion	Bass	Main Vocal	Backing Vocals
Eye In The Sky			2	2			2	2			2	2	2	2		2	3	2
			3	1				3										2
Walk of Life		2	2	1				3			3	2	3	2		2	3	2
Hey Jude	2	2	2		2	2						1	2	2	2		3	2
													2	1	2			2
														2				2
What God Wants	1	2	2	1			1	3				2	3	2	2		2	2
								2							1		3	
															2		3	
Layla	3	2	2	2				2				2	2	2	2		3	3
			2					2						2				2
								2										
Morph The Cat			2	2	2			2	3	2	1	2	2	2	1	2	3	2
								1		3	1							2
								3										
Here We Go Again	2			2				1	3		2	1	2	1		3	3	
																	3	
MEAN	**2**	**2**	**2.1**	**1.6**	**2**	**2**	**1.5**	**2.2**	**3**	**2.5**	**1.8**	**1.7**	**2.2**	**1.8**	**1.7**	**2.2**	**2.9**	**2.1**
STANDARD DEVIATION	**0.7**	**0**	**0.3**	**0.5**	**0**	**0**	**0.5**	**0.7**	0	**0.5**	**0.7**	**0.5**	**0.4**	**0.4**	**0.5**	**0.4**	**0.3**	**0.3**
CATEGORY MEAN	**1.9**							**2.2**				**1.9**					**2.9**	**2.1**

Figure A.18: Table with amplitude data relative to all songs in the stereo study

Data Analysis Contents - Tables

Appendix B

Diagrams From the Surround Sound Song Analysis

B.1 Contains all the diagrams for all the sections of each song analyzed in their surround sound versions

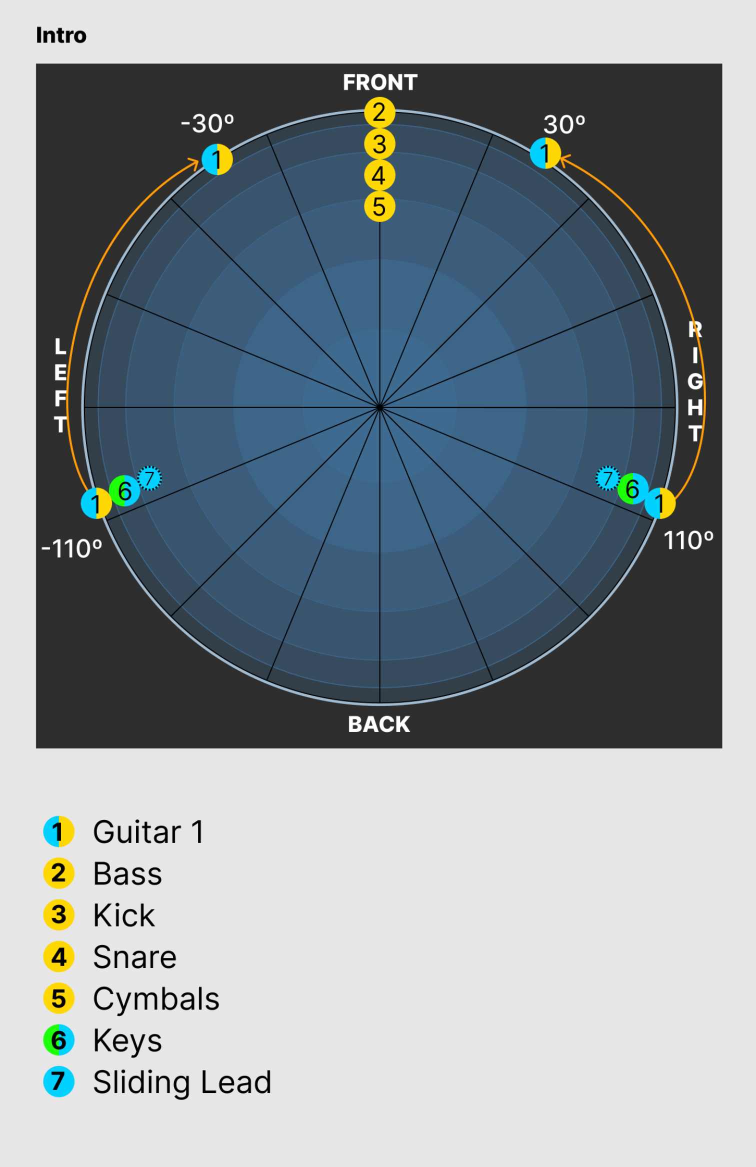

Figure B.1: Diagram for the **Intro** of the song “Eye in the Sky” in the **surround sound** analysis.

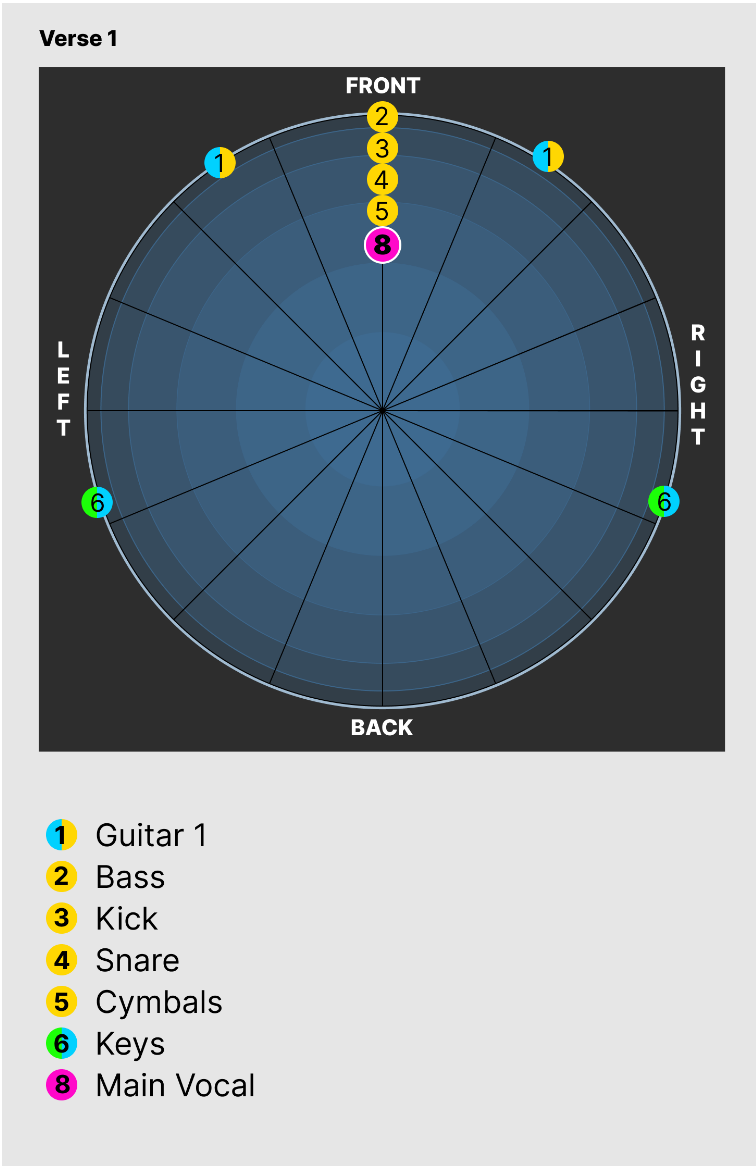

Figure B.2: Diagram for the **Verse 1** of the song "Eye in the Sky" in the **surround sound** analysis.

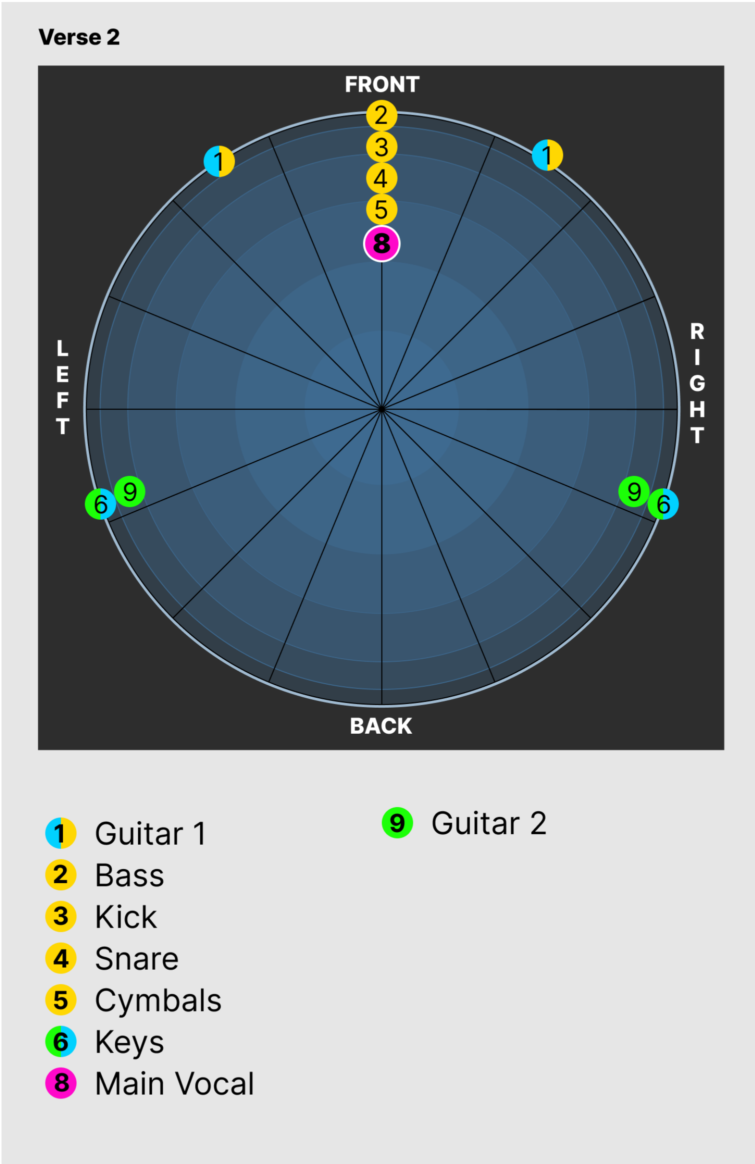

Figure B.3: Diagram for the **Verse 2** of the song “Eye in the Sky” in the **surround sound** analysis.

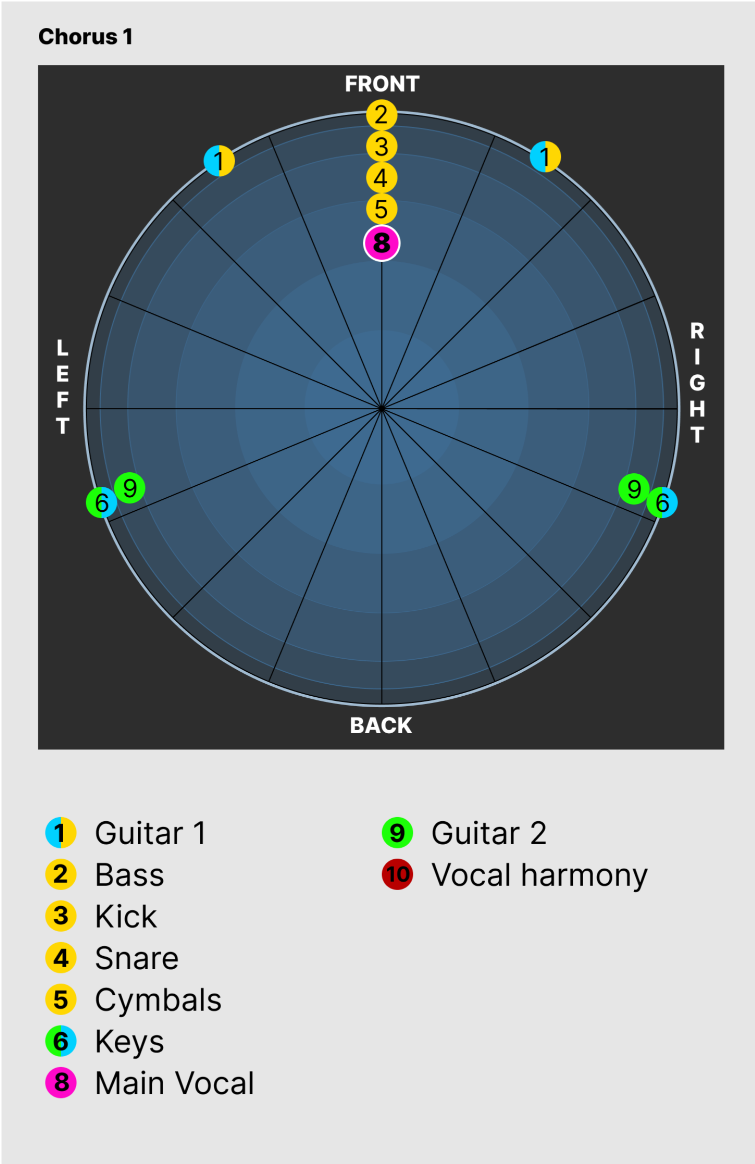

Figure B.4: Diagram for the **Chorus 1** of the song “Eye in the Sky” in the **surround sound** analysis.

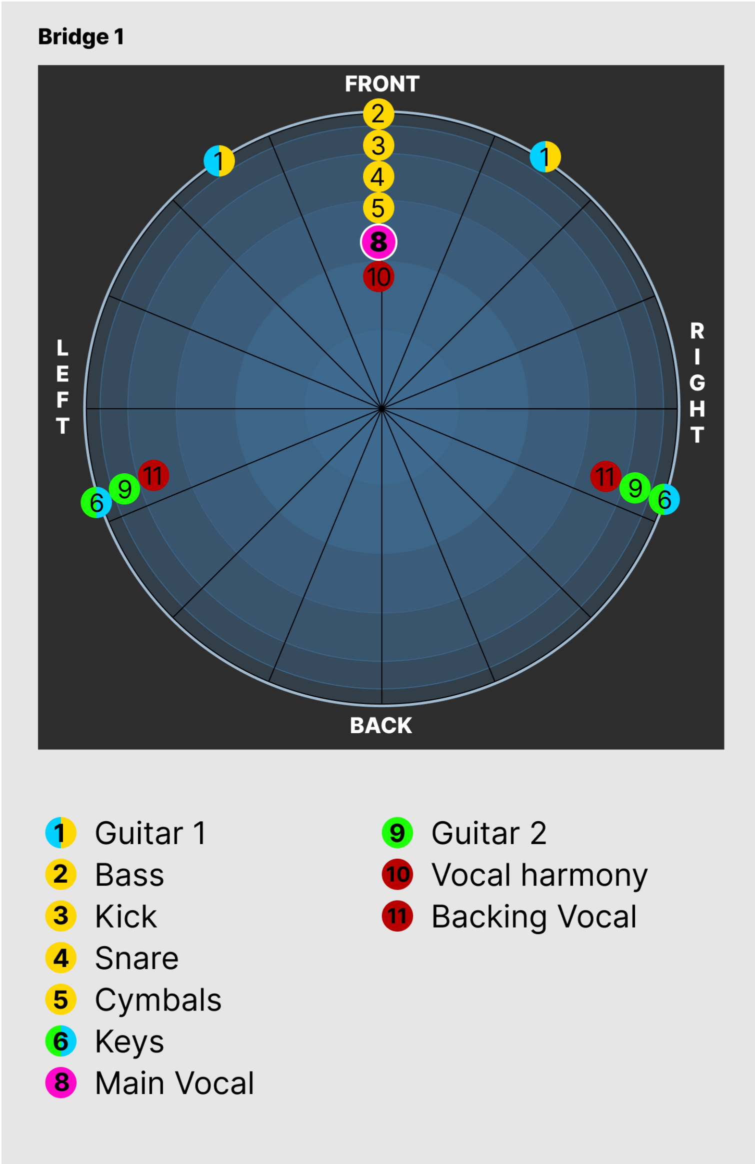

Figure B.5: Diagram for the **Bridge 1** of the song "Eye in the Sky" in the **surround sound** analysis.

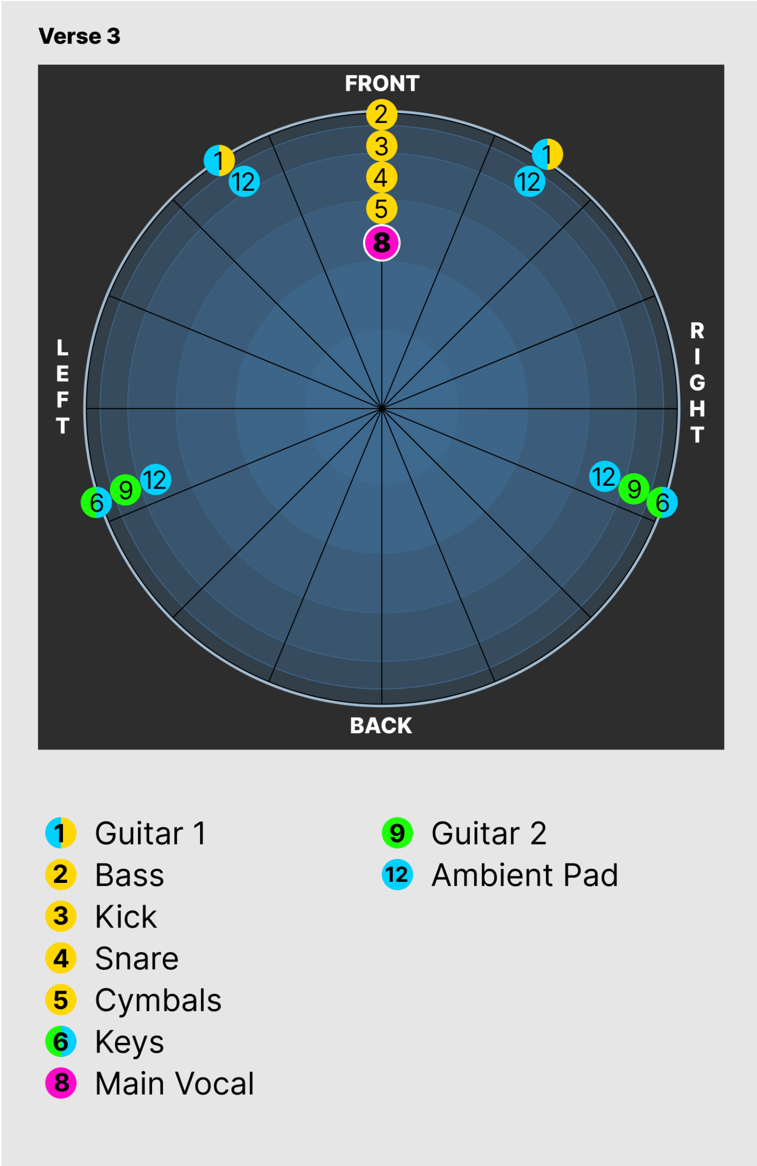

Figure B.6: Diagram for the **Verse 3** of the song “Eye in the Sky” in the **surround sound** analysis.

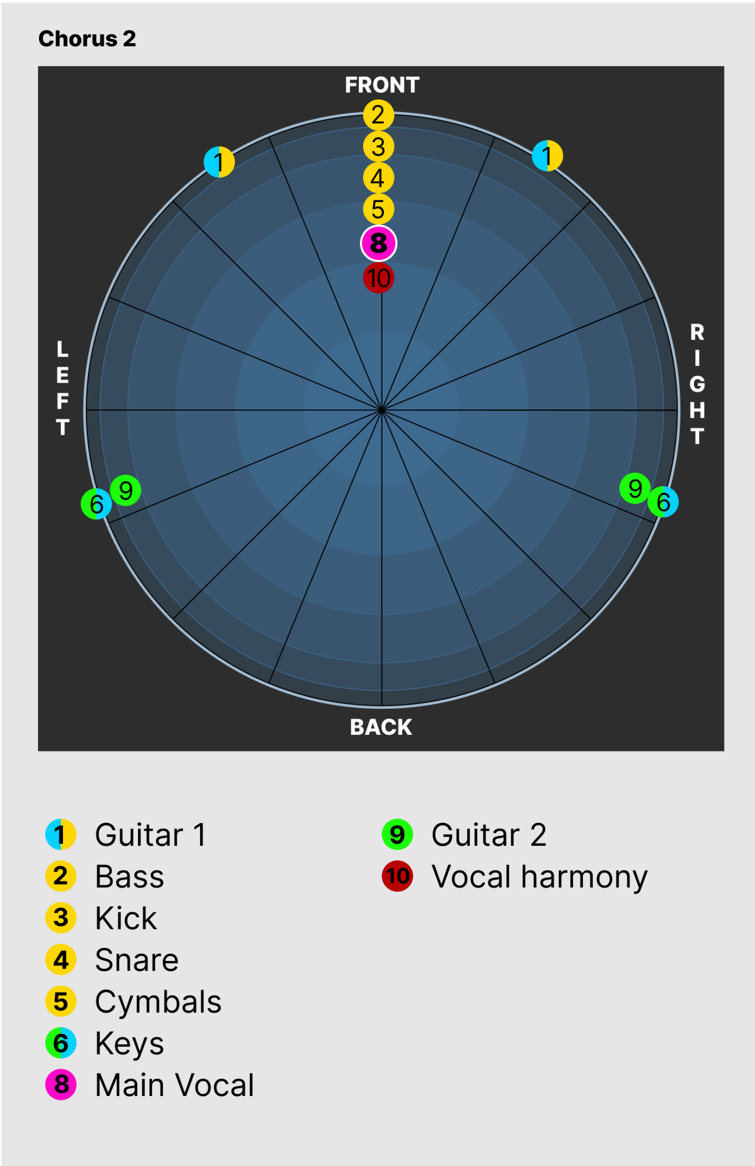

Figure B.7: Diagram for the **Chorus 2** of the song “Eye in the Sky” in the **surround sound** analysis.

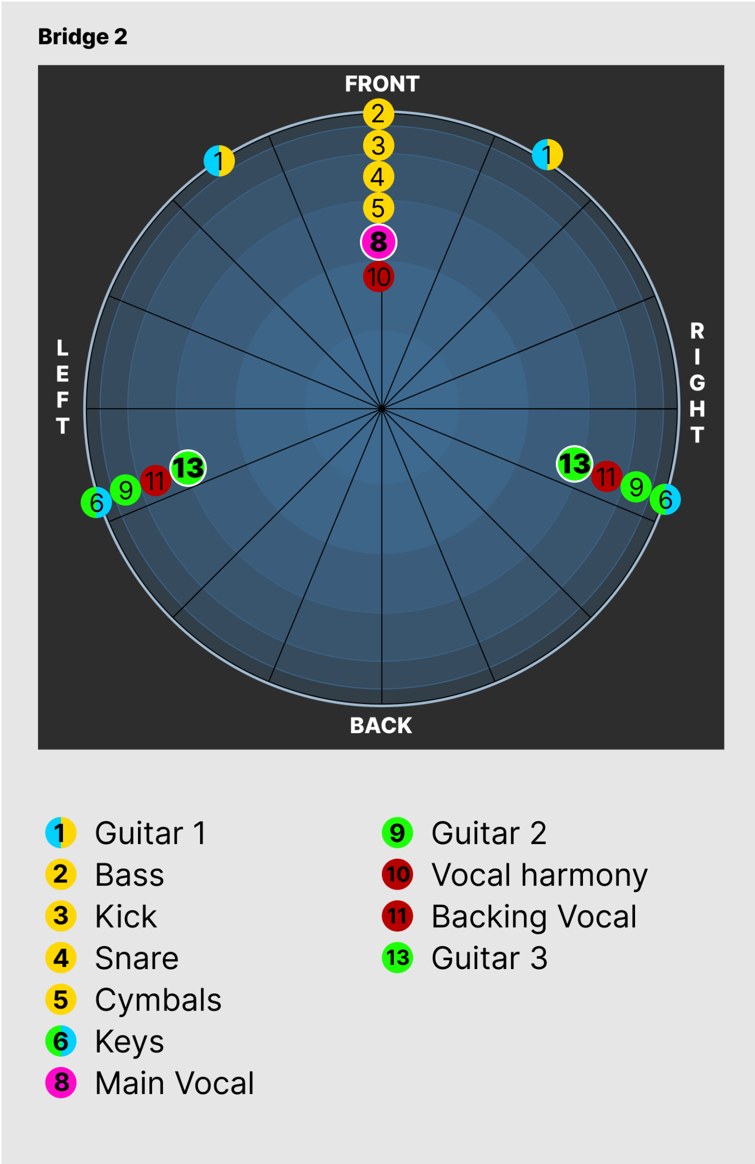

Figure B.8: Diagram for the **Bridge 2** of the song "Eye in the Sky" in the **surround sound** analysis.

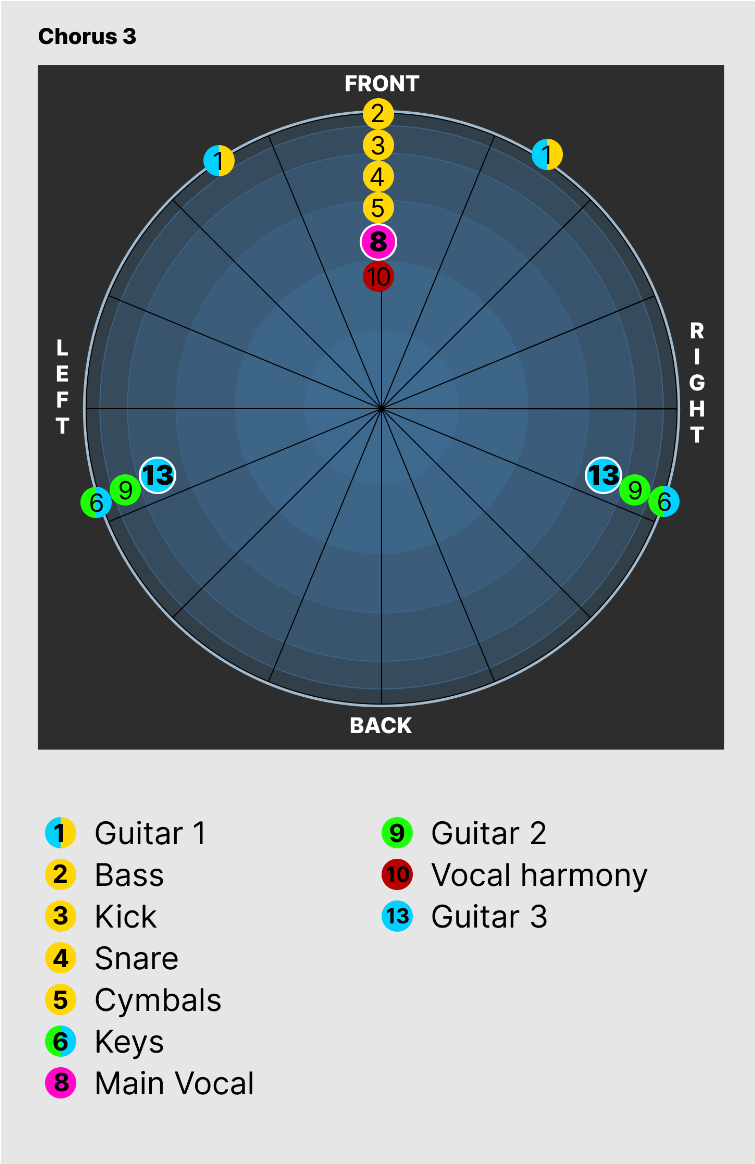

Figure B.9: Diagram for the **Chorus 3** of the song “Eye in the Sky” in the **surround sound** analysis.

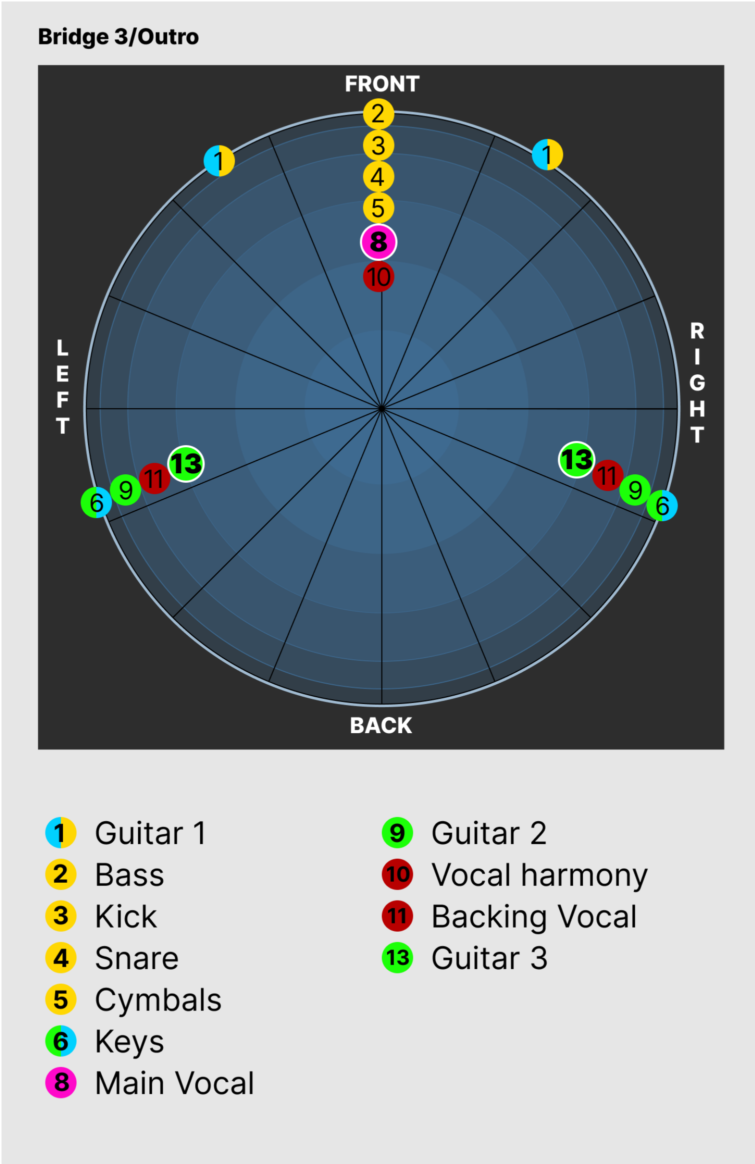

Figure B.10: Diagram for the **Bridge 3/Outro** of the song “Eye in the Sky” in the **surround sound** analysis.

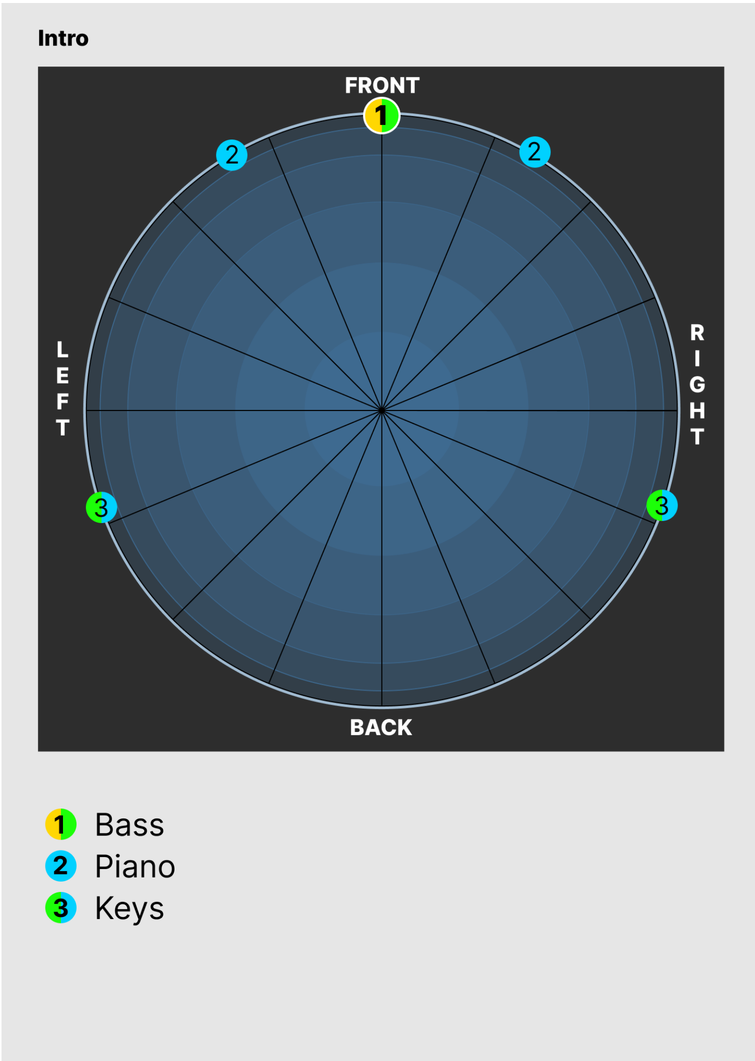

Figure B.11: Diagram for the **Intro** of the song "Here We Go Again" in the **surround sound** analysis.

