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Wilson, AD and Fazenda, BM

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NAVIGATING THE MIX-SPACE: THEORETICAL AND PRACTICAL LEVEL-BALANCING TECHNIQUE IN MULTITRACK MUSIC MIXTURES

Alex Wilson

Acoustics Research Centre
School of Computing, Science and Engineering
University of Salford
a.wilson1@edu.salford.ac.uk

Bruno M. Fazenda

Acoustics Research Centre
School of Computing, Science and Engineering
University of Salford

ABSTRACT

The mixing of audio signals has been at the foundation of audio production since the advent of electrical recording in the 1920's, yet the mathematical and psychological bases for this activity are relatively under-studied. This paper investigates how the process of mixing music is conducted. We introduce a method of transformation from a “*gain-space*” to a “*mix-space*”, using a novel representation of the individual track gains. An experiment is conducted in order to obtain time-series data of mix engineers exploration of this space as they adjust levels within a multi-track session to create their desired mixture. It is observed that, while the exploration of the space is influenced by the initial configuration of track gains, there is agreement between individuals on the appropriate gain settings required to create a balanced mixture. Implications for the design of intelligent music production systems are discussed.

1. INTRODUCTION

The task of the mix engineer can be seen as one of solving an optimisation problem [1], with potentially thousands of variables once one considers the individual level, pan position, equalisation, dynamic range processing, reverberation and other parameters, applied in any order, to many individual audio components.

The objective function to be optimised varies depending on implementation. Conceptually, one should maximise ‘*Quality*’, an often-debated concept in the case of music production. In this context, borrowing from ISO 9000 [2], we can consider ‘*Quality*’ to be the degree to which the inherent characteristics of a mix fulfil certain requirements. These requirements may be defined by the mix engineer, the artist, the producer or some other interested party. In a commercial sense, we consider the requirement to be that the mix is enjoyed by a large amount of people.

This paper considers how the mix process could be represented in a highly simplified case, investigates how high-quality outcomes are achieved by human mixers and offers insights into how such results could be achieved by intelligent music production systems.

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2. BACKGROUND

For many decades the mixing console has retained a recognisable form, based on a number of replicated channel strips. Audio signals are routed to individual channels where typical processing includes volume control, pan control and basic equalisation. Channels can be grouped together so that the entire group can be processed further, allowing for complex cross-channel interactions.

One of the most fundamental and important tasks in music mixing is the choice of relative volume levels of instruments, known as level-balancing. Due to its ubiquity and relative simplicity, level-balancing using fader control is a common approach to the study of mixing. It has been indicated that balance preferences can be specific to genre [3] and, for expert mixers, can be highly consistent [4].

As research in the area has continued, a variety of assumptions regarding mixing behaviours have been put forward and tested. A number of automated fader control systems have used the assumption that equal perceptual loudness of tracks leads to greater inter-channel intelligibility [5, 6]. This particular practice was investigated in a study of “best-practice” concepts [7], which included panning bass-heavy content centrally, setting the vocal level slightly louder than the rest of the music or the use of certain instrument-specific reverberation parameters. A number of these practices were tested using subjective evaluation and the equal-loudness condition did not necessarily lead to preferred mixes [7].

Much of these “best-practice” techniques may be anecdotal, based on the experience of a small number of professionals who have each produced a large number of mixes (see [8,9] for reviews). Due to the proliferation of the Digital Audio Workstation (DAW) and the sharing of software and audio via the internet, it has now become possible to reverse this paradigm, and study the actions of a large number of mixers on a small number of music productions. This allows both quantitative and qualitative study of mixing practice, meaning the dimensions of mixing and the variation along these dimensions can be investigated.

To date, there have been few quantitative studies of complete mixing behaviour, as lack of suitable datasets can be problematic. One such study focussed on how a collection of students mixed a number of multitrack audio sessions [10]. It was shown that, among low-level features of the resultant audio mixes, most features exhibited less variance across mixers than across songs.

3. THEORY

When considering a realistic mixing task the number of variables becomes very large. An equaliser alone may have dozens of parameters, such as the center frequency, gain, bandwidth and filter type of a number of independent bands, leading to a large number of combinations. There are methods to reduce the number of variables in these situations. In [11], the combination of track gains and simple equalisation variables was reduced to a 2D map by means of a self-organising map, where the simple equalisation parameter was the first principal component of a larger EQ system, showing further dimensionality reduction. While these approaches can create approximations of the mix-space, the true representation is difficult to conceive for all but the most simple mixing tasks.

