Mood-Dynamic Playlist: Interpolating a Path of Emotions Using a KNN Algorithm

By
Shaurya Gaur

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Users curate music playlists based on emotion to focus or relax, so streaming services often create playlists of songs to aid this process. Prior research focuses on generating playlists of a single mood or genre, although a few studies work to construct automatic playlists that transition between the genres of their first and last songs. Building upon previous methods, we present a novel method for efficiently generating smooth and even playlists dynamic in both mood and genre. Given starting and target songs and a desired length, our two-stage algorithm sequentially chooses each track in between. It first uses a K-Nearest Neighbor model to retrieve potential songs based on emotional annotations in the Valence-Arousal emotion space, and then a vector distance metric to choose the next song based on audio features. We evaluate the smoothness and evenness of playlists across various regions of an emotional feature space. Our experiments indicate that the quality of track transitions from our algorithm's playlists is dependent on various input parameters and the distribution of the songs in our emotion dataset. This algorithm has potential as a novel music therapy tool, allowing users to create playlists in specific genres that nudge them to a desired mood.

Key Words: Music Information Retrieval, Music Emotion Recognition, Automatic Playlist Generation, K-Nearest Neighbor

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Contents

1 Introduction **3**

2 Modeling Music and Emotions **5**
2.1 Models of Emotion . . . 5
2.2 Musical Features . . . 6

3 Distance-Based Algorithms **8**
3.1 Distance Metrics . . . 8
3.1.1 Minkowski Distances . . . 8
3.1.2 Cosine Similarity . . . 9
3.1.3 Jaccard Index . . . 9
3.2 K-Nearest Neighbor . . . 9

4 Related Work **11**
4.1 Playlist Continuations . . . 11
4.2 Dynamic Playlists . . . 11
4.3 Mood Playlists . . . 12

5 Datasets **13**
5.1 Music Emotion Datasets . . . 13
5.2 Audio Feature Datasets . . . 15
5.2.1 Spotify Audio Features . . . 15
5.2.2 Million Song Dataset . . . 18
5.2.3 Spotify Audio Segments . . . 20

6 Preprocessing **23**
6.1 Principal Component Analysis . . . 23
6.2 Data Cleaning Process . . . 24
6.3 Song Dataset Class . . . 26

7 Mood-Dynamic Playlist Algorithm **27**
7.1 Stage 1: K-Nearest Neighbors . . . 29
7.2 Stage 2: Distance-based Song Selection . . . 30
7.3 Time Complexity Analysis . . . 31

8 Evaluation **32**
8.1 Experimental Design . . . 32
8.2 Evaluation Metrics . . . 33
8.2.1 Smoothness: Pearson Correlation Coefficient . . . 33
8.2.2 Evenness: Step Size Variance . . . 34

9 Experiments & Results **36**

9.1 Distance Metrics . . . 36
9.2 Audio Datasets . . . 37
9.3 K Values . . . 42
9.4 Playlist Lengths . . . 43
9.5 Dataset Segment Durations . . . 45
9.6 Regional Variances . . . 46

10 Discussion **49**
10.1 Summary of Findings . . . 49
10.2 Limitations . . . 50
10.3 Future Work . . . 50
10.4 Applications . . . 51
10.5 Conclusion . . . 51

References **52**

1 Introduction

Imagine yourself feeling frustrated and tense, late into the night. You need to go to sleep soon in order to wake up early in the morning, but you have far too much energy or are in a foul mood. To help yourself relax, you might listen to music. Studies have shown that listening to music for as little as five minutes can improve a user's mood and energy level [27], revitalize focus and productivity [34, 38], and break the monotony of work [48]. Music has been shown to be effective in elementary school classrooms as well, encouraging positive and productive behavior among children [74]. Using music can help children stay relaxed [23] and even provide a means of therapy for children with autism or dyslexia [44].

Researchers in the psychological effects of music have found that different types of music have varying impacts on a listener's mood. Faster songs [26] with a major-key [6] are linked with happiness [23], and more energetic music such as rock can increase a listener's stress and adrenaline, which can distract from exercise pain [26]. However, these effects also depend on the listener, as background music is more likely to distract introverted people than extroverted people [28]. Additionally, a listener's familiarity with a song can foster productivity in writing [18].

Streaming services such as Spotify [33] and Deezer [8] generate personalized automatic playlists for listeners. Recommending music for users is an important task in this field. Most systems in automatic playlist generation rely on data collected from tracks and users, including songs' audio characteristics [17], the popularity or genres of their artists [37], and user listening history [49]. Given this data, music recommendation systems often perform one of two tasks: choose the next song to play given a user's listening history, or produce a playlist of songs for them to enjoy.

Ongoing research efforts in this area strive to choose songs that are similar in features or mood to the current song being played. This requires tools and metrics that determine how similar two songs are to each other. Many approaches represent songs as a vector of relevant features, and calculate their distances to each other using metrics such as the Euclidean [22], Jaccard [2], and Cosine [42] scores. These allow researchers to use a K-Nearest Neighbor (KNN) model which returns a playlist of the K closest songs to one in the user's listening history or library [46, 49]. Some approaches use data which maps songs to emotions, which are in turn used to create playlists of tracks with a similar mood [10, 17].

While most studies focus on recommending similar songs, recent methods also aim to create dynamic playlists which smoothly transition between songs or artists. Some of these processes build graphs of similar artists [37, 64], which allow playlists to follow a path from one artist in one genre to another artist of a different genre. In one approach, Flexer et al. [25] use probability models to choose a playlist that bridges

the gap between two songs of different genres. However, this method only uses the genre categories of songs to evaluate the transitions between tracks in a playlist.

In this thesis, we present a novel algorithm that builds playlists which gradually transition from the mood of an origin song to that of a destination song. First, we collect and analyze public datasets of songs and their values in a two-dimensional emotional space [16] alongside their audio features [5, 70]. We then apply a KNN model and various distance scores in a two-stage algorithm, which analyzes our data to choose songs that lie in a linear path between the start and end songs of a playlist. To our knowledge, this method is the first to successfully generate playlists that are dynamic in both the mood and genre of the songs within it.

To evaluate the transitions between songs, we identify two key traits in a successful dynamic playlist: smoothness and evenness. We present a novel methodology to measuring these qualities empirically by analyzing playlists as points in a continuous space. In our experiments, we generate a large number of playlists that travel between various moods to examine the effectiveness of our algorithm in various conditions. We test the impact of various factors in our playlist algorithm, including the recall of the KNN model, the distance metric to compare songs, and the dataset of audio features.

Our algorithm can allow users to create playlists that slowly nudge them from their current mood to a desired state of mind. This approach will enable development of powerful new therapeutic tools to help users gain focus to work [18], calm down before sleep [74], maintain intensity in exercise [26], or improve happiness [62].

2 Modeling Music and Emotions

Research in computational methods of emotion recognition have produced models that represent moods as a set of categories and as a spectrum of values in a multi-dimensional space. Similarly, investigators in the field of music information retrieval (MIR) have created methods to distill a song's audio characteristics into numerical features. This foundational background enables computational methods, such as our algorithm, to interface with mood and audio to generate playlists that use music to travel through emotions.

2.1 Models of Emotion

To build technology that effectively interfaces with human emotion, researchers have established various frameworks to model different moods. Studies in emotion classification often examine affect as either a series of discrete categories, or as multi-dimensional points in a continuous space. Two of the most popular approaches in discrete categorization are Ekman's six basic mood labels [20] and Plutchik's concentric circle model [57]. For continuous representations, Russell's circumplex model [63] maps emotions as points in a two-dimensional space by their Valence (positivity) or Arousal (intensity). This representation of affect has been used in several music emotion studies [10, 17, 36, 46].

Discrete frameworks allow researchers to classify emotions into a handful of categorical labels, shown in Table 1. Models that attempt to recognize emotions from facial expressions have reported an accuracy of over 80% when classifying discrete moods [19, 66], but found far weaker performance when trying to predict continuous values in the Russell continuous space [36]. However, studies have found that mapping discrete labels from Plutchik and Ekman to the Russell space [52], or using quadrants of this space [50] have also been effective in classifying emotions.

	Author	**Basic Emotions**
[20]	Ekman	Anger, Disgust, Fear, Happiness, Sadness, Surprise
[57]	Plutchik	Joy, Sadness, Anger, Fear, Trust, Disgust, Surprise, Anticipation

Table 1: List of the simple emotions proposed by Plutchik and Ekman.

However, using only six or eight categories fails to capture the full spectrum of human emotion. The ability to better approximate this granularity is a strength of continuous models, which have been used in recent studies on mood-based playlist generation [10, 46]. These models typically have mapped emotions in the Valence and Arousal dimensions, as seen in Figure 1, but some studies also augment these

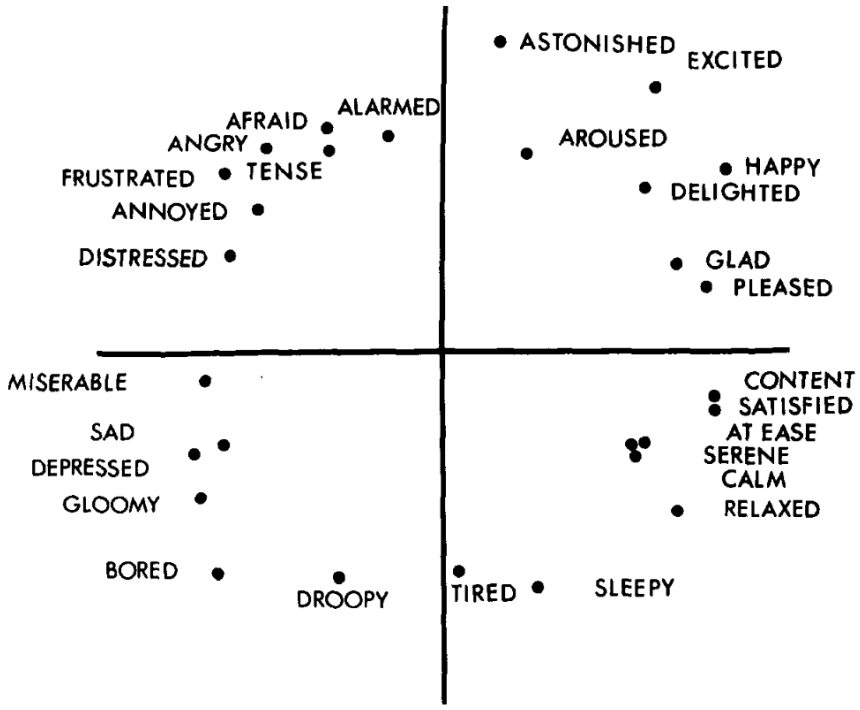

Figure 1: Russell's circumplex model of emotion (from [63]).

with dominance (regarding the locus of control in an emotion) or harmonic resonance, which can factor in a user's satisfaction in a song [17]. These dimensions and models are often interrelated, as Russell claims that the emotions from Ekman's and Plutchik's models can be represented in the Valence-Arousal plane [63].

2.2 Musical Features

Researchers in MIR focus on extracting the most essential features of songs from audio, symbolic music scores or user-based data. Many studies extract features from a song's raw audio, [30] such as the tempo in beats per minute (BPM), pitch from 12 chroma feature classes [22, 30, 31], and timbre, represented through Mel-Frequency Cepstral Coefficients (MFCC) [71, 73]. Figure 2 shows the distribution of timbre and pitch values throughout the duration of a song. This numerical data is popularly found in large datasets such as the Million Song Dataset [5] or through the application programming interfaces (API) of streaming services such as Spotify [70]. Other studies [22, 68] use MIDI data to represent the musical notes of songs, though MIDI-based datasets in MIR have often been limited to genres such as folk or jazz.

While many studies use data that represents the audio features of songs, some collect user-created descriptions from social media platforms like Twitter [55] or album review scores from Pitchfork [56]. Other approaches collect descriptive tags from

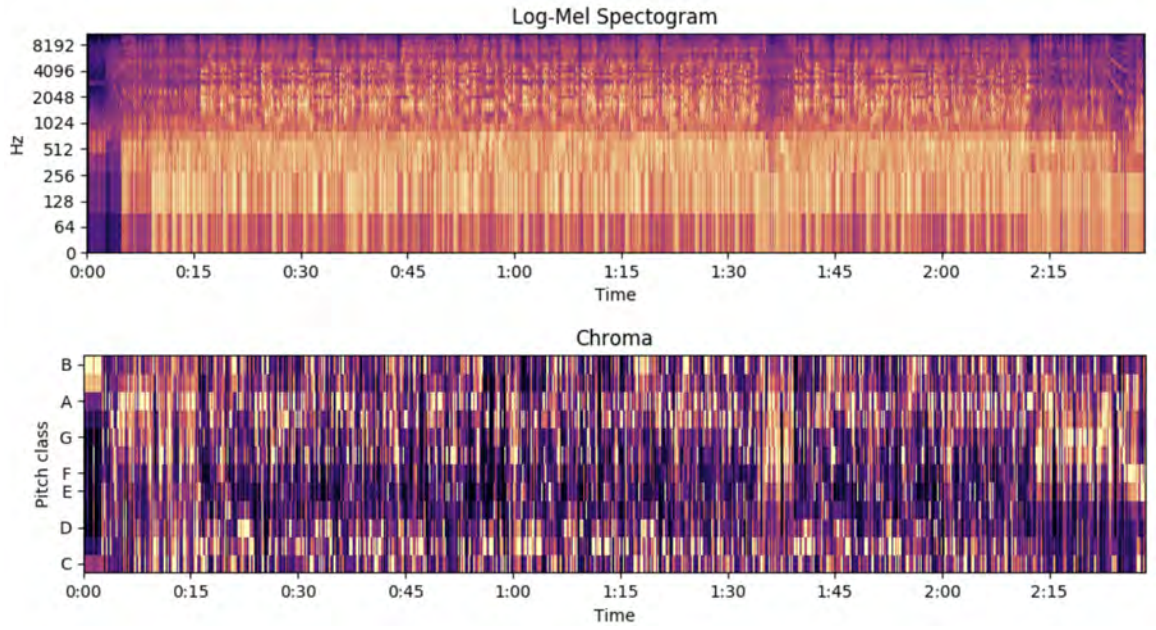

Figure 2: Mel-frequency spectral values, representing timbre, and chroma features, representing pitch classes, throughout the duration of Black Sabbath's song *Sabbath Bloody Sabbath*, from [58].

music information services like Last.FM [16], DBPedia or MusicBrainz [2]. Data is often collected at the artist [2, 37], album [56] or playlist [42] level as well. While these datasets are descriptive and plentiful, a 2020 study by Daikoku et al. [15] found that current MIR methods do not generalize well to non-Western music, underscoring the lack of cultural and stylistic diversity in these widely-used music datasets.