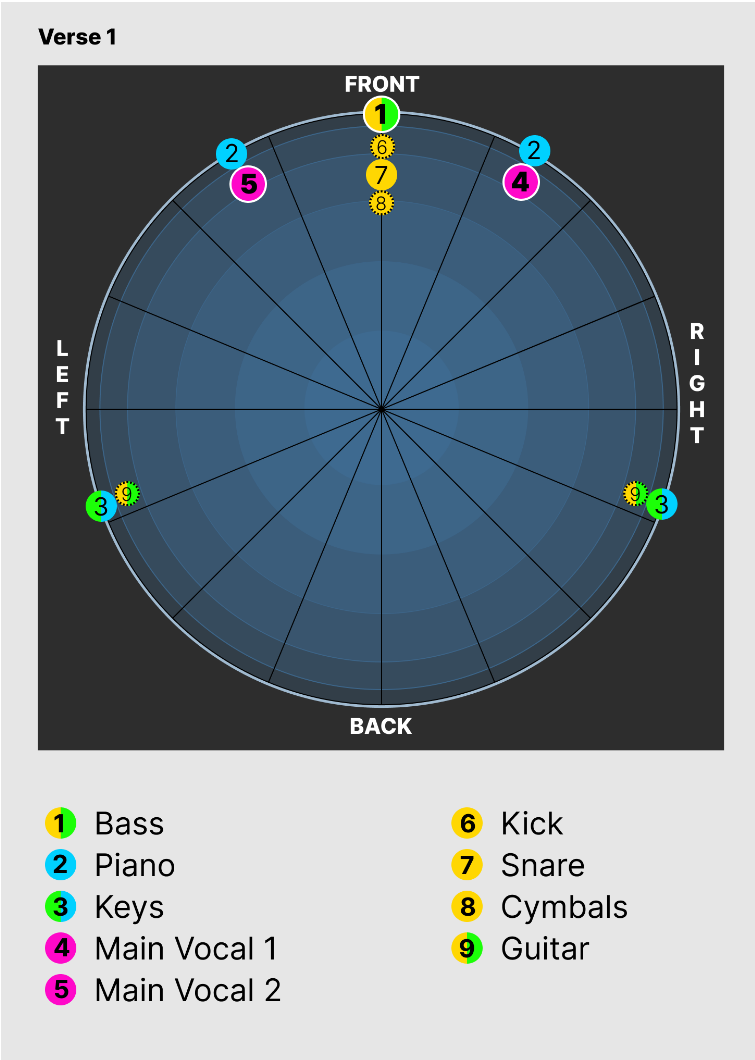

Figure B.12: Diagram for the **Verse 1** of the song “Here We Go Again” in the **surround sound** analysis.

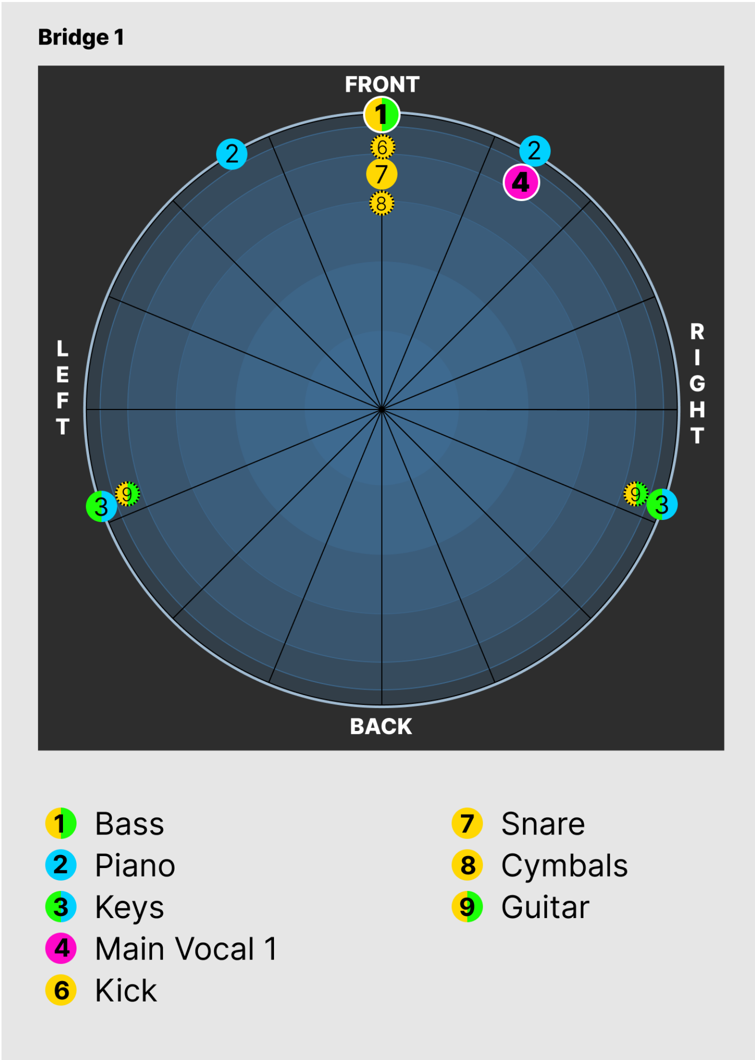

Figure B.13: Diagram for the **Bridge 1** of the song “Here We Go Again” in the **surround sound** analysis.

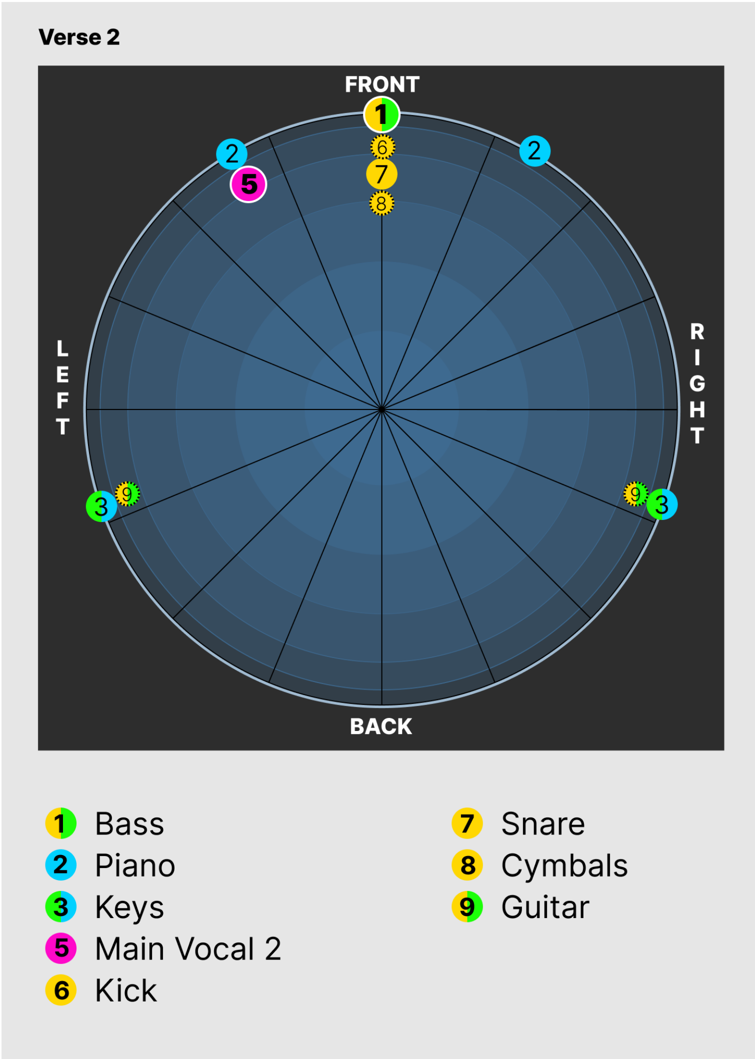

Figure B.14: Diagram for the **Verse 2** of the song "Here We Go Again" in the **surround sound** analysis.

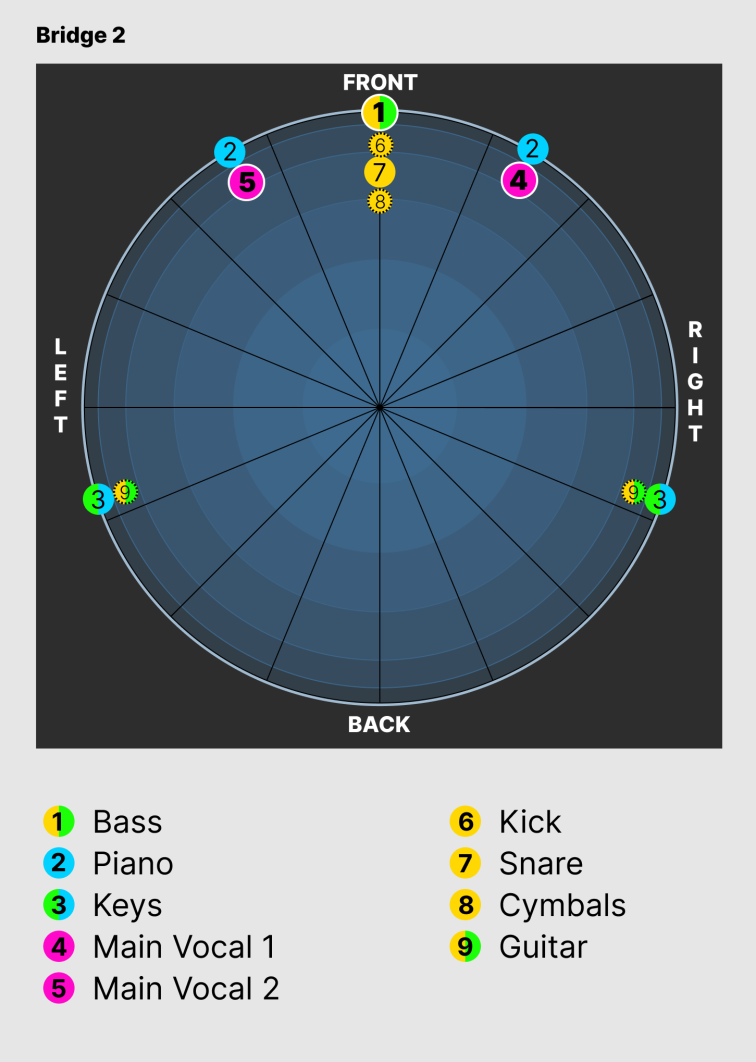

Figure B.15: Diagram for the **Bridge 2** of the song “Here We Go Again” in the **surround sound** analysis.

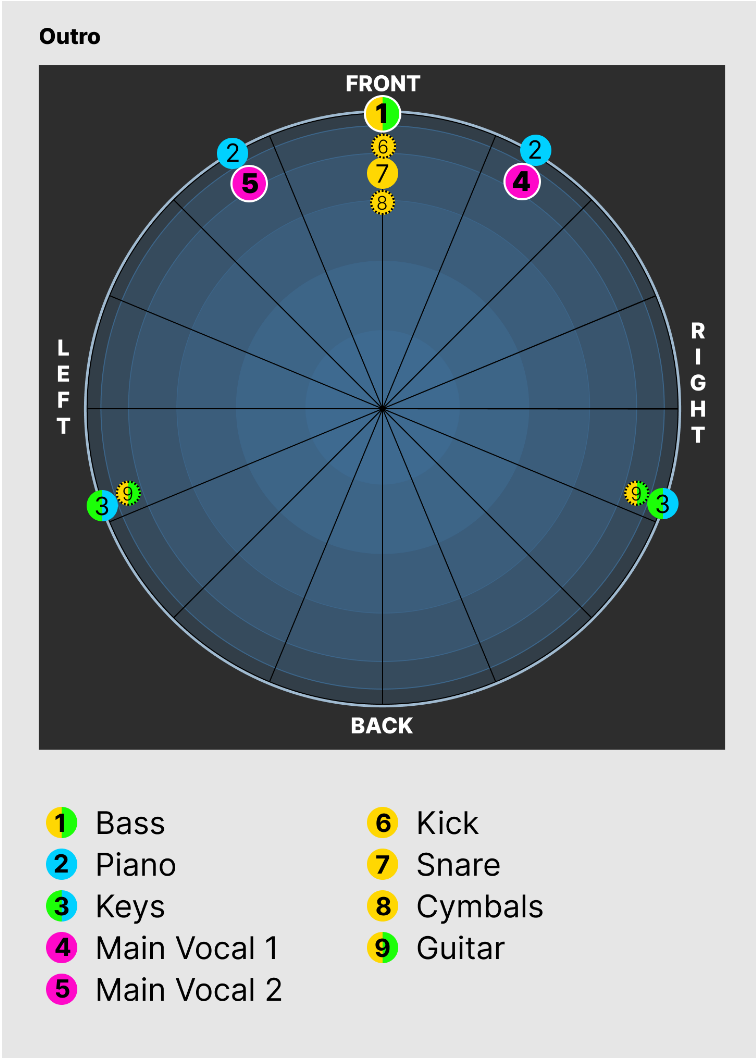

Figure B.16: Diagram for the **Outro** of the song “Here We Go Again” in the **surround sound** analysis.

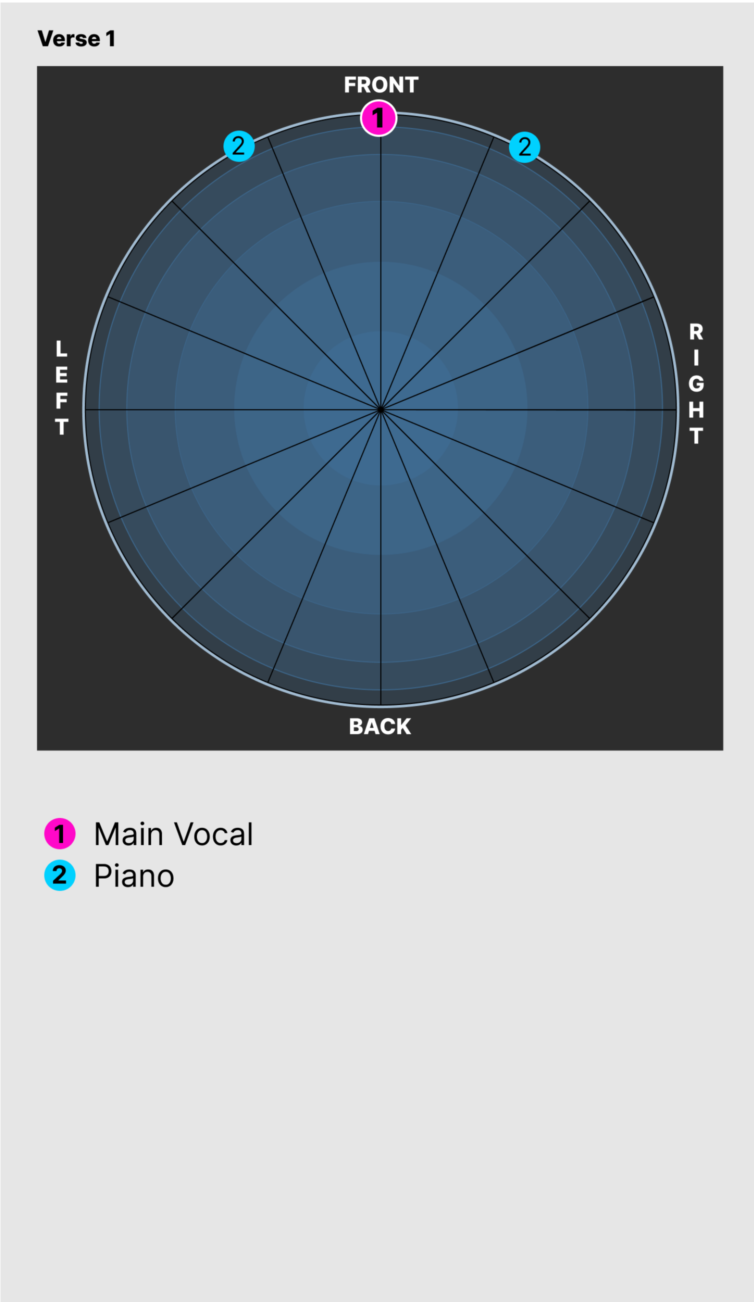

Figure B.17: Diagram for the **Verse 1** of the song “Hey Jude” in the **surround sound** analysis.

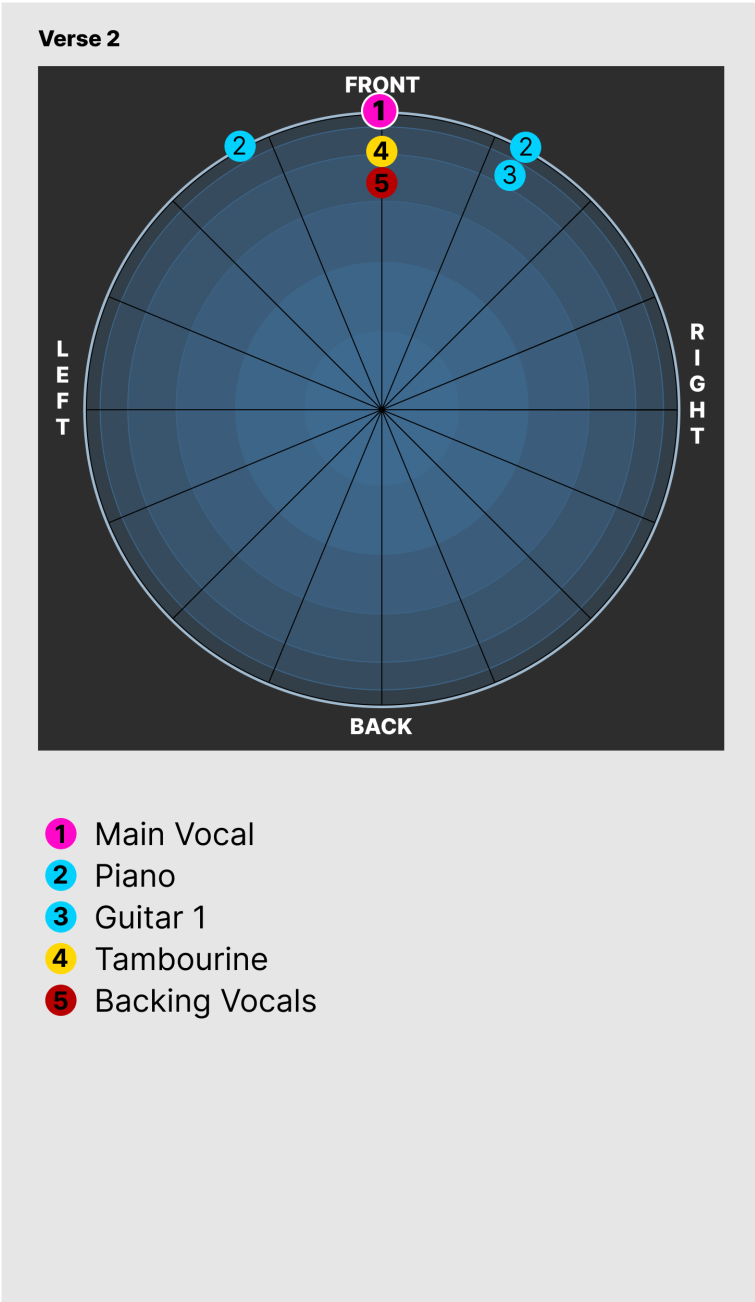

Figure B.18: Diagram for the **Verse 2** of the song “Hey Jude” in the **surround sound** analysis.

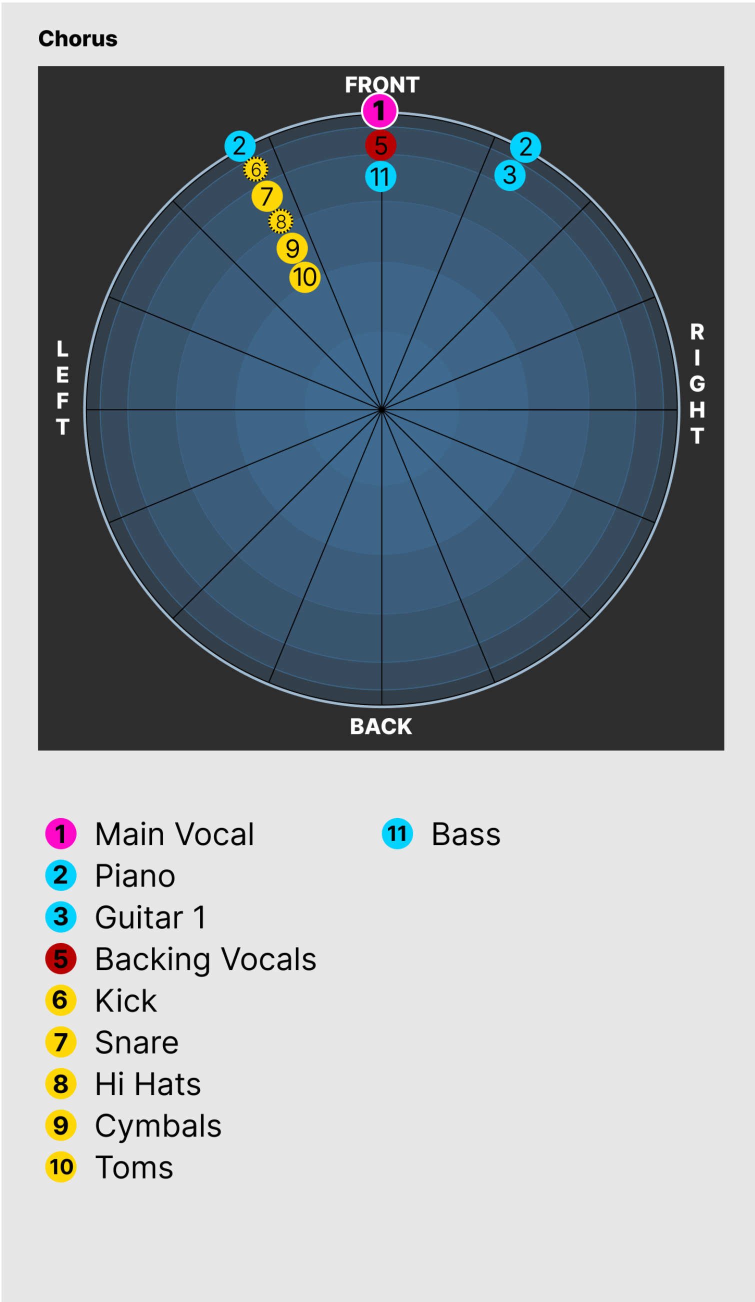

Figure B.19: Diagram for the **Chorus** of the song “Hey Jude” in the **surround sound** analysis.

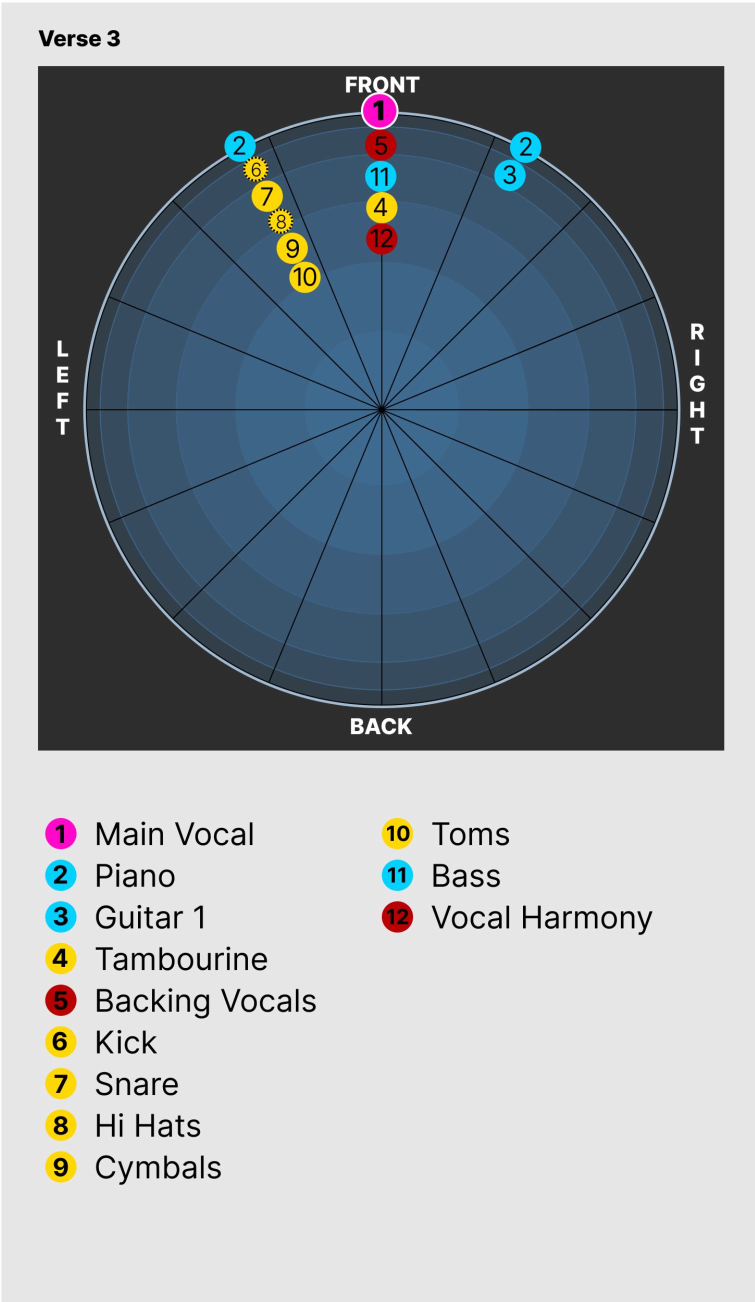

Figure B.20: Diagram for the **Verse 3** of the song “Hey Jude” in the **surround sound** analysis.

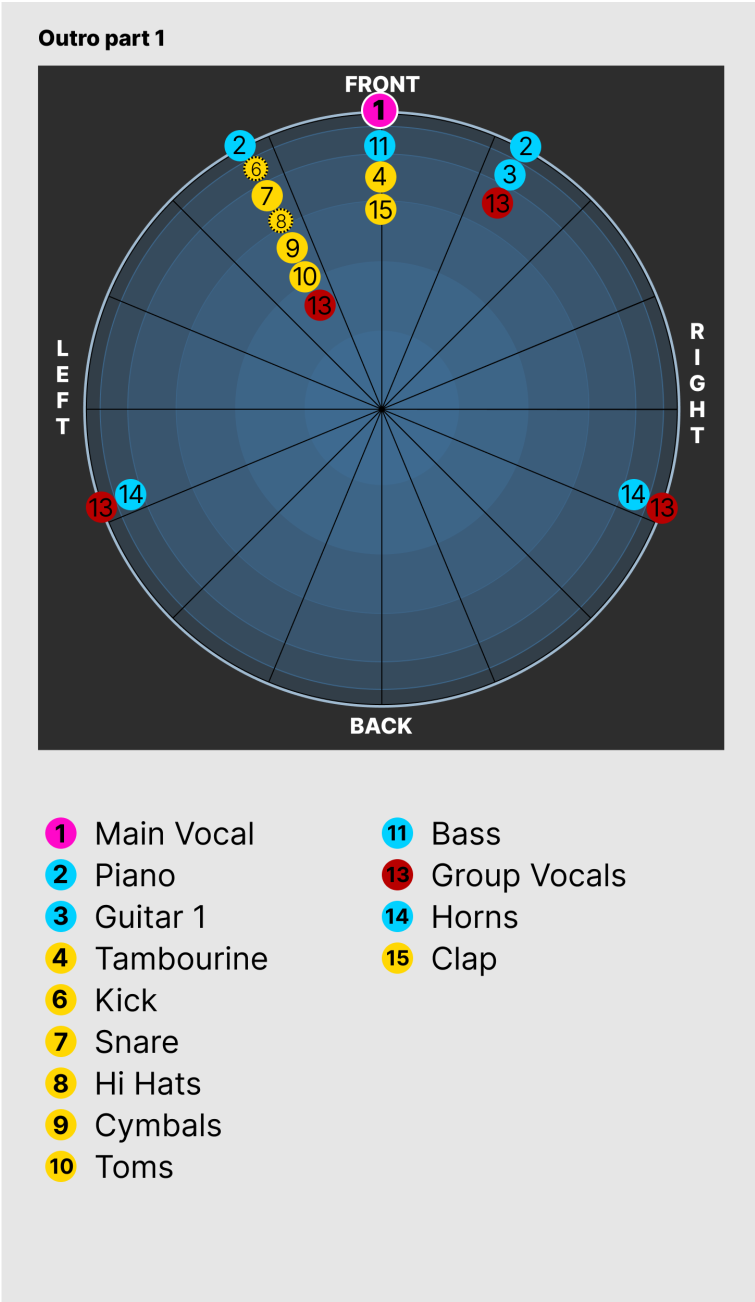

Figure B.21: Diagram for the **Outro Part 1** of the song "Hey Jude" in the **surround sound** analysis.

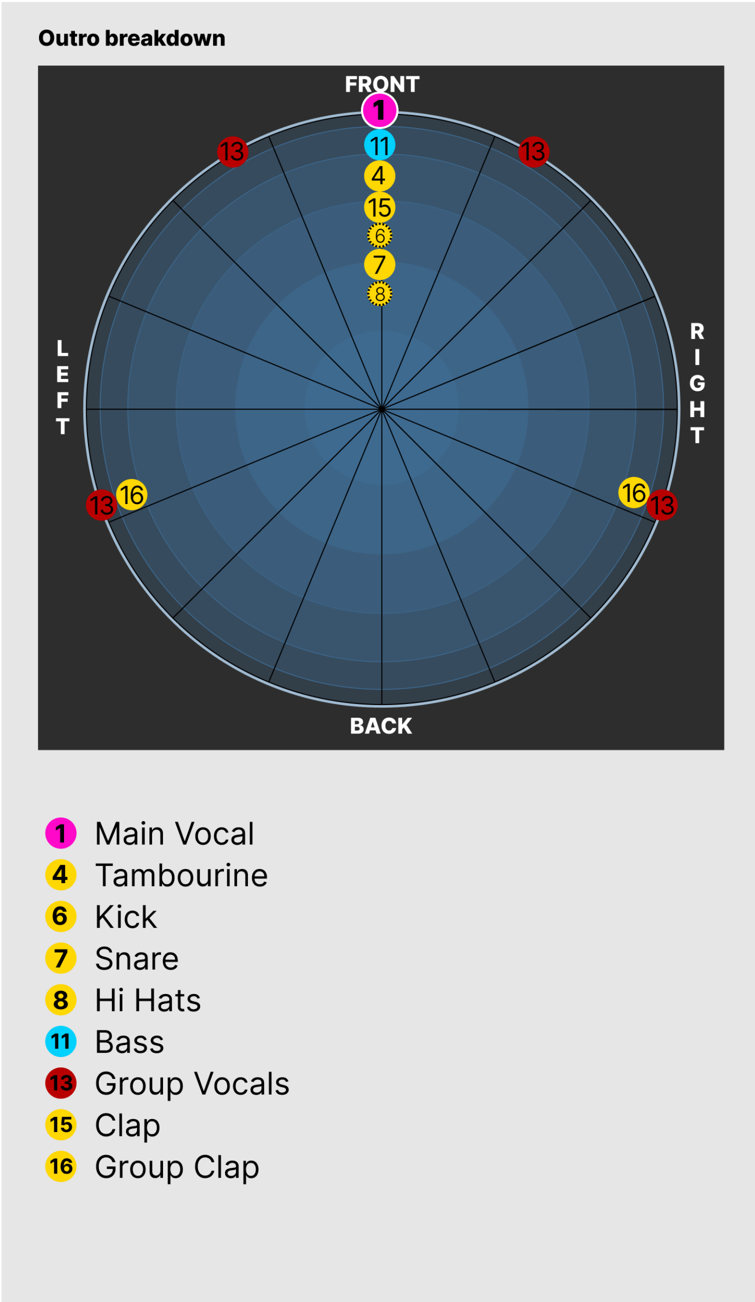

Figure B.22: Diagram for the **Outro Breakdown** of the song “Hey Jude” in the **surround sound** analysis.

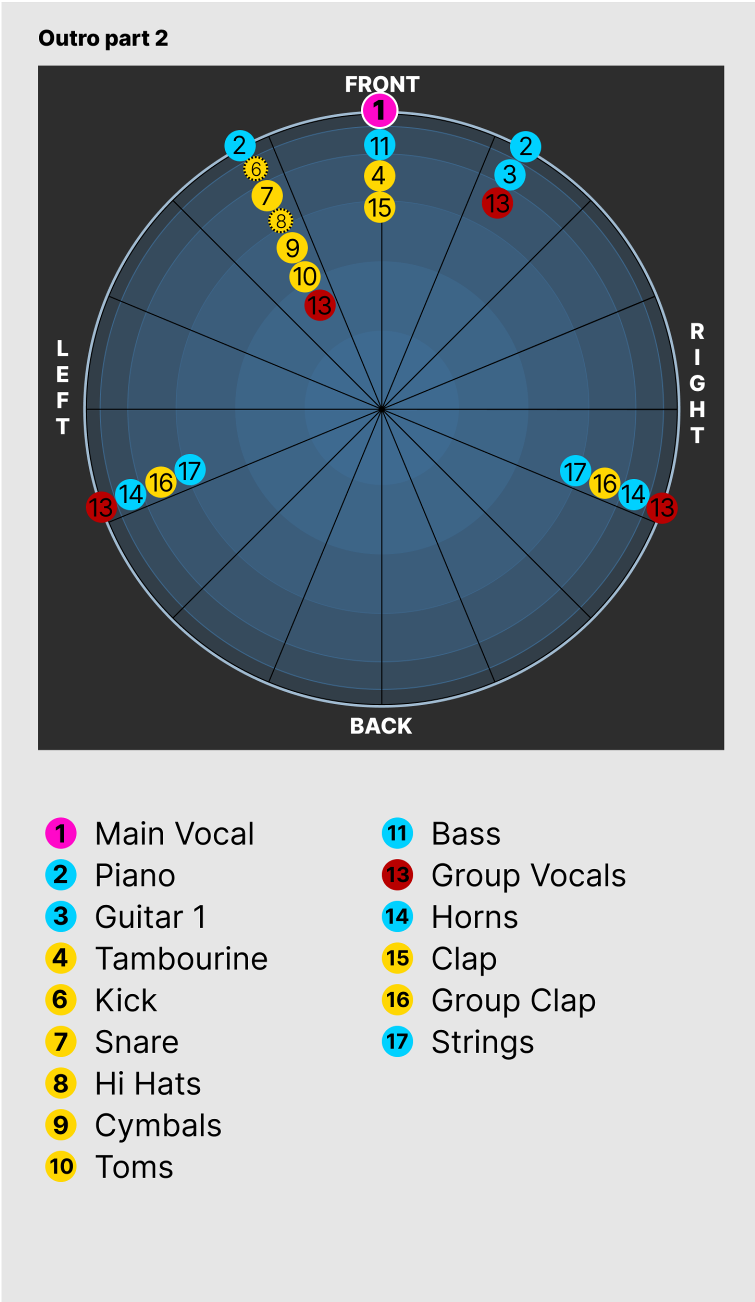

Figure B.23: Diagram for the **Outro Part 2** of the song "Hey Jude" in the **surround sound** analysis.