3.1 Defining the “mix-space”

We introduce a new definition for “mix-space”. Fig. 1 shows a trivial example of just two tracks. When mixing, the gains of the two tracks, g_1 and g_2 , are adjusted. Here it can be seen that, using polar coordinates, the angle ϕ provides most information about the mix, as it is the proportional blend of g_1 and g_2 . Any other point on the line at angle ϕ would represent the same balance of instruments, thus r is a scaling factor, corresponding to the combined mix volume. As the gains are normalised to $[0,1]$, ϕ is bound from 0 to $\pi/2$ radians.

For a system of n audio signals, $x_1(t), \dots, x_n(t)$, we can define an n -dimensional *gain-space* with time-varying gains $g_1(t), \dots, g_n(t)$. As the n gains are adjusted this *gain-space* is explored. Consider the case when all n gains are increased or decreased by an equal amount. While there is a clear displacement in the gain-space, there is no change to the overall mix, only a change in volume. Acknowledging this, and by extending the concept shown in Fig. 1, the hyperspherical co-ordinates of a point in the gain-space are used to transform to the mix-space. This co-ordinate system, written as $(r, \phi_1, \phi_2, \dots, \phi_{n-1})$, is defined by Eqn. 1.

$$r = \sqrt{g_n^2 + g_{n-1}^2 + \dots + g_2^2 + g_1^2} \quad (1a)$$

$$\phi_1 = \arccos \frac{g_1}{\sqrt{g_n^2 + g_{n-1}^2 + \dots + g_1^2}} \quad (1b)$$

$$\phi_2 = \arccos \frac{g_2}{\sqrt{g_n^2 + g_{n-1}^2 + \dots + g_1^2}} \quad (1c)$$

⋮

$$\phi_{n-2} = \arccos \frac{g_{n-2}}{\sqrt{g_n^2 + g_{n-1}^2 + g_{n-2}^2}} \quad (1d)$$

$$\phi_{n-1} = \begin{cases} \arccos \frac{g_{n-1}}{\sqrt{g_n^2 + g_{n-1}^2}} & g_n \geq 0 \\ 2\pi - \arccos \frac{g_{n-1}}{\sqrt{g_n^2 + g_{n-1}^2}} & g_n < 0 \end{cases} \quad (1e)$$

Consider a system of four tracks, as shown in Fig. 2. Here, ϕ_3 denotes the balance of the drum and bass tracks, to form the rhythmic foundation of the mix. ϕ_2 describes the projection of this balance onto the guitar dimension,

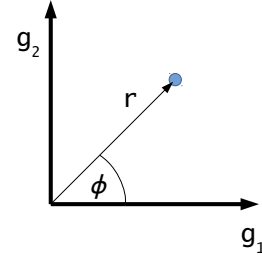


Figure 1: The point represents a balance of two instruments, controlled by gains g_1 and g_2 . Any other point on the line at angle ϕ would represent the same balance of instruments, thus r is a scaling factor.

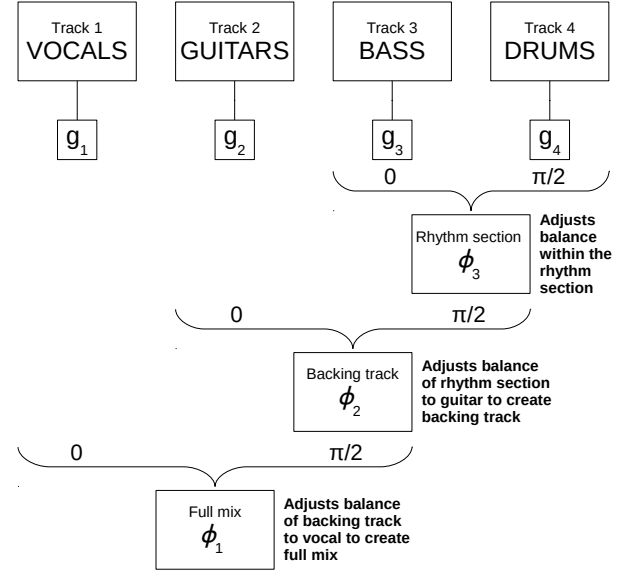


Figure 2: Schematic representation of a four-track mixing task and the semantic description of the three ϕ terms.

and thus, the complete musical backing track. ϕ_1 then describes the balance between this backing track and the vocal. Using this notation, ϕ_1 has been studied in isolation in previous studies [3, 4]. For a system with four tracks only three ϕ terms must be determined to construct the mix-space. Convention typically dictates that ϕ_{n-1} describes an equatorial plane and ranges over $[0, 2\pi]$ and that all other angles range from $[0, \pi]$, however since all gains are positive, each angle ranges over $[0, \pi/2]$, as in Fig. 1.