Representing the audio and emotional characteristics of songs numerically enables the use of mathematical formulas to calculate the similarities and differences between them. These methods compare songs as points in a multi-dimensional vector space, allowing researchers to represent playlists as a collection of points.

3 Distance-Based Algorithms

A key task in automatic playlist generation is determining how similar one song is to another. To model this similarity, researchers employ mathematical scores that determine the distances between songs, and store this information in models that allow developers to efficiently retrieve the closest songs to a sample.

3.1 Distance Metrics

Techniques in MIR rely on mathematical metrics that calculate the differences between songs, based on their data from a variety of features. Several studies calculate the discrete differences of MIDI notes [22, 68] or pitch values [9, 30] through different song segments to identify transformations within a song or between two songs. Others [31] create Gaussian probability models to predict discrete genre values, representing songs as distributions to compare using the Kullback-Leibler (KL) divergence. Some studies build graphs [45, 41, 37, 64] to model similarity, such as the MusicLynx[1] platform [2], a visualizer that connects similar artists based on a weighted metric that compares their genres.

While researchers employ various methods to compare discrete or categorical data, our work focuses on a song's numerical features. These represent songs as vectors in a multi-dimensional space, and allow us to use mathematical metrics to calculate the distance between them. Some scores calculate vector similarity instead of distance, which we easily convert to distance metrics by subtracting these similarities from their maximum values. We examine three metrics below.

3.1.1 Minkowski Distances

Perhaps the most popular vector distance metrics in mathematics are the Manhattan and Euclidean distances [22, 46, 73]. These are specific versions of the Minkowski distance [69], a formula for calculating the distance between two vectors in a space of a specific order, as shown in Equation (1).

$$D_M(X,Y) = (\sum_{i=1}^{n} |X_i - Y_i|^p)^{\frac{1}{p}} \tag{1}$$

This is equivalent to the p-norm of a vector $X - Y$. The Manhattan distance, also known as the taxicab distance, uses $p = 1$, which is the sum of the distances between two vectors in every single dimension. The Euclidean distance uses $p = 2$, and it is often used as the default norm for vector problems.

[1] https://musiclynx.github.io/

3.1.2 Cosine Similarity

Several researchers in playlist generation also measure the Cosine Similarity, or angular similarity, between two vectors [17, 42, 64]. This score calculates the cosine of the angle θ between two vectors. The domain of $\cos\theta$ is bound in the range of $[-1, 1]$, where a value of 1.0 indicates $\theta = 0$, or that the two vectors lie on the same line. Therefore, to determine the similarity of two vectors [59], we can rearrange the formula for the vector dot product to Equation (2).

$$S_C(X, Y) = \cos\theta = \frac{X * Y}{||X||\ ||Y||} = \frac{\sum_{i=1}^{n} X_i Y_i}{\sqrt{\sum_{i=1}^{n} X_i^2}\sqrt{\sum_{i=1}^{n} Y_i^2}} \tag{2}$$

To utilize this as a distance metric, we calculate $D_C(X, Y) - 1 - S_C(X, Y)$ as the Cosine distance between songs in our algorithm.

3.1.3 Jaccard Index

This metric was designed to examine the similarity of two sample sets by comparing the size of their intersection (the common elements in both sets) to that of their union (the combined set of both samples) [32]. This "intersection-over-union" approach functions similarly to a Venn diagram and has been used in models that detect objects like stop signs in images [72]. MIR researchers have previously used the Jaccard index to calculate the similarities between users [55] and artists [2]. For vectors, the Jaccard index is calculated by comparing the minimum and maximum values for two vectors at each dimension, as seen in Equation (3).

$$J_W(X, Y) = \frac{\sum_i \min(X_i, Y_i)}{\sum_i \max(X_i, Y_i)} \tag{3}$$

A value of 1.0 means that the two vectors are the same, and a smaller value indicates a greater distance between them. We calculate $D_J(X, Y) = 1 - J_W(X, Y)$ as the Jaccard distance in our algorithm.

3.2 K-Nearest Neighbor

In MIR studies, these distance metrics are often employed as part of larger algorithms that model the relationships between different songs or artists. One popular model is K-Nearest Neighbor (KNN), which makes decisions on a sample based on the values of the K nearest points around it, as determined by a distance metric. Proposed in 1951 [24], KNN was originally designed for classification problems in machine learning in which a classification for a sample point is the most frequent label among its neighbors (see Figure 3). However, this example-based learning algorithm also found success

in regression problems, where a point's numerical value is calculated as the mean of the values of its K nearest neighbors [3]. KNN-based regression has proven useful in handling non-linear patterns in data.

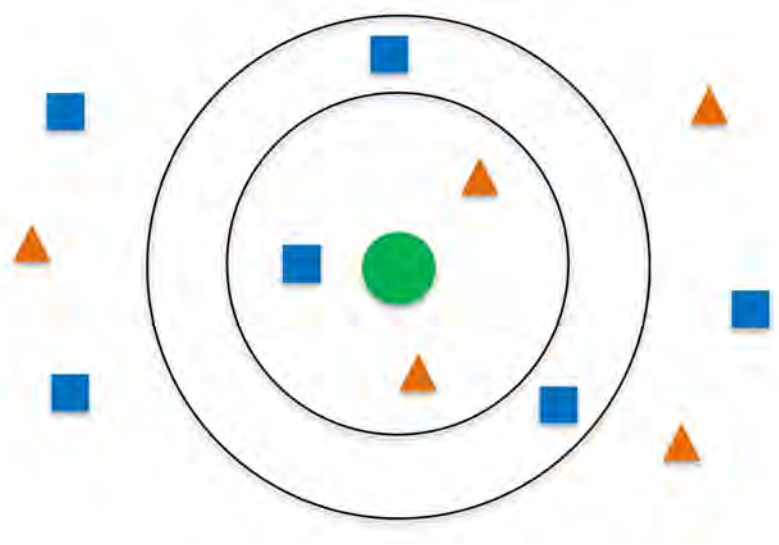

Figure 3: Example of a KNN classification problem. The green sample point is labeled as orange when $k = 3$ but as blue when $k = 5$.

Several researchers employ KNN for not only classification [51, 66] and regression [55, 47], but also to search for the neighbors of a sample or target point [46]. We employ this latter approach and utilize an unsupervised `NearestNeighbors` model[2] provided by the `scikit-learn` Python package [54], a popular collection of tools used in machine learning (ML). This model uses efficient data structures to store neighboring songs, varying its approach based on the number of songs and the dimensionality of their features. When a dataset has few points, or the distances between points are already computed, this model stores the distances between every pair of points. However, this approach becomes unfeasible with a large dataset, so the `scikit-learn` team resorts to tree-based approaches, which group nearby points to each other [54]. Often, these are K-dimensional trees, which partition each dimension in half based on its median value. This effectively creates quadrants for two-dimensional data, or octants for three-dimensional data [4]. Constructing this tree and returning neighbors is fast for fewer dimensions but grows inefficient with the number of features. In these cases, the `NearestNeighbors` model uses a Ball Tree, which clusters data into spheres of points that extend from various centroids [54]. The adaptability and efficiency of KNN models make them an effective tool in automatic playlist generation.

[2] https://scikit-learn.org/stable/modules/generated/sklearn.neighbors.NearestNeighbors

4 Related Work

People have curated lists of songs to play ever since we started listening to music. As a result, the MIR community is highly motivated to develop methods that automatically create playlists [10, 12, 17, 25] or recommend the next song for a user to play [42, 46, 49, 76]. These researchers build models based on data from songs, or in the case of streaming platforms like Spotify, data from users' listening tastes [46] or existing playlists [42, 76]. Some approaches also create playlists of emotionally similar songs [10, 17, 45], or playlists that gradually transition in audio features from an origin to a destination song [12, 25, 64].

4.1 Playlist Continuations

Playlist generation can be seen as a continuation problem, where a model recommends the next song to play given a list of the user's recently played tracks. Many approaches exist for these problems, such as Pampalk's method [49] of comparing the similarity of songs' audio features to previously played and skipped songs to choose the next song for the user.

Contestants in the 2018 ACM Recommendation Systems challenge used various methods to choose the next track, given a playlist of previous songs from a Million Playlist Dataset (MPD) provided by Spotify [42]. Many techniques used collaborative filtering (CF) to choose tracks based on their occurrence in other similar playlists [42]. CF can be a popular approach in playlist generation, and has been employed by Spotify [33] and Pichl et al. [55] to recommend songs based on the listening histories of other users. While this has proven effective with large datasets and popular streaming services, it suffers from a cold-start problem when it lacks initial users and skews towards popular tracks [46].

In contrast to CF, Ludewig [42] found that an approach using matrix factorization algorithms and KNN techniques was simpler, yet almost as effective, as more complex natural language processing (NLP) or convolutional neural network (CNN) systems. Zamani's examination of approaches in this challenge [76] found that the highest performing systems created a two-stage algorithm to recommend songs. This type of system uses a high-recall first stage to choose many candidate songs, and then re-scores these in a second stage, in which the most relevant candidate is chosen as the next song.

4.2 Dynamic Playlists

Previous studies have employed various methods to create playlists that smoothly transition between the audio characteristics of start and end songs. Pauws [53] and Chen [12] gather data on existing playlists using Markov embeddings or simulated

annealing to generate playlists with smooth track transitions. Sakurai [64] constructs similarity graphs based on songs' audio features using Reinforcement Learning to create playlists with high diversity and smooth track transitions. On the other hand, Lemare [37] creates playlists that transition between artists, using data on artist popularity and the energy of their tracks to determine a playlist of songs.

Flexer [25] creates playlists that gradually transition from a start to an end song, modeling songs as Gaussian probability models based on MFCC features. Their approach computes each song's KL divergence from the start and end song to create a playlist of songs in between. However, they only evaluate the transition between the playlists' first, middle, and last three songs, and only examine transitions in discrete genre categories rather than numerical audio features.

4.3 Mood Playlists

Various studies have worked to classify the emotions of users and songs to recommend music of similar emotions. Rumiantcev [62] designs a high-level model of a system which uses user and sensor data to recommend songs similar to a user's predicted mood using KNN or Random Forest approaches. Several other studies take strides in implementing such a design. Meyers [45] models the moods of artists, albums and songs into several discrete categories using a graph-based method [41] and compares these emotions to those extracted from mapping the words from a user's writing. EMOSIC [47] is a music player that performs similar emotion recognition on a user's face and songs' audio. They use Support Vector Machines and KNN approaches to predict values in the Valence-Arousal plane, and recommend songs emotionally similar to each other and the user's current mood.

While the above studies use data on songs, users, and albums, some other studies employ a purely song-based approach. Deng [17] predicts the emotions of the user's previously-listened songs from audio features to continue their current playlist, while Pao [51] implements a weighted-density KNN model to map emotions into discrete quadrants of the Valence-Arousal space. Moscato's approach [46] uses data from the Deezer 2018 dataset [16] and MFCCs to train a CNN to predict the Valence-Arousal mood values of songs outside the dataset. Their system uses a KNN model powered by the Euclidean distance to continue playlists with emotionally similar songs. While most studies recommend music to users that maintains their current mood, Cardoso [10] enables users to draw a path in the Valence-Arousal plane. Their approach chooses the closest songs to that path within a certain threshold, yet does not explicitly order these songs or evaluate the quality of these path-based playlists.

5 Datasets

To create playlists which are dynamic in emotion and audio, we require datasets which contain these features for a large number of songs. These datasets will function as a space in which our algorithm will select songs to form a path, representing a playlist. We combine datasets of songs and their points in both the Valence-Arousal emotional space, and various audio-based feature spaces.

5.1 Music Emotion Datasets

Many different datasets have been used for MIR and Music Emotion Recognition (MER) which provide ratings for songs in a continuous emotional space. To generate playlists that travel through emotions, we seek datasets that include information on songs and their values in the Valence-Arousal space. Typically, high-quality MER datasets consist of manual ratings provided by human annotators listening to music [1, 11, 77], but these only provide such data on either a few hundred songs. To find a sufficiently large dataset for our task, we primarily use the Deezer 2018 [16] dataset of 18,644 songs with synthetic values for Valence and Arousal.