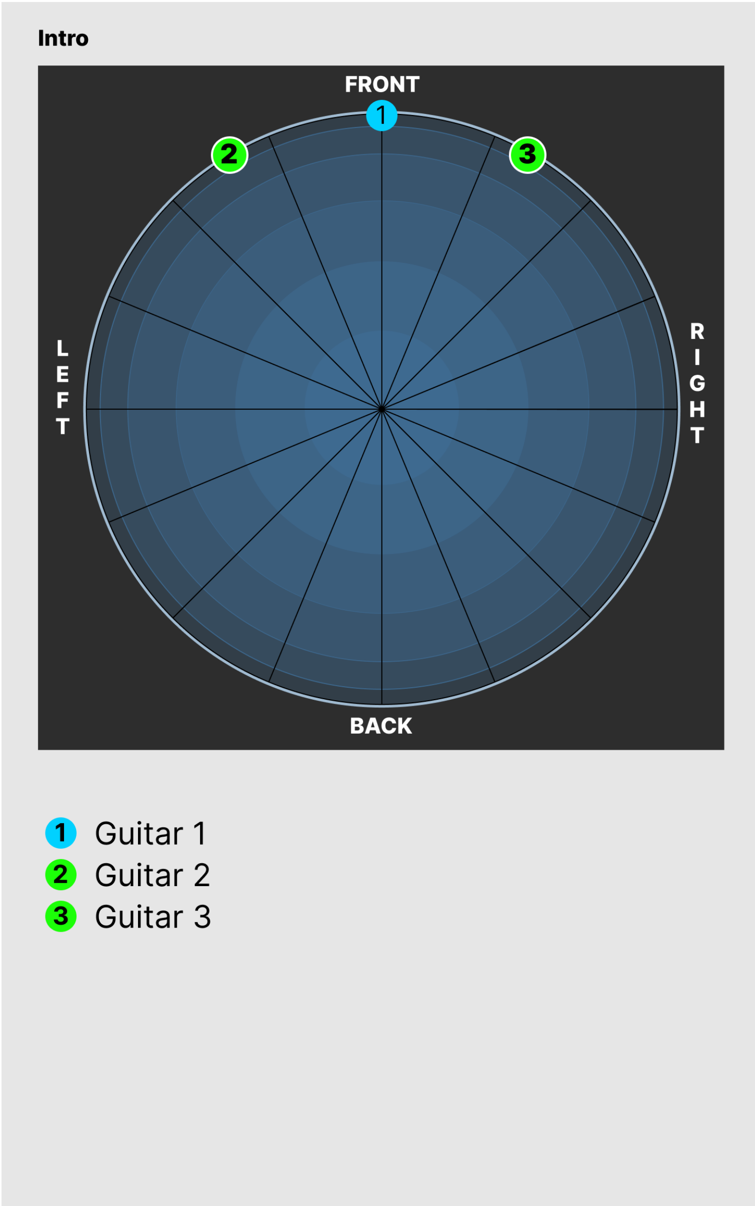

Figure B.24: Diagram for the **Part 1 - Intro** of the song “Layla” in the **surround sound** analysis.

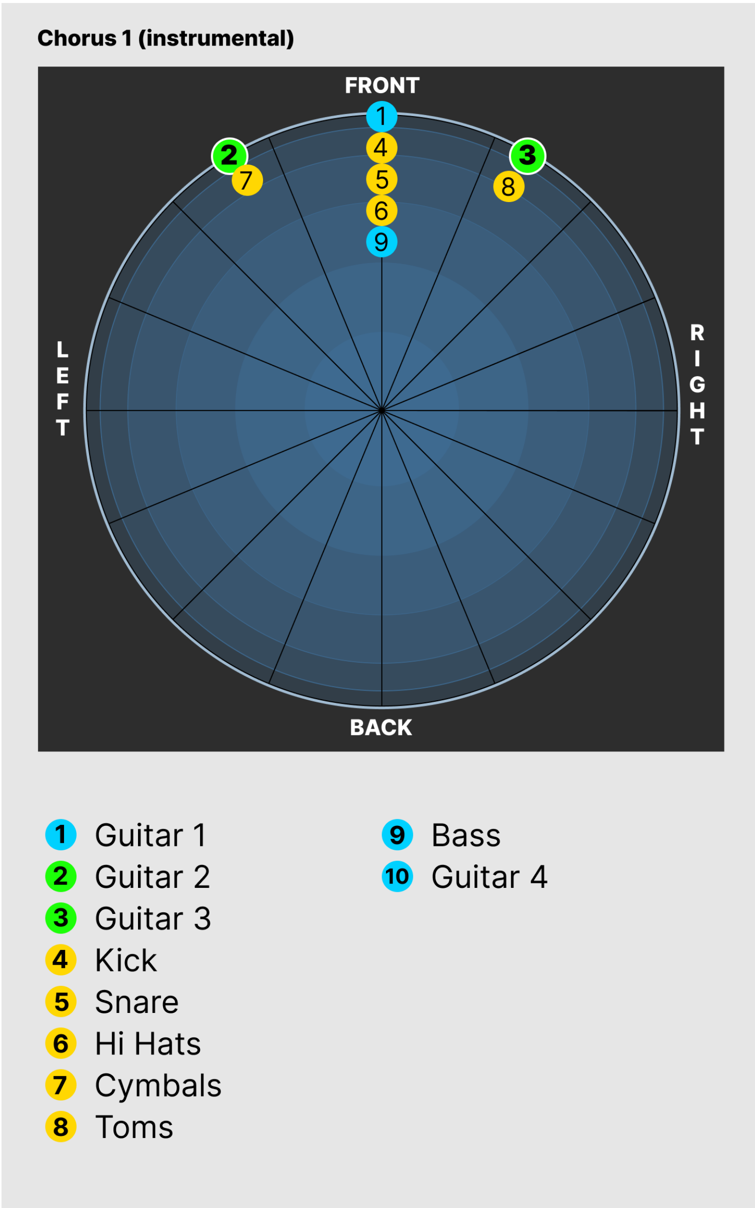

Figure B.25: Diagram for the **Part 1 - Chorus (instrumental)** of the song “Layla” in the **surround sound** analysis.

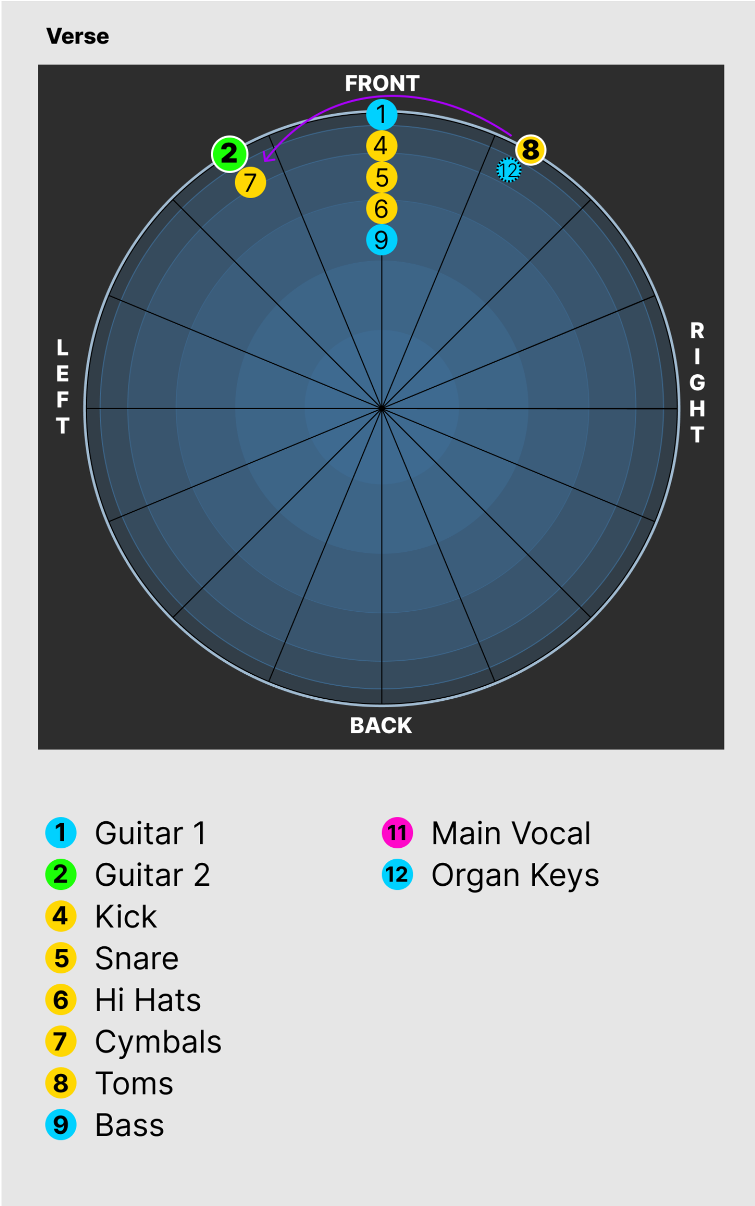

Figure B.26: Diagram for the **Part 1 - Verse** of the song "Layla" in the **surround sound** analysis.

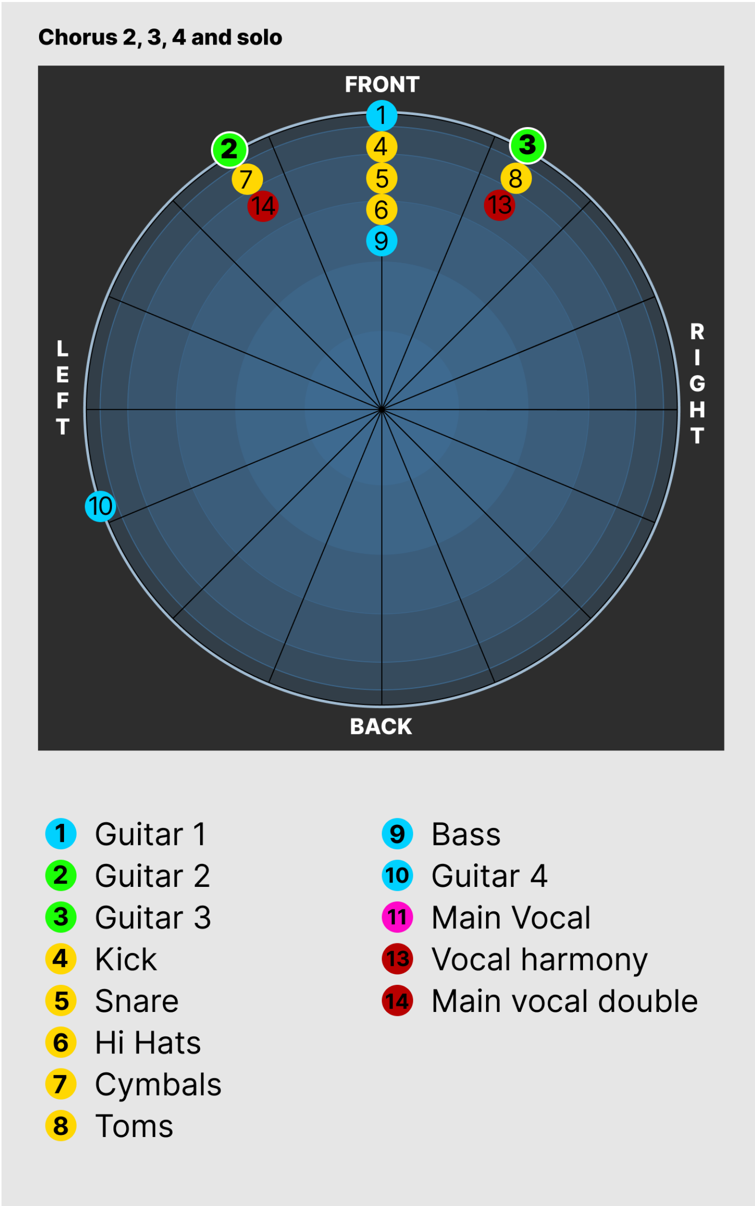

Figure B.27: Diagram for the **Part 1 - Chorus 2, 3, 4 and Solo** of the song “Layla” in the **surround sound** analysis.

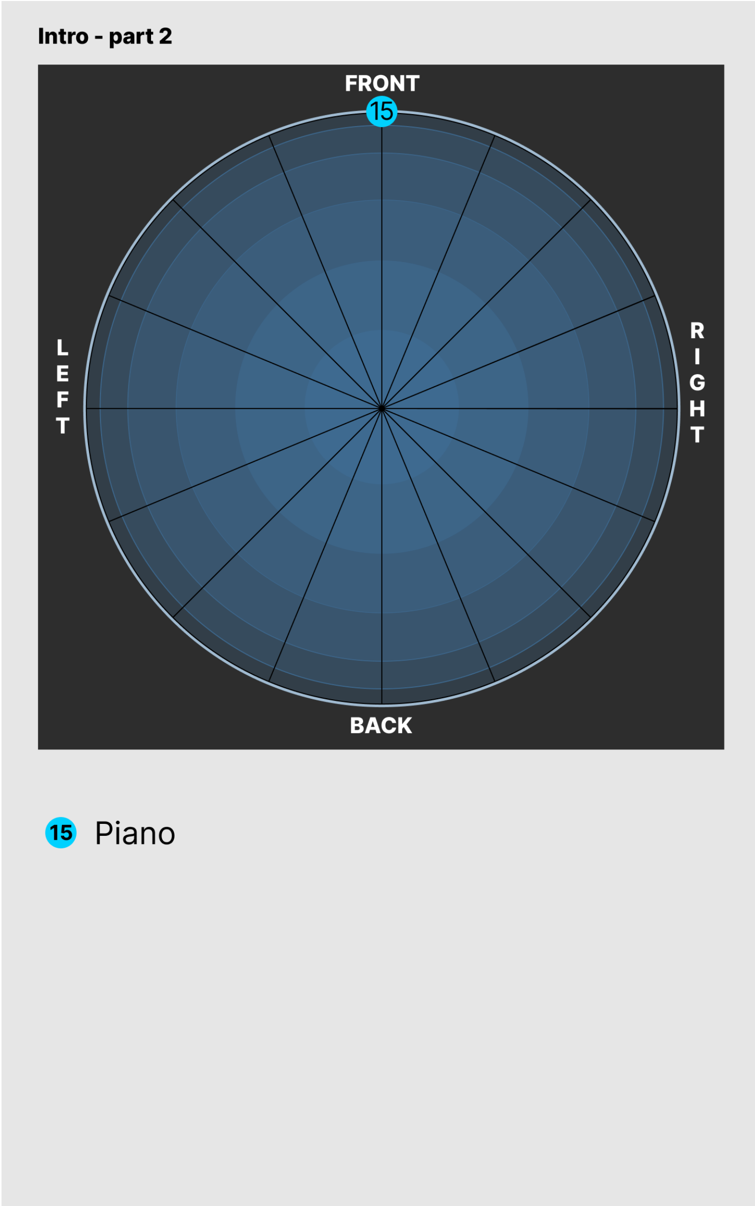

Figure B.28: Diagram for the **Part 2 - Intro** of the song “Layla” in the **surround sound** analysis.

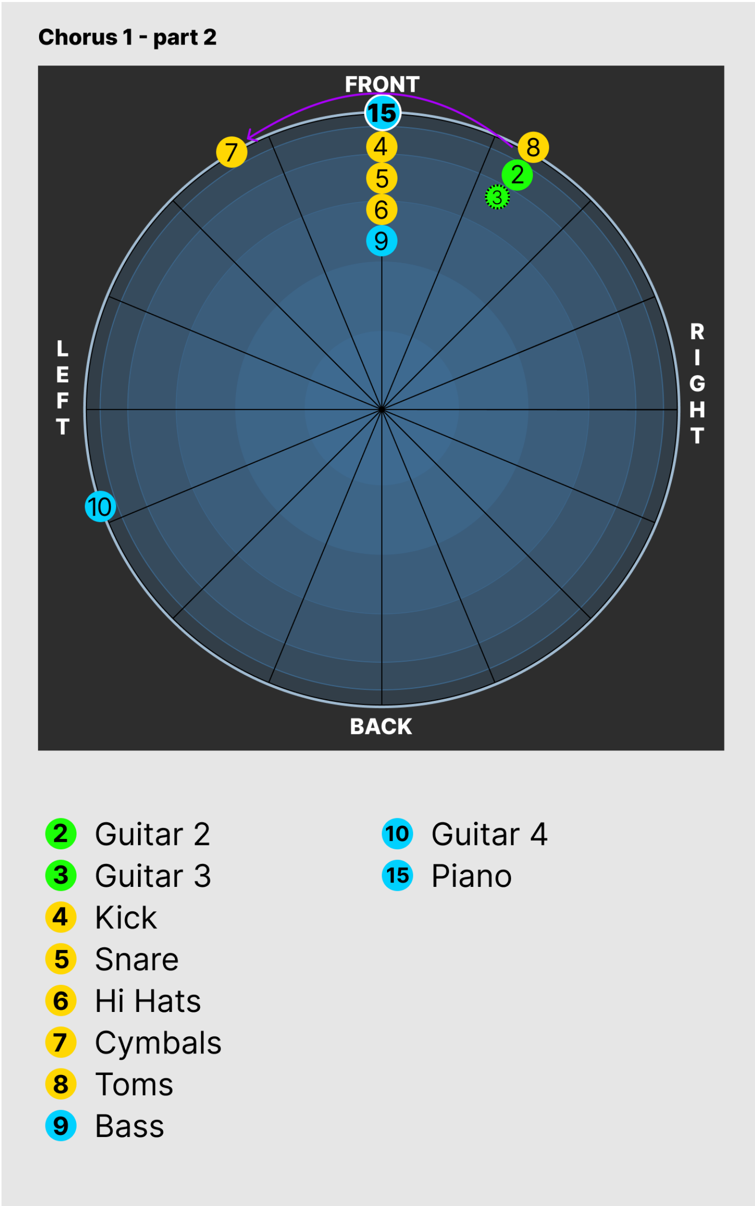

Figure B.29: Diagram for the **Part 2 - Chorus 1** of the song “Layla” in the **surround sound** analysis.

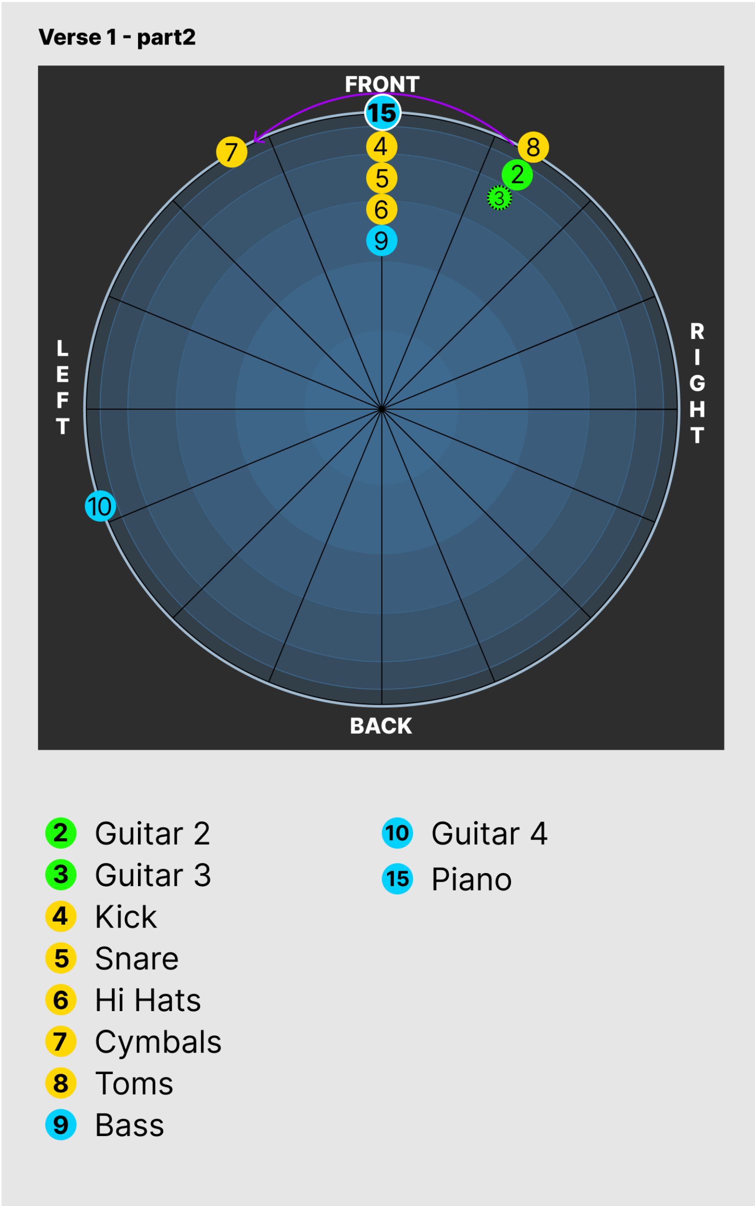

Figure B.30: Diagram for the **Part 2 - Verse 1** of the song “Layla” in the **surround sound** analysis.

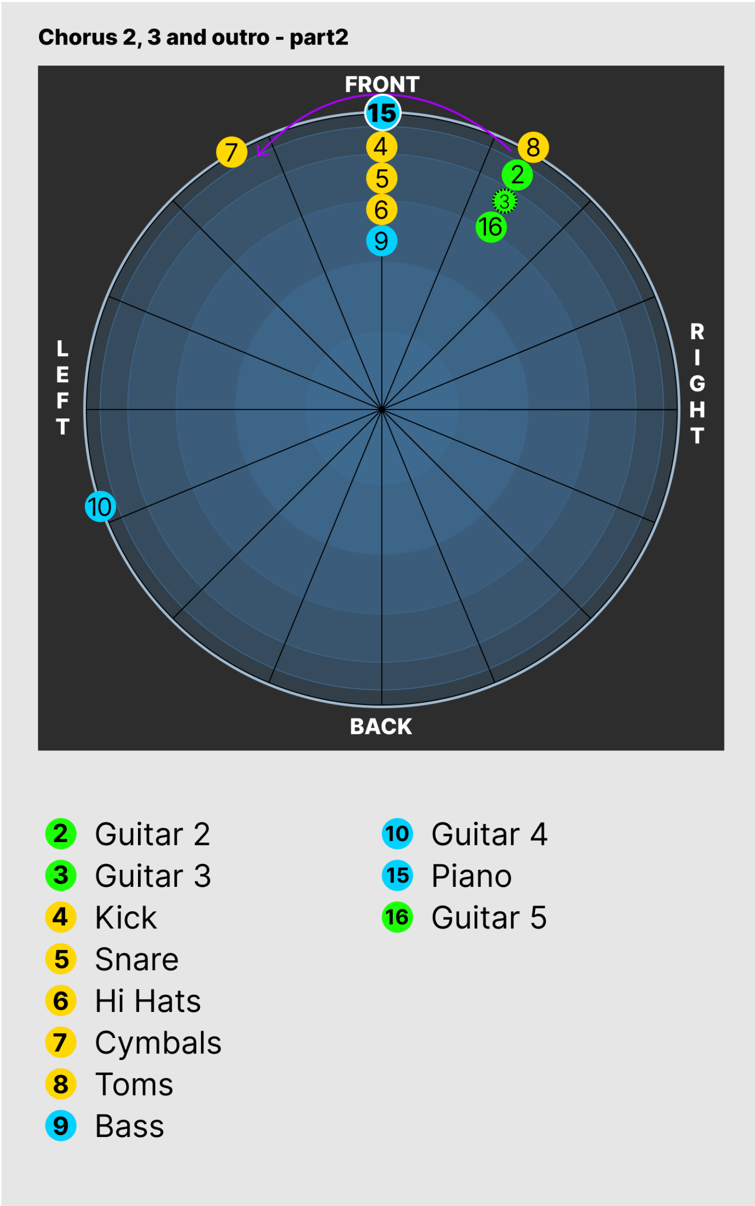

Figure B.31: Diagram for the **Part 2 - Chorus and Outro** of the song "Layla" in the **surround sound** analysis.

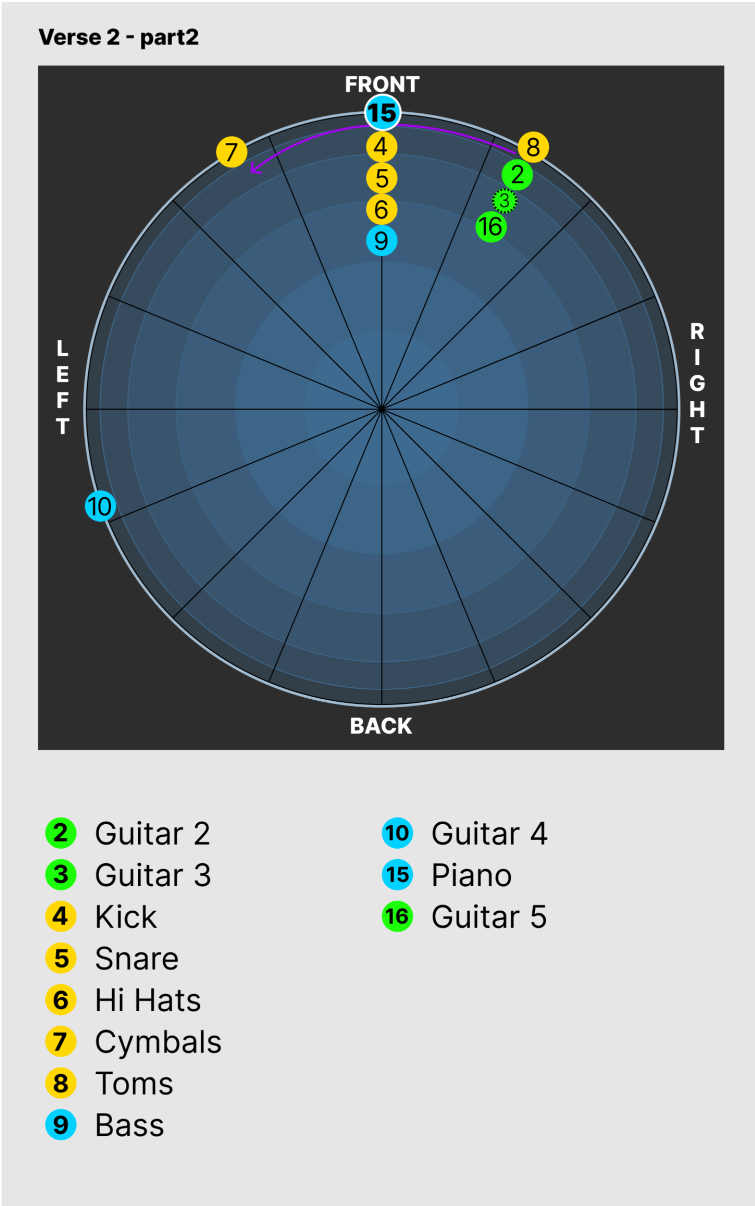

Figure B.32: Diagram for the **Part 2 - Verse 2** of the song "Layla" in the **surround sound** analysis.

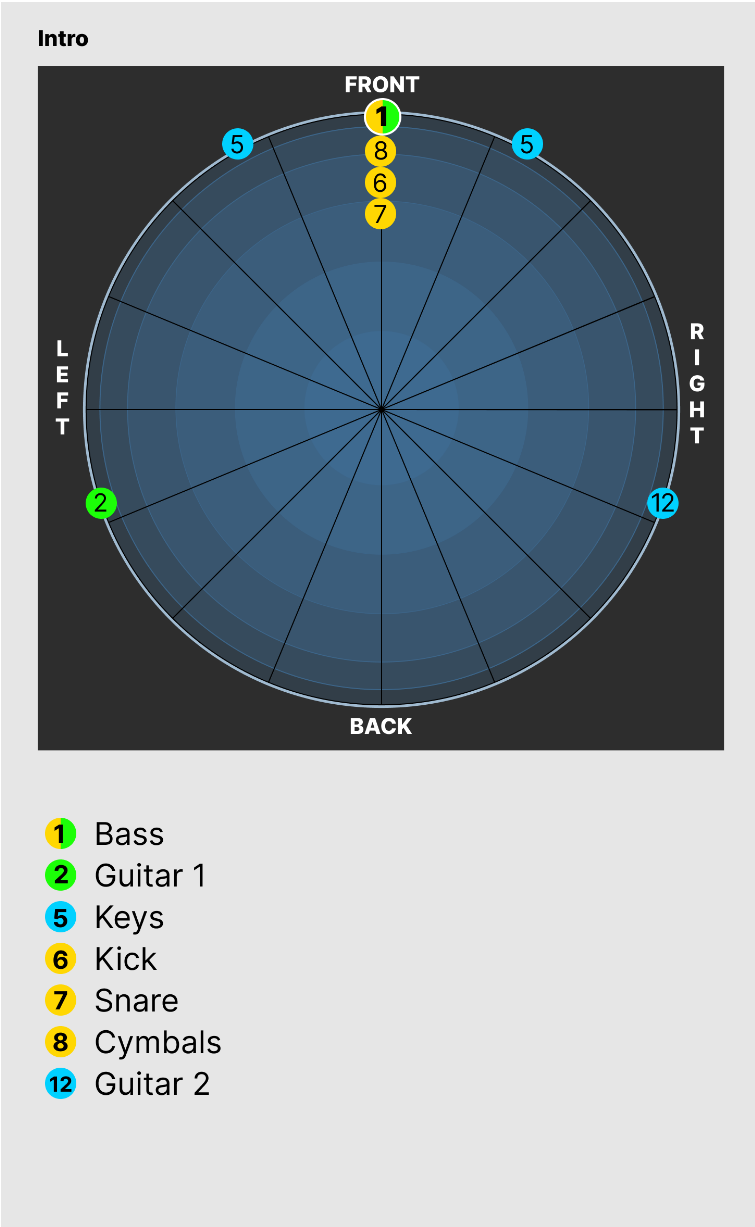

Figure B.33: Diagram for the **Intro** of the song “Morph the Cat” in the **surround sound** analysis.

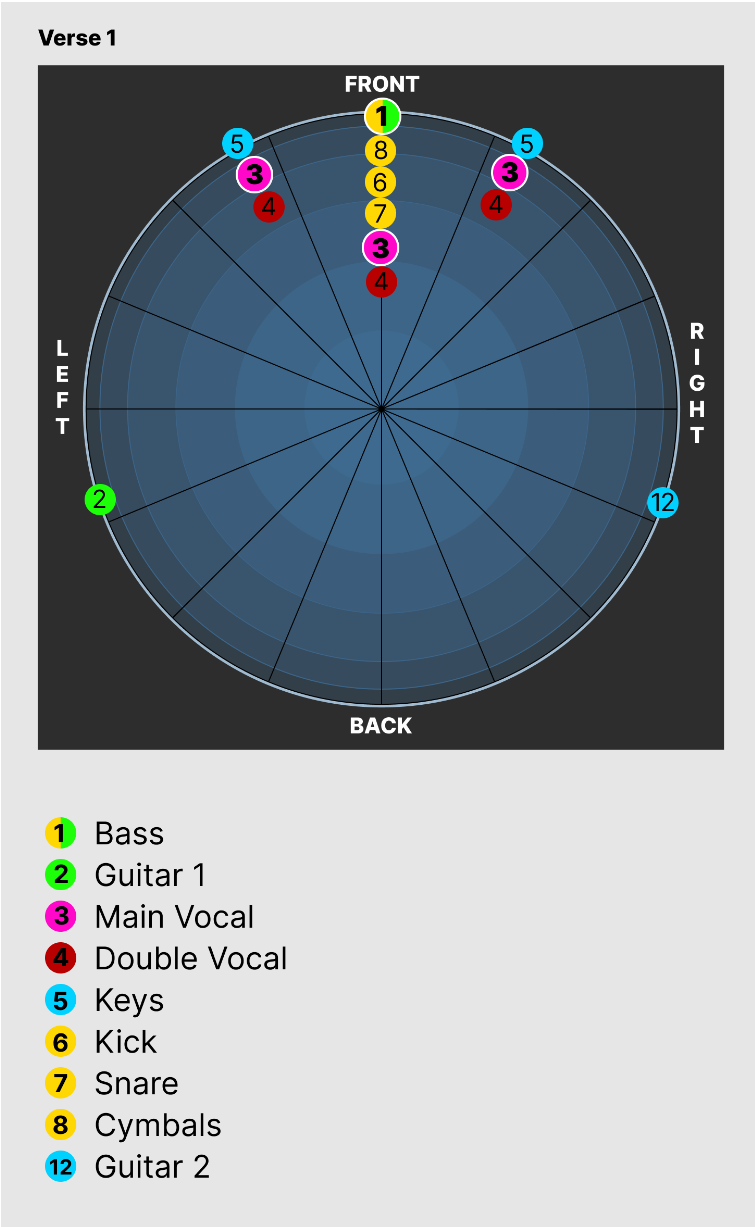

Figure B.34: Diagram for the **Verse 1** of the song “Morph the Cat” in the **surround sound** analysis.