Since r is a scaling factor, when the values of all ϕ terms are held constant, there is a constant difference in the relative gains of each track, when expressed in decibels. This can be illustrated by converting ϕ terms back to gain terms, which can be achieved using Eqn. 2.

$$g_1 = r \cos(\phi_1) \quad (2a)$$

$$g_2 = r \sin(\phi_1) \cos(\phi_2) \quad (2b)$$

$$g_3 = r \sin(\phi_1) \sin(\phi_2) \cos(\phi_3) \quad (2c)$$

⋮

$$g_{n-1} = r \sin(\phi_1) \cdots \sin(\phi_{n-2}) \cos(\phi_{n-1}) \quad (2d)$$

$$g_n = r \sin(\phi_1) \cdots \sin(\phi_{n-2}) \sin(\phi_{n-1}) \quad (2e)$$

3.2 Characteristics of the mix-space

With a mix-space having been defined, what characteristics does the space have? How does the act of mixing explore this space? We now discuss three scenarios - beginning at a ‘source’, exploring the ‘mix-space’ and arriving at a ‘sink’

3.2.1 The ‘source’

In a real-world context, when a mixer downloads a multitrack session and first loads the files into a DAW, each mixer will initially hear the same mix, a linear sum of the raw tracks¹. While each of these raw tracks can be presented in various ways if we presume each track is recorded with high signal-to-noise ratio (as would have been more important when using analogue equipment) then, with all faders set to 0dB, the perceived loudness of those tracks with reduced dynamic range (such as synthesisers, electric bass and distorted electric guitars) would be higher than that of more dynamic instruments.

Much like the final mixes, this initial ‘mix’ can be represented as a point in some high-dimensional, or feature-reduced, space. It is rather unlikely that a mixer would open the session, hear this mix and consider it ideal, therefore, changes will most likely be made in order to move away from this location in the space. For this reason, this position in the mix-space is referred to as a ‘source’.

In practice, the session, as it has been received by the mix engineer, may be an “unmixed sum” or may be a rough mix, as assembled by the producer or recording engineer. In a real-world scenario, the work may be received as a DAW session, where tracks have been roughly mixed. Alternatively, where multitrack content is made available online, such as in mix competitions, the unprocessed audio tracks are usually provided without a DAW session file. The latter approach is assumed in this study, in order for mix engineers to have full creative control over the mixing process. If mixers were to make unique changes to the initial configuration then that source can be considered to be radiating omni-directionally in the mix-space. However, it is possible that, for a given session, there may be some changes which will seem apparent to most mixers, for example, a single instrument which is louder than all others requiring attenuation. For such sessions, the source may be unidirectional, or if a number of likely outcomes exist, there may exist a number of paths from the source.

3.2.2 Navigating the mix-space

The path from the source to the final mix could be represented as a series of vectors in the mix-space, henceforth named ‘mix-velocity’, and defined in Eqn. 3, for the three dimensions shown in Fig. 2.

¹ Here it is significant that a DAW typically defaults to faders at 0dB, while a separate mixing console may default to all faders at $-\infty$ dB. This allows an experimenter to ensure that all mixers begin by hearing the same ‘mix’. This has been referred to in previous studies as an ‘unmixed sum’ or a ‘linear sum’. While the term ‘unmixed’ can be misleading, it does reflect the fact that the artistic process of mixing has not yet begun.

$$u_t = \phi_{(1,t)} - \phi_{(1,t-1)} \quad (3a)$$

$$v_t = \phi_{(2,t)} - \phi_{(2,t-1)} \quad (3b)$$

$$w_t = \phi_{(3,t)} - \phi_{(3,t-1)} \quad (3c)$$

If all mixers begin at the same source then a number of questions can be raised in relation to movement through the mix-space.

- Moving away from the source, at what point do mix engineers diverge, if at all?
- How do mix engineers arrive at their final mixes? What paths through the mix-space do they take?
- Do mix engineers eventually converge towards an ideal mix?

3.2.3 The ‘sink’

Complementary to the concept of a source in the mix-space, a ‘sink’ would represent a configuration of the input tracks which produces a high-quality mix that is apparent to a sizeable portion of mix engineers and to which they would mix towards. As the concept of quality in mixes is still relatively unknown there are a number of open questions in the field which can be addressed using this framework.

- Is there a single sink, i.e. one ideal mix for each multitrack session? In this case the highest mix-quality would be achieved at this point.
- Are there multiple sinks, i.e. given enough available mixes, are these mixes clustered such that one can observe a number of possible alternate mixes of a given multitrack session? These multiple sinks would represent mixes that are all of high mix-quality but audibly different.

4. EXPERIMENT

To the authors’ knowledge, there is a lack of appropriate data available to directly test the theory presented in Section 3. In order to examine how mix engineers navigate the mix-space a simple experiment was conducted. In this instance the mixing exercise is to balance the level of four tracks, using only a volume fader for each track. Importantly, the participants will all begin with a predetermined balance, in order to examine the source directivity. This experiment aims to answer the following research questions:

- Q1. Can the source be considered omni-directional or are there distinct paths away from the source?
- Q2. Is there an ideal balance (single sink)?
- Q3. Are there a number of optimal balances (multiple sinks)?
- Q4. What are the ideal level balances between instruments?