Researchers from the Deezer music streaming service collected mood-related tags from the Last.FM service to describe each song, and used a dataset to map these words to their embeddings in the Valence-Arousal emotion space. They collected and normalized the means of these embeddings, releasing valence and arousal labels, IDs for the songs on Deezer and the Million Song Dataset [5], and the artist and track names for all 18,644 songs.

However, the synthetic nature of this dataset's ratings means that songs with the same or similar Last.FM tags may share the same value in the Valence-Arousal space [16]. This is a major limitation of this dataset, as the 18,644 songs only occupy 2,720 unique points. Table 2 shows that around seven songs on average share an emotional point, with as many as 1,700 songs occupying a single point.

	All Songs (N=18,644)		**Unique Points** (N=2,720)		
	Valence	*Arousal*	*Valence*	*Arousal*	*Frequency*
Mean	-0.067258	0.195720	-0.370665	0.059615	6.854412
St.Dev.	1.057872	0.960662	0.798128	0.722372	59.394308
Min	-2.148097	-2.333604	-2.148097	-2.333604	1
Median	0.032224	0.040198	-0.464615	-0.014126	1
Max	1.546714	2.755091	1.546714	2.755091	1732

Table 2: Summary statistics for all Deezer songs (left) and unique points (right).

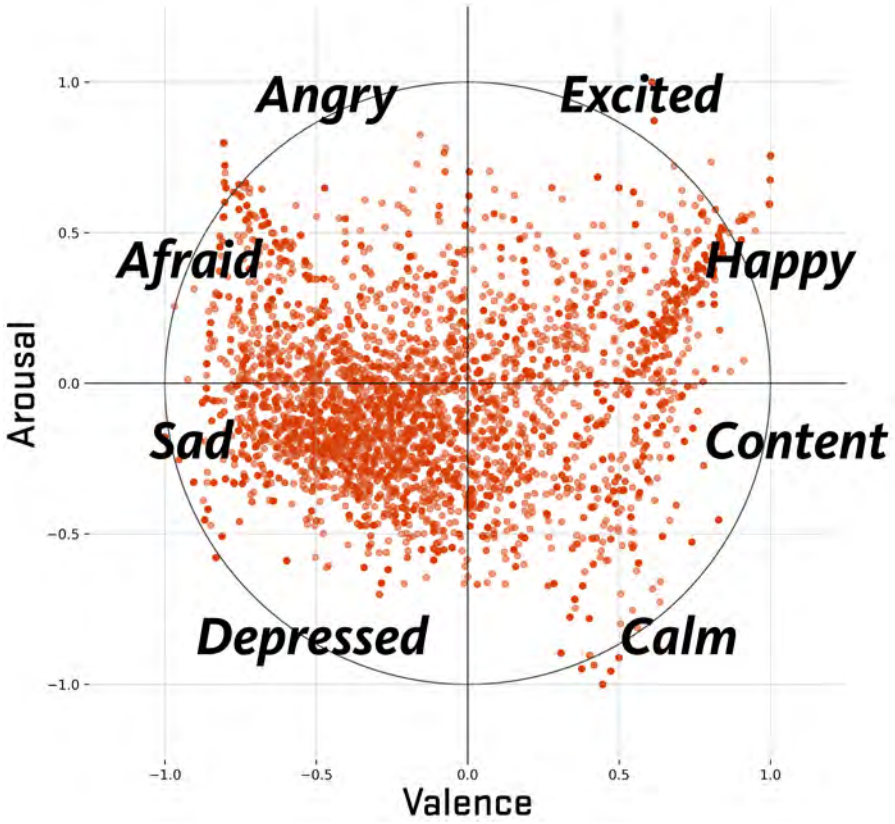

Figure 4: Scatter-plot of the distribution of Valence and Arousal in the Valence-Arousal circumplex space, each scaled to the [-1,+1] range.

Additionally, Table 2 and Figure 4 indicate that the distributions of the points in the dataset are uneven. While the distribution of Valence scores seems standardized between songs, this changes when filtering only for the unique points, which implies that happy and upbeat songs are more likely to share the same point in the Valence-Arousal space. The opposite is true for the Arousal values, which show a skew towards high-energy songs, but are fairly standardized when only considering unique points.

These two skews compound each other when considering the quadrants of the dataset. Table 3 shows that the Deezer dataset is more skewed towards songs that are either positive or negative in both valence and arousal, but sad and depressing songs have far more unique points in this space than any other type of song. This creates various regions in our dataset that are denser and sparser. Despite these limitations, Deezer's set of popular songs provides a large sample from which to build playlists and retrieve audio features from other public datasets.

Quadrant	Valence	Arousal	Emotions	Songs	Points
I	+	+	Excited, Happy	6001	502
II	+	-	Angry, Afraid	3638	832
III	-	-	Sad, Depressed	5444	1047
IV	-	+	Calm, Content	3561	339

Table 3: Descriptions and the number of songs and unique points in each Cartesian quadrant of the Deezer 2018 dataset.

5.2 Audio Feature Datasets

Since user preferences in genres of music have an effect on their mood, our goal is to create mood-dynamic musical playlists that also traverse smoothly between the genres of chosen origin and destination songs. Therefore, we augment our music emotion data of the songs from the Deezer dataset with acoustic features and other relevant metadata from the Spotify API [70] and the Million Song Dataset [5]. We compare these feature sets in Section 9.2.

5.2.1 Spotify Audio Features

As a first step, we extract additional features from Spotify, a large, popular streaming service for songs, with more than 500 million users, including 205 million subscribers in more than 180 markets[3]. The company uses collaborative filtering algorithms augmented with audio feature data driven by its 2014 acquisition of the Echo Nest API, which specialized in extracting feature embeddings from a song's audio and metadata [50]. The Spotify API includes endpoints for fetching audio features and other metadata for almost every song in its catalog [70].

To match a song from the Deezer dataset to a track from Spotify's catalog, we queried the API for a Spotify track ID using a search term that concatenates the artist and title of each song. This successfully queried for the URI for 17,755 of the Deezer dataset's 18,644 songs, and 2,672 unique points out of a total of 2,720. All audio-related features from the Get Audio Features[4] API endpoint were extracted. From the Get Track[5] API endpoint, we extract the popularity metric and the explicit tag of a track, since the popularity or explicit content of a song may have an effect on the user listening experience.

[3] newsroom.spotify.com/company-info/

[4] developer.spotify.com/documentation/web-api/reference/get-audio-features

[5] developer.spotify.com/documentation/web-api/reference/get-track

	Mean	St.Dev.	Min	Median	Max
acousticness	0.2618	0.3051	0	0.1110	0.995
danceability	0.5242	0.1590	0	0.5270	0.978
duration_ms	251336	81137	35587	239	1449973
energy	0.6222	0.2462	0	0.6510	0.999
instrumentalness	0.0844	0.2089	0	0.0002	0.983
key	5.2506	3.5622	0	5	11
liveness	0.1878	0.1557	0.0136	0.1250	1
loudness	-8.4547	3.9755	-46.2840	-7.6410	3.744
mode	0.6823	0.4656	0	1	1
speechiness	0.0605	0.0632	0	0.0387	0.954
tempo	122.0198	29.2322	0	120.1160	217.520
time_sig	3.9018	0.3680	0	4	5
valence	0.4609	0.2481	0	0.4360	0.984
popularity	34.1625	16.6780	0	33	84
explicit	0.0444	0.2059	0	0	1

Table 4: Statistics for 13 features from Spotify's Get Audio Features API endpoint, and two features from the Get Track endpoint, on 17,755 Deezer songs collected.

Overall, we extracted 15 features from Spotify, listed in Table 4. From this, we can see that most features have relatively little skew, except for the duration of a song in milliseconds. Additionally, most features are floating-point values between 0.0 and 1.0, representing confidence values for the feature described in the endpoint. However, some features represent values at different scales, as described in Table 5.

Feature	Type	Min	Max	Description
duration	*integer*	35587	1449973	song's duration in milliseconds
key	*integer*	-1	11	Pitch Class for a track (-1 for no key)
loudness	*float*	-60	0	average decibel level of the track
mode	*binary*	0	1	1 for major-mode, 0 for minor-mode)
tempo	*float*	0.00	217.52	tempo in beats per minute (BPM)
time_sig	*integer*	3	7	3/4 to 7/4 time signature range
popularity	*integer*	0	100	index based on number of recent plays
explicit	*Boolean*	0	1	1 (true) if a song is tagged as explicit

Table 5: Descriptions of Spotify features that do not lie on a 0.0 to 1.0 feature scale.

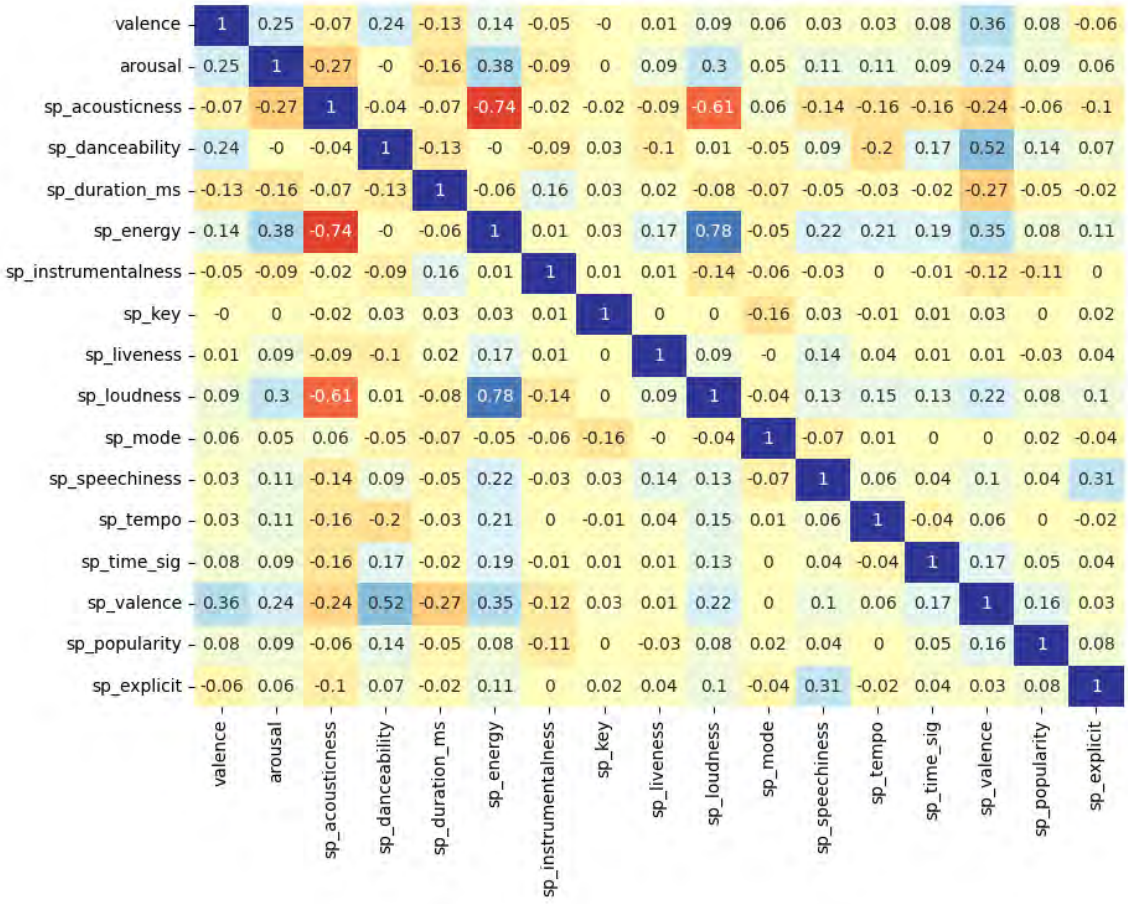

Figure 5: Correlation matrix for Valence and Arousal from Deezer 2018 and all collected Spotify features (prefixed with `sp_`).

The correlation matrix in Figure 5 shows that these features are mostly uncorrelated, save for energy, loudness, and acousticness. A 2021 study from Panda et al. found that these three features are the most relevant to MER [50]. Their study used an audio dataset of 900 songs to compare the effectiveness of Spotify features to other raw audio features in MER. This was measured by the correlation between each feature and synthetic labels for the Valence-Arousal quadrants which were validated by volunteers [50]. While the acousticness, valence, energy, and mode features had relatively high correlations individually, the whole set of Spotify features had a lower correlation with labeled emotions than other feature datasets, and were thus subpar for predicting a song's mood [50]. While this may be a detriment to other music emotion applications, it implies that these features account for characteristics unrelated to mood. This is useful in our application, since our audio feature datasets are meant to balance the genres of our playlist, and are not meant to signify emotion.

5.2.2 Million Song Dataset

One dataset frequently used in MIR is the Million Song Dataset [2, 16, 39], also known as the MSD. Created by a 2011 collaboration between researchers at Columbia University and The Echo Nest, with support from the National Science Foundation, this dataset includes audio-derived features and metadata for 1,000,000 songs from 44,745 unique artists [5]. Using the included `MSD_track_id` and `MSD_sng_id` for each track on the Deezer 2018 dataset, we extract audio-based fields which describe each track as a whole from the MSD[6], described in Table 6.