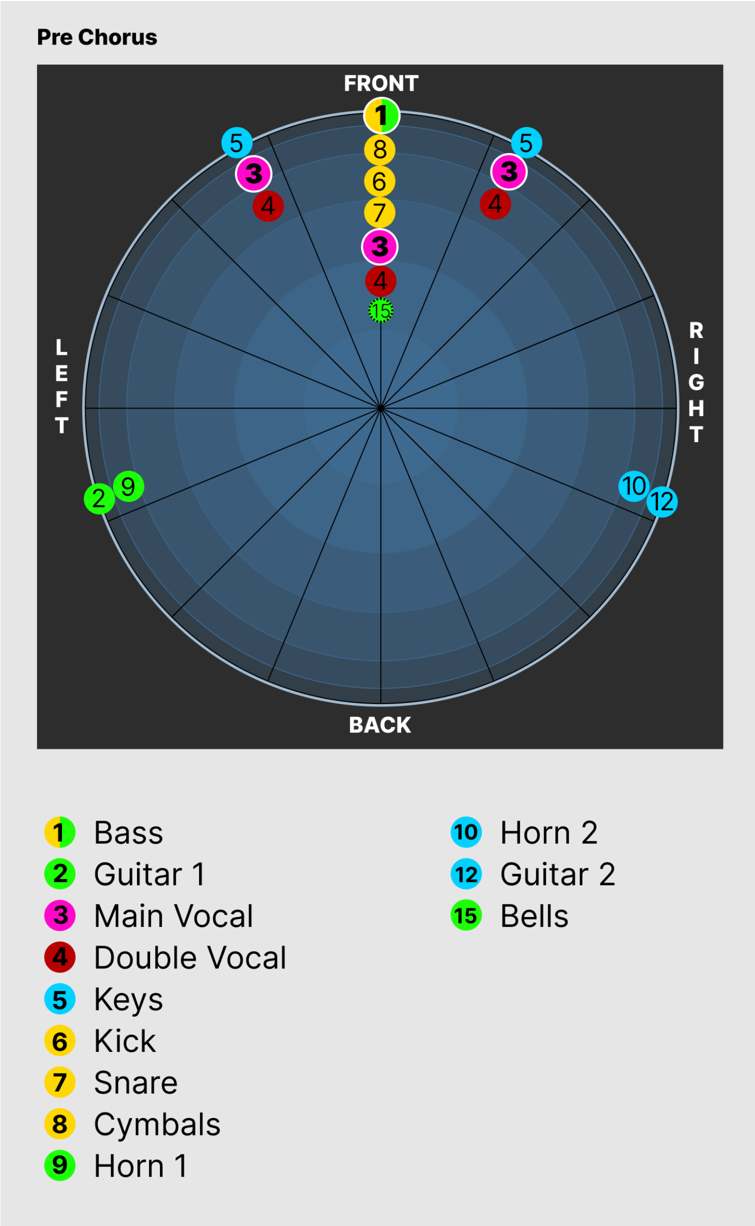

Figure B.35: Diagram for the **Pre Chorus** of the song "Morph the Cat" in the **surround sound** analysis.

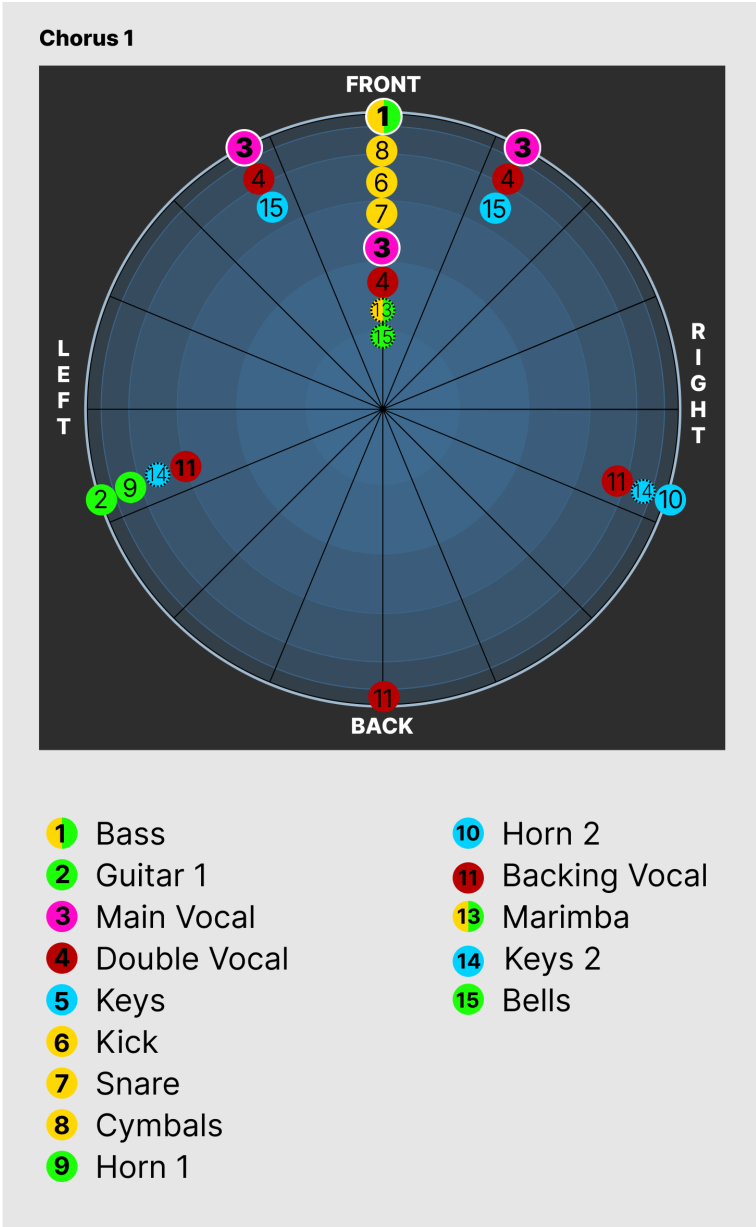

Figure B.36: Diagram for the **Chorus 1** of the song "Morph the Cat" in the **surround sound** analysis.

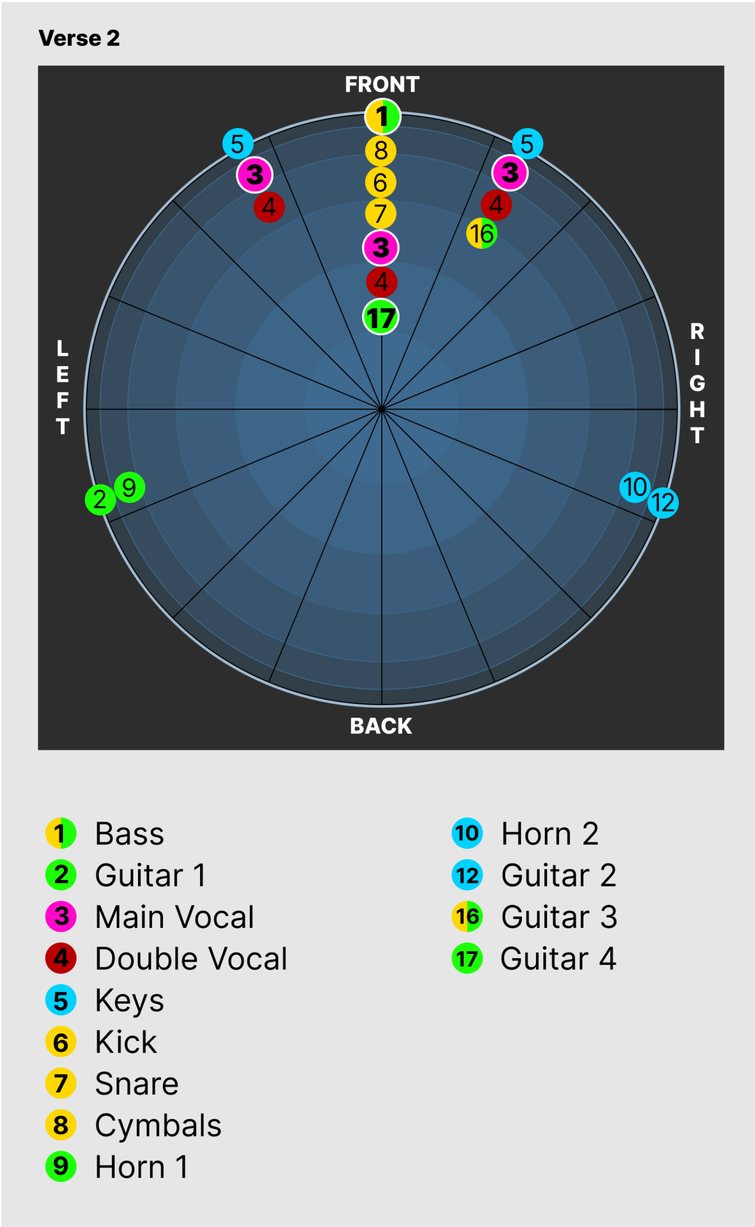

Figure B.37: Diagram for the **Verse 2** of the song "Morph the Cat" in the **surround sound** analysis.

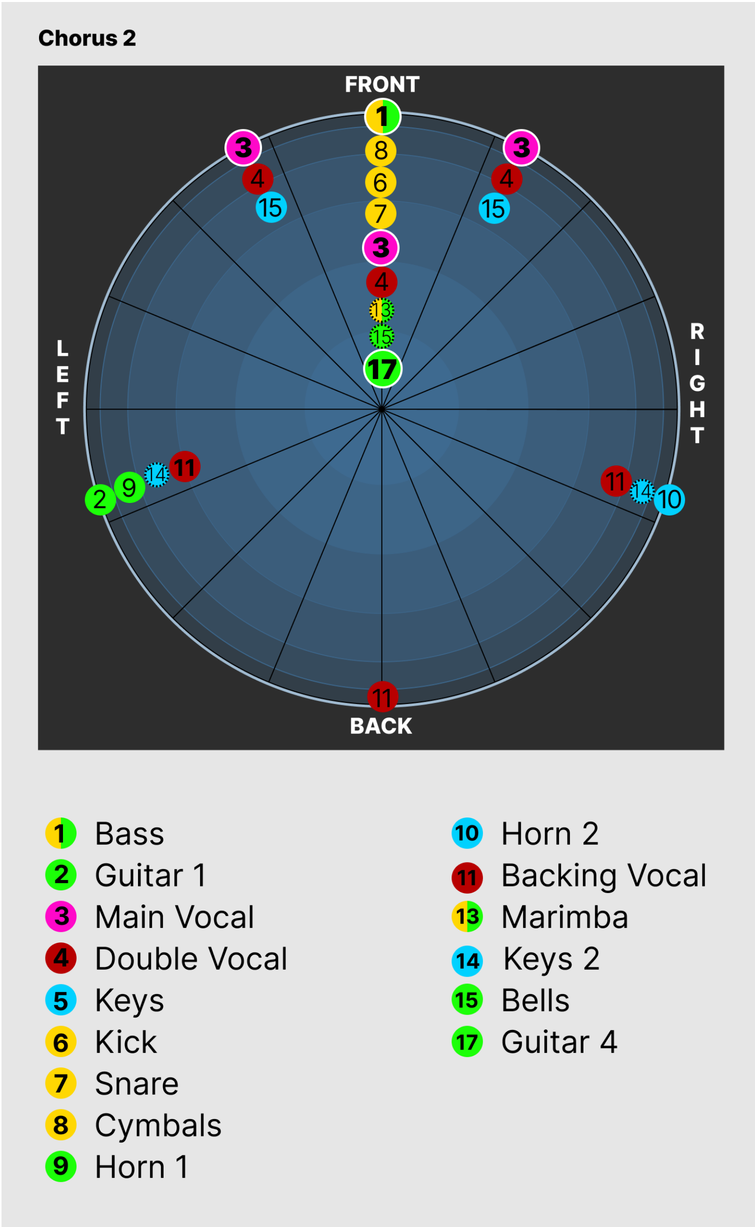

Figure B.38: Diagram for the **Chorus 2** of the song “Morph the Cat” in the **surround sound** analysis.

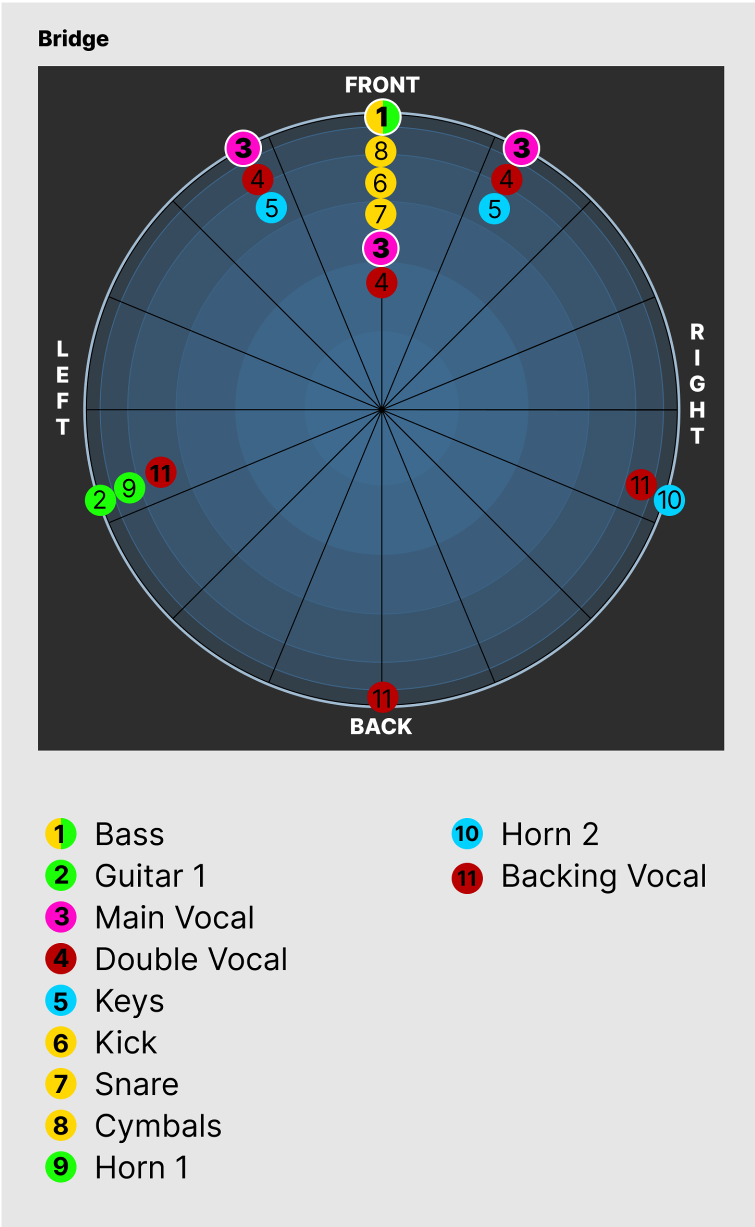

Figure B.39: Diagram for the **Bridge** of the song “Morph the Cat” in the **surround sound** analysis.

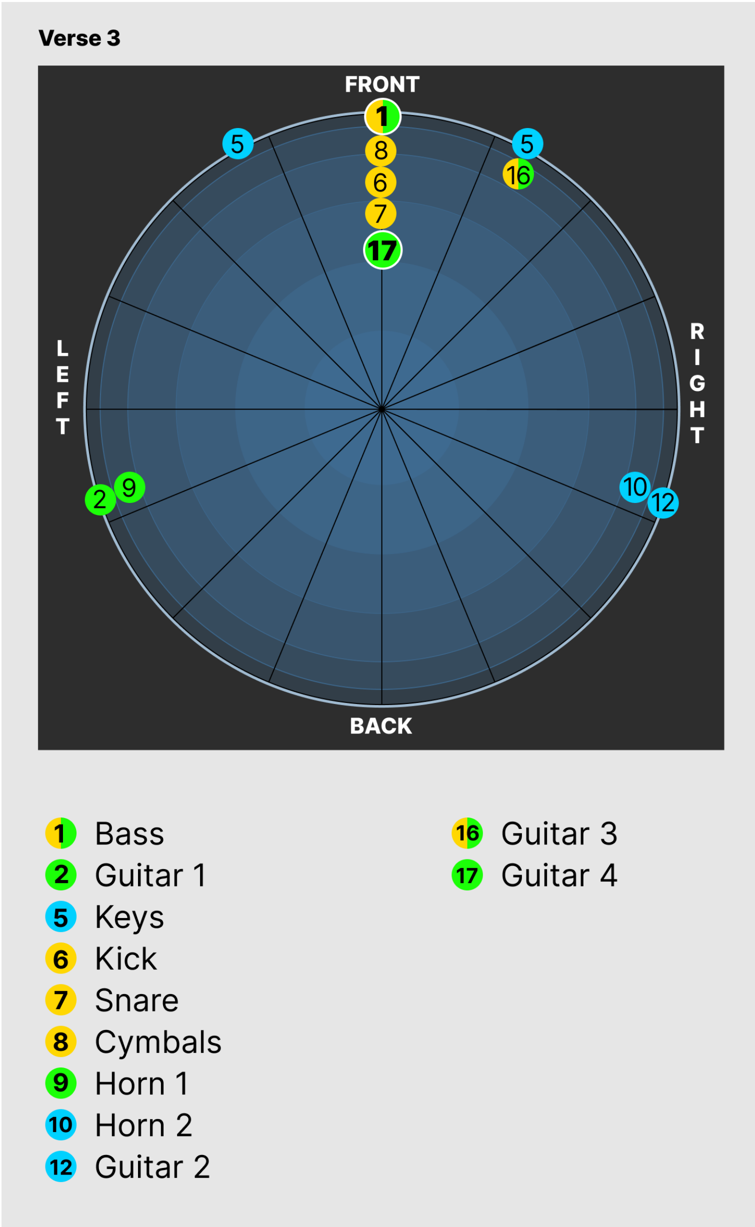

Figure B.40: Diagram for the **Verse 3** of the song “Morph the Cat” in the **surround sound** analysis.

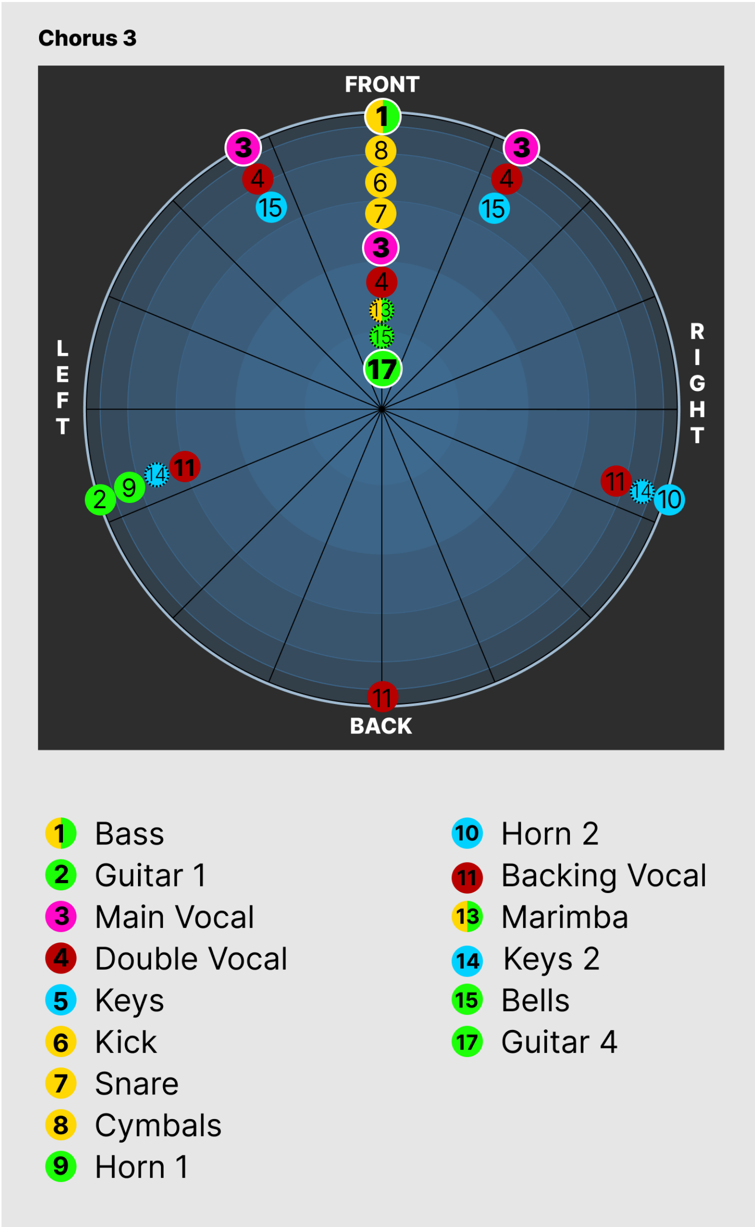

Figure B.41: Diagram for the **Chorus 3** of the song "Morph the Cat" in the **surround sound** analysis.

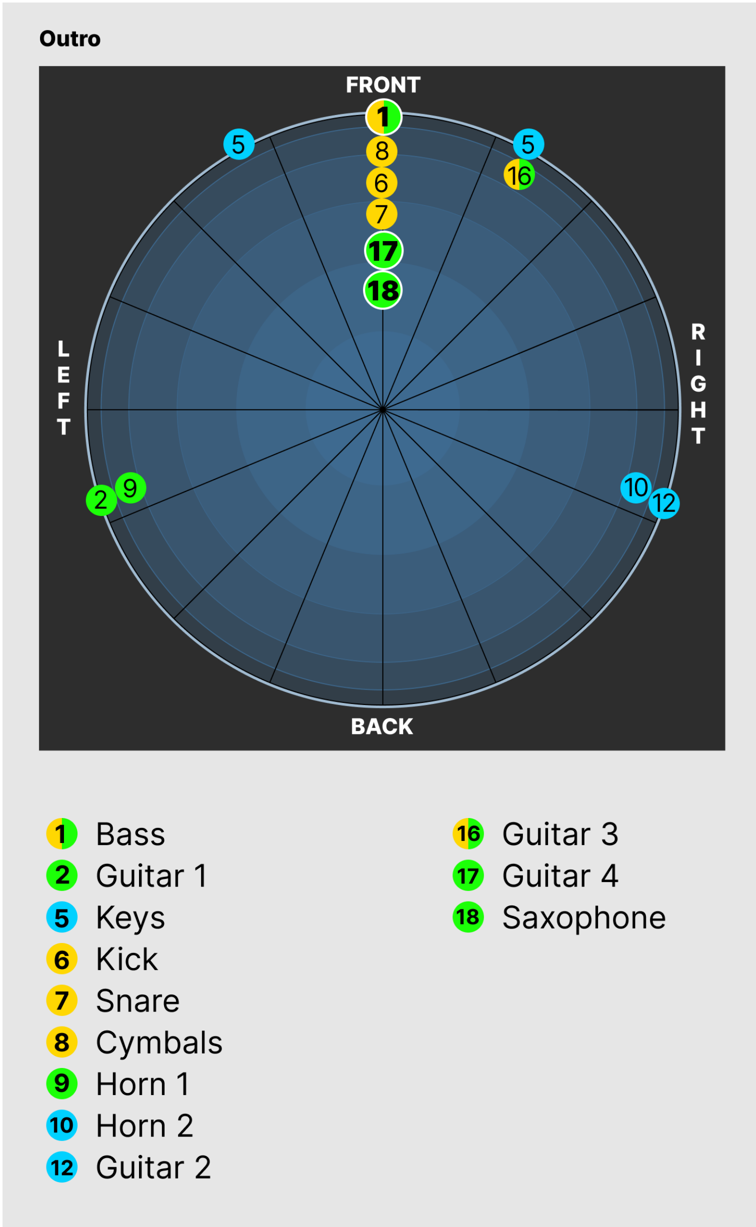

Figure B.42: Diagram for the **Outro** of the song “Morph the Cat” in the **surround sound** analysis.

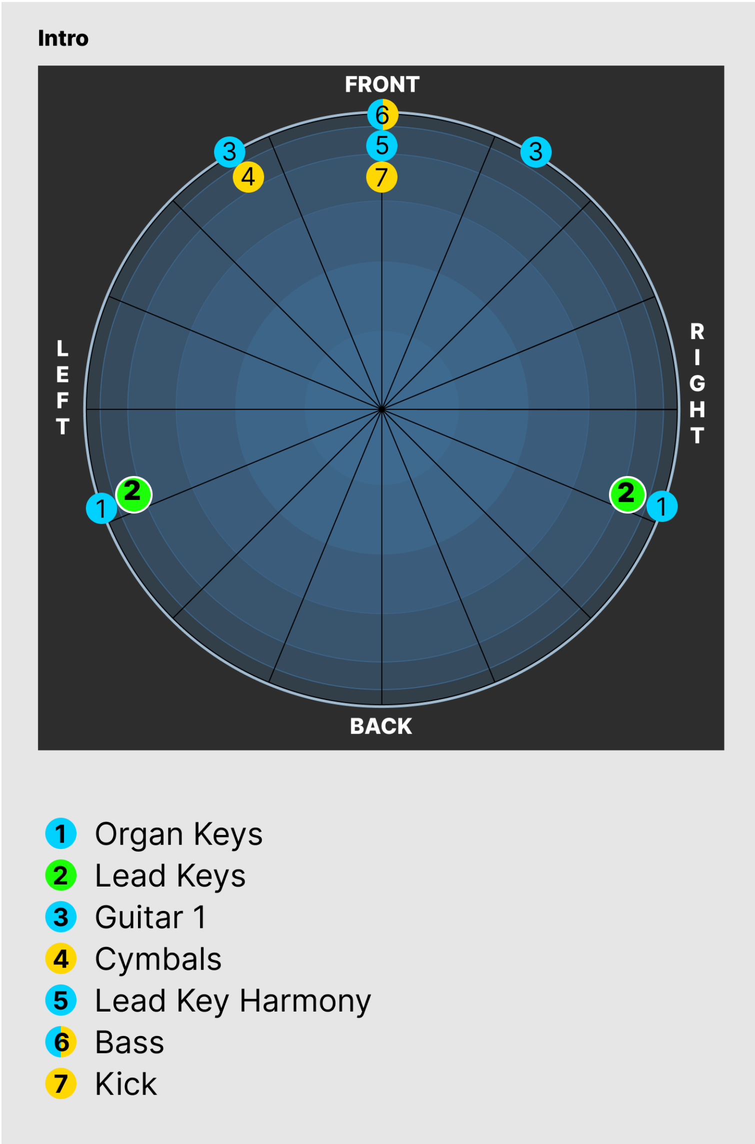

Figure B.43: Diagram for the **Intro** of the song "Walk of Life" in the **surround sound** analysis.

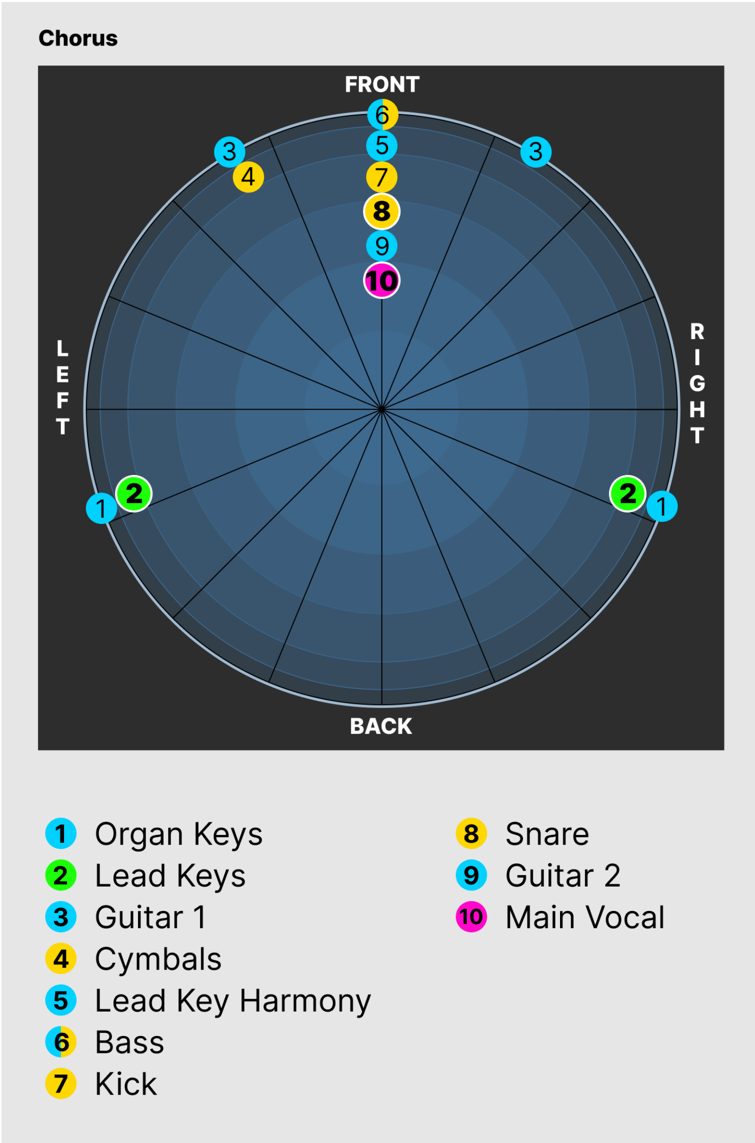

Figure B.44: Diagram for the **Chorus** of the song “Walk of Life” in the **surround sound** analysis.

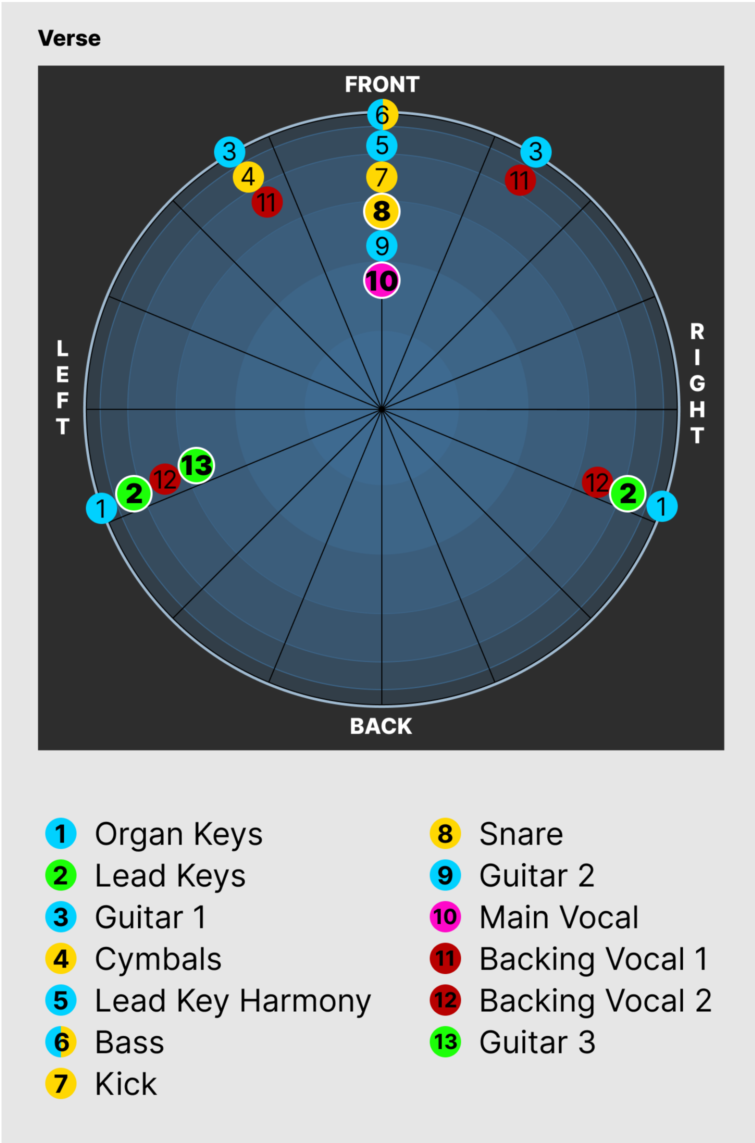

Figure B.45: Diagram for the **Verse** of the song “Walk of Life” in the **surround sound** analysis.

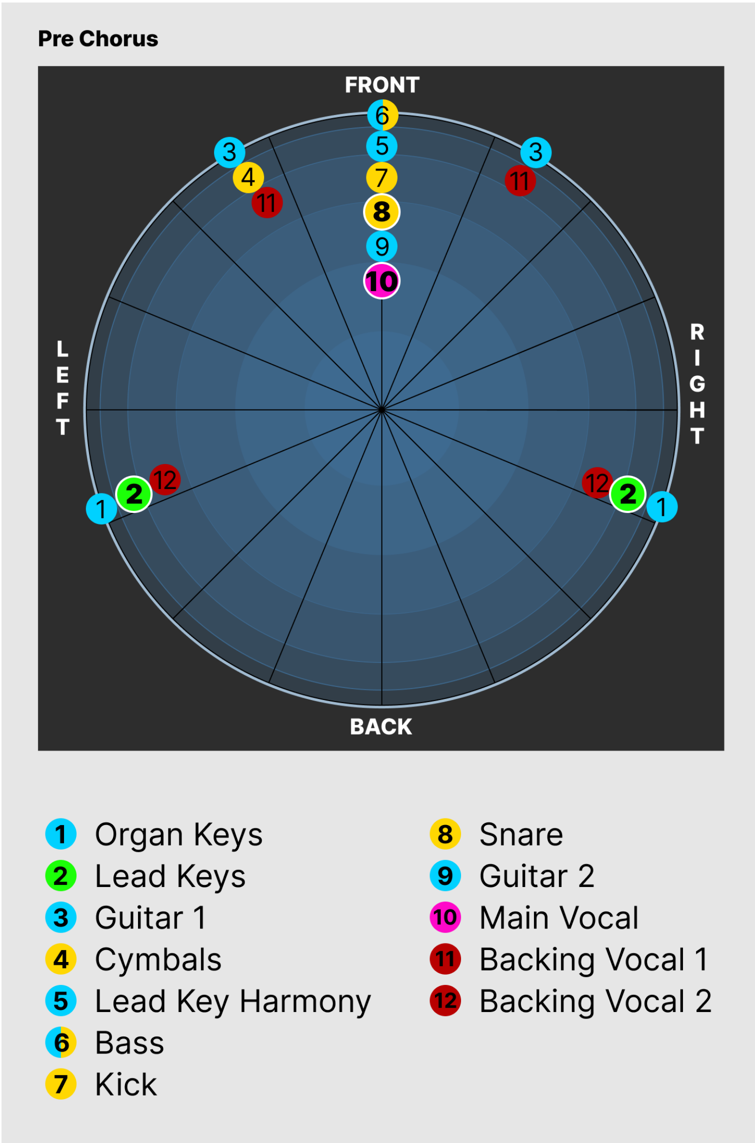

Figure B.46: Diagram for the **Pre Chorus** of the song "Walk of Life" in the **surround sound** analysis.