Previous studies have indicated that perceptions of quality and preference in music mixtures are related to subjective and objective measures of the signal, with distortion, punch, clarity, harshness and fullness being particularly important [12, 13]. By using only track gain and no panning, equalisation or dynamics processing, most of these parameters can be controlled.

4.1 Stimuli

The multitrack audio sessions used in this experiment have been made available under a creative commons license^{2 3}. These files are also indexed in a number of databases of multitrack audio content^{4 5}. Three songs were used for this experiment, which consisted of vocals, guitar, bass and drums, as per Fig. 2, and as such the interpretations of ϕ_n from here on are those in Fig. 2.

The four tracks used from “*Borrowed Heart*” are raw tracks, where no additional processing has been performed apart from that which was applied when the tracks were recorded⁶. The tracks from “*Sister Cities*” also represent the four main instruments but were processed using equalisation and dynamic range compression. These can be referred to as ‘stems’, as the 11 drum tracks have been mixed down, the two bass tracks (a DI signal and amplifier signal) have been mixed together, the guitar track is a blend of a close and distant microphone signals and the vocal has undergone parallel compression, equalisation and subtle amounts of modulation and delay. In the case of “*Heartbeats*”, the tracks used are complete ‘mix stems’, in that the song was mixed and bounced down to four tracks consisting of ‘all vocals’, ‘all music’ (guitars and synthesisers), ‘all bass’ and ‘all drums’. For testing, the audio was further prepared as follows:

- 30-second sections were chosen, so that participants would be able to create a static mix, where the desired final gains for each track are not time-varying.
- Within each song, each 30-second track was normalised according to loudness. In this case, loudness is defined by BS.1770-3, with modifications to increase the measurements suitability to single instruments, rather than full-bandwidth mixes [14]. This allows the relative loudness of instruments to be determined directly from the mix-space coordinates.
- For each song, two source positions were selected. The ϕ terms were selected using a random number generator, with two constraints: to ensure the two sources are sufficiently different, the pair of sources must be separated by unit Euclidean distance in the mix-space and to ensure the sources are not mixes where any track is muted, the values were chosen from the range $\pi/8$ to $3\pi/8$ (see Fig. 2).

² <http://weathervanemusic.org/shakingthrough>

³ <http://www.cambridge-mt.com/ms-mtk.htm>

⁴ <http://multitrack.eecs.qmul.ac.uk/>

⁵ <http://medleydb.weebly.com/>

⁶ <https://s3.amazonaws.com/tracksheets/Hezekiah+Jones+-+Tracksheet.xlsx>

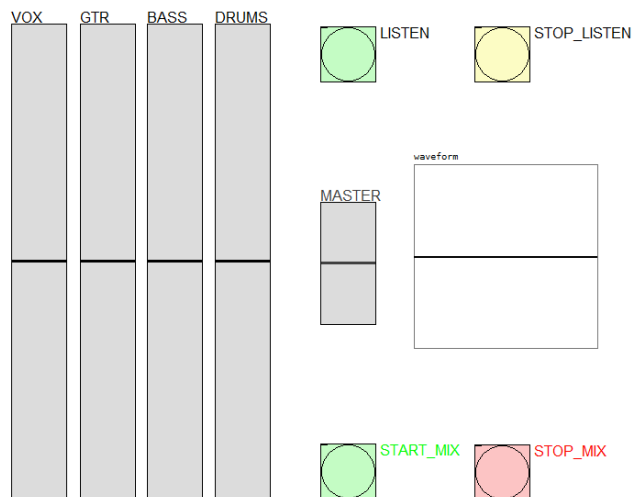


Figure 3: GUI of mixing test. The faders are unmarked and all begin at the same central value, which prevents participants from relying on fader position to dictate their mix.

4.2 Test panel

In total, 8 participants (2 female, 6 male) took part in the mixing experiment. As staff and students within Acoustics, Digital Media and Audio Engineering at University of Salford, each of these participants had prior experience of mixing audio signals. The mean age of participants was 25 years and none reported hearing difficulties.

4.3 Procedure

Rather than use loudspeakers in a typical control room, the test set-up used a more neutral reproduction. The experiment was conducted in a semi-anechoic chamber at University of Salford, where the background noise level was negligible. Audio was reproduced using a pair of Sennheiser HD800 headphones, connected to the test computer by a Focusrite 2i4 USB interface. Due to the nature of the task, each participant adjusted the playback volume as required. Reproduction was monaural, presented equally to both ears. While the choice between loudspeakers and headphones is often debated [15], in this case, particularly as reproduction was mono, headphones were considered to be the choice with greater potential for reproducibility.