Feature	Type	Description
`key`	*integer*	predicted key of the song
`mode`	*integer*	major or minor key of the song
`time_signature`	*integer*	number of beats per bar
`key_confidence`	*float*	confidence measure of `key`
`mode_confidence`	*float*	confidence measure of `mode`
`time_signature_confidence`	*float*	confidence measure of `time_signature`
`loudness`	*float*	overall loudness in decibels
`tempo`	*float*	estimated tempo in BPM

Table 6: Descriptions of MSD features for tracks overall from its official field list.

In addition, we aggregated the loudness and timbre features of all segments of our song. A segment in a song is the smallest unit of time collected by the MSD, and contains a consistent sound throughout its duration [5]. We extract the loudness and timbre of segments by including the value and duration of each segment's peak decibel value, and its 12 MFCCs respectively. For each song, we calculated the average, variance, minimum, maximum, and median values across segments as a representation of an aggregated measurement of timbre and loudness. Table 7 shows descriptive statistics for all features and selected timbre aggregations. While many features are relatively centered, they exist on widely different scales and could result in certain features, such as the maximum loudness and timbre, overpowering others.

We extracted 78 features from MSD for all 17,755 songs from the Deezer dataset which also contained Spotify features. While the MSD is a large dataset with many features, it lacks album and song-level metadata and tags, and contains almost no music from different cultures or classical music [5]. Also, the MSD has not been updated since its release in 2011, so musical sample is restricted to tracks released between 1922 and 2011, diminishing its relevance towards future MIR studies that consider more contemporaneous music.

[6] http://millionsongdataset.com/pages/field-list/

	Mean	St.Dev	Min	Median	Max
key	5.2544	3.5671	0	5	11
key_confidence	0.4727	0.2694	0	0.492	1
loudness	-8.7548	4.0393	-34.022	-7.881	-0.227
mode	0.6759	0.468	0	1	1
mode_confidence	0.5082	0.1868	0	0.519	1
tempo	122.9944	32.0993	0	120.752	262.412
time_signature	3.722	1.0331	0	4	7
time_signature_conf...	0.5543	0.358	0	0.606	1
loudness_max_avg	-12.1558	4.9524	-42.4203	-11.3151	-1.4755
loudness_max_var	36.9183	22.6442	0.5162	32.7954	270.1014
loudness_max_min	-54.0999	10.5726	-60	-60	-5.056
loudness_max_max	-3.7329	2.9353	-25.451	-3.115	6.37
loudness_max_med	-10.9841	5.0924	-48.624	-9.99	-0.864
loudness_max_time_avg	0.0607	0.0166	0.0215	0.0581	0.418
loudness_max_time_var	0.0092	0.382	0.0001	0.0032	50.7472
loudness_max_time_min	0.0037	0.0041	0	0	0.0319
loudness_max_time_max	0.8673	2.2284	0.1052	0.5913	269.3235
loudness_max_time_med	0.0432	0.01	0.019	0.042	0.1376
timbre_0_avg	44.2645	5.1914	15.2725	44.9773	55.7646
timbre_0_var	37.421	22.0484	1.1725	33.2962	249.3499
timbre_0_min	3.7664	7.7711	0	0	47.743
timbre_0_max	52.9363	3.2002	29.65	53.604	61.504
timbre_0_med	45.469	5.3997	9.568	46.308	56.13
...	...	...	...	...	...
timbre_11_avg	2.3729	7.3529	-39.9886	2.1727	47.7089
timbre_11_var	287.0263	117.2919	50.5546	267.3146	1934.4954
timbre_11_min	-56.8164	16.3461	-157.703	-55.137	-1.489
timbre_11_max	60.2111	16.8135	10.323	58.719	171.616
timbre_11_med	2.5286	7.3425	-42.053	2.309	49.9985

Table 7: Statistics for some of the 78 MSD features on 17,755 Deezer songs collected. Aggregations for MFCCs 1 through 10 not shown for brevity. Features for `loudness_max` and `timbre` are for segments and have `segments_` as a prefix in usage.

5.2.3 Spotify Audio Segments

The MSD and Spotify features aggregate data at the level of an entire song, which implies that a song's sound is the same throughout its duration. Yet this does not reflect the reality of music, which often transitions between characteristics over the course of a song. Since a playlist involves transitions between the end of one song and the start of the next, collecting audio features for the start and end of each song could potentially yield smoother transitions. The Spotify API's "Get Audio Analysis" endpoint[7] contains data for various subdivisions of a song, as shown in Table 8.

Subdivision	**Meaning**
Sections	large variations in rhythm or timbre
Bars	measure, given number of beats
Beats	basic unit in music (e.g. metronome tick)
Tatums	lowest regular pulse train that listener intuitively infers
Segments	unit with consistent sound throughout its duration

Table 8: Descriptions of song subdivisions from Spotify's Audio Analysis API.

We successfully extracted data on segments for 17,751 out of 17,755 songs. The remaining four songs lacked lacked audio analysis data in the Spotify API. We choose to extract data from segments since they are one of the smallest units of data in a song. This is verified visually in Figure 6, generated from a community tool[8]. Segments also contain the most data when compared to other subdivisions, since they include the peak and onset loudness of a song (in dB), as well as 12 chroma vector values for pitch, and 12 MFCC features for the timbre.

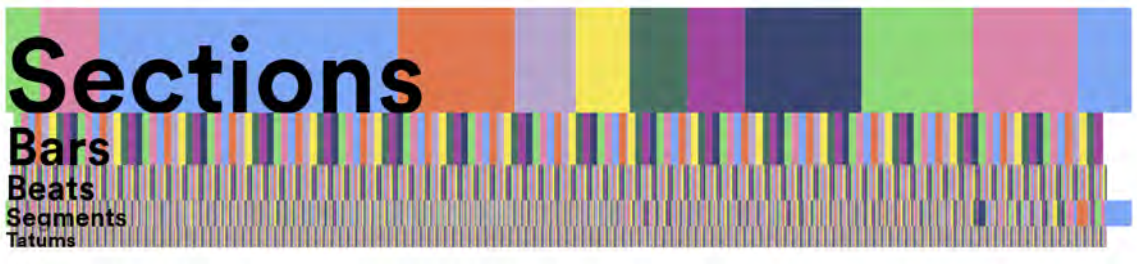

Figure 6: Visualization of subsections of *Digital Love* by Daft Punk.

[7] developer.spotify.com/documentation/web-api/reference/get-audio-analysis
[8] spotify-audio-analysis.glitch.me

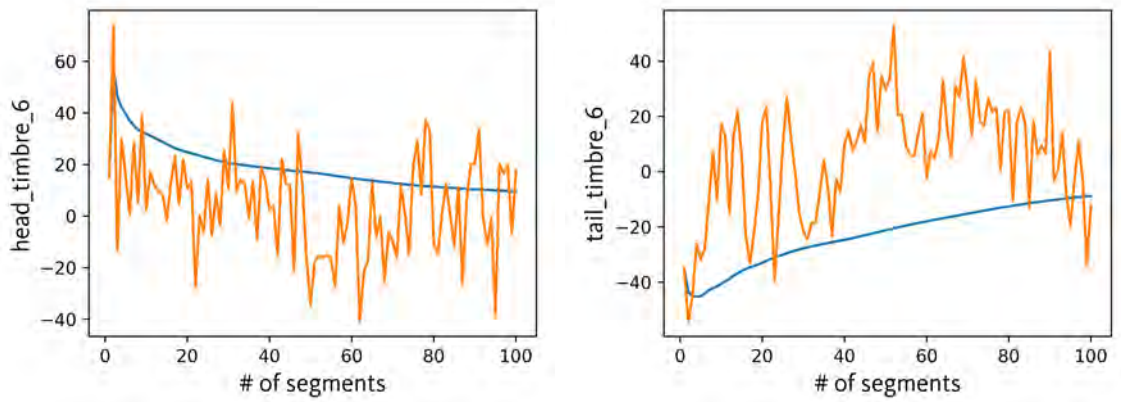

Figure 7: Custom weighted averages of up to the first and last $N = 100$ segments respectively for the `timbre_6` feature. Example song is *Gone* by Pearl Jam.

For each of these features, we compute weighted averages for the head (or first N segments) and tail (or last N segments) of each song. Segments have a specific order in a song, and each segment has a varying duration in terms of the length of the song. Therefore, we decided to create a custom weighted average that considers the order − defined as the closeness to the head or tail − and duration of each segment when creating our weighted average:

$$W = \frac{\sum_{i=0}^{N-1} f_i d_i (N-i)}{\sum_{i=0}^{N-1} d_i (N-i)} \tag{4}$$

where $N =$ the number of segments in the calculation, $f_i =$ value of feature at the i^{th} segment, and $d_i =$ duration of the i^{th} segment. In this formula, segments closer to the start or end with longer duration hold greater weight than later, shorter segments, since they are heard prominently at the beginning or end of a song. As more segments are factored into the weighted average, our custom weighted average value tends to stabilize around certain values. This is illustrated in Figure 7.

We collect various segment feature datasets based on the number and total duration of segments (e.g., the first 30 seconds) and round each to six decimal places. These datasets contain 26 features for the head of the song (12 from pitch vectors, 12 from timbre MFCCs, and 2 from loudness) and for the tail, for a total of 52 features. Table 9 describes the distribution of the averaged features for the first 100 segments of Deezer songs. These statistics imply that segment-based features are not skewed, but that the timbre and loudness features are at much larger scales than the pitch.

	Mean	St.Dev.	Min	Median	Max
head_loudness_max	-16.1074	7.4773	-55.929	-15.3226	0.5292
head_loudness_start	-26.1861	7.9473	-58.8554	-26.0611	-4.4365
head_pitches_0	0.3627	0.1857	0.0098	0.3455	0.9999
head_pitches_1	0.3473	0.1834	0.0199	0.3263	0.9987
head_pitches_2	0.3264	0.171	0.0155	0.3063	0.992
head_pitches_3	0.2657	0.1485	0.012	0.2413	0.9974
head_pitches_4	0.3219	0.1681	0.0097	0.3017	0.9986
head_pitches_5	0.2842	0.1534	0.0099	0.2636	0.9845
head_pitches_6	0.2857	0.1466	0.0111	0.2658	0.9915
head_pitches_7	0.3181	0.1632	0.0112	0.299	0.9992
head_pitches_8	0.2767	0.1489	0.0148	0.2544	0.9919
head_pitches_9	0.3198	0.1688	0.0074	0.2969	0.9998
head_pitches_10	0.2593	0.1444	0.007	0.2349	0.9959
head_pitches_11	0.3114	0.1606	0.0026	0.2923	1
head_timbre_0	39.2529	7.5379	2.32	39.7333	58.4351
head_timbre_1	18.5281	61.975	-281.1501	22.838	369.1475
head_timbre_2	-5.1866	45.059	-203.8026	-4.3076	239.6
head_timbre_3	0.5451	26.534	-105.625	-3.9182	254.2491
head_timbre_4	19.9278	23.7255	-66.6107	18.5872	191.5217
head_timbre_5	-17.6264	14.7215	-106.4868	-18.8081	71.0534
head_timbre_6	-6.7193	15.0338	-72.4662	-6.8596	76.7225
head_timbre_7	-1.8159	10.8272	-71.919	-1.7113	87.3362
head_timbre_8	-7.5361	9.6454	-71.3813	-7.3055	50.1824
head_timbre_9	0.3965	6.1872	-44.9041	0.3477	45.4983
head_timbre_10	-10.9828	7.7418	-92.756	-9.7548	23.8244
head_timbre_11	1.6325	7.6403	-48.6695	1.6404	51.5329

Table 9: Descriptive statistics for 26 features for a segment dataset averaging data for the first $N = 100$ segments for 17,751 Deezer songs. We also collect the same 26 features for the tail, or the last N segments, of all of our songs.

6 Preprocessing

We see from Tables 2, 4, 7, and 9 that the audio feature datasets vary greatly in their dimensionality, the number of songs collected, and the scales of their features. To prepare these datasets for our playlist algorithm, we must account for these factors by transforming the data. We begin by removing any songs from our dataset that do not have features from all three audio datasets, leaving each dataset with 17,751 songs out of a possible 18,644. This results in the loss of 893 songs but we retain 95.2% of the Deezer dataset. Next, we apply a set of transformations to account for the dataset's varying dimensionality and feature scales.

6.1 Principal Component Analysis

Spotify and the MSD provide audio feature datasets that differ in dimensionality. More specifically, there are only 15 Spotify features compared to the 78 features of the MSD. Inputs with high dimensionality have typically hindered the performance of many approaches in ML, including KNN methods [43]. We examine the effect of this dimensionality in song transitions by comparing playlists made by the full Spotify and MSD features against those made by a reduction of these datasets.

We employ a Principal Component Analysis (PCA) to reduce the Spotify features, MSD features, and a combination of Spotify and MSD features to 12 dimensions each. Table 10 shows that this number explains over 95% of the variance in Spotify features, using an approach in line with common ML practices [65].

Dataset	Original Feature Count	Variance Retained
Spotify	15	96.7%
MSD	78	68.3%
All (Spotify + MSD)	93	62.7%

Table 10: The proportion of variance kept after performing a PCA to 12 features on each audio feature dataset.

We employ the `PCA`[9] module from `scikit-learn` [54] for this transformation, which uses Singular Value Decomposition (SVD) to project the feature data into a lower-dimensional space. Figure 8 illustrates the effects of this PCA transformation on the Spotify features, showing that a PCA yields 12 features with zero correlation, or maximum covariance. Only musical features from Spotify and MSD are transformed with PCA, and the Valence-Arousal values from Deezer are untouched.