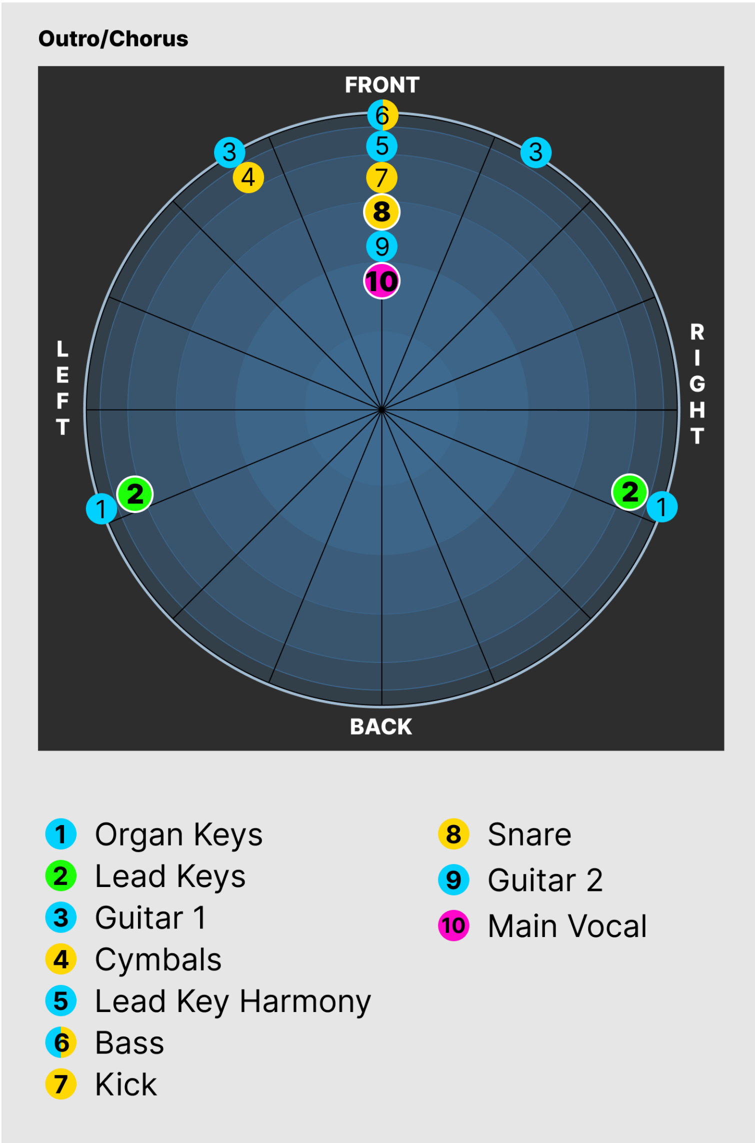

Figure B.47: Diagram for the **Outro/Chorus** of the song “Walk of Life” in the **surround sound** analysis.

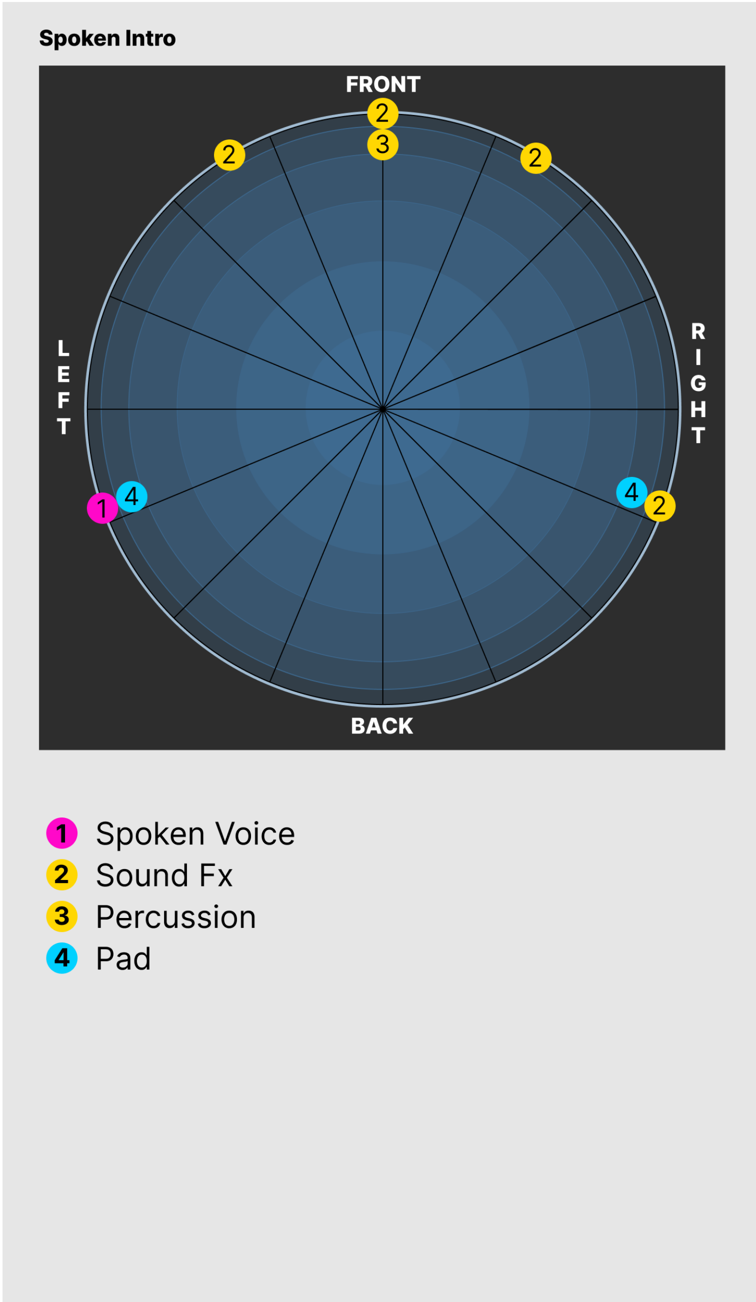

Figure B.48: Diagram for the **Spoken Intro** of the song “What God Wants” in the **surround sound** analysis.

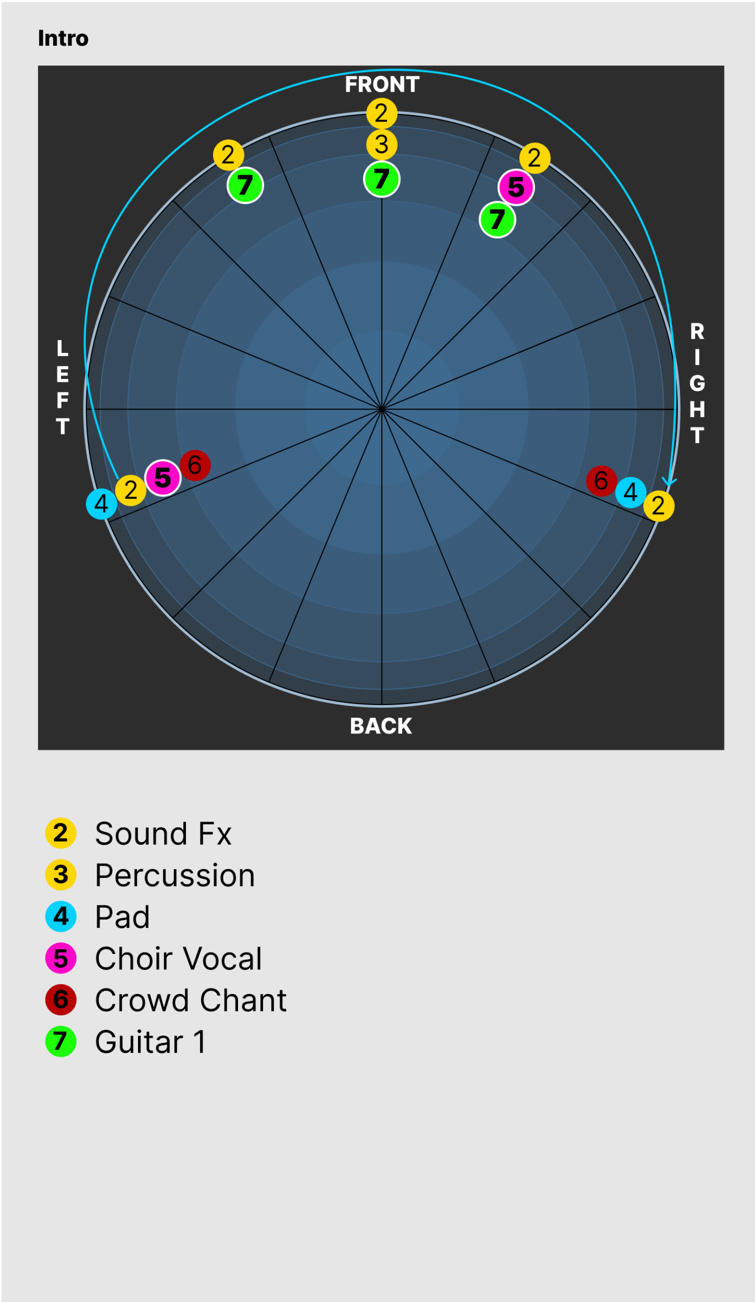

Figure B.49: Diagram for the **Intro** of the song “What God Wants” in the **surround sound** analysis.

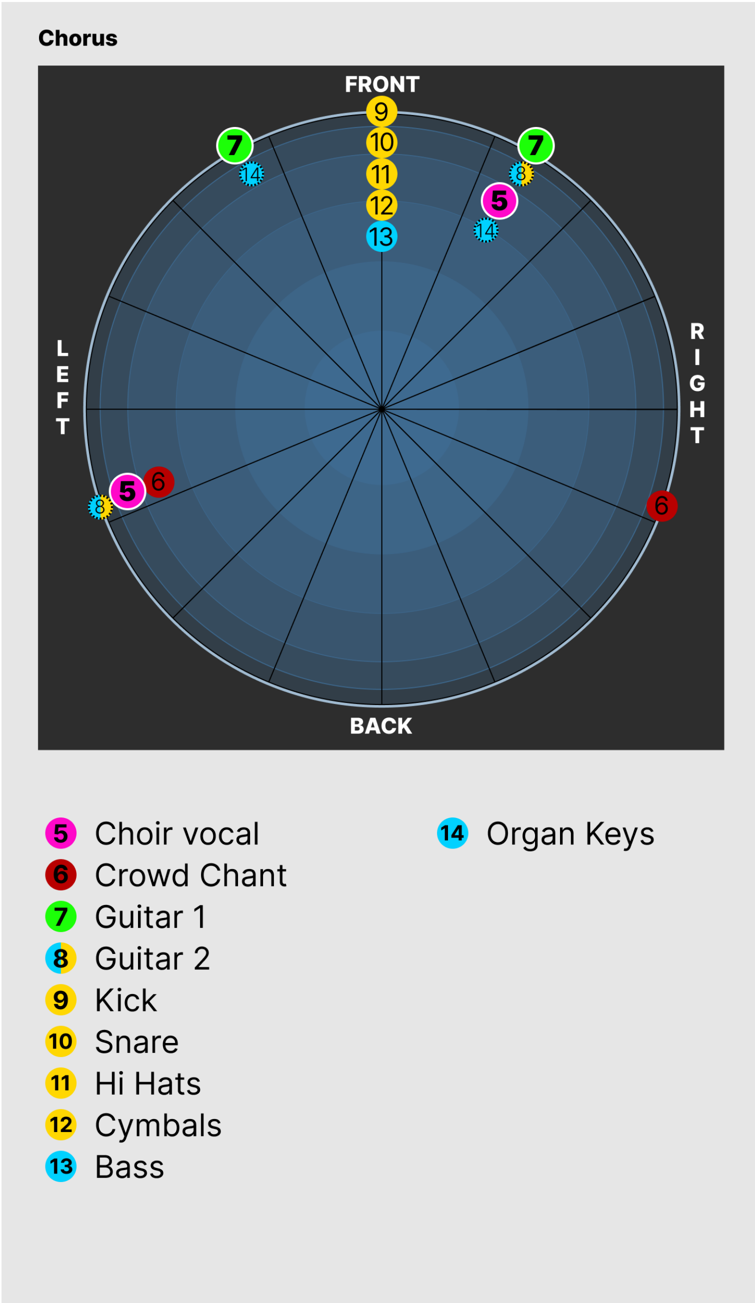

Figure B.50: Diagram for the **Chorus** of the song “What God Wants” in the **surround sound** analysis.

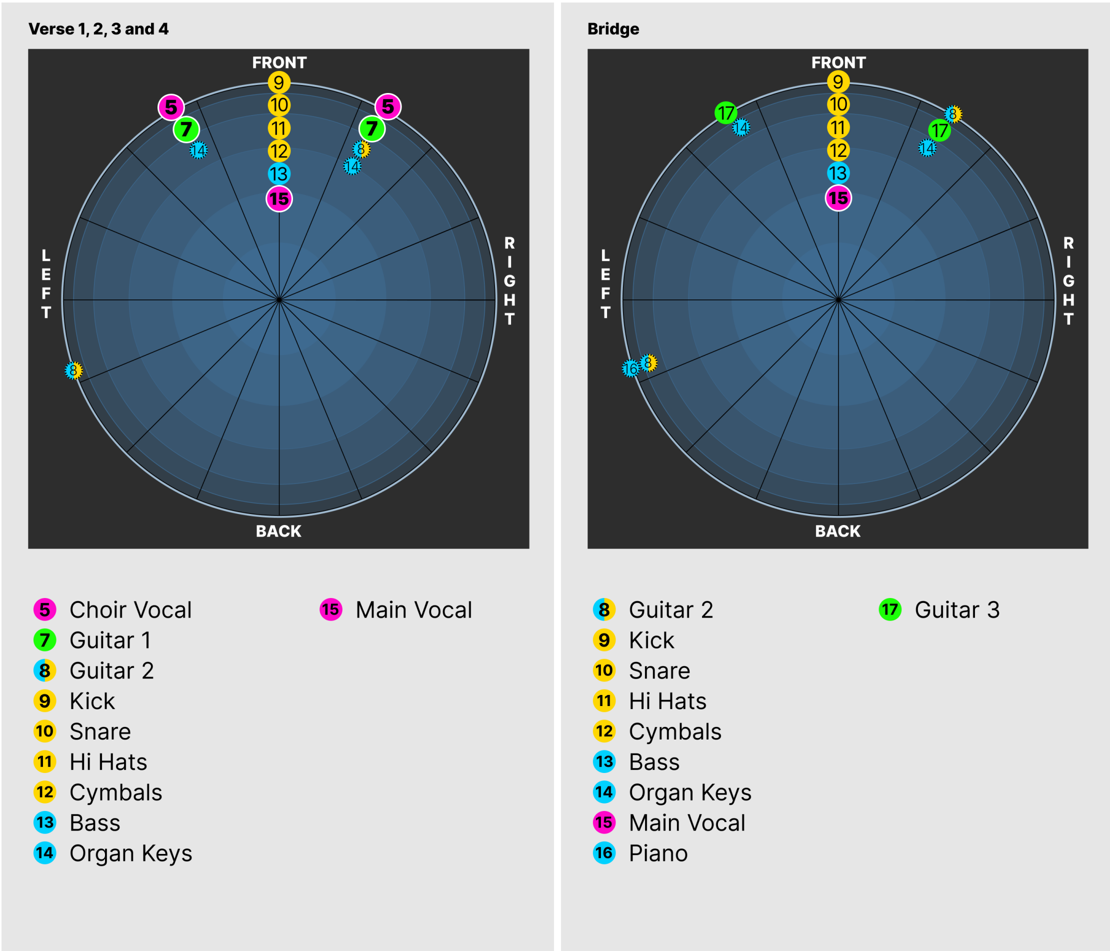

Figure B.51: Diagrams for the **Verses 1, 2, 3 and 4** and **Bridge** of the song “What God Wants” in the **surround sound** analysis.

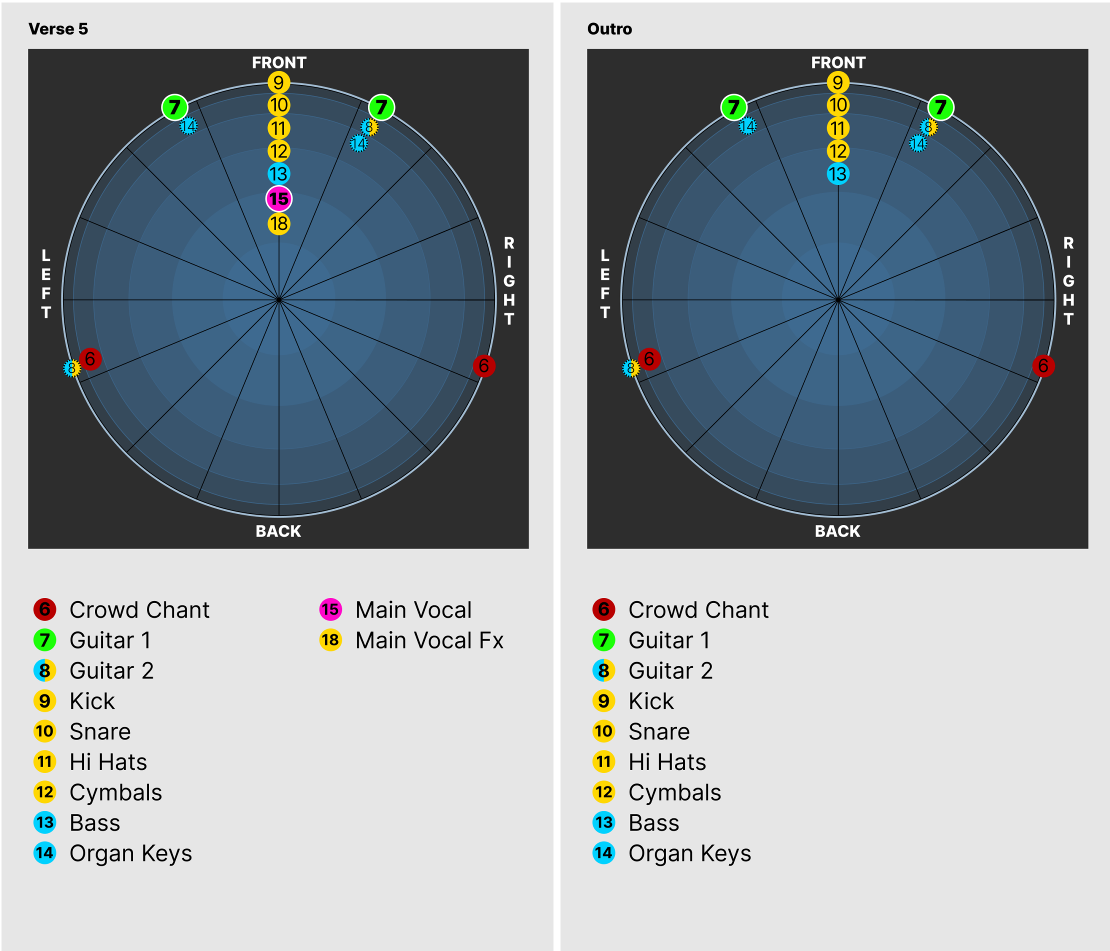

Figure B.52: Diagrams for the **Verse 5** and **Outro** of the song “What God Wants” in the **surround sound** analysis.

Diagrams From the Surround Sound Song Analysis

Appendix C

Diagrams From the Stereo Song Analysis

C.1 Contains all the diagrams for all the sections of each song analyzed in their stereo versions

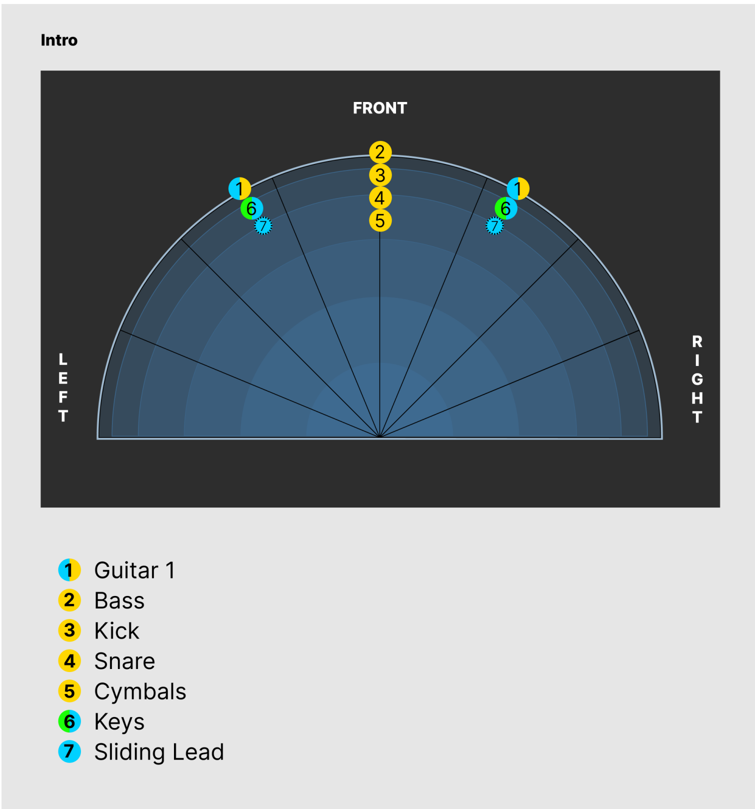

Figure C.1: Diagram for the **Intro** of the song "Eye in the Sky" in the **stereo** analysis.

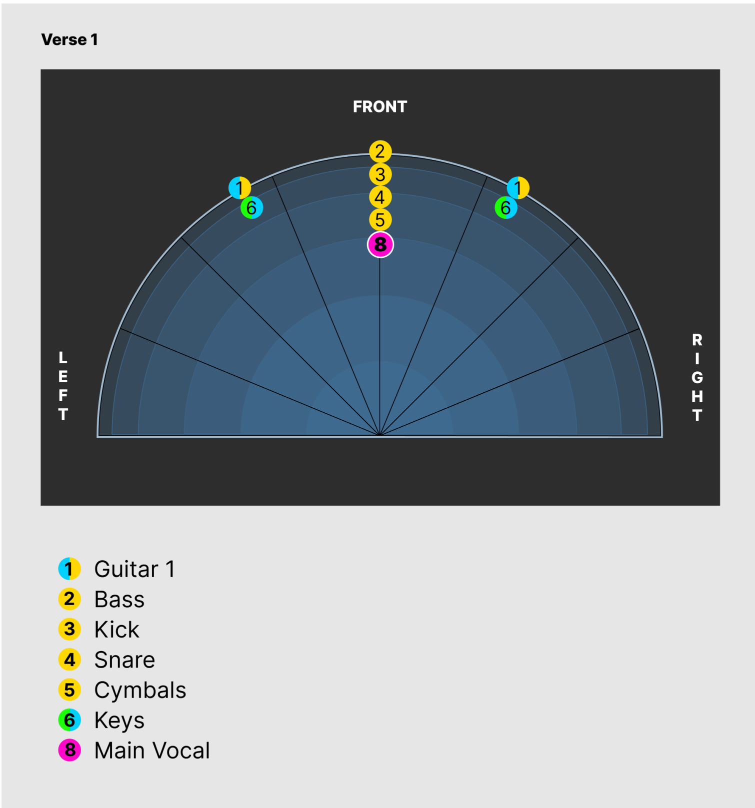

Figure C.2: Diagram for the **Verse 1** of the song “Eye in the Sky” in the **stereo** analysis.

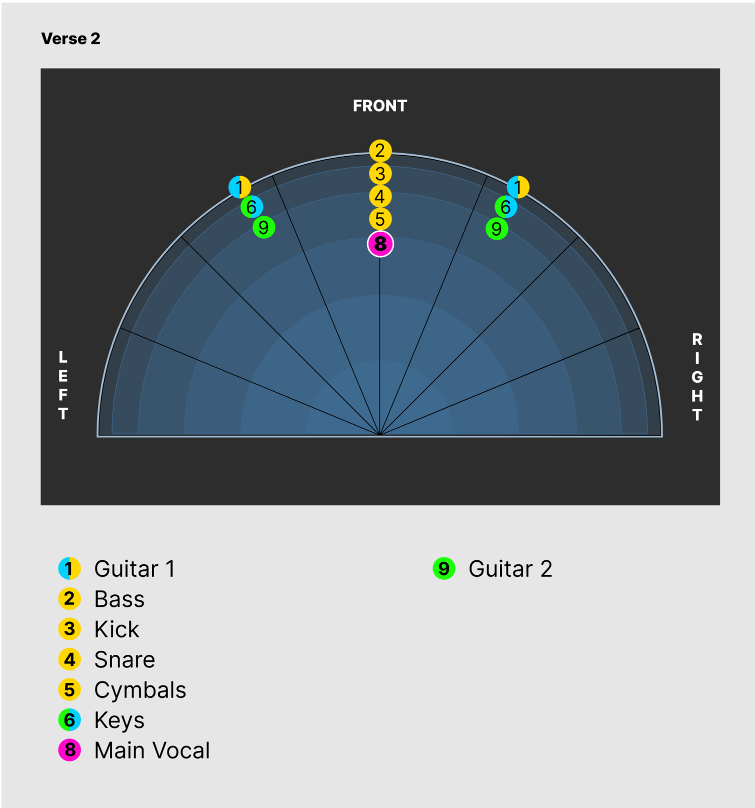

Figure C.3: Diagram for the **Verse 2** of the song “Eye in the Sky” in the **stereo** analysis.

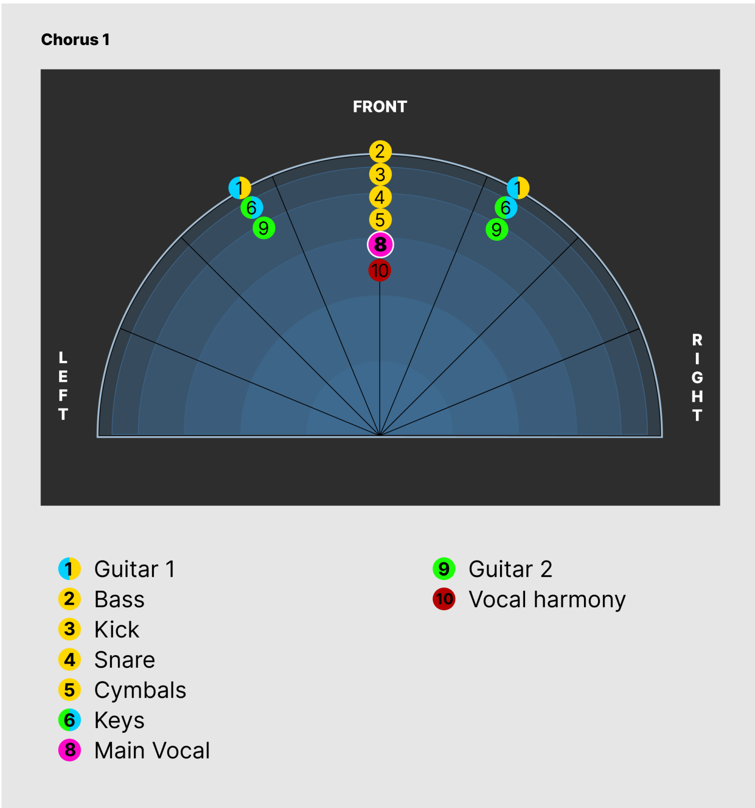

Figure C.4: Diagram for the **Chorus 1** of the song “Eye in the Sky” in the **stereo** analysis.

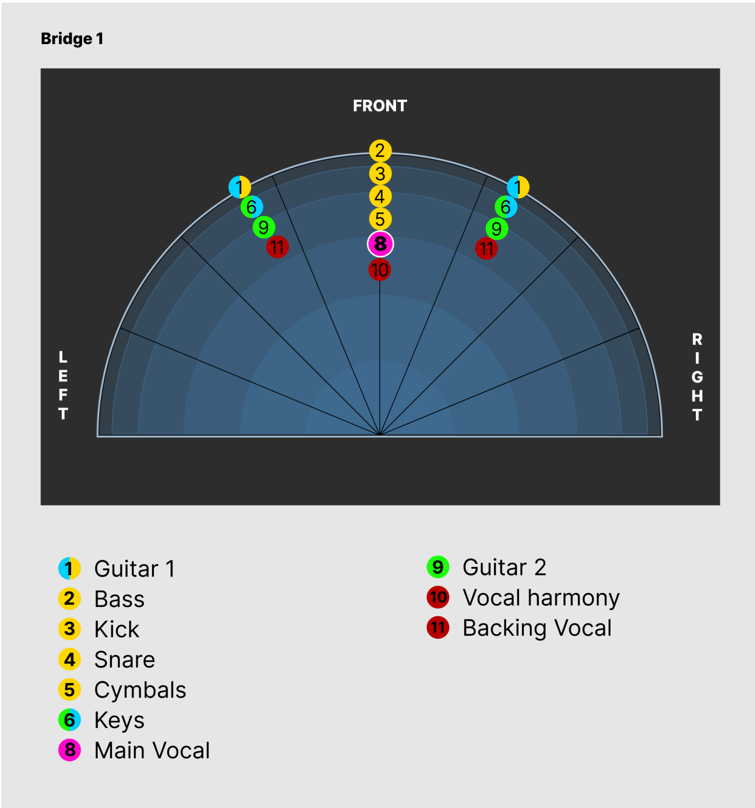

Figure C.5: Diagram for the **Bridge 1** of the song “Eye in the Sky” in the **stereo** analysis.

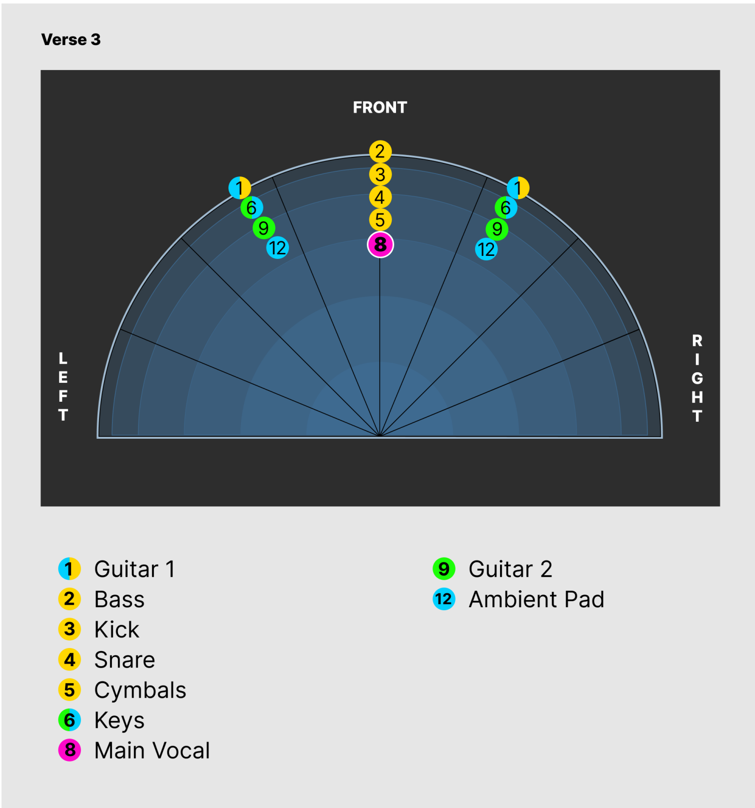

Figure C.6: Diagram for the **Verse 3** of the song “Eye in the Sky” in the **stereo** analysis.

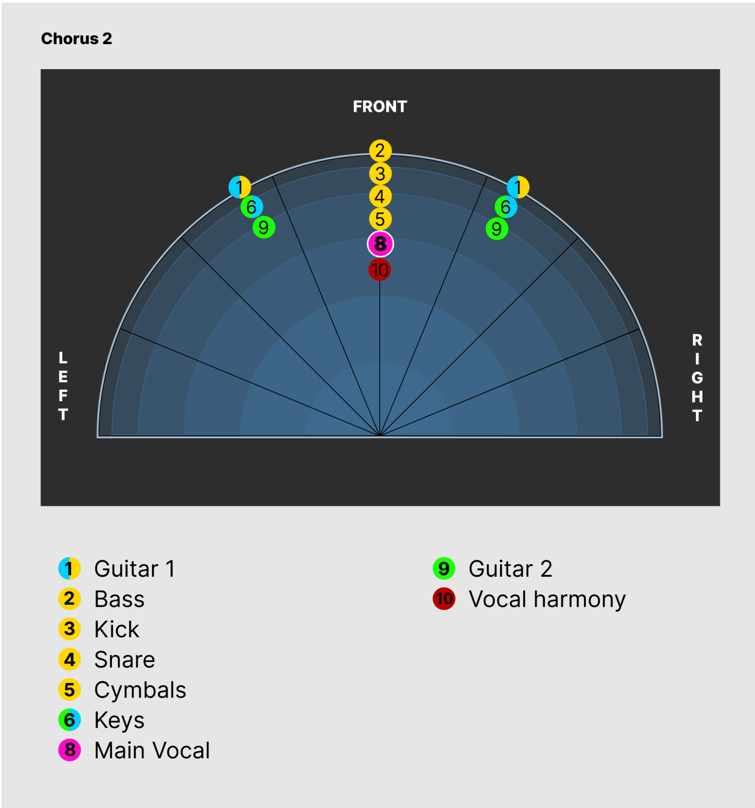

Figure C.7: Diagram for the **Chorus 2** of the song "Eye in the Sky" in the **stereo** analysis.