The experimental interface was designed using Pure Data, an open source, visual programming language. The GUI used by participants is shown in Fig. 3. Each participant listens to the audio clip in full at least once, then the audio is looped while mixing takes place and fader movement is recorded. The participant then clicks ‘stop mix’ and the next session is loaded. For each session the user is asked to create their preferred mix by adjusting the faders.

An initial trial was provided in order for participants to become familiar with the test procedure, after which the six conditions (3 songs, 2 sources each) were presented in a randomised order. The mean test duration was 14.2 minutes, ranging from 11 to 17 minutes. The real-time audio output during mixing was recorded to .wav file at a sampling rate of 44,100Hz and a resolution of 16 bits. Fader positions were also recorded to .wav files using the same

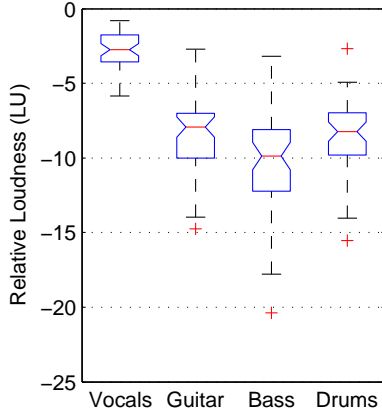


Figure 4: Normalised gain levels of each track, evaluated over all final mix positions.

format. As shown in Fig. 3, the true instrument levels were hidden from participants by displaying arbitrary fader controls. The range of the faders was limited to ± 20 dB from the source, to prevent solo-ing any instrument, due to the uniqueness of the mix-space breaking down at boundaries.

5. RESULTS AND DISCUSSION

For each participant, song and source, the recorded time-series data was downsampled to an interval of 0.1 seconds, then transformed from gain to mix domains using Eqn. 1. From this data the vectors representing *mix-velocity*, described in Section 3.2.2, were obtained using Eqn. 3.

5.1 Instrument levels

Since the experiment is concerned with relative loudness levels between instruments and not the absolute gain values which were recorded, normalised gains can be calculated from Eqn. 2, with $r = 1$. When all songs, sources and participants are considered, the distribution of normalised gains at the final mix positions is shown in Fig. 4, expressed in LU. In Fig. 4 and 5 the boxplots show the median at the central position and the box covers the interquartile range. The whiskers extend to extreme points not considered outliers and outliers are marked with a cross. Two medians are significantly different at the 5% level if their notched intervals do not overlap. Fig. 4 shows good agreement with previous studies, particularly a level of $\approx -3LU$ for vocals [7, 10] and $\approx -10LU$ for bass (see Fig. 1 of [10]). Fig. 6 also shows the final positions of all mixes of each song, where mix ‘1A’ is the mix produced by mixer 1, starting at source A, etc. This indicates a clustering of mixes based on the source position. Fig. 5d shows the box-plot of each ϕ value when data for all songs, sources and participants is combined. Since the audio tracks were loudness-normalised, the median value can be used to determine the preferred balance of tracks in terms of relative loudness, using Eqn 4. The results are shown in Table 1. Had the experiment been performed in a more conventional control room with studio monitors, less variance might have been observed [15].

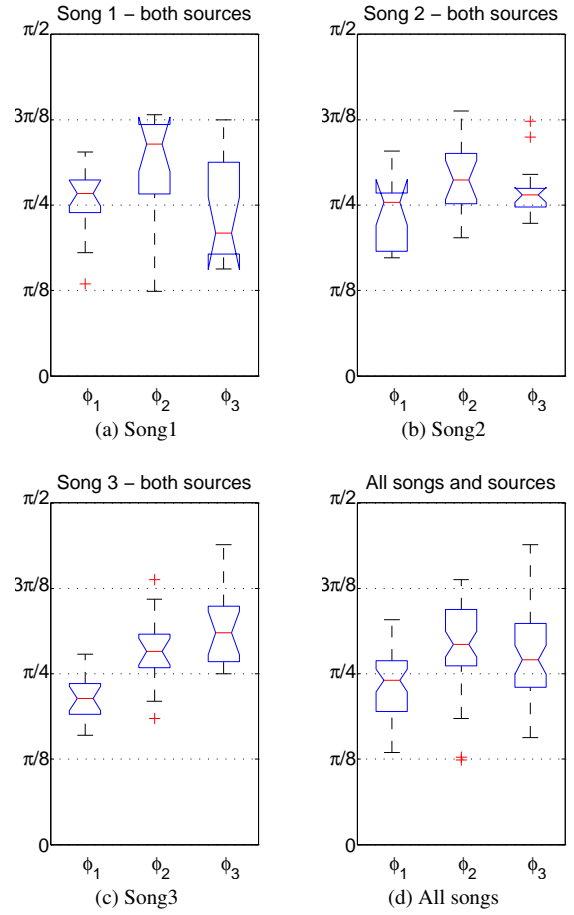


Figure 5: Boxplots showing the distribution of ϕ terms at final mix positions. While balances vary with song, vocal/backing balance and guitar/rhythm balance are more consistent than the bass/drums balance.