[9] scikit-learn.org/stable/modules/generated/sklearn.decomposition.PCA

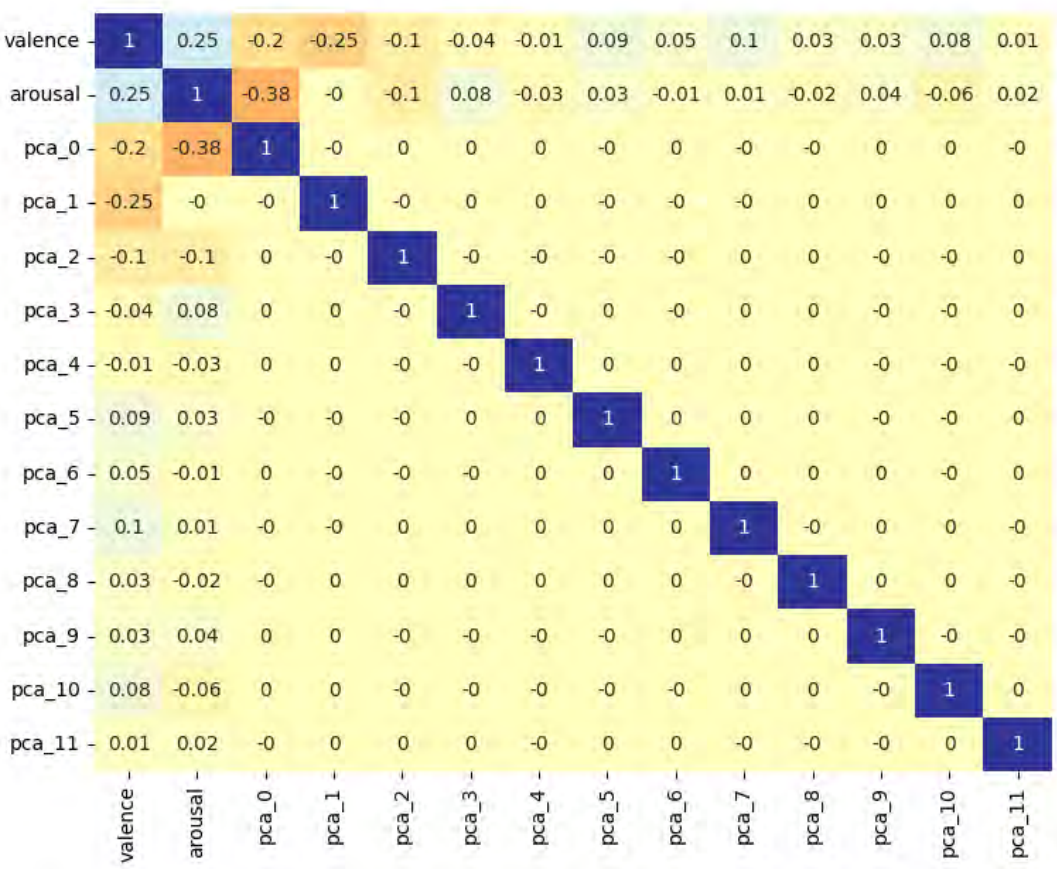

Figure 8: Correlation of Spotify features after PCA, with Deezer features untouched.

6.2 Data Cleaning Process

Since we aim to create playlists that travel across various feature spaces, it is imperative to transform each feature to a consistent scale. Originally, we hypothesized that transforming data to have zero mean and unit variance would suffice. However, we observed that transforming data using the `StandardScaler`[10] included with the `scikit-learn` Python package [54] still resulted in different tail sizes between features with large numbers of outliers, as depicted in Figure 9. This is a problem because features with larger or more extreme values would have an outsized effect on the path of the song. To reduce the effect of outliers, we employ a power transformation on each feature to rein in each distribution. To achieve this, we apply `scikit-learn`'s [54] `PowerTransformer`[11], which employs the Yeo-Johnson transformation [75], to reduce the range of outliers.

[10] scikit-learn.org/stable/modules/generated/sklearn.preprocessing.StandardScaler

[11] scikit-learn.org/stable/modules/generated/sklearn.preprocessing.PowerTransformer

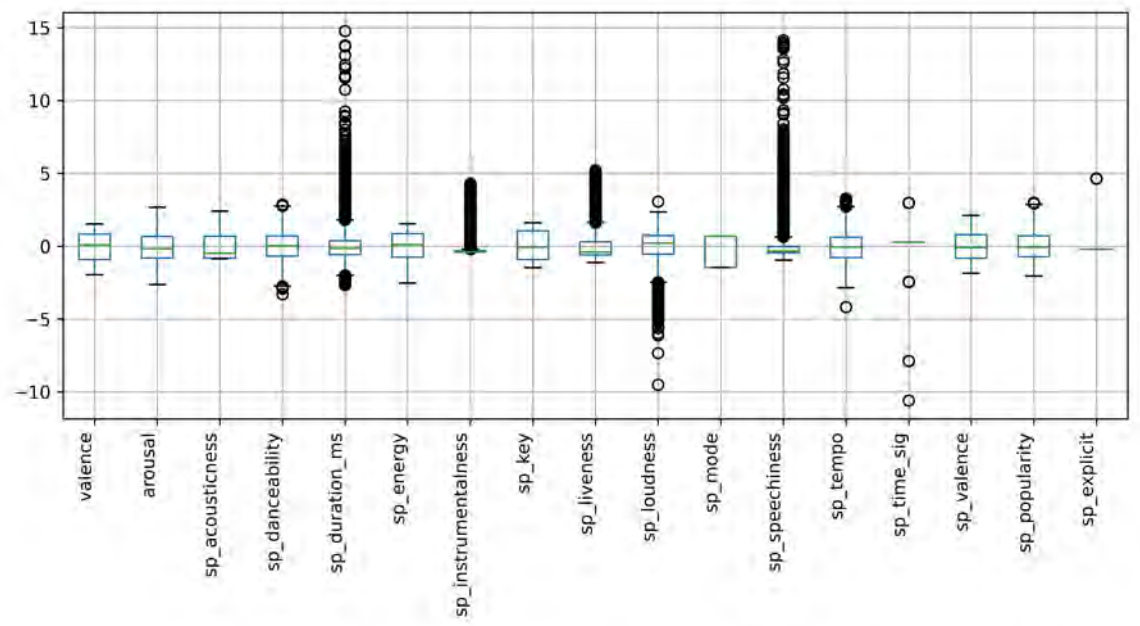

Figure 9: Deezer dataset and Spotify features after standardization. Notice the outliers on most features and the inconsistent ranges between features.

While this transformation manages most outliers to reasonable levels, some features still retain extreme outliers outside the interquartile range (IQR). We define extreme outliers as any features that had values that strayed $5.5 \times IQR$ from the median. Features that contain extreme outliers are discretized into 20 bins using `scikit-learn`'s [54] `KBinsDiscretizer`[12].We determined 5.5 as an appropriate coefficient since smaller coefficients (i.e. 2.5 or 3) would discretize almost every feature for some datasets, such as those with segment data. In our preliminary experiments, we find that a coefficient of 5.5 provided a balance between keeping the data continuous and removing the most extreme outliers.

After discretization, all features are normalized into a $[-1, 1]$ range, with a minimum value of -1.0 and a maximum value of $+1.0$, to keep the total distance for each feature the same and ensure no single feature is given undue weight in calculation for the transition between songs. We use the `MinMaxScaler`[13] from `scikit-learn` [54] to achieve this goal. Figure 10 presents the Deezer and Spotify features after transformation. We apply this transformation to all datasets: the original Deezer Valence-Arousal data, Spotify and MSD audio features, segment-based data, and PCA datasets.

[12] scikit-learn.org/stable/modules/generated/sklearn.preprocessing.KBinsDiscretizer

[13] scikit-learn.org/stable/modules/generated/sklearn.preprocessing.MinMaxScaler

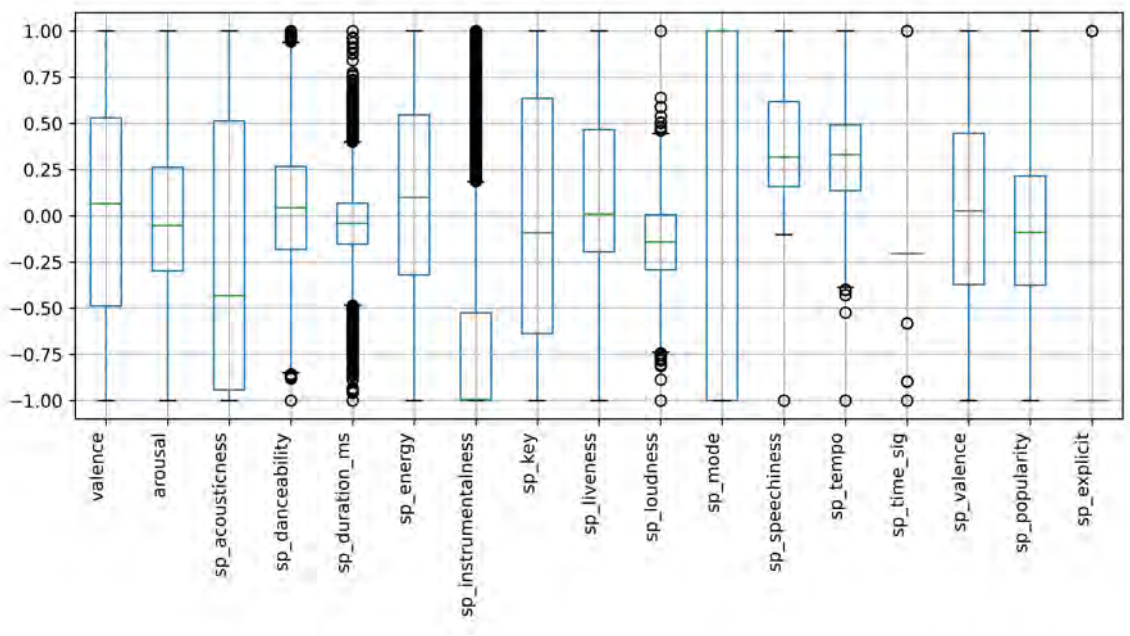

Figure 10: Deezer dataset and Spotify features after the power transformation, discretization, and normalization process.

6.3 Song Dataset Class

To manage mood, audio and segment-based features for 17,751 songs, we build a custom object to contain our datasets. Using the `pandas` package in Python, we create a separate `DataFrame`, or table, for each audio feature dataset and the Deezer 2018 dataset, containing features for each song. For a segment-based dataset, we split the audio feature tables into two tables − one for the features for the head of the song and another for the tail.

For the purposes of this study, we generate large numbers of playlists to test the algorithm's capability. To save time when running our experiments, we build an unsupervised `scikit-learn` [54] KNN model using the unique points of the Deezer 2018 dataset in our class, which is reused for creating every playlist. Finally, for the purposes of our algorithm in Section 7, we save a map which returns the Deezer song IDs that share a given Valence-Arousal point.

7 Mood-Dynamic Playlist Algorithm

In this work, we build upon existing approaches to create an algorithm that generates mood-dynamic playlists. Given an origin song, a destination song, and a desired length, our tool can generate a playlist in which the songs form a path between the origin and destination. This path lies in the Valence-Arousal emotional space, with additional considerations given to an audio feature space.

Our playlist generator requires a few key input parameters. First, the user provides the algorithm with a dataset that contains Valence-Arousal data and audio features for songs. In addition, they specify an origin song S_1 and a destination song S_N, which must be IDs for songs that exist inside the dataset. Finally, the user specifies the number of songs N desired in the playlist.

In a different approach to Cardoso [10], our playlist algorithm works sequentially. choosing each subsequent song in a loop until the length L of the playlist is equal to $N-1$. Each iteration of this loop begins with the knowledge of the most recently chosen song, the destination song, and the number of songs remaining.

Within this loop lies a two-stage algorithm to select the next song, which we use to ensure a balance between emotional and genre transitions. This approach is similar to approaches outlined in Zamani [76], where the first stage of the algorithm recalls a large number of candidate points to be re-scored for accuracy in the second stage. Such a method is required, since the high dimensionality in each audio feature dataset could vastly overpower the two Valence and Arousal features in the Deezer dataset if not separated. For example, a combined KNN model with 15 Spotify features and two Valence-Arousal features would primarily choose neighbors based on audio characteristics. We describe our two-stage generator with pseudocode in Algorithm 1, and explain each stage fully in Sections 7.1 and 7.2.

Algorithm 1: Two-stage mood-dynamic playlist algorithm.

Input : Dataset D. KNN mood model K, and audio vectors V, $\forall\ S \in D$.
Origin and destination songs for the playlist $S_1, S_N \in D$.
Length of the final playlist N.

Output: A playlist P of N ordered songs $[S_1, ..., S_N] \in D$.

$P, L \leftarrow [S_1], 1;$
while $L < N - 1$ **do**
  $[S_{candidates}] \leftarrow \text{neighbors}(K, S_L, S_N, L)$; `/* Stage 1 */`
  $[S_{candidates}] \leftarrow \text{filter}([S_{candidates}], P);$
  $S_{L+1} \leftarrow \text{distance}(V, [S_{candidates}], S_L, S_N, N - L)$; `/* Stage 2 */`
  $P, L \leftarrow [P, S_{L+1}], L + 1;$
end
$P \leftarrow [P, S_N];$

After the execution of the loop shown in Algorithm 1, the destination song is added to the playlist. This is returned as a `pandas DataFrame` table containing Deezer IDs for each song in the playlist, along with the Valence and Arousal points, artist and name for each song. Table 11 describes the songs in an example playlist that charts a path through the Valence-Arousal space shown in Figure 11, starting at a sad, depressed region and eventually ending at a happy, excited song.