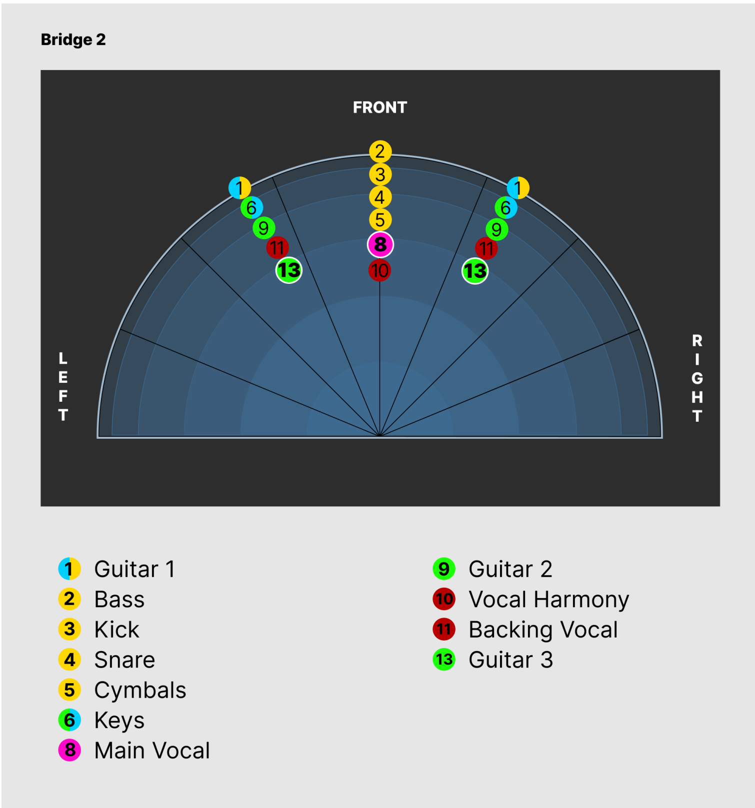

Figure C.8: Diagram for the **Bridge 2** of the song "Eye in the Sky" in the **stereo** analysis.

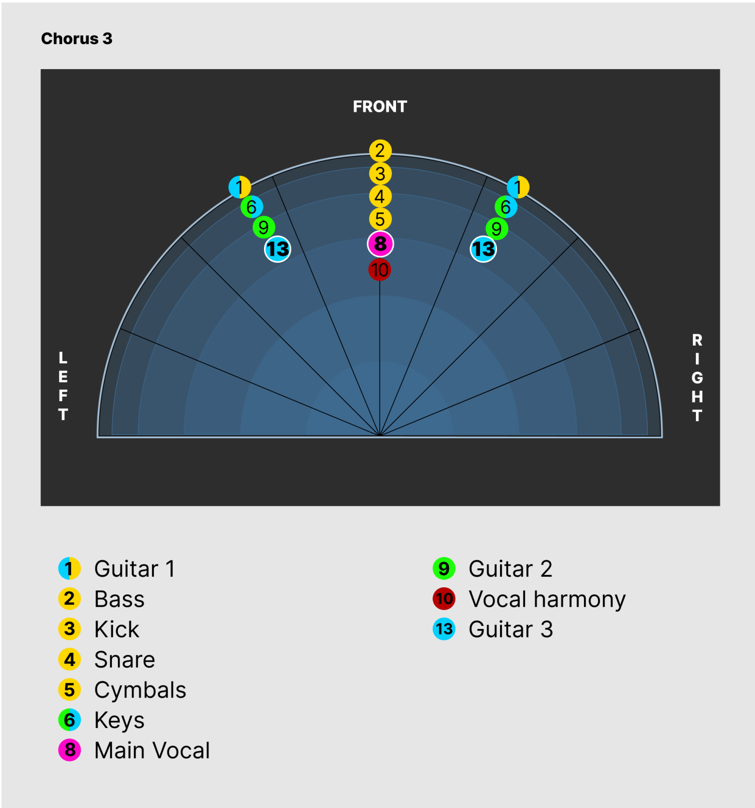

Figure C.9: Diagram for the **Chorus 3** of the song “Eye in the Sky” in the **stereo** analysis.

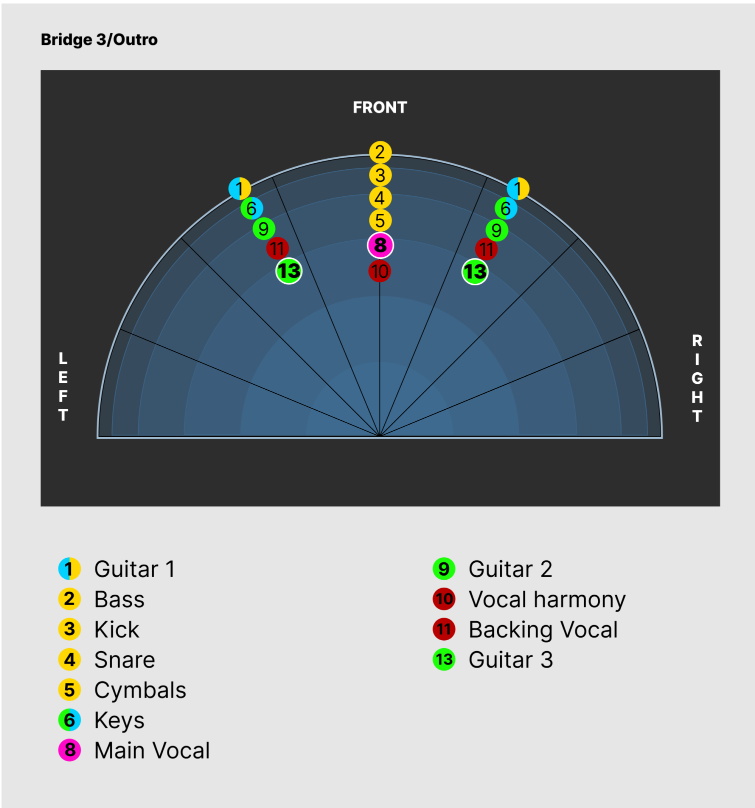

Figure C.10: Diagram for the **Bridge 3/Outro** of the song “Eye in the Sky” in the **stereo** analysis.

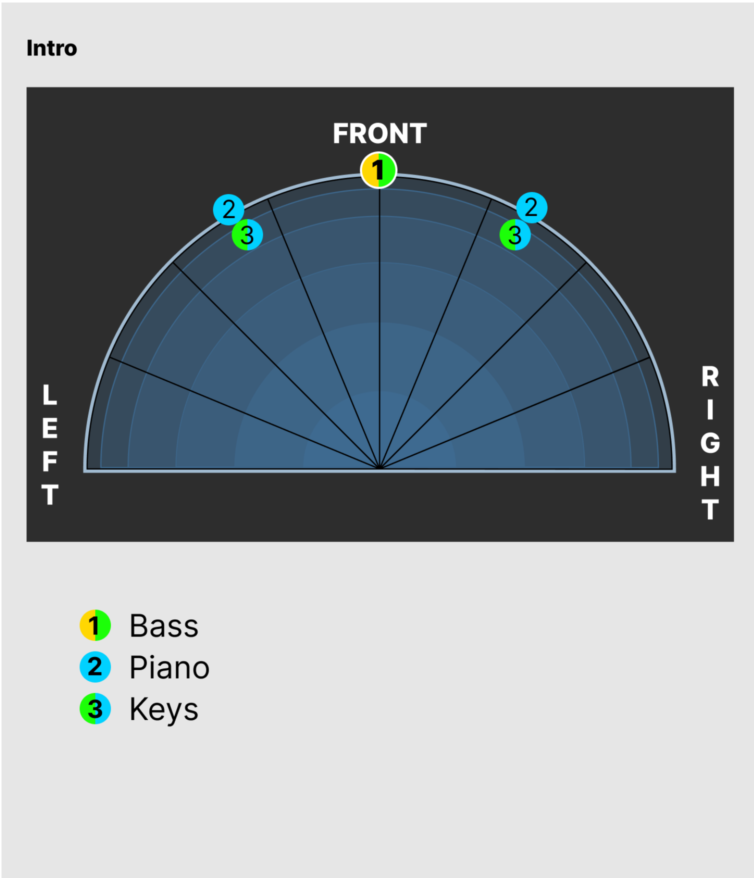

Figure C.11: Diagram for the **Intro** of the song “Here We Go Again” in the **stereo** analysis.

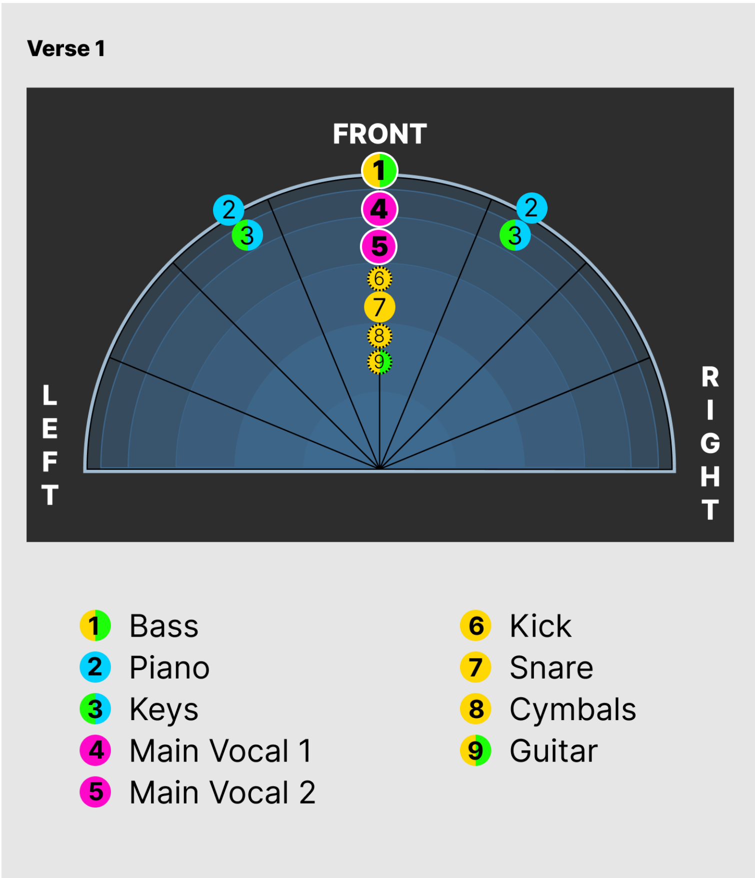

Figure C.12: Diagram for the **Verse 1** of the song “Here We Go Again” in the **stereo** analysis.

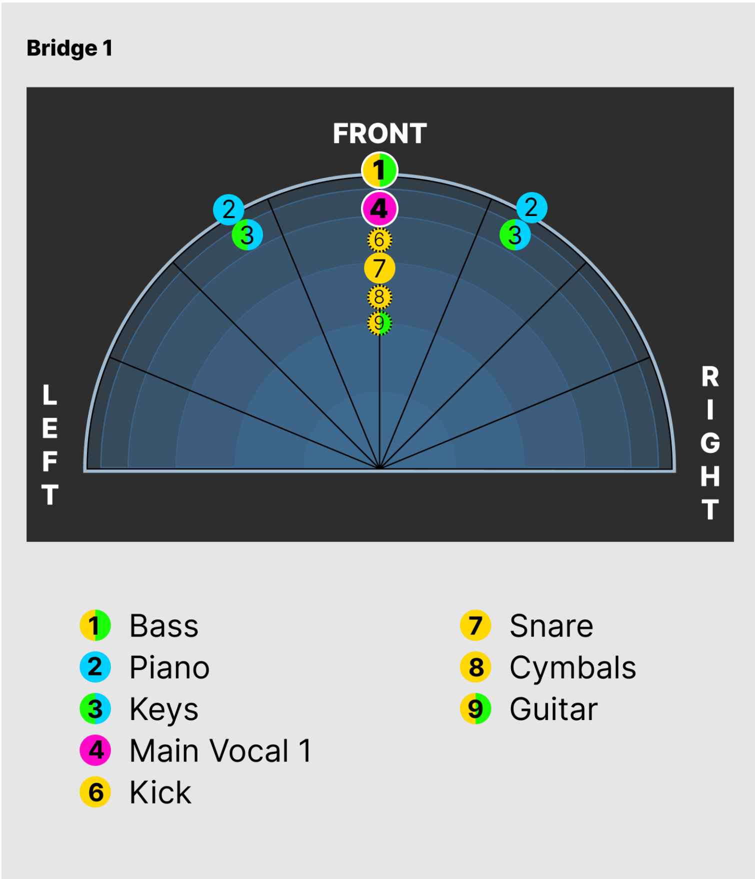

Figure C.13: Diagram for the **Bridge 1** of the song “Here We Go Again” in the **stereo** analysis.

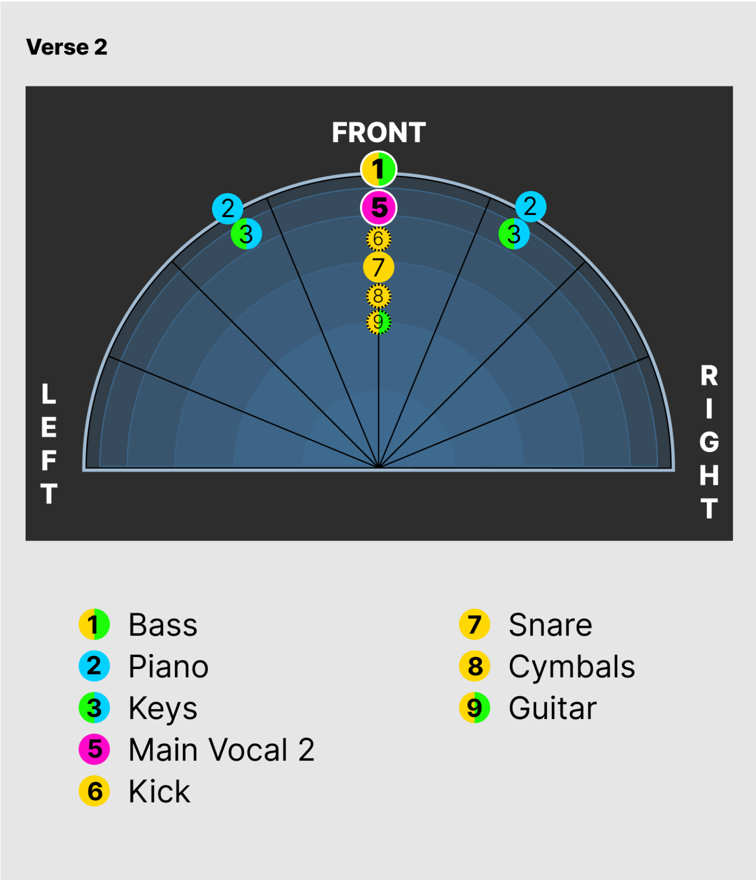

Figure C.14: Diagram for the **Verse 2** of the song “Here We Go Again” in the **stereo** analysis.

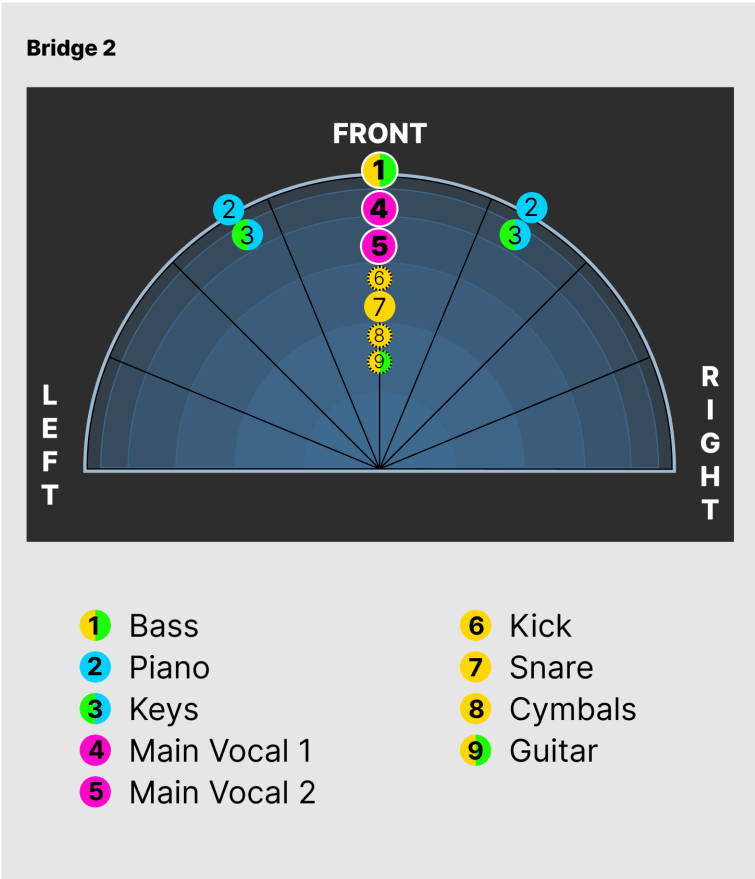

Figure C.15: Diagram for the **Bridge 2** of the song "Here We Go Again" in the **stereo** analysis.

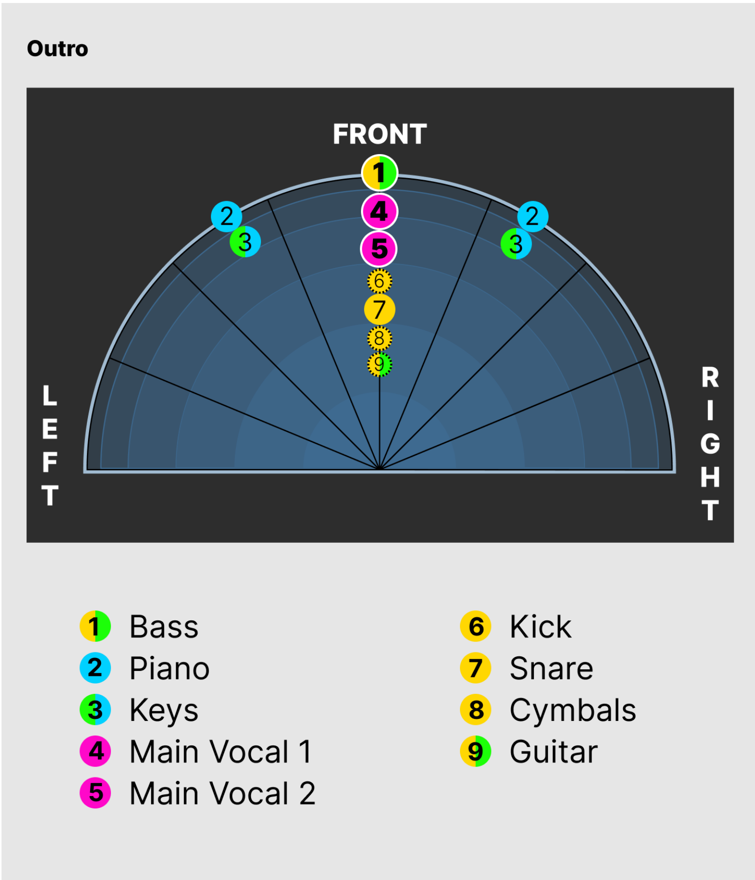

Figure C.16: Diagram for the **Outro** of the song “Here We Go Again” in the **stereo** analysis.

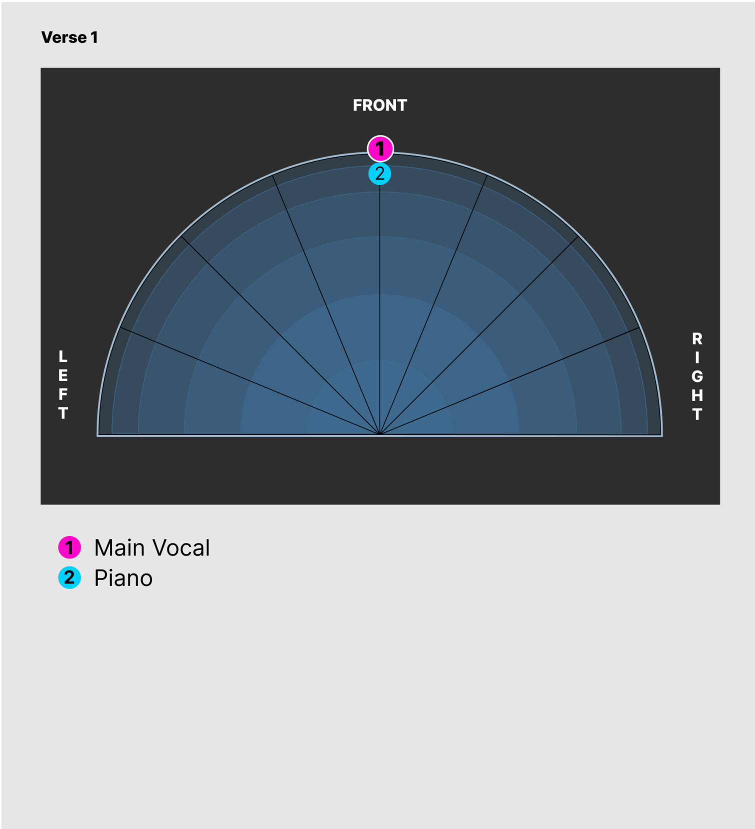

Figure C.17: Diagram for the **Verse 1** of the song “Hey Jude” in the **stereo** analysis.

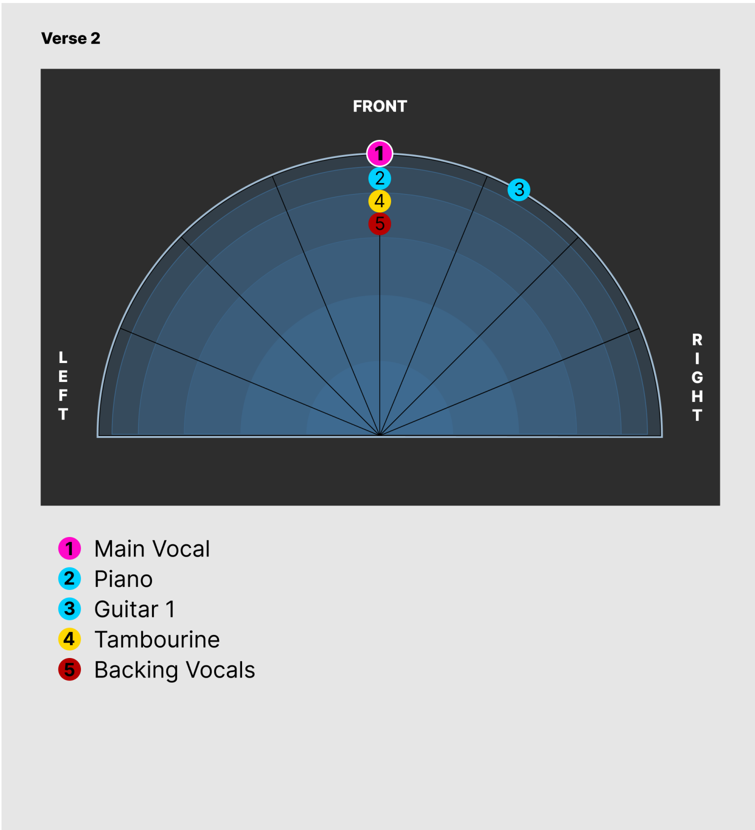

Figure C.18: Diagram for the **Verse 2** of the song “Hey Jude” in the **stereo** analysis.

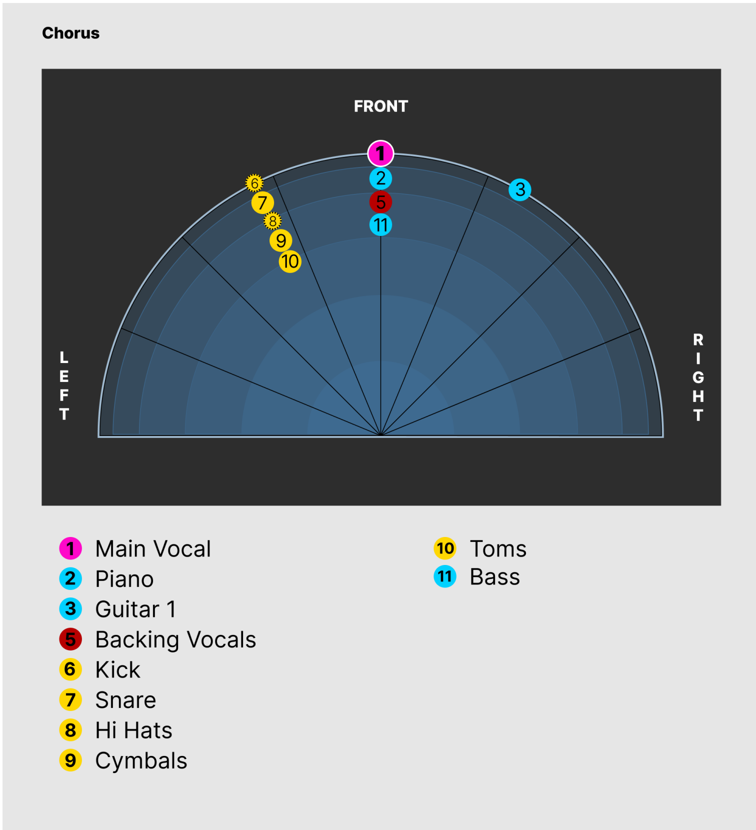

Figure C.19: Diagram for the **Chorus** of the song "Hey Jude" in the **stereo** analysis.

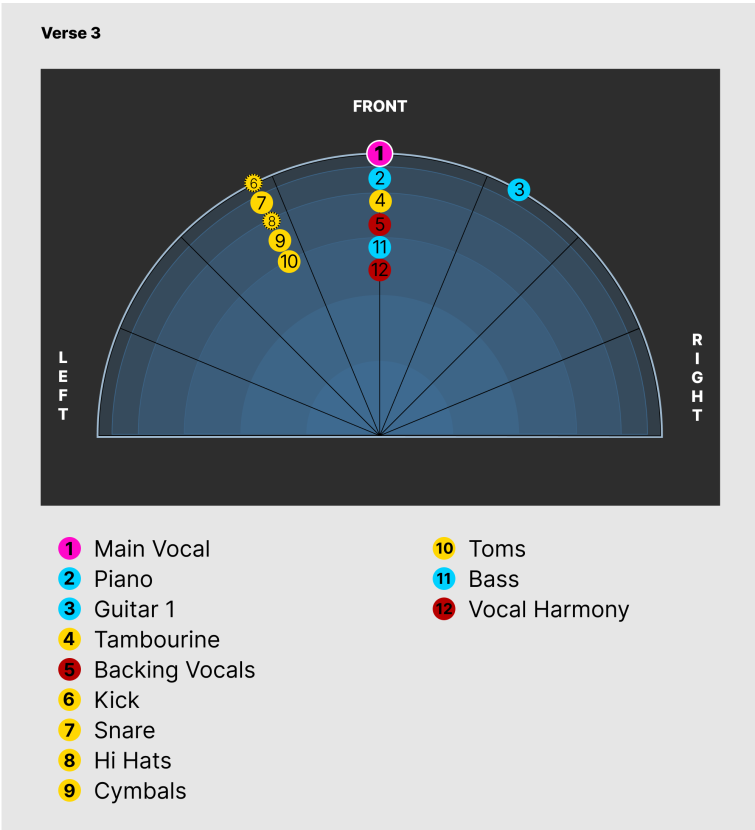

Figure C.20: Diagram for the **Verse 3** of the song “Hey Jude” in the **stereo** analysis.

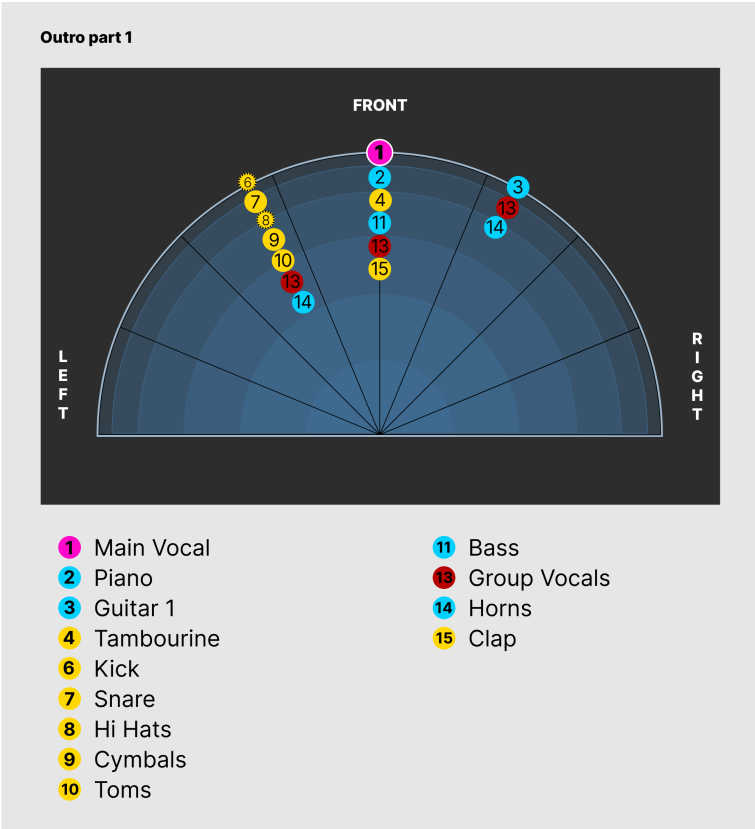

Figure C.21: Diagram for the **Outro Part 1** of the song “Hey Jude” in the **stereo** analysis.

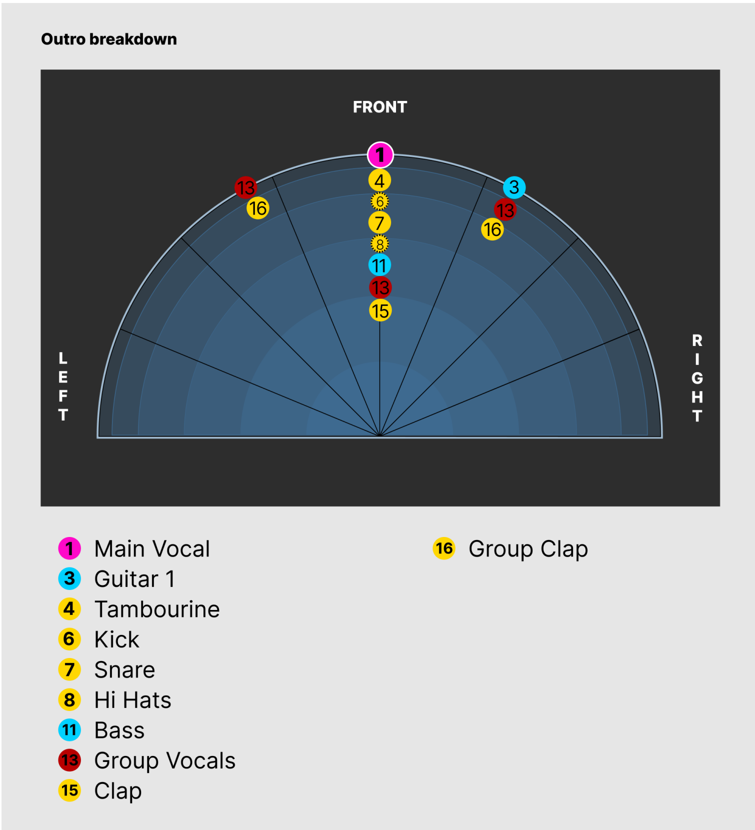

Figure C.22: Diagram for the **Outro Breakdown** of the song “Hey Jude” in the **stereo** analysis.

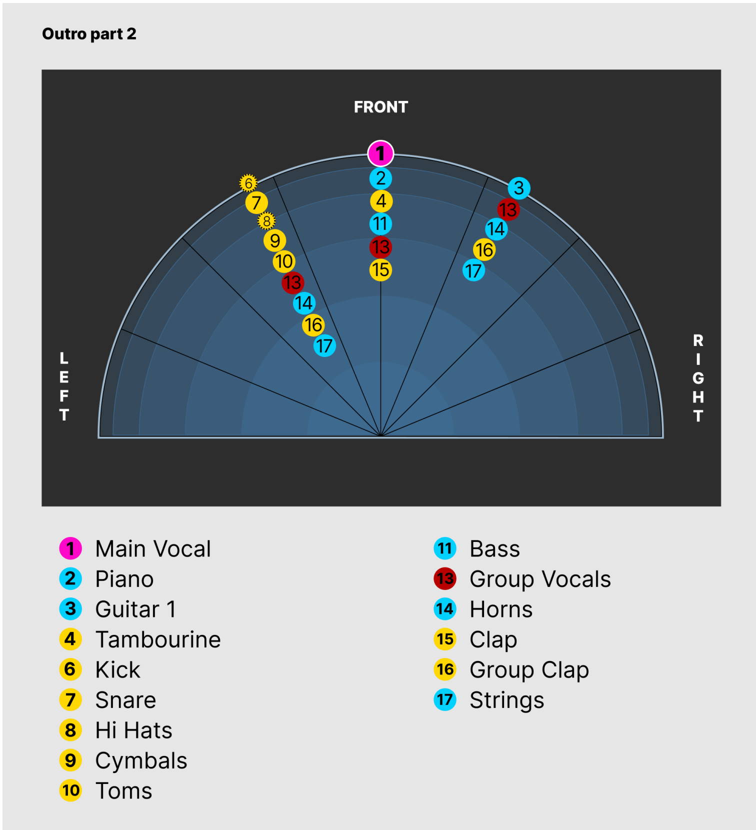

Figure C.23: Diagram for the **Outro Part 2** of the song “Hey Jude” in the **stereo** analysis.