$$\text{vocals/backing} = 20 \times \log_{10} \left(\frac{\cos(\phi_1)}{\sin(\phi_1)} \right) \quad (4a)$$

$$\text{guitar/rhythm} = 20 \times \log_{10} \left(\frac{\cos(\phi_2)}{\sin(\phi_2)} \right) \quad (4b)$$

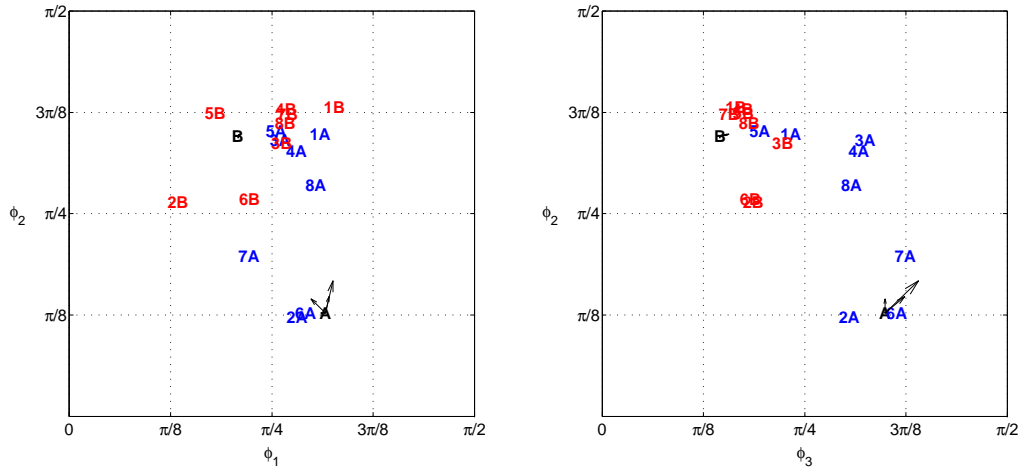
$$\text{bass/drums} = 20 \times \log_{10} \left(\frac{\cos(\phi_3)}{\sin(\phi_3)} \right) \quad (4c)$$

Balance	Song 1	Song 2	Song 3	All
vocals/backing	-0.95	-0.23	+1.98	+0.54
guitar/rhythm	-5.15	-2.04	-1.78	-2.38
bass/drums	+2.27	-0.83	-3.35	-1.12

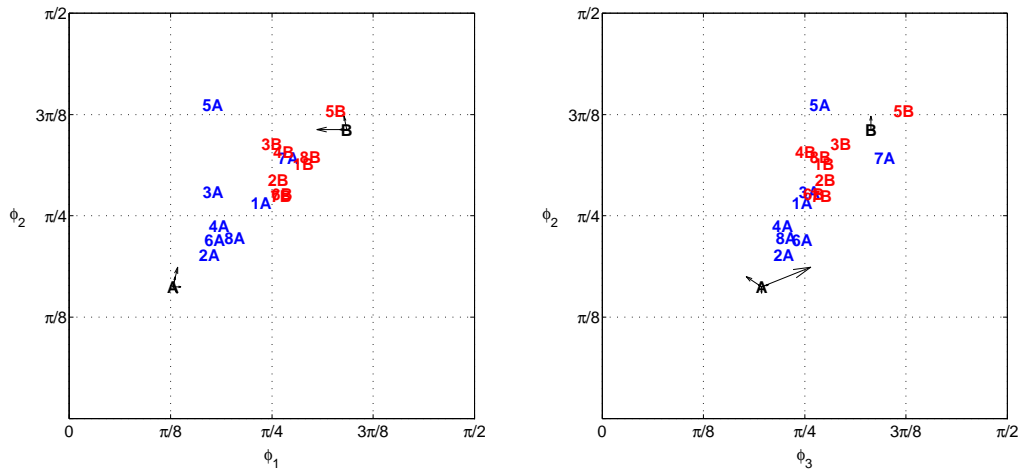
Table 1: Median level-balances (in loudness units) from Fig. 5, between sets of instruments defined by Fig. 2.