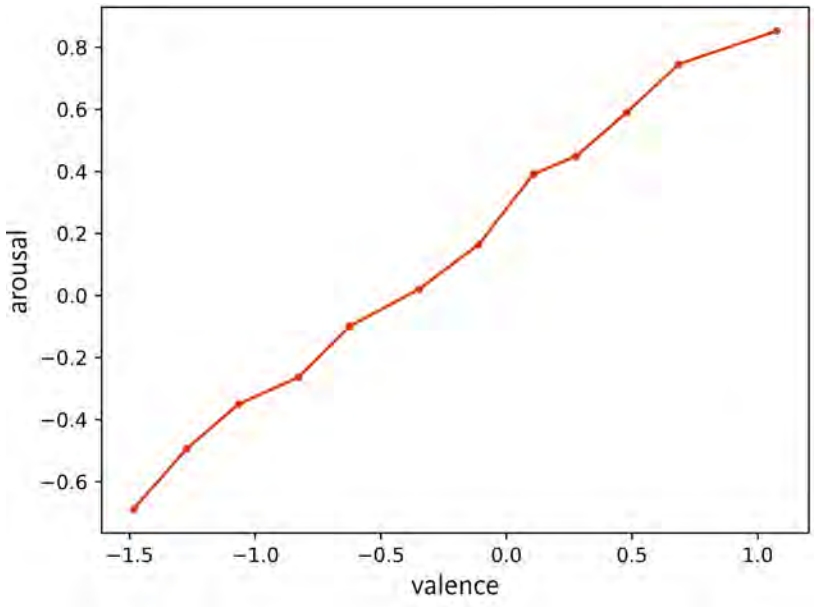

Figure 11: An example playlist traveling through the Valence-Arousal space. Each point is a song listed in Table 11.

Artist	**Song Title**	**Valence**	**Arousal**
Patty Loveless	*How Can I Help You Say Goodbye*	-1.483343	-0.688598
Elefant	*Ester*	-1.272664	-0.494736
Crossfade	*Cold*	-1.066284	-0.350541
Vanessa Carlton	*Paradise*	-0.827658	-0.264024
Julian Casablancas	*Tourist*	-0.623428	-0.099001
Aimee Mann	*Going Through the Motions*	-0.347825	+0.019559
Röyksopp	*The Girl and The Robot*	-0.110919	+0.163753
Black Kids	*Love Me Already*	+0.107500	+0.391261
Carpenters	*Yesterday Once More*	+0.277763	+0.448938
Interpol	*C'mere*	+0.478983	+0.589929
311	*Mindspin*	+0.685363	+0.745339
Rachael Yamagata	*1963*	+1.075764	+0.852684

Table 11: Artists, titles, and points for the songs in the playlist shown in Figure 11.

Figure 12: A diagram showing the target point in Stage 1 as the first step in a linear trajectory from the current point in the playlist to the destination.

7.1 Stage 1: K-Nearest Neighbors

The first stage in the playlist loop uses a K-Nearest Neighbor (KNN) model to choose K points in the Valence-Arousal space that represent songs in our music emotion dataset, similar to approaches in Cardoso [10] and Flexer [25].

Given the current S_L and destination S_N songs as points in the Valence-Arousal space, and the number of loop iterations remaining $N-L$ to achieve the playlist length desired by the user, we calculate a hypothetical target point S_T using Equation (5). This equation divides the line between the current and destination songs into even steps in the Valence-Arousal space, and determines a hypothetical point as a single step down this path. Figure 12 visualizes the relationships between these three points, with the target point as the first step in a linear path of $N-L$ songs from the current to the destination song.

$$S_T = S_L + \frac{S_N - S_L}{N - L} \tag{5}$$

We collect the songs in our dataset nearest to our hypothetical target point using `scikit-learn`'s `NearestNeighbor` model, fit to the unique Valence-Arousal points in our music emotion dataset [54]. Because of the two dimensions and 2762 unique points in the Deezer 2018 dataset, this algorithm uses a K-dimensional tree to store points for a search, achieving a computational cost of $O[DN\log(N)]$, or $O[N\log(N)]$ given the consistent use of $D = 2$ Valence-Arousal dimensions in our KNN stage. In this model, `scikit-learn` uses the Euclidean distance to determine the K nearest neighbors to a point.

We extract the LK nearest neighbors to the target point from this model, where L is the current length of the playlist. Occasionally, the `NearestNeighbors` model returns points already chosen for the playlist. To avoid repeating points in the Valence-Arousal space, we manually filter to receive the K nearest neighbors that have not been already chosen. We test various values for K in Section 9.3.

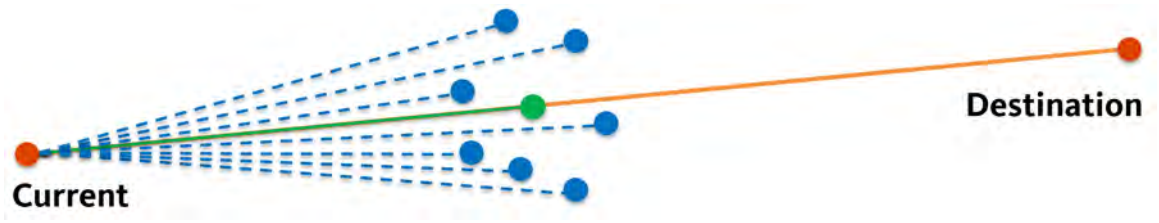

Figure 13: A visualization showing the candidate points and vectors (blue, dashed lines) which are compared to the target vector (green solid line) in Stage 2.

7.2 Stage 2: Distance-based Song Selection

Stage 1 produces a set of K Valence-Arousal points representing songs that are candidates for the next song in our playlist. From these candidate points, we query our dataset for all of their corresponding Deezer songs and their acoustic features from the provided audio dataset. For datasets that contain separate features for the head and tail segments of each song, the features at the head of a song are returned.

When the current point nears the destination, one of the neighboring points from Stage 1 may be the destination point itself. This may occur if there are less than K points from the Deezer dataset between the current point and the destination in the Valence-Arousal space. In this case, one of the K points returned may be the destination point, which may contain the destination song as well as some songs that share that point. Here, we remove this point to prevent the playlist from finishing early and having a length shorter than what the user requested.

Next, we feed the candidate songs' audio features into Stage 2, where we employ a distance metric configurable by the user to choose a single song. Here, we compare the distance between two vectors extending from the current song point: the vector from the current song to the candidate song, and a vector representing a single step on the line from the current song to the destination, calculated in a similar fashion to Equation (5). For segment-based data, we use the features at the tail of the current song to create a transition from the end of one song to the start of the next. Figure 13 demonstrates these points and vectors in two dimensions, with a vector to the target point as a step towards the destination in green, and blue vectors from the current song to each candidate being compared with various distance metrics.

These two vectors are compared using a distance metric which can be specified by the user. We test and compare various metrics in Section 9.1, including Cosine Similarity [59], Euclidean and Manhattan Distances [69], and Jaccard Distance [32]. The candidate song whose audio feature vector has the lowest distance score based on the metric specified is chosen as the next song. This song is added to the playlist and becomes the current song to continue to the next iteration of the loop.

7.3 Time Complexity Analysis

Given a dataset of P unique Valence-Arousal points and D audio features, creating a playlist of N songs, we analyze our algorithm's computational complexity below. Before the loop runs, we construct a K-dimensional tree of the unique Valence-Arousal points. The `scikit-learn` model constructs this structure by sorting each value in the two dimensions and splitting along their medians, with a complexity of $O[P\log(P)]$ [4]. During Stage 1 of the loop, we first select up to NK neighbors from the KNN model at a cost of $O[P\log(P)]$ as well.

For the algorithm's first stage, we filter up to NK neighboring points to a total of K songs. This has a worst-case time complexity of $O[N^2K]$, since each candidate point is compared to N previous songs in the playlist. For the second stage, evaluating the songs for the K neighbors along D audio features takes a time complexity of $O[KD]$. Since $P = 2,762$ unique points is far larger than the maximum values this experiment uses for $N(19), K(31), D(78)$, the first stage is more expensive than the second, and each song is selected in $O[P\log P]$ time. This loop runs L times for the length of the playlist, so the total time complexity of the algorithm is $O[LP\log(P)]$.

8 Evaluation

We rigorously test our algorithm using a wide variety of parameters in order to better understand the quality of its playlists. These parameters include the K values for the algorithm's first stage, the distance metrics and audio datasets for the second stage, desired playlist lengths, and the number of segments in segment-based datasets.

8.1 Experimental Design

Our algorithm generates playlists in the Valence-Arousal feature space from the Deezer dataset, and is thus subject to its uneven distribution, as shown in Section 5.1. Therefore, a thorough test requires playlists that travel across various sections of this space. To ensure this diversity in travel, we create playlists that traverse between the four Cartesian quadrants in the Valence-Arousal space, in a similar approach to Deng [17]. For each quadrant in this space, we gather 100 Valence-Arousal points and choose a random song for each, resulting in 100 songs from each quadrant. We visualize this sample's distribution and label these quadrants in Figure 14.

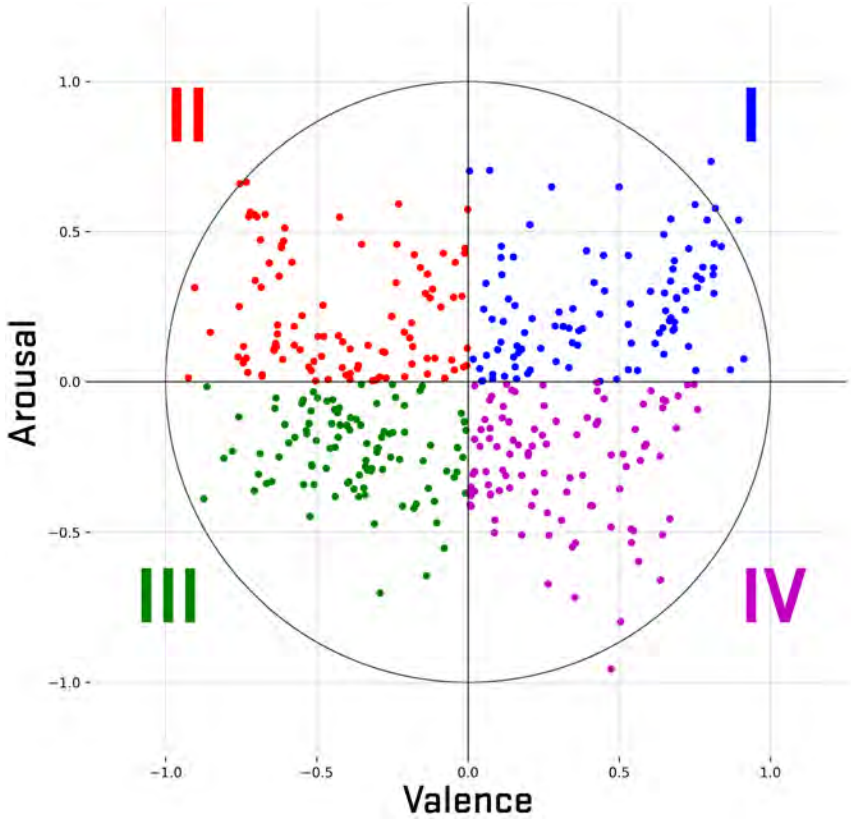

Figure 14: Map of the sample songs for each quadrant ($N = 100$ each), split by the Valence and Arousal axes, from the Deezer 2018 dataset [16].

Quadrants		Direction	Songs	Points
I	II	Horizontal	8448	1069
I	III	Diagonal	11407	1613
I	IV	Vertical	9236	902
II	III	Vertical	8515	1770
II	IV	Diagonal	6344	1059
III	IV	Horizontal	9303	1603

Table 12: The direction of travel, number of songs, and number of unique Valence-Arousal points for each pair of quadrants in the Deezer dataset.

We create playlists that traverse from one quadrant in the Valence-Arousal space to another. Table 12 shows that the number of songs and unique points in the Deezer dataset for each pair of quadrants has a relatively uneven distribution, highlighting the need to traverse various regions with our playlists. For each of these six pairs, we build playlists from each point in the first quadrant to each point in the second quadrant, and vice versa. This yields 20,000 playlists for each of the six quadrant pairs, or 120,000 playlists total, for each dataset and parameter we test in our experiments.

8.2 Evaluation Metrics

Each song can be represented as a point (or vector) in the Valence-Arousal and audio feature spaces. Therefore, we evaluate the qualities of the playlist as a path of points from the origin to the destination. We adopt two key priorities for our playlists − smoothness and evenness − and create measurements for each.

8.2.1 Smoothness: Pearson Correlation Coefficient

First, the path should be *smooth*: the songs should fall in a linear path from the origin to the destination. This ensures that all of the emotional and audio characteristics of a point are consistently making changes from one song to the next. Nonlinear paths could result in playlists that change only in arousal for the first half of the playlist, and then abruptly change in valence while keeping a consistent energy level.