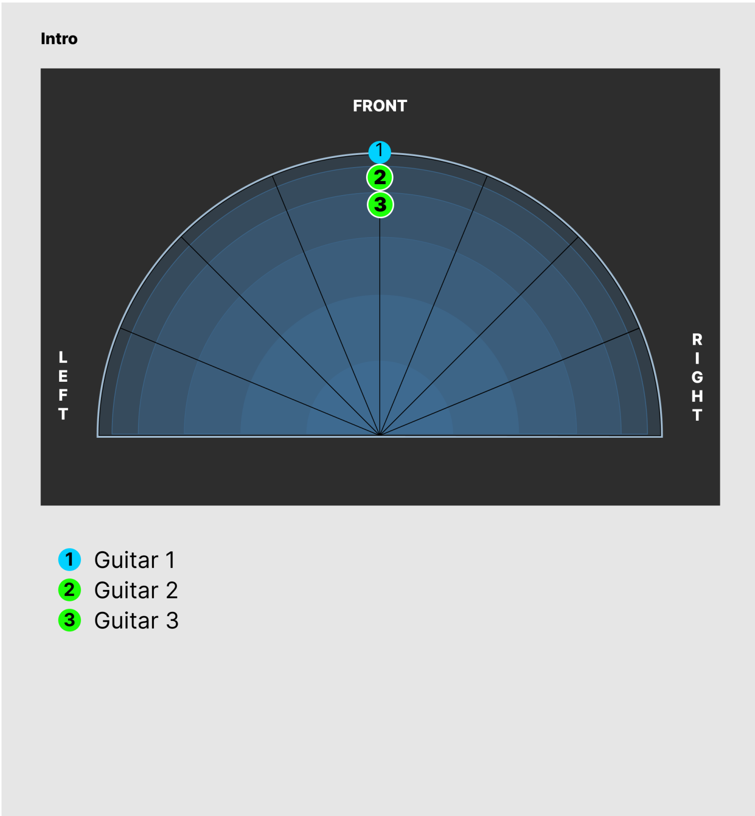

Figure C.24: Diagram for the **Part 1 - Intro** of the song “Layla” in the **stereo** analysis.

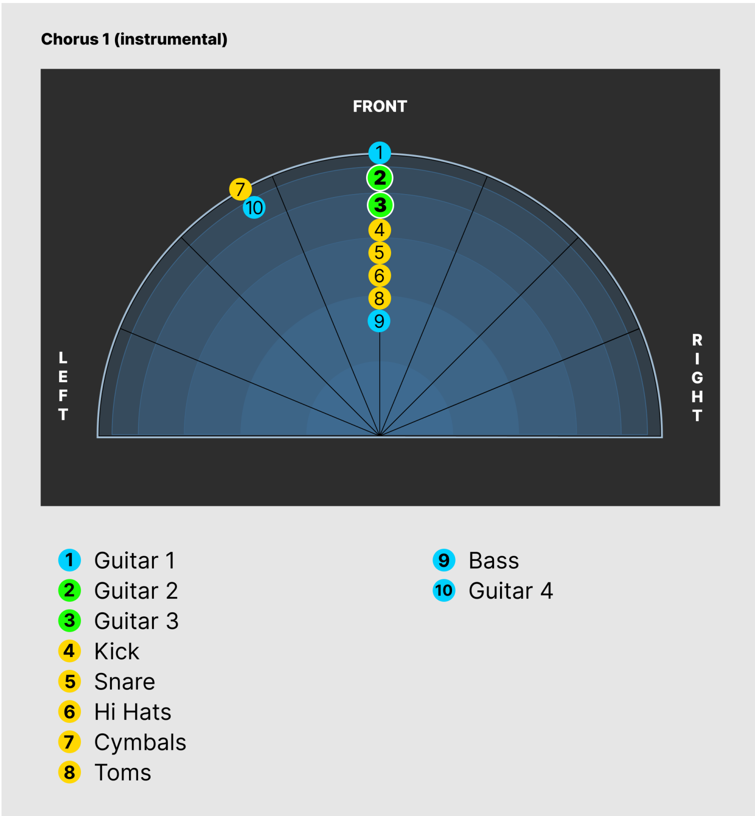

Figure C.25: Diagram for the **Part 1 - Chorus (instrumental)** of the song “Layla” in the **stereo** analysis.

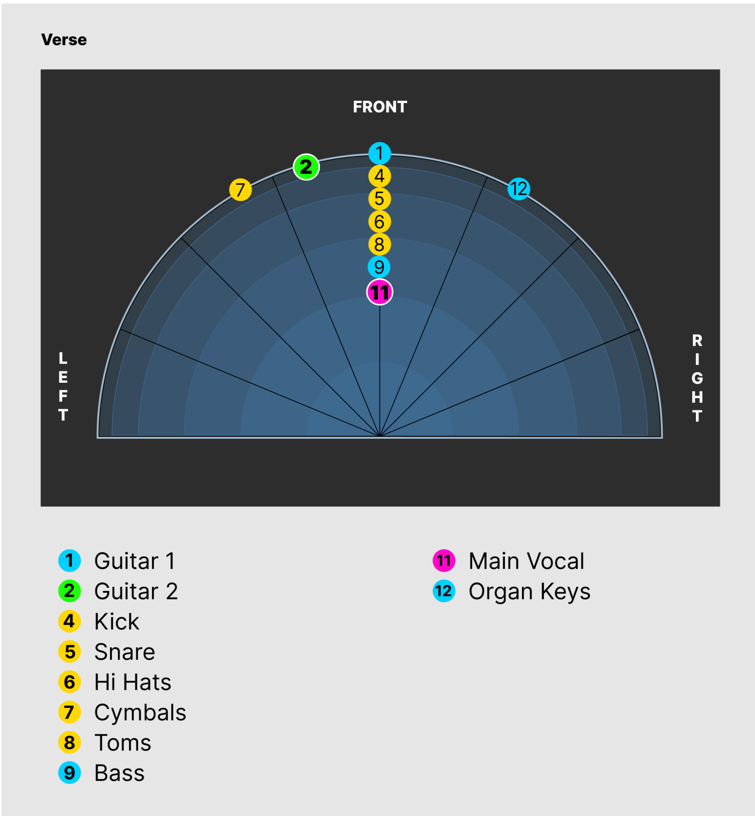

Figure C.26: Diagram for the **Part 1 - Verse** of the song “Layla” in the **stereo** analysis.

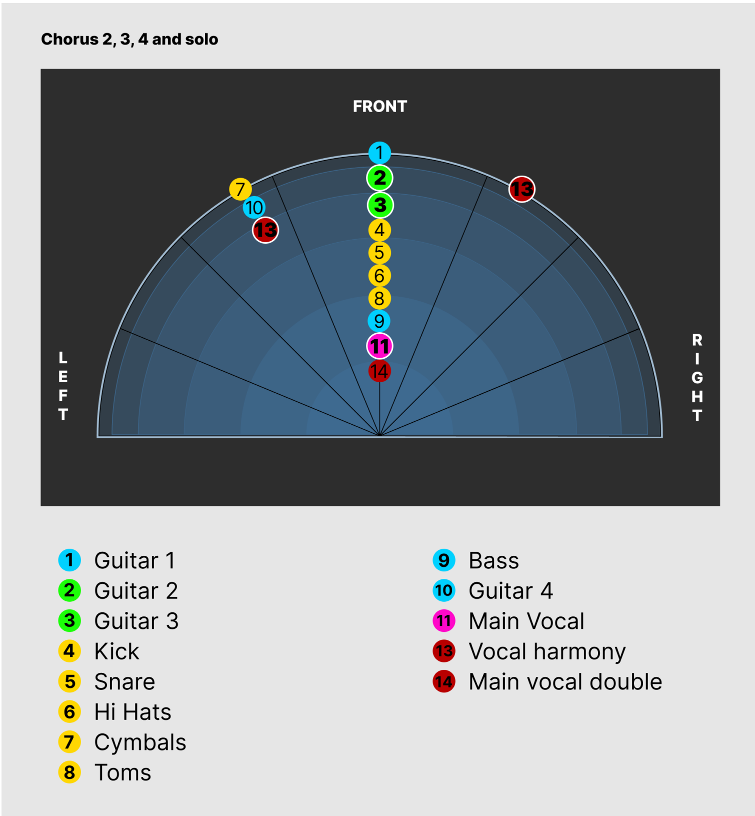

Figure C.27: Diagram for the **Part 1 - Chorus 2, 3, 4 and Solo** of the song “Layla” in the **stereo** analysis.

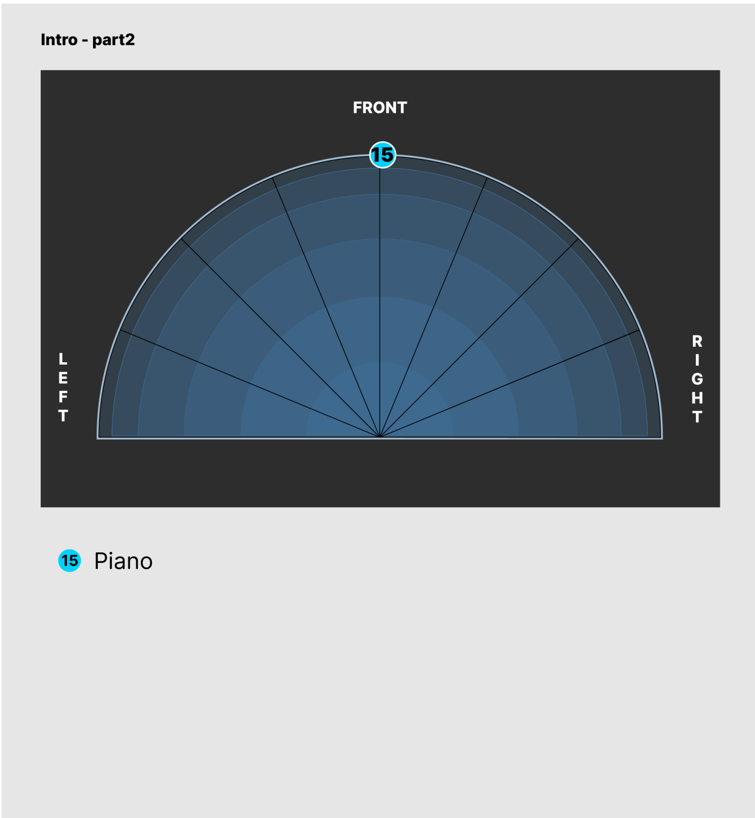

Figure C.28: Diagram for the **Part 2 - Intro** of the song “Layla” in the **stereo** analysis.

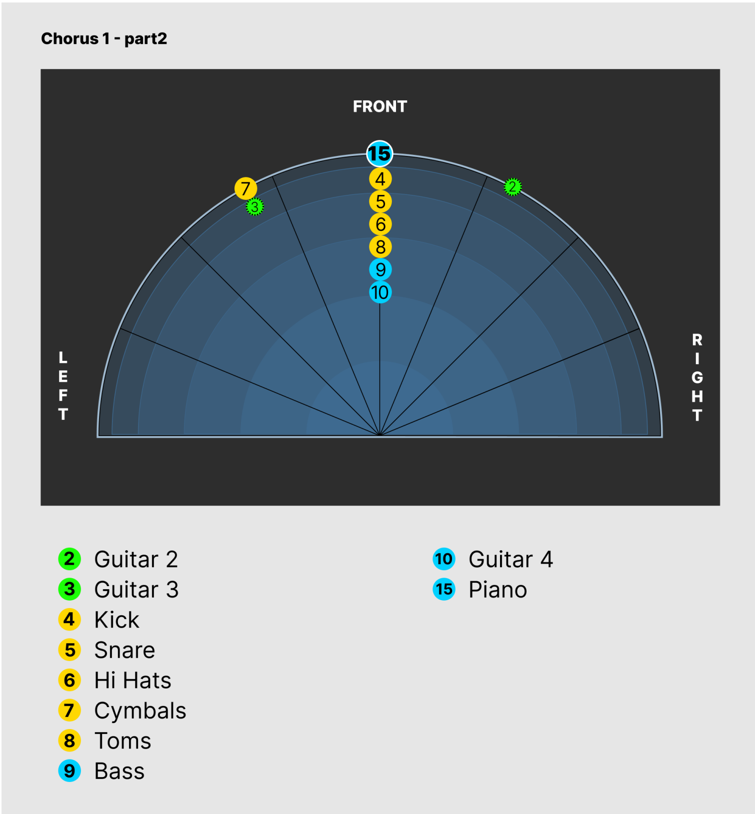

Figure C.29: Diagram for the **Part 2 - Chorus 1** of the song “Layla” in the **stereo** analysis.

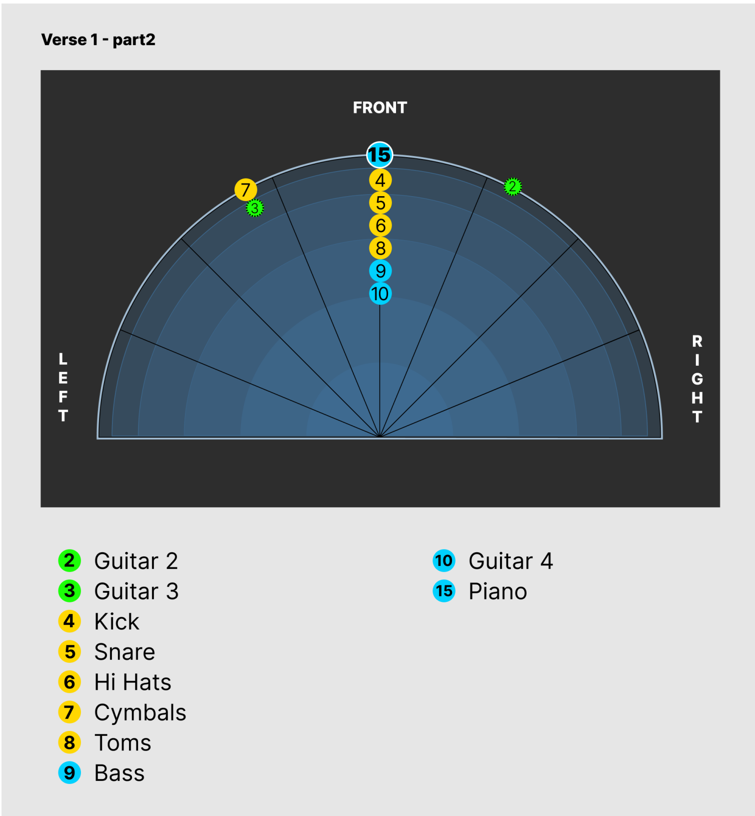

Figure C.30: Diagram for the **Part 2 - Verse 1** of the song “Layla” in the **stereo** analysis.

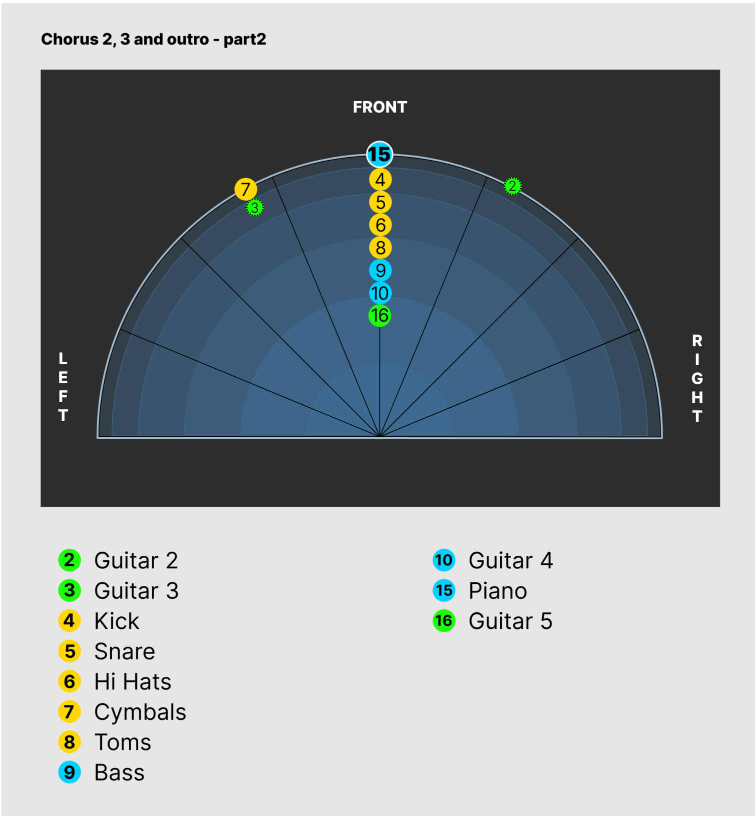

Figure C.31: Diagram for the **Part 2 - Chorus and Outro** of the song “Layla” in the **stereo** analysis.

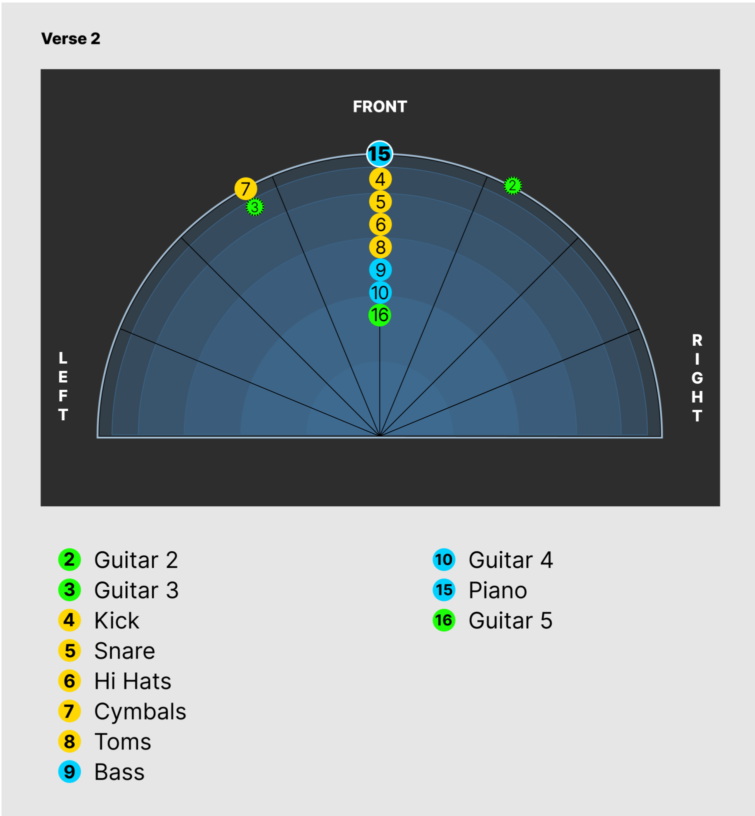

Figure C.32: Diagram for the **Part 2 - Verse 2** of the song “Layla” in the **stereo** analysis.

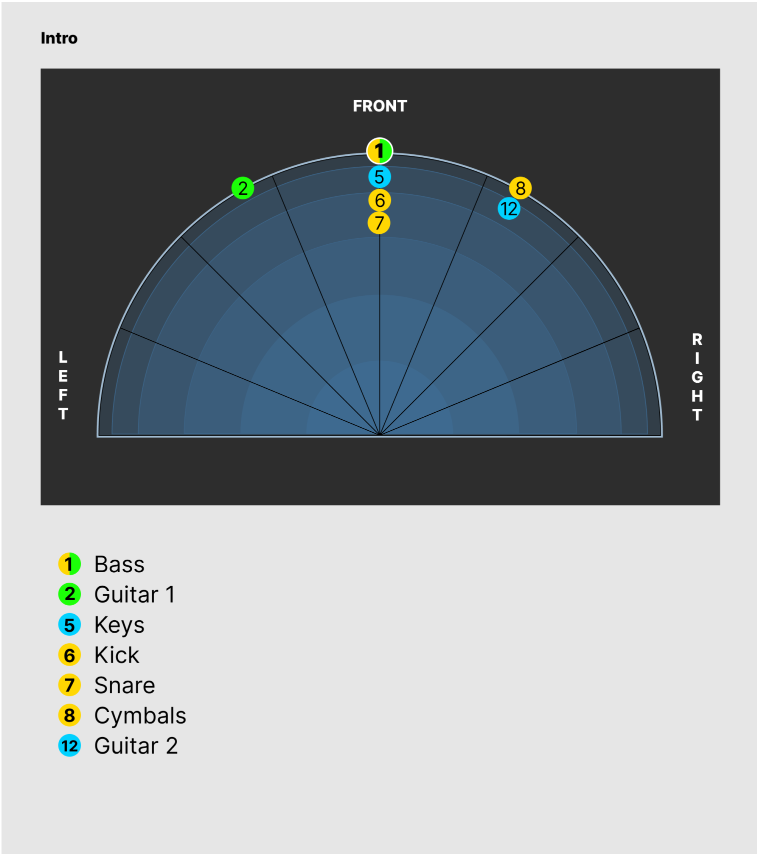

Figure C.33: Diagram for the **Intro** of the song "Morph the Cat" in the **stereo** analysis.

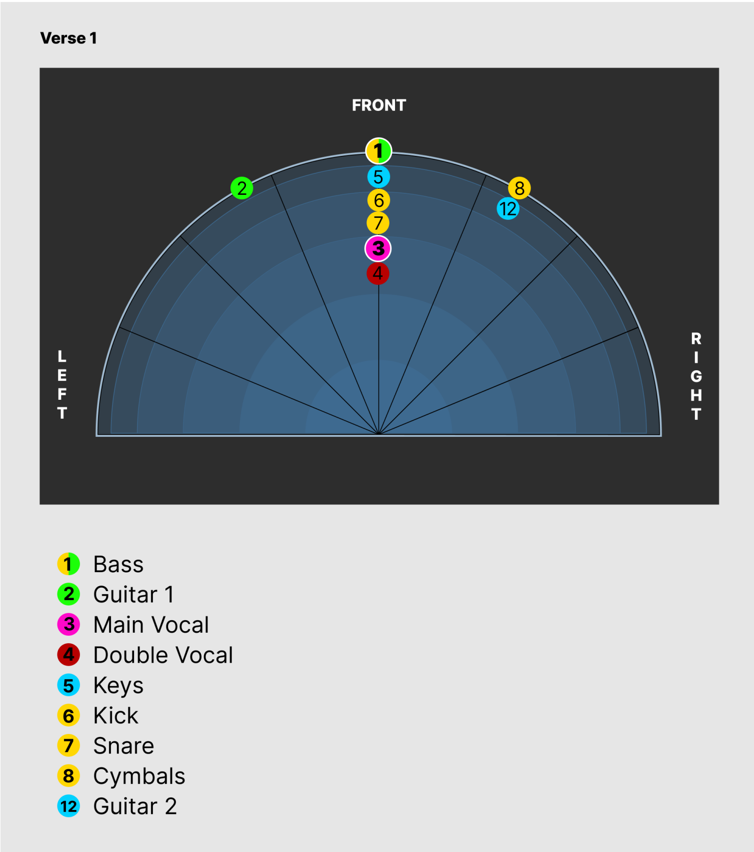

Figure C.34: Diagram for the **Verse 1** of the song “Morph the Cat” in the **stereo** analysis.

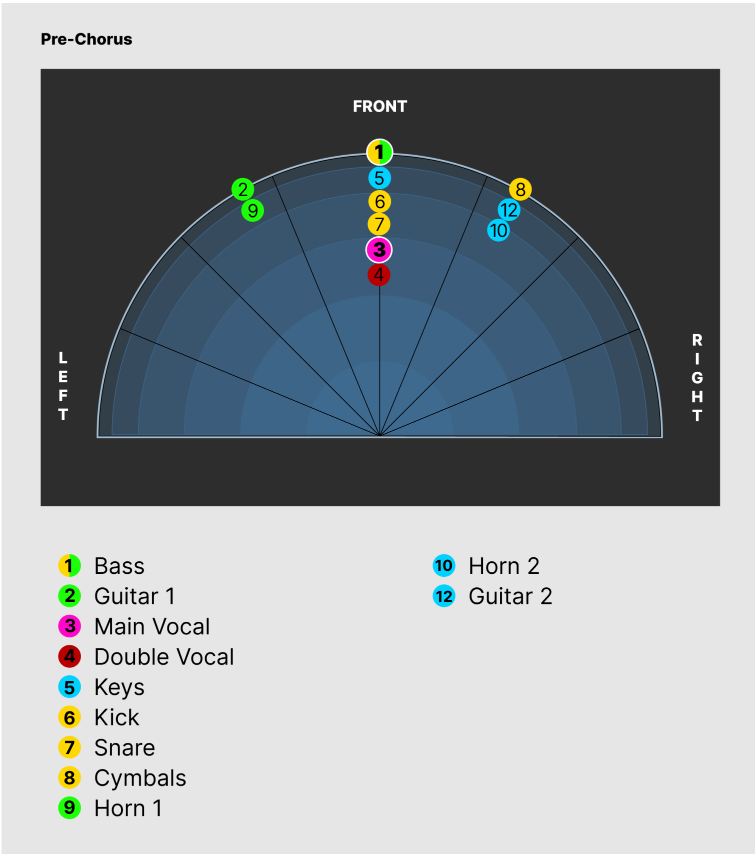

Figure C.35: Diagram for the **Pre Chorus** of the song “Morph the Cat” in the **stereo** analysis.

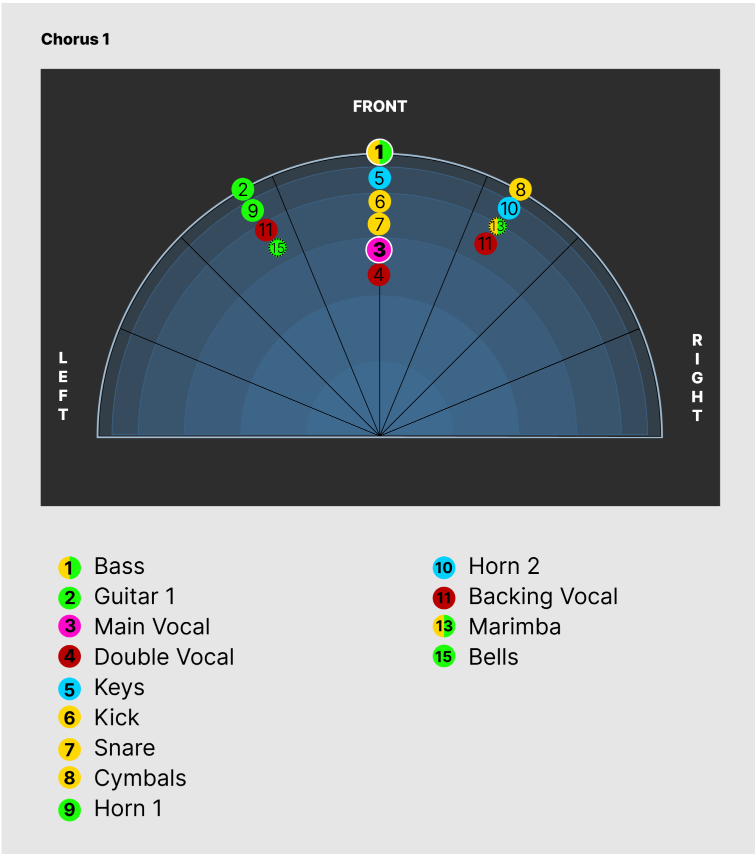

Figure C.36: Diagram for the **Chorus 1** of the song “Morph the Cat” in the **stereo** analysis.

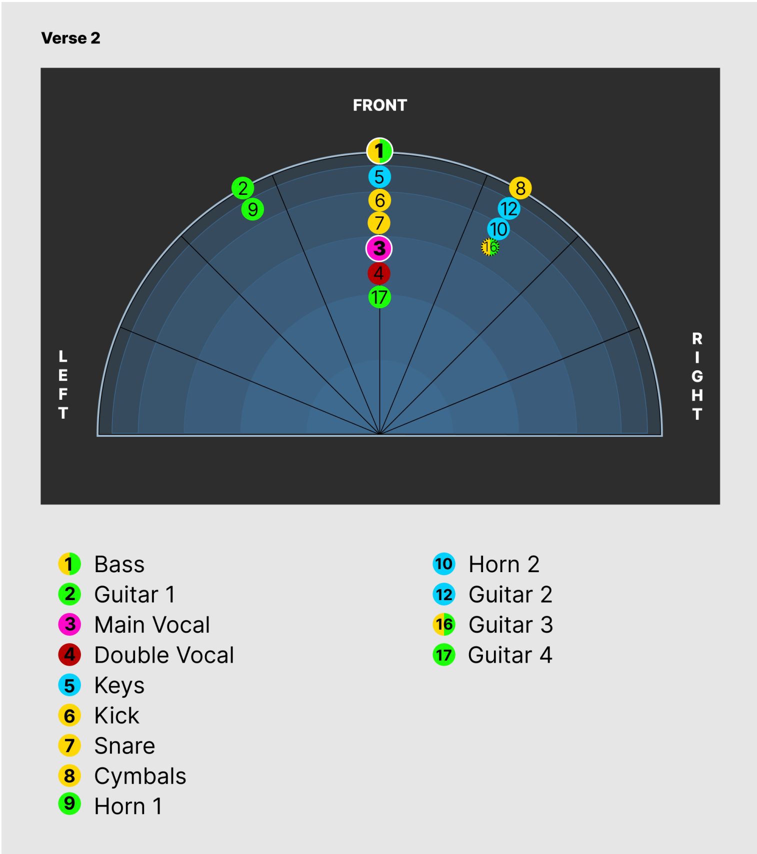

Figure C.37: Diagram for the **Verse 2** of the song “Morph the Cat” in the **stereo** analysis.

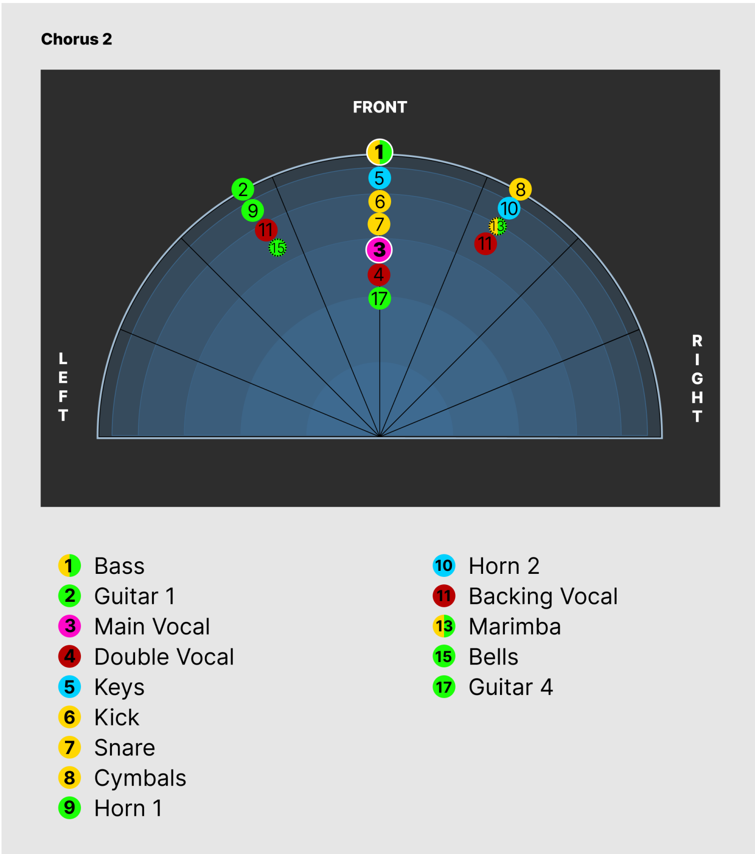

Figure C.38: Diagram for the **Chorus 2** of the song “Morph the Cat” in the **stereo** analysis.

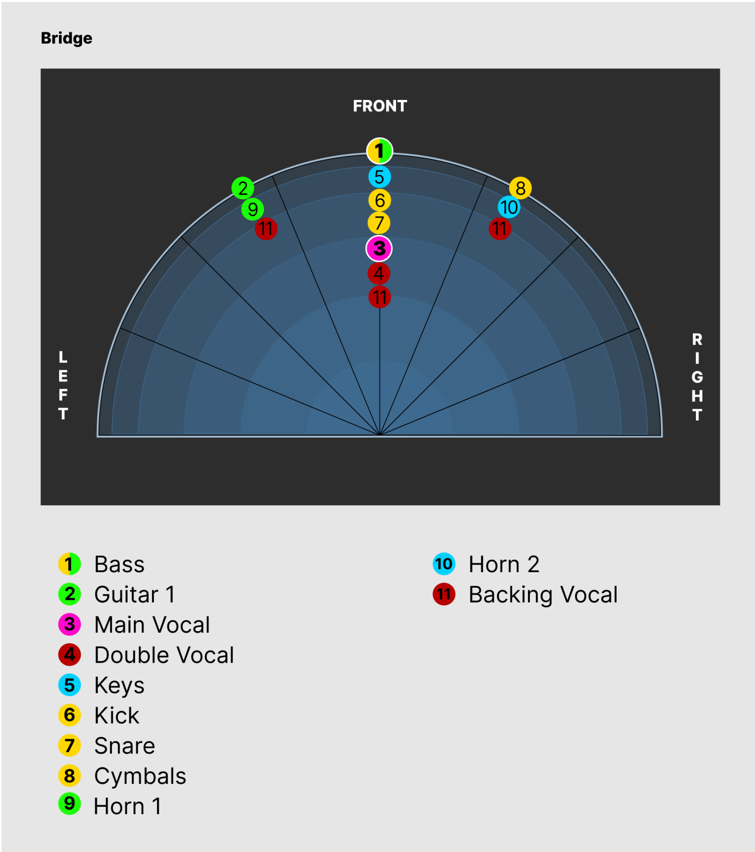

Figure C.39: Diagram for the **Bridge** of the song “Morph the Cat” in the **stereo** analysis.