5.2 Source-directivity

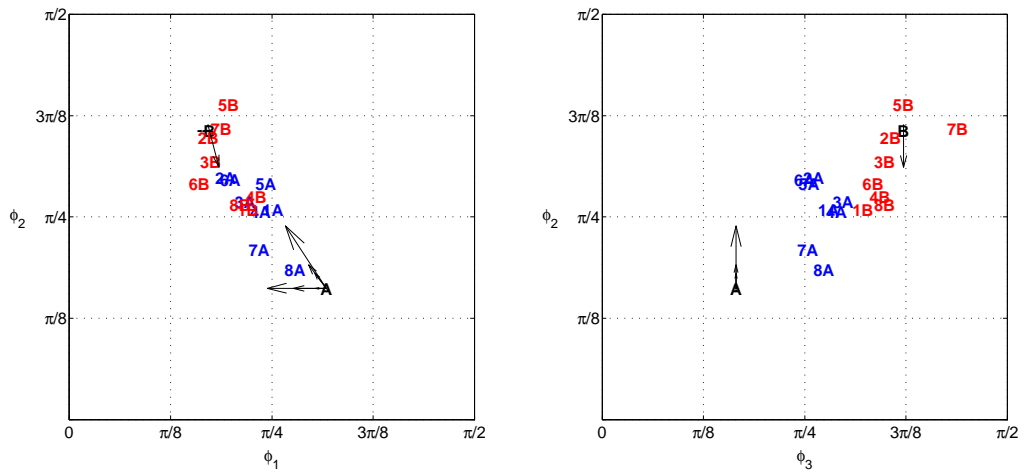
Movement away from the source is characterised by the first non-zero element of the mix-velocity triple u, v, w (see Eqn. 3). The displacement and direction of this move is used to investigate the source directivity. Fig. 6 shows



(a) Song 1 - the central cluster of mixes contains mixes originating at both sources.



(b) Song 2 - 7A is the only mix in this study which has more nearest neighbours from the other source.



(c) Song 3 - distinct cluster of mixes formed of those which started from source A

Figure 6: Positions of sources and final mixes in the mix-space. Source-directivity is indicated by added vectors.

the source positions within the mix-space, marked ‘A’ and ‘B’. The initial vectors are also shown, indicating the direction and step size of the first changes to the mix. None of the sources can be considered omnidirectional, as certain mix-decisions are more likely than others. This directivity indicates that the source position has an immediate influence on mixing decisions.

5.3 Mix-space navigation

Fig. 7 shows the probability density function (PDF) of $\phi_{n,t}$ when averaged over the eight mixes depicted in Fig. 6. The function is estimated using Kernel Density Estimation, using 100 points between the lower and upper bounds of each variable. This plot displays the mix configurations