Figure 15 visualizes three 11-song playlist paths with different smoothness. The leftmost playlist has extreme divergence from the dotted ideal line between the origin and destination. The middle playlist contains less variation from the ideal line, but the rightmost playlist stays closest to the ideal line and is thus the smoothest.

To evaluate a playlist's smoothness, we use a version of the Pearson Correlation Coefficient (PCC) [61]. Shown in Equation (6), this score measures how well two feature vectors A and B fall on a straight line on a score between 0.0 and 1.0, where

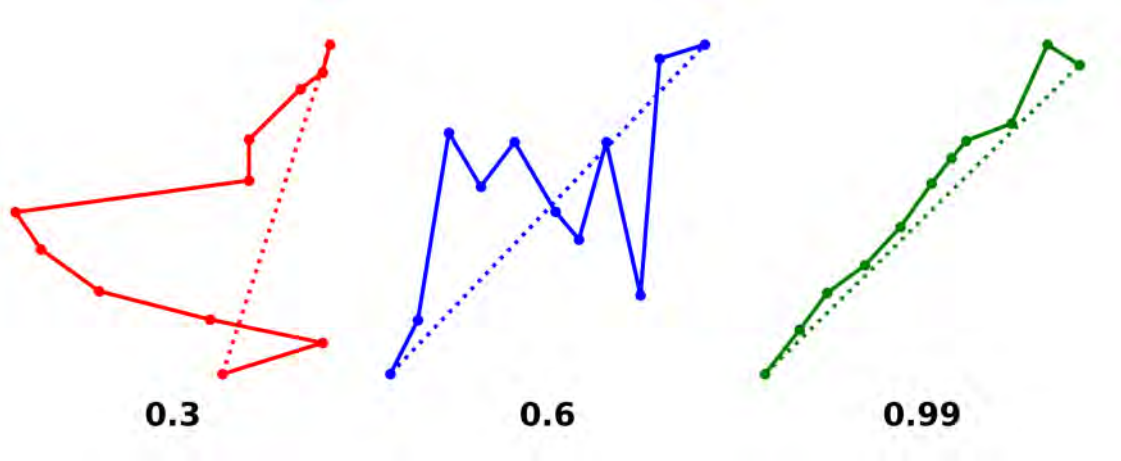

Figure 15: Example playlist paths with different Pearson Correlation Coefficients, representing playlists with poor, fair and strong smoothness respectively.

1.0 signifies perfect linear correlation. In their study of line smoothing techniques, Rosen and Quadri verify that PCC is an effective metric to evaluate linearity [61].

$$\rho_{AB} = |\frac{\text{Cov}(A, B)}{\sigma_A \sigma_B}| \tag{6}$$

For the Valence-Arousal emotion space, we consider the PCC between Valence and Arousal to evaluate the smoothness of a playlist. For audio feature spaces, we calculate the average PCC for all pairs of audio features in the given space.

8.2.2 Evenness: Step Size Variance

Second, the path should be *evenly spaced*: there should be an equivalent jump in the emotional and audio characteristics from one song to the next. Uneven playlists could startle users in the case of an unusually large differences in the mood or audio characteristics between two songs.

Figure 16 illustrates three paths of playlists with varying evenness, accompanied by a score showing the variance of their step sizes. The leftmost playlist contains a few emotional transitions that are much larger than others, seen by the longer line segments in the path. The middle playlist has more consistent step sizes in its path, but the rightmost playlist is the most even, with the most evenly-sized transitions.

To quantify the evenness of a playlist, we measure the variance of the distribution of step sizes between each pair of songs in the playlist. To find distances between adjacent songs S_k and S_{k+1} over D features, we calculate their Root Mean Square Error (RMSE), as shown in Equation (7).

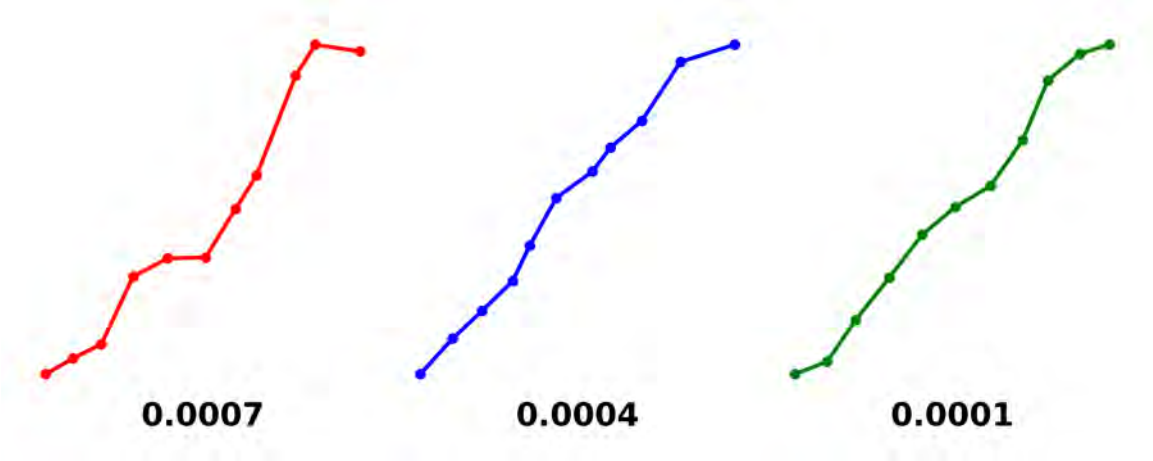

Figure 16: Example playlist paths with different step size variances, representing playlists with poor, fair and strong evenness respectively.

$$RMSE_k = \sqrt{\frac{||S_{k+1} - S_k||_2}{N}} \tag{7}$$

To calculate the RMSE, we employ the Euclidean distance to find the distance between S_k and S_{k+1}. We average these distances by the number of features to create a standard measure between feature sets of varying dimensionality. The RMSE is used as the step size between point transitions, such that their variance indicates the difference between each transition's magnitude.

To understand our algorithm's behavior in mood and audio spaces, we calculate step size variances separately for both the Valence-Arousal emotion space and the various feature spaces of audio datasets.

9 Experiments & Results

We empirically test our playlist algorithm's behavior against a wide variety of tunable parameters: the distance metrics and audio feature datasets for Stage 2, the K values for Stage 1, desired playlist lengths, and different numbers of segments for segment-based datasets. When we are not testing these specific parameters, we use $K = 7$ for our algorithm's first stage, Euclidean distance for the second stage, and various audio feature datasets. By default, we generate 12-song playlists, since a 2014 survey of automatic playlist generation studies found that three datasets of playlists from popular sources contained 11.6 tracks on average [7].

9.1 Distance Metrics

We first test the effects of different common distance metrics on Stage 2 of our algorithm, measuring the evenness and smoothness of the playlists it generates across audio and mood spaces. Here, we examine the impact of using the Euclidean, Manhattan, Cosine, and Jaccard distances to compare candidate songs, against a baseline method which randomly chooses a single neighboring song.

Table 13 indicates that the choice of distance metric for the audio features in Stage 2 has no significant effect on a playlist's smoothness or evenness in mood. Since the first stage chooses the K closest songs in the Valence-Arousal space to the target, the candidate songs are already highly similar in mood. This mitigates the effect of the second stage, which could choose the song that provides the best audio transition but the worst emotional transition. This finding allows developers and users to choose a distance metric that optimizes audio transitions without worrying about mood.

Table 14 reveals that using the Cosine, Euclidean and Manhattan distances for Stage 2 generate the smoothest playlists in audio feature spaces, as measured by the PCC. The Jaccard distance performs poorly in comparison, performing similarly to the random neighbors baseline, since it does not consider the vector between two points, but only the minima and maxima of their numerical values.

	Pearson Correlation			**Step-Size Variance**		
	Mean	*St.Dev.*	*Median*	*Mean*	*St.Dev.*	*Median*
Cosine	0.928681	0.162085	0.988357	0.001140	0.001299	0.000749
Euclidean	0.929177	0.161056	0.988305	0.001143	0.001304	0.000750
Jaccard	0.928412	0.162658	0.988152	0.001149	0.001332	0.000744
Manhattan	0.929301	0.160845	0.988395	0.001132	0.001289	0.000745
Random	0.928845	0.161913	0.988449	0.001134	0.001303	0.000745

Table 13: Mood-based scores of playlists based on the distance metric in Stage 2.

Dataset	**All (Spotify + MSD)**			**Spotify**		
PCC	*Mean*	*St.Dev.*	*Median*	*Mean*	*St.Dev.*	*Median*
Cosine	**0.458472**	**0.021189**	**0.454996**	0.463596	0.045715	0.457373
Euclidean	0.456487	0.021741	0.452252	0.462629	0.048104	0.455204
Jaccard	0.454744	0.019066	0.451646	0.449793	0.040179	0.444198
Manhattan	0.457390	0.022524	0.452986	**0.464987**	**0.049874**	**0.457012**
Random	0.453964	0.018526	0.451040	0.447270	0.037652	0.442471

Table 14: Audio-based PCC of playlists by distance metric, measuring smoothness across two audio feature spaces, with $N = 600,000$ playlists total.

The use of the Cosine distance metric in Stage 2 yields the smoothest playlists in most audio feature spaces. Since the Pearson Correlation Coefficient is a measure of linearity, smoother playlists have songs that lie closer to a line. The Cosine distance measures the angle between candidate songs and a target point that falls in a perfect line. Minimizing this angle yields the closest songs to that ideal line, yielding smooth and linear playlists. However, while this approach creates smoother playlists than Euclidean and Manhattan distances in a combined feature space, it fails to improve upon them when only considering Spotify audio features. This may be a result of the distributions of features we observe in the Spotify and MSD feature spaces.

Figure 17 reveals that using Euclidean and Manhattan distances creates more evenly-spaced playlists than any other metric. While using the Cosine distance yields somewhat smoother playlists, its singular consideration of the angle between two vectors means that it does not factor the magnitude of the vector between them. As a result, a song with a far larger or smaller step size than the target vector, but with a smaller angle to it, may minimize the Cosine distance. This can lead to more linear playlists but at the expense of an uneven step size.

Using the Euclidean and Manhattan distances yields songs with the shortest vectors to the target point at each loop in our algorithm. This approach yields songs that are the closest to the ideal target points, or playlists that are both smooth and even, because the target points fall at even steps in the line between the playlist's origin and destination songs. These results indicate that the vector p-Norms are the strongest distance metrics for our algorithm's second stage.

9.2 Audio Datasets

We next examine the audio feature spaces to be traversed by our playlist algorithm in Stage 2. In this test, we compare the effectiveness of using *Spotify* features, *MSD* features, and a combined set of both (titled *All*) in our algorithm, against a baseline of reusing the mood features from the Deezer dataset. To inspect the impact of variance

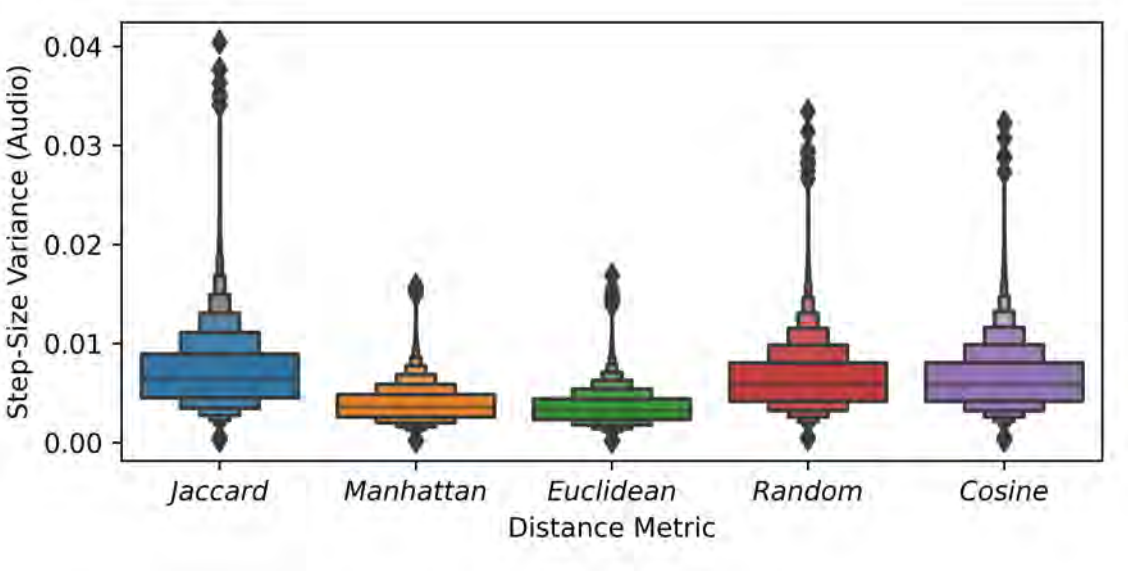

Figure 17: Evenness of playlists by distance metric in an audio feature space.

and dimensionality, we include 12-feature PCA datasets of the Spotify, MSD, and combined sets of features in our tests. We also juxtapose the aggregate audio feature datasets with two segment-based datasets, that collect average scores of features for the first and last 100 segments, and the first and last 30 seconds, of each song.

Table 15 displays the smoothness and evenness in the Valence-Arousal space of playlists created with various datasets. When evaluating emotion-based travel, using the Deezer features for both spaces leads to smoother and more even playlists based on mood. The choice in audio feature dataset has no impact on mood-based smoothness or evenness. This performance discrepancy is expected, since using only mood features effectively turns our algorithm into a 1-NN model, where the song emotionally closest to a target is chosen every time. By introducing separate audio feature spaces into the algorithm, we require playlists to balance emotional and audio transitions, which results in playlists that may be less smooth or even in mood transitions but provide songs that are more consistent in genre.