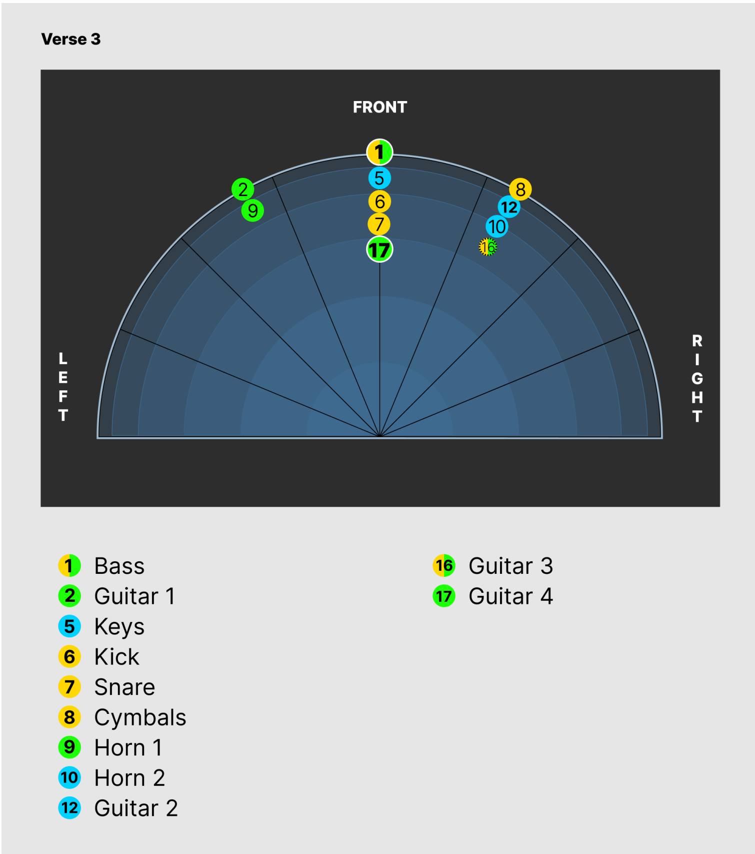

Figure C.40: Diagram for the **Verse 3** of the song “Morph the Cat” in the **stereo** analysis.

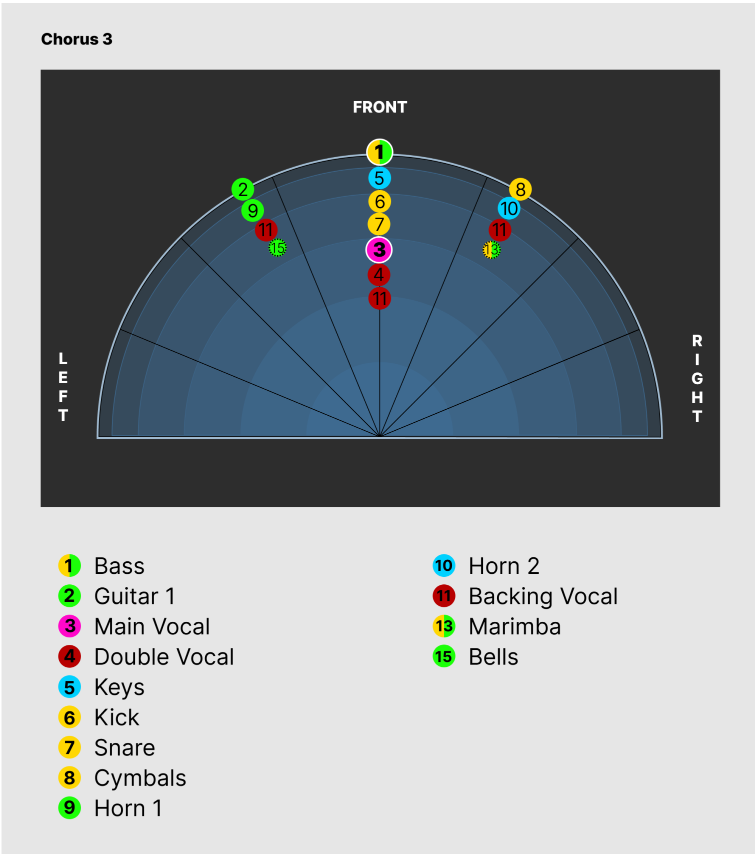

Figure C.41: Diagram for the **Chorus 3** of the song “Morph the Cat” in the **stereo** analysis.

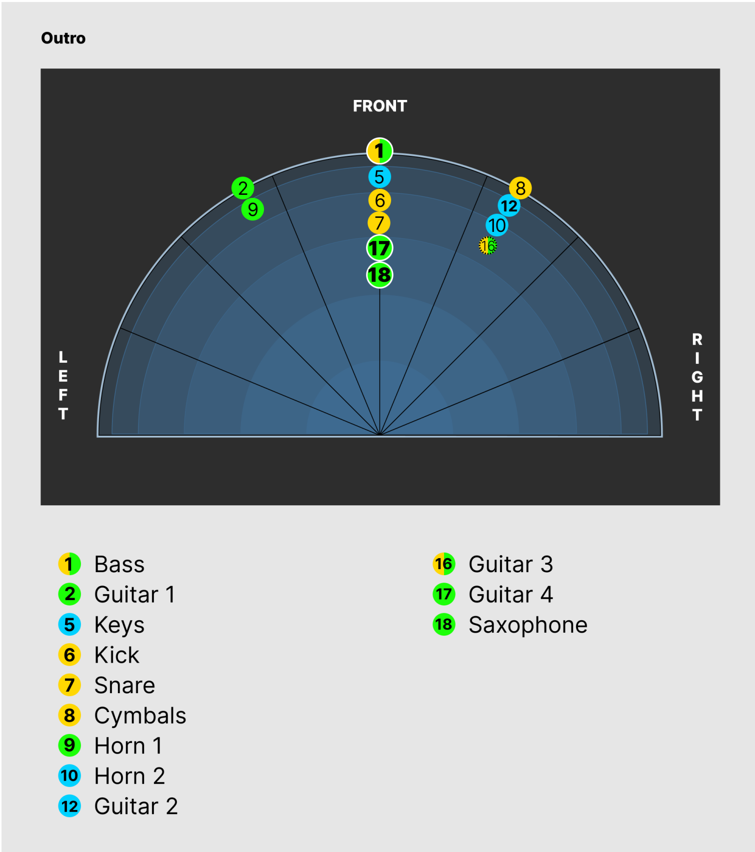

Figure C.42: Diagram for the **Outro** of the song “Morph the Cat” in the **stereo** analysis.

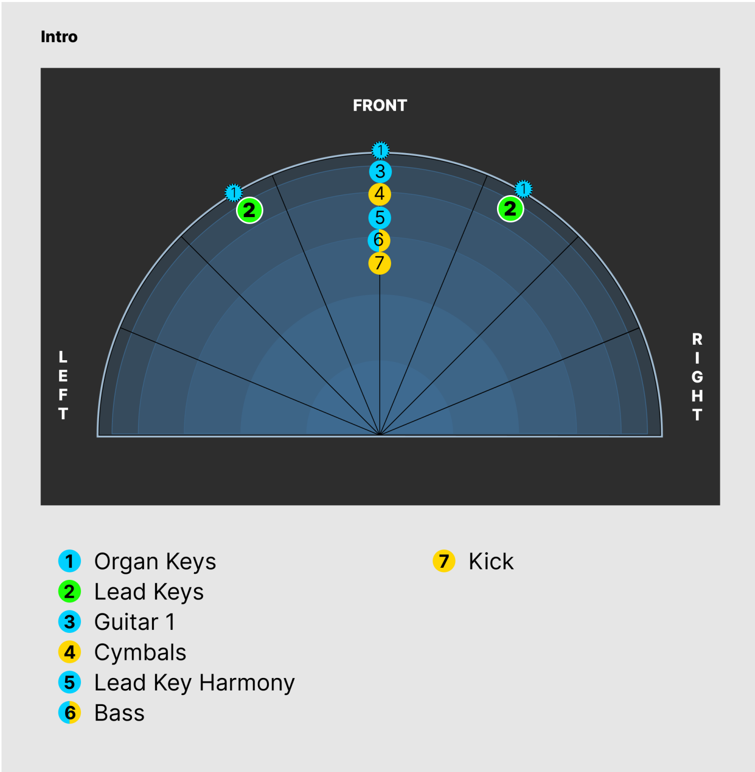

Figure C.43: Diagram for the **Intro** of the song “Walk of Life” in the **stereo** analysis.

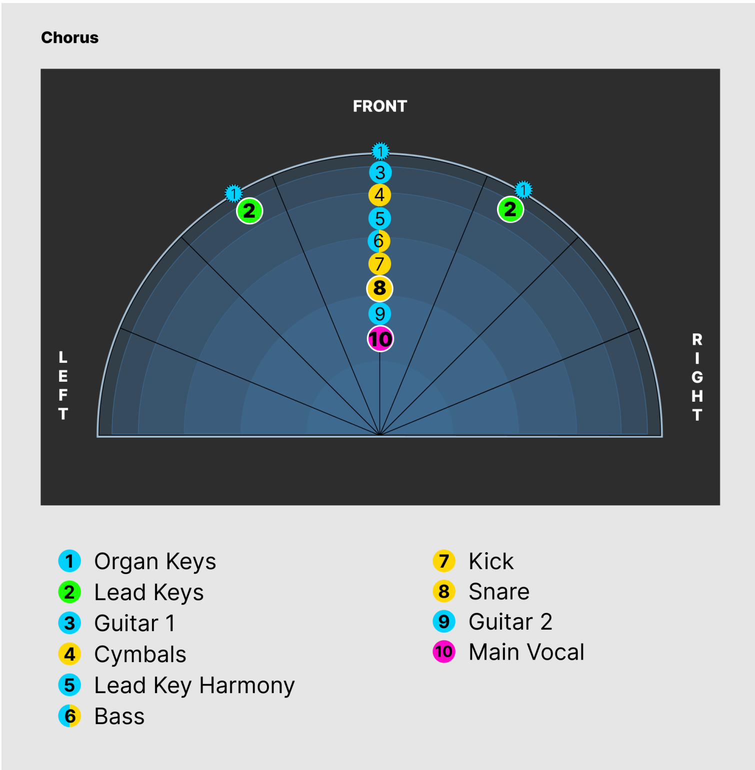

Figure C.44: Diagram for the **Chorus** of the song “Walk of Life” in the **stereo** analysis.

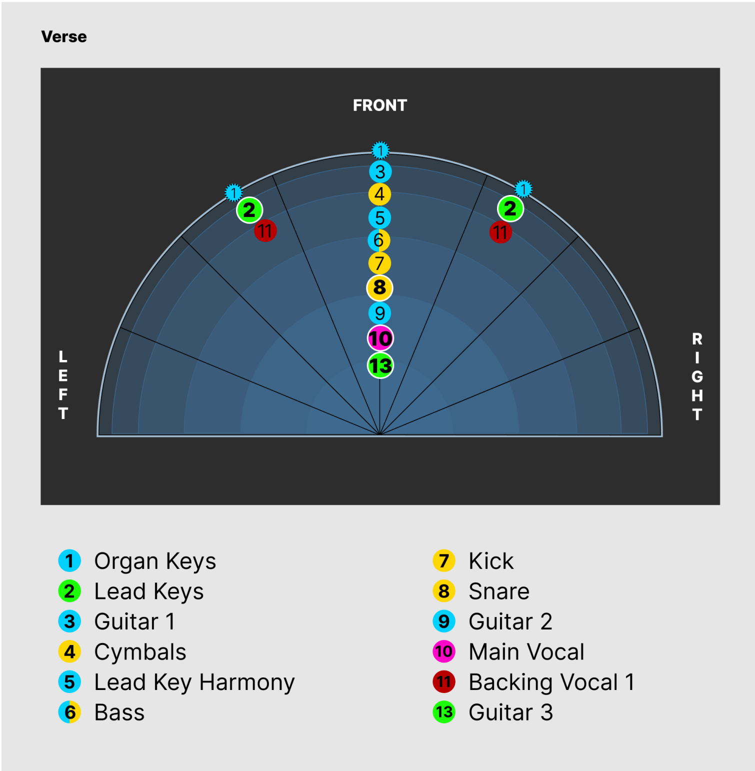

Figure C.45: Diagram for the **Verse** of the song “Walk of Life” in the **stereo** analysis.

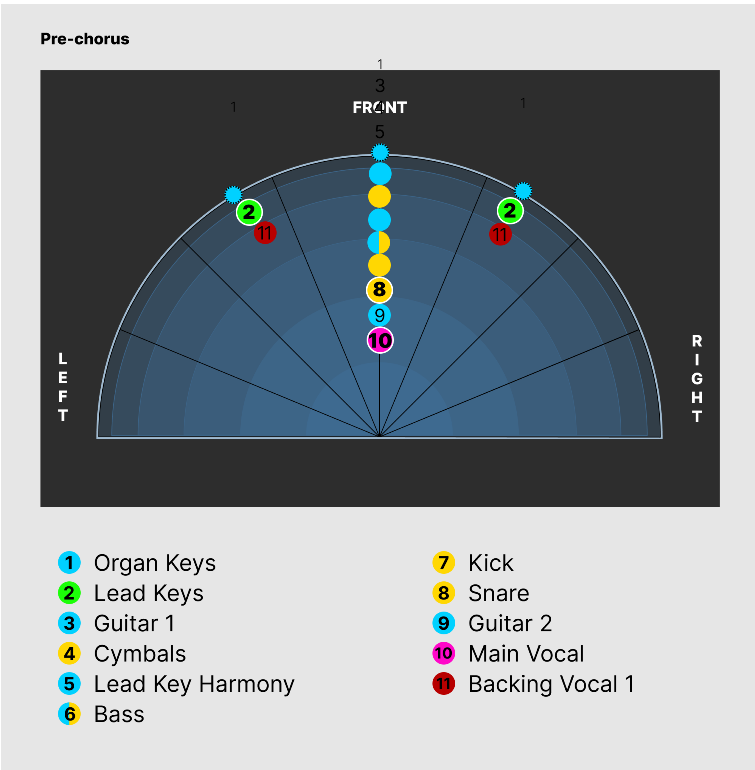

Figure C.46: Diagram for the **Pre Chorus** of the song “Walk of Life” in the **stereo** analysis.

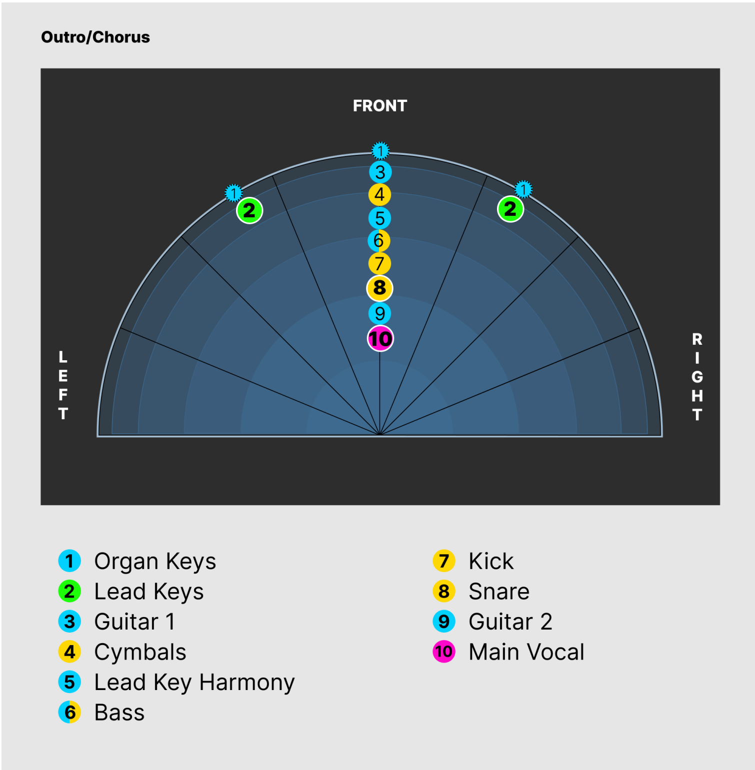

Figure C.47: Diagram for the **Outro/Chorus** of the song “Walk of Life” in the **stereo** analysis.

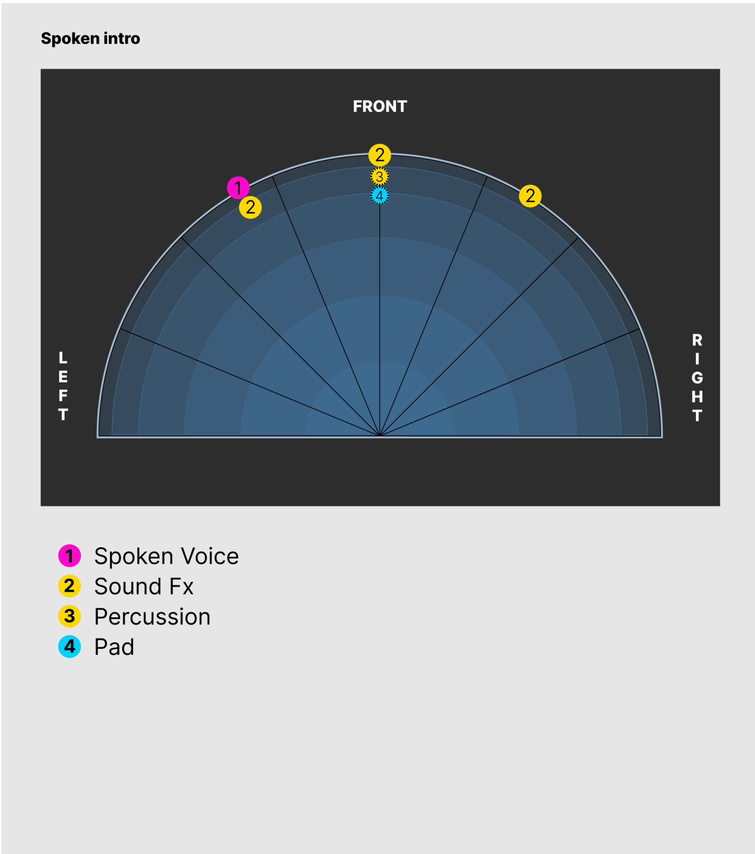

Figure C.48: Diagram for the **Spoken Intro** of the song “What God Wants” in the **stereo** analysis.

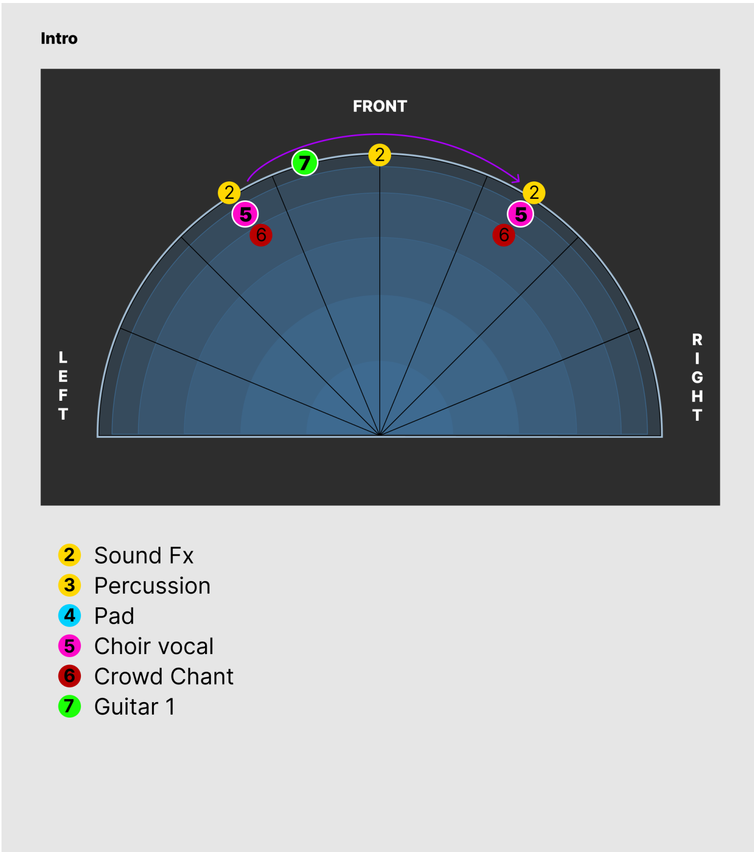

Figure C.49: Diagram for the **Intro** of the song “What God Wants” in the **stereo** analysis.

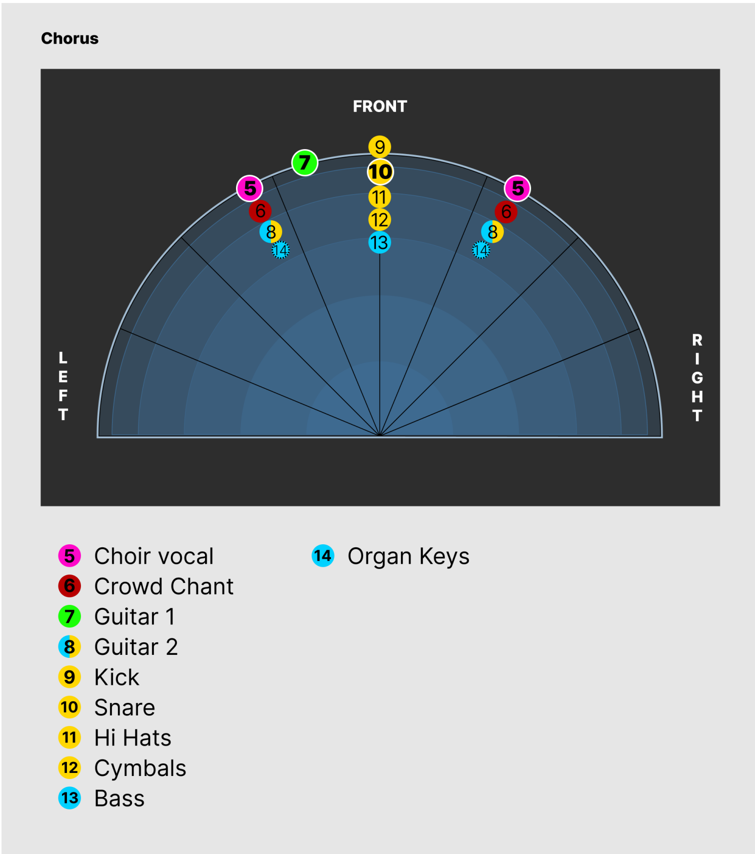

Figure C.50: Diagram for the **Chorus** of the song “What God Wants” in the **stereo** analysis.

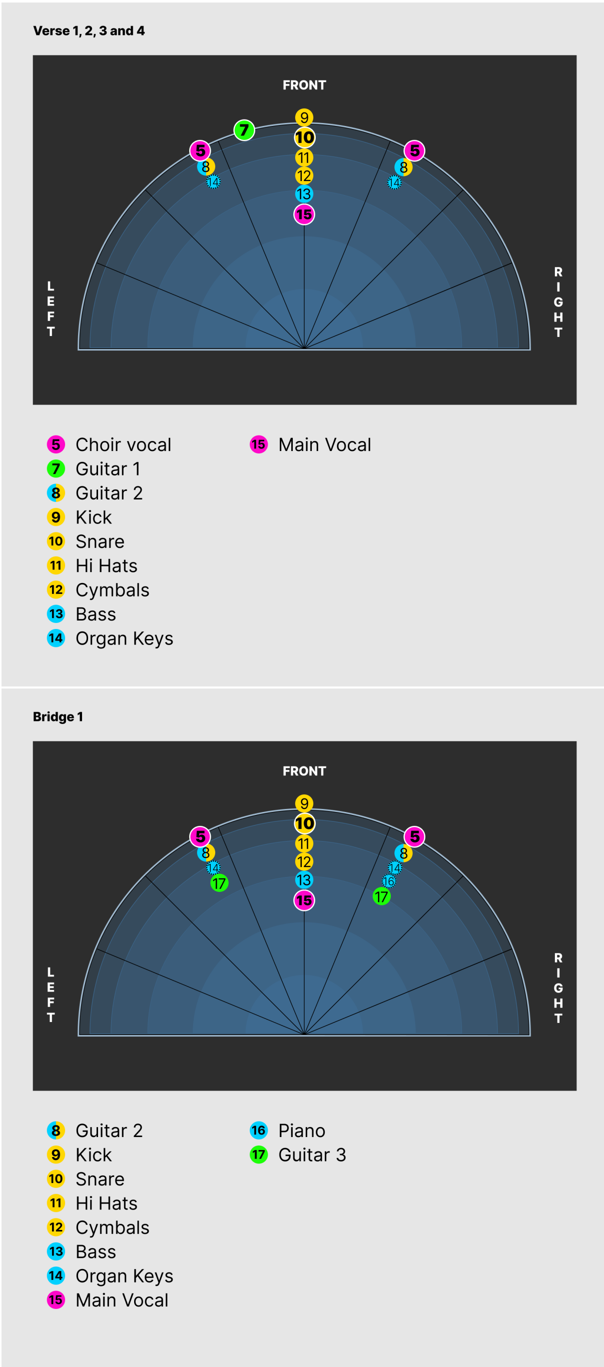

Figure C.51: Diagram for the **Verses 1, 2, 3 and 4** and **Bridge 1** of the song "What God Wants" in the **stereo** analysis.

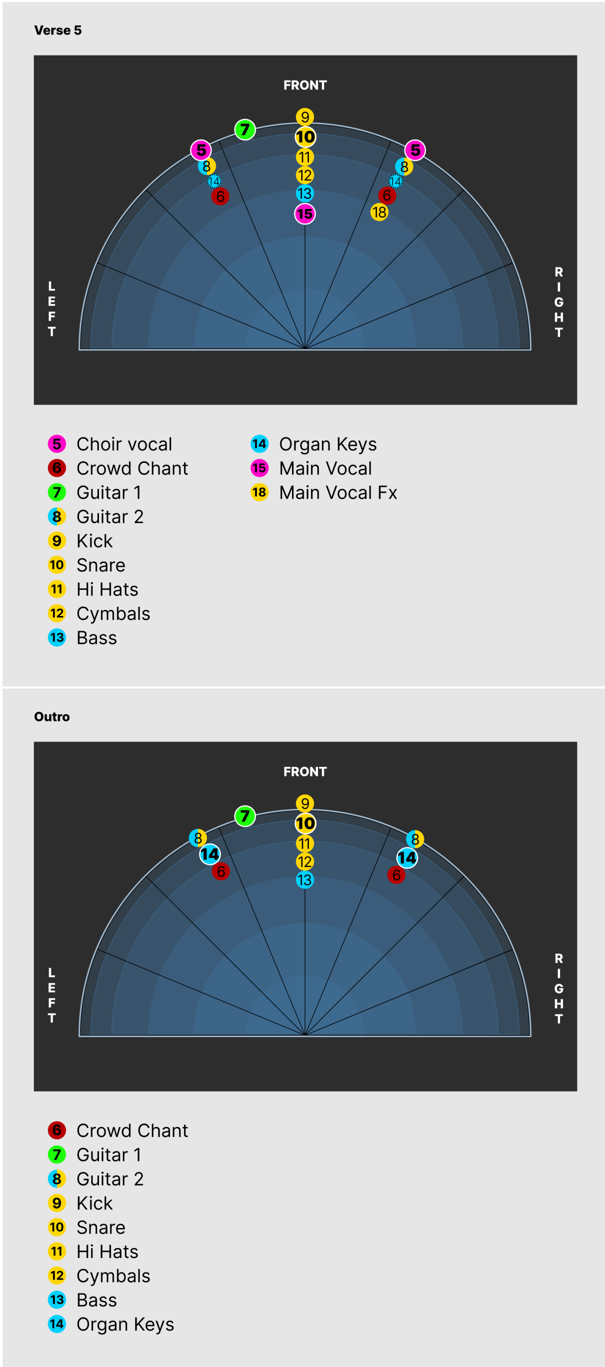

Figure C.52: Diagrams for the **Verse 5** and **Outro** of the song “What God Wants” in the **stereo** analysis.

Appendix D

Extensive Observations for the Surround Sound Versions in the style of a logbook

"Morph the Cat"

The perceptual analysis reveals that the instruments positioned in the center are perceived as occupying a "space" constituted by the three front channels, whether listening to the music with all channels active or solely with the three front channels isolated. Most centrally positioned instruments predominantly contain information in the right and left channels, while very few instruments primarily utilize the center channel for their main sound content. Instruments positioned at the front mainly provide complementary information in the center channel, while their primary sound content is reproduced in the right and left channels. Despite this arrangement, the perception of instrument positioning remains centered.

The vocals, being the prominent element in the composition, are perceived as originating from the three front channels. However, there is also a substantial amount of vocal information reproduced in the surround channels. The backing vocals, in particular, create a sonic "wall" spanning across the surround channels, as confirmed by adjusting the listener's head position to accurately discern the location of these backing vocals. Initially, it was hypothesized that the backing vocals were positioned slightly further back compared to other instruments placed at 110° and -110° in the surround channels. However, this perception was found to be a result of the listener facing forward, and upon head movement for improved auditory precision, it was discovered that these instruments shared the same location as others.

Although none of the audio sources for the lead vocal exhibit exceptionally high dynamics individually, their collective contribution assumes significant importance in the mix. Solo instruments consistently occupy the center position, which is defined by the three front channels, while the dynamics of instruments remains consistent across different sections of the music. Rhythmic instruments, serving as the rhythmic foundation of the song, are consistently positioned in the center throughout the duration of the composition, anchoring the overall groove.

Furthermore, the center of the mix is regarded as the “main stage”, with all instruments that enter at different sections to perform solos being placed in the center. Overall, there are no substantial deviations from the conventional positions dictated by the traditional channel-based audio approach when it comes to locating the audio sources.

“Here We Go Again”

The mix demonstrates a deliberate intention to emulate the immersive experience of a live performance. The instrumentation is kept simple, comprising only a few elements. Notably, the keys are mixed with reverb and delay effects, effectively simulating rapid movements between the left surround and right surround channels.

Furthermore, the keys exhibit notable fluctuations in volume, particularly in relation to the attack of specific melodic phrases. These variations in volume further contribute to the dynamic and expressive nature of the composition.

Despite the low dynamics classification of certain instruments, their presence and contribution remain readily discernible. This is primarily attributed to the straightforward and simple nature of the instrumentation, allowing for clear perceptibility within the mix.

“Eye In The Sky”

It was imperative to attenuate the track volumes to -16dB instead of the specified -12dB to prevent clipping in the master track.

During the introductory section, the guitars exhibit a wider spatial presence, occupying lateral positions. However, as the remaining instrumentation enters, they shift towards the left and right channels, seemingly creating space within the mix for the other elements.

In contrast to other songs analyzed in this study, where greater instrumentation density is observed in sections like the chorus, this particular song employs an increase in dynamics to establish dynamics between sections. Nevertheless, despite the volume adjustments relative to each other, the instruments’ overall dynamics levels do not undergo significant changes.

Unlike the findings in “Morph the Cat”, this song does not adhere to the treatment of the center as a distinct spatial entity. Instead, the main content of the lead vocals predominantly resides in the central channel.

During the second verse, an ambient pad designated as number 12 is introduced. Its perceived sound source is either challenging to discern due to the layered instrumentation complexity, or it is intentionally positioned from multiple directions, possibly originating from at least four distinct sources.

This particular song presented difficulties in determining the precise positioning of sound sources. The intricate layering of instruments, combined with the applied mixing effects and recording quality, contributed to the perceptual challenges.

In bridge 2, Guitar 3 assumes a melodic role, transitioning to a harmonic role in the subsequent chorus 3 section, before resuming its melodic function and even performing a solo during the outro segment.

“Walk of Life”

It was necessary to attenuate the track volumes to -14dB, as opposed to the specified -12dB, in order to prevent clipping during the mastering stage.

In this particular song, the lead keys and their accompanying harmonies play a prominent role as the main melody in the introduction and chorus sections. However, their role transitions to that of harmonic instruments during the verses.

Notably, harmonic and melodic instruments such as the lead keys and organ keys, despite originating from positions perceived at 110°and -110°, exhibit a significant amount of instrument information being reproduced in the front side channels. This characteristic creates a pronounced sense of spatial expansion, effectively filling the left and right sides of the listener’s ears. This observation is equally applicable to the instrumental arrangement of the composition “Eye in the Sky”.

“Layla”

In the analyzed song, the drums and their various components are strategically positioned across the front soundstage, occupying the right, center, and left channels, closely resembling their physical arrangement in a drum kit. Specifically, the kick and snare drums, along with the hi-hats, are centered, while the cymbals are predominantly placed in the left channel. The toms, on the other hand, exhibit movement depending on their position within the drum kit.

During the first verse, when the organ is introduced, the perception of its sound source is predominantly on the right side. However, it is important to consider that this perception may be influenced by the relatively low dynamics of the organ. Although the organ may exist in other channels, its reproduction might be masked by the instruments occupying those channels. Given that the channels on the right side contain less information, the organ appears to have its source predominantly on that side.

The piano, identified as #15, originates from the center channel but extends its presence widely across the three front channels, creating a spacious and encompassing sound.

The utilization of the surround channels in introducing instrument sound sources is relatively limited in this song. Instead, these channels predominantly contribute to the spatial representation of front instruments, such as capturing the ambiance of the drum room.

The composition can be divided into two distinct parts, wherein the instruments employed remain the same. However, their significance and prominence differ between these sections, leading to a variation in their relative dynamics.

"Hey Jude"

In this particular song, the vocal and its melodic elements take center stage, explicitly positioned in the center channel. This is in contrast to other analyzed songs where the vocals are spread across the three front channels, creating a wider spatial presence.

The drums, on the other hand, are predominantly positioned at approximately -30°, showcasing a distinct approach compared to other songs where percussion elements tend to be centered.

Similar to the patterns observed in other analyzed songs, the surround channels are extensively utilized to reproduce residual information associated with the primary melodies presented in front of the listener, particularly emphasizing the vocals.

"What God Wants, Pt. I"

In this particular mix, the utilization of the center channel is minimal, as there are no instruments exclusively assigned to that channel. Instead, it serves as a supplementary channel to the left and right, primarily reproducing residual information from other instruments.

The ambient pad introduced in the introduction poses difficulty in pinpointing its specific position. Isolating individual channels indicates that its source originates from the surround channels. However, the wide mixing of this instrument creates a perception where it seems to envelop the listener from all directions along the x-axis.

Identifying several instruments and their sound sources proved to be challenging due to the high instrumental density and the expansive width with which multiple instruments are mixed.