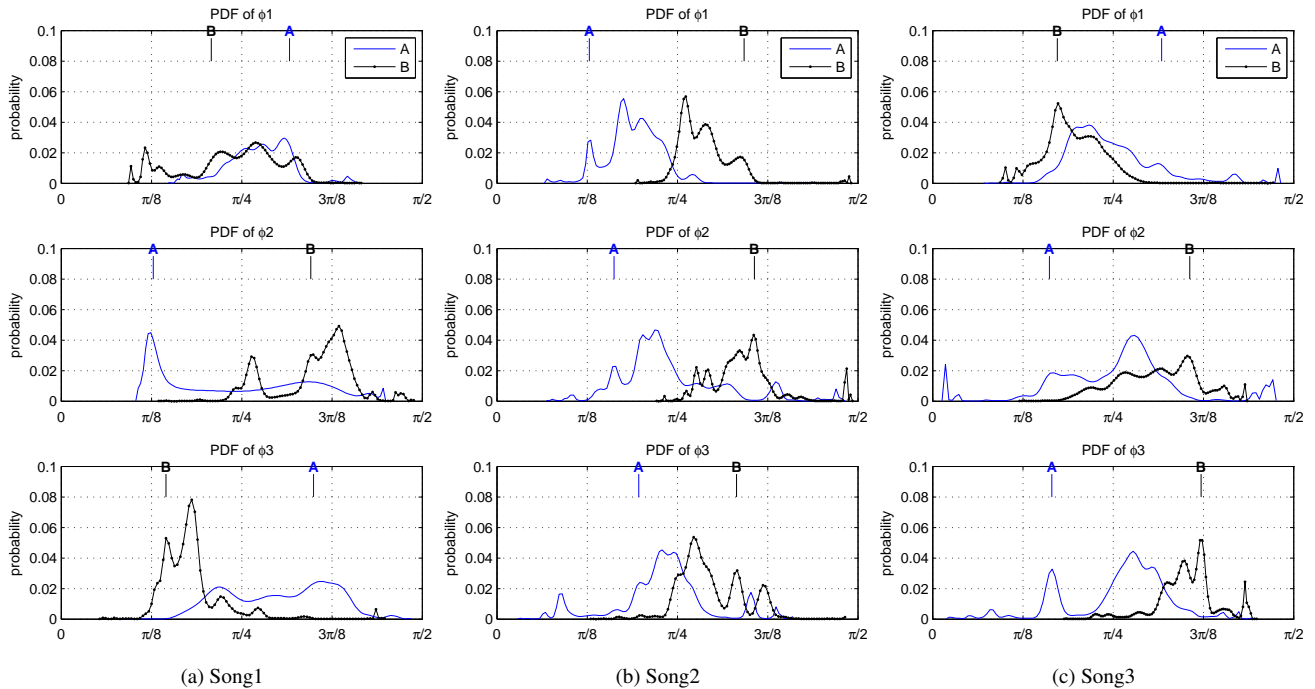


Figure 7: Estimated probability density functions of ϕ terms, for each of the three songs, averaged over all mixers. Sources positions are highlighted with **A** and **B**. As the functions often differ it can be seen that exploration of the mix-space is dependant on initial conditions.

which the participants spent most time listening to and it is seen that all distributions are multi-modal. There are peaks close to the initial positions, the final positions and other interim positions that were evaluated during the mixing process. There are a number of different approaches to multitrack mixing of pop and rock music, one of which is to start with one instrument (such as drums or vocals) and build the mix around this by introducing additional elements. Some participants were observed mixing in this fashion, shown in Fig. 7, where peaks at extreme values of ϕ_n show that instruments were attenuated as much as the constraints of the experiment would allow.

For Song 1, ϕ_1 is well balanced and centered close to $\pi/4$. This indicates that mixers tended to listen in states where the relative loudness of the vocal and backing track were similar. A similar pattern is observed for Song 2, where ϕ_3 , shows that the level of drum and bass tend to be adjusted such that the tracks have similar loudness (Table 1 shows the median loudness difference within final mixes was $<1\text{dB}$). The distributions of ϕ_2 indicates that the guitar was often set to be of lower loudness than the rhythm section, as also shown in Table 1.

There are notable differences due to the source. The distributions for Song 2 suggest that exploration depended on the initial source configuration, with Source A leading to louder vocals and louder guitar than Source B. However, for Song 2, the distributions of ϕ terms are similar for both source positions, simply offset. This suggests that, while different regions of the mix-space were explored, they were explored in a similar fashion.

Overall, for Song 3, the distributions in Fig. 7, the me-

dian balances in Fig. 5c and the clustering of final positions shown in Fig. 6c indicate that mixers were more consistent with this song than others. This may be due to the tracks representing processed stems of a full mix, where the inter-channel balances in these stems, subject to dynamic range compression as well as the relative level of reverb and other effects, may have provided clues as to how the groups were balanced in that final mix from which stems were obtained. This further suggests that the more prior work that has been put into the mix, the less likely subsequent mixers are to explore the entire mix-space.

Since this experiment gathered data for only three songs, the results should be considered as specific rather than general. It is not known at this time how many songs would need to be studied to be able to generalise to mixing as a whole, however, these three songs are considered to be typical, due to their conventional instrumentation.

5.4 Application of results

In automatic fader control, rather than aiming for equal loudness across all instruments, the preferred balances between semantic pairings of instruments, shown in Fig. 5d, could be used as the target for optimisation. This would require the unsupervised clustering of audio tracks into semantically-linked instrument groups, a task which is currently an active area of research [16–18].

Intelligent mixing systems aim to generate audio mixtures based on some desired criteria, ideally ‘Quality’. With a defined *mix-space* it is possible to utilise a number of dynamic techniques in generating mixes. The results of the

experiment outlined in this paper could be used to train an intelligent mixing system to produce a number of alternate mixes which the user could select from, in order to further train the system. Further information regarding mixing style can be found from the data. For example, the probability density function of *mix-velocity* could differentiate between mixers who mixed using either careful adjustment of the faders towards a clear goal or by alternating large displacements with fine-tuning. Knowing the distribution of step size used by human mixers will aid optimisation of search strategies in intelligent mixing systems.

6. CONCLUSIONS

For a level-balancing task, a mix-space has been defined using the gains of each track. A number of features of the space have been presented and an experiment was performed in order to investigate how mix engineers explore this space for a four track mixture of modern popular music.

From these early results it has been observed that each source has a directivity that is not equal in all directions, i.e. that not all possible first decisions in the mix process are equally likely. For each song there are varying degrees of clustering of final mixes and it is seen that the final mix is dependant on the initial conditions. The exploration of the space is also dependant on the initial conditions. This experiment has indicated a certain level of agreement between participants regarding the ideal balances between groups of instruments, although this varies according to the song in question.

Ultimately, the theory presented here could be expanded to include other mix parameters. Since panning, equalisation and dynamic range compression/expansion are each an extension to the track gain (either channel-dependant, frequency-dependant or signal-dependant), it should be possible to add these parameters to the existing framework.

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