A closer inspection of the mood-based Pearson Correlation scores reveals a slightly more optimistic story for audio feature datasets. While the mean difference between mood-only playlists (those that use Valence-Arousal data for both stages) and playlists that use audio-based data for the second stage is quite large, the median smoothness scores are much closer. The left-hand side of Figure 18 visualizes this difference using box-and-whisker plots, showing the distribution of the PCC scores across playlists made with different audio datasets. The plots indicate that over half of the playlists created in this scenario are almost perfectly linear in emotional travel, with PCC scores of over 0.96 (see Table 15). The distribution's large tail implies

	Pearson Correlation			Step-Size Variance		
	Mean	*St.Dev.*	*Median*	*Mean*	*St.Dev.*	*Median*
Deezer	0.933566	0.159031	0.990886	0.000311	0.000302	0.000224
MSD	0.873421	0.205108	0.963398	0.001037	0.000869	0.000801
Spotify	0.873176	0.205091	0.962892	0.001043	0.000848	0.000816
All	0.873134	0.205579	0.963379	0.001040	0.000883	0.000796
PCA-MSD	0.871881	0.206737	0.962992	0.001040	0.000870	0.000805
PCA-Spotify	0.873293	0.205178	0.963092	0.001038	0.000852	0.000808
PCA-All	0.872370	0.205998	0.963027	0.001046	0.000864	0.000804
30 seconds	0.873470	0.205019	0.962998	0.001046	0.000876	0.000798
100 segments	0.873356	0.205373	0.963230	0.001051	0.000894	0.000804

Table 15: Mood-based scores of all playlists based on the dataset used Stage 2, with $N = 1,080,000$ playlists total ($120,000$ playlists per dataset). We compare eight audio datasets against reusing the Deezer dataset's mood features.

that playlists of low smoothness in mood are the outlier. This reveals that using audio-based features for Stage 2 yields playlists that travel smoothly in mood.

Traveling through different pairs of quadrants of the Valence-Arousal space often results in varied performance. To provide an example, the right-hand side of Figure 18 isolates for playlists that travel from the third quadrant, with negative Valence and Arousal, to the first quadrant, with positive values for each. As a pair, these two quadrants induce diagonal travel in playlists and contain the most songs and a high number of unique Valence-Arousal points, as shown in Table 12. In this subset, playlists generated by audio are much smoother than the entire set, and their PCC scores are much closer to those using Deezer data for both stages. The variance of density is a result of the Deezer dataset's uneven distribution, and implies that the smoothness of mood-dynamic playlists is dependent on the distribution of points across the Valence-Arousal plane.

We measure the performance of each dataset in each audio feature space that we test, to evaluate the merits of different audio datasets and employing PCA among them. Table 16 shows playlists' performance by dataset when evaluated against a combined Spotify and MSD feature space, shown as *All*. Here, the playlists created using MSD-based features (including the *All* feature space) outperformed not only the Deezer dataset but other audio datasets as well. This implies that the combined dataset was far more influenced by the 78 features of the MSD data than the 15 features from Spotify, and that the different audio datasets describing features of the same songs are not highly correlated with each other.

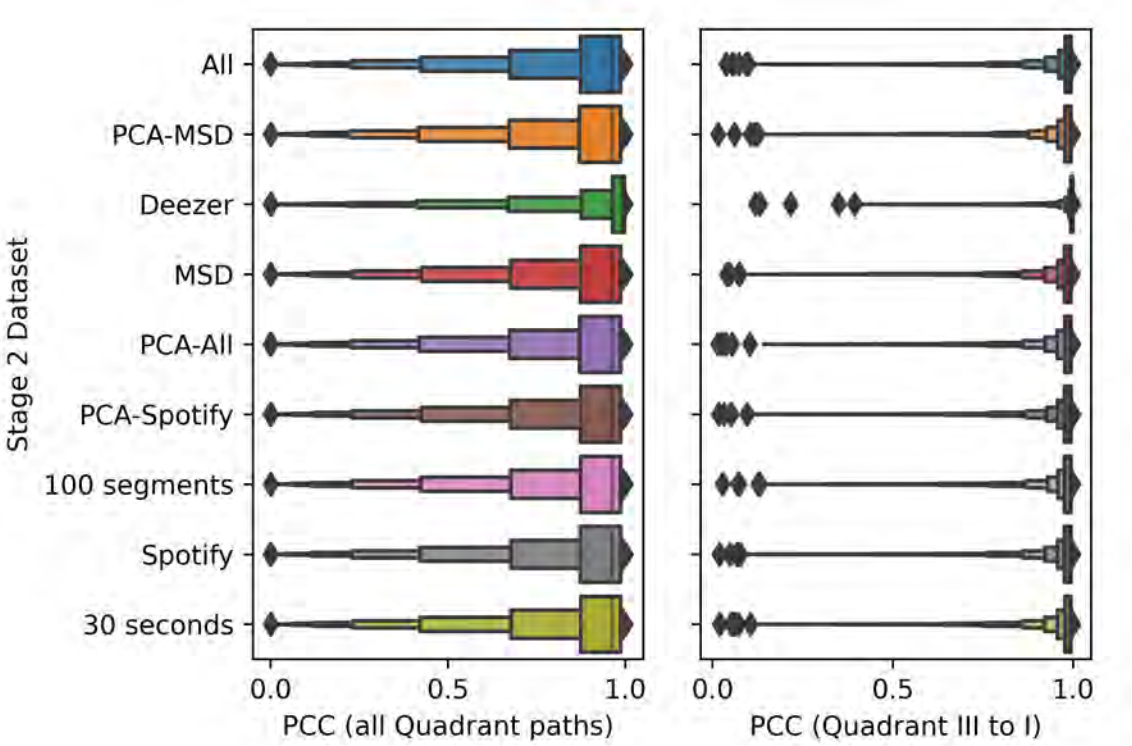

Figure 18: Smoothness of playlists by dataset, for all 1,080,000 playlists (left), and 90,000 playlists that travel only from Quadrant III to Quadrant I (right).

	Pearson Correlation			**Step-Size Variance**		
	Mean	*St.Dev.*	*Median*	*Mean*	*St.Dev.*	*Median*
Deezer	0.294501	0.014783	0.293004	0.006281	0.002941	0.005821
MSD	0.294415	0.018481	0.291252	**0.004019**	**0.001832**	**0.003746**
Spotify	0.292482	0.016099	0.290243	0.005449	0.002574	0.005030
All	0.294538	0.018706	0.291339	**0.003500**	**0.001625**	**0.003247**
PCA-MSD	**0.300396**	**0.017297**	**0.298441**	0.005870	0.002734	0.005438
PCA-Spotify	0.292421	0.015304	0.290586	0.005851	0.002665	0.005454
PCA-All	**0.299186**	**0.017052**	**0.297231**	0.005800	0.002692	0.005371
30 seconds	0.292375	0.014951	0.290564	0.005828	0.002736	0.005391
100 segments	0.293484	0.015424	0.291664	0.005857	0.002724	0.005418

Table 16: Audio-based scores of $N = 1,080,000$ playlists based on dataset, scored in a combined Spotify and MSD feature space.

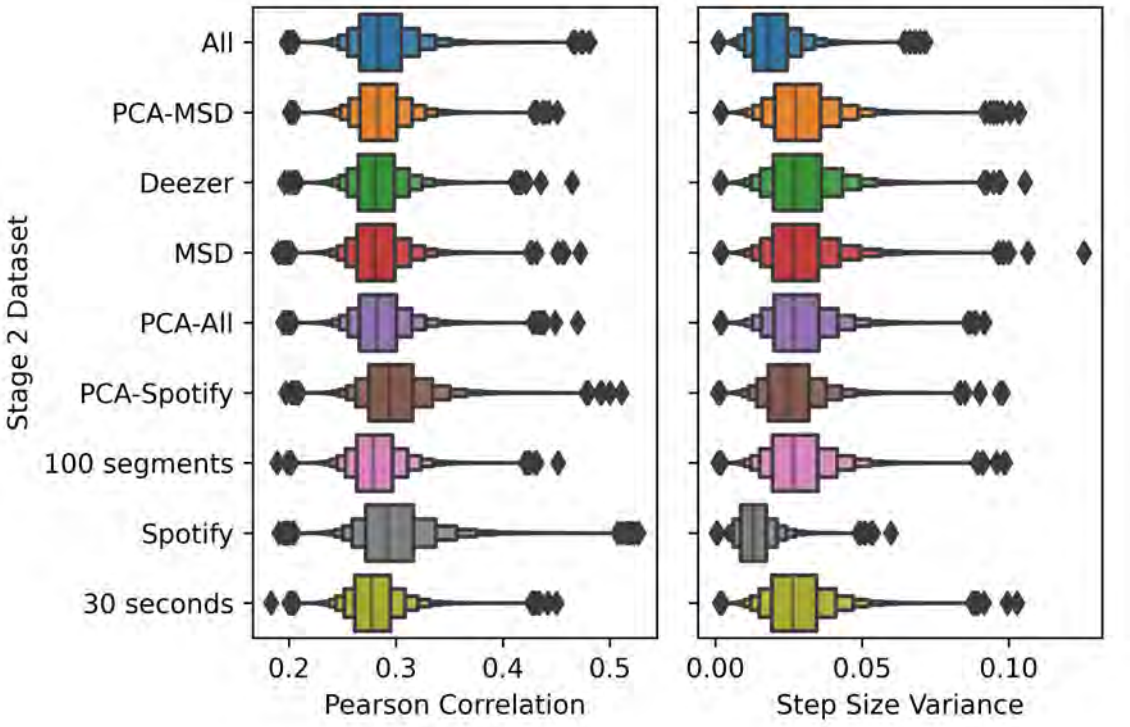

Figure 19: Smoothness (left) and evenness (right) scores of playlists based on dataset, scored in a Spotify feature space.

More interestingly, we observe in Table 16 that playlists were only smoother when applying PCA to MSD-related data, yet this came at the expense of a playlist's evenness. However, when evaluating against Spotify features alone, as shown in Figure 19, our algorithm generates smoother playlists when considering the Spotify dataset with or without PCA applied. Using the combined dataset also yields much more even playlists than other datasets, second to the Spotify features alone.

These findings reveal a few key findings in the smoothness and evenness of playlists across audio features. First, different audio feature datasets share little correlation, and segment-based datasets fail to yield improvements in these spaces compared to the baseline of purely mood-based playlists. In addition, using audio datasets with lower dimensionality yields smoother playlists, since applying PCA to 12 features yielded strong improvements over a 78-feature MSD dataset, but only mild improvements over the 15-feature Spotify data. However, while applying a PCA transformation can can retain the relative differences between songs, it loses their true differences, so thus sacrifices even transitions when evaluating against the original feature space.

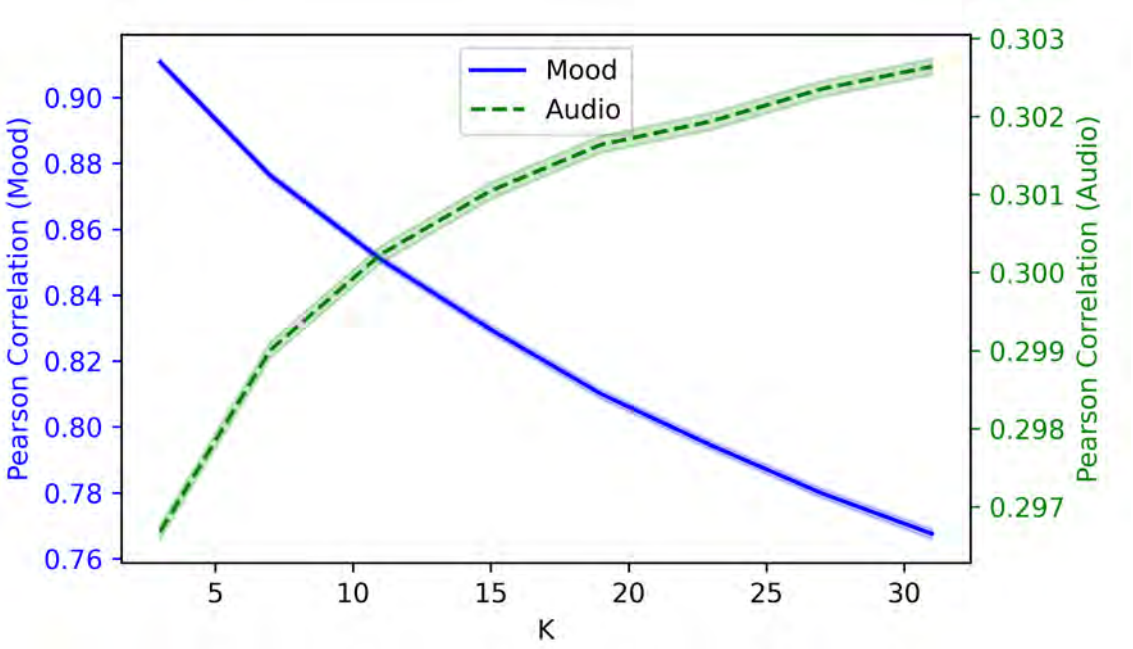

Figure 20: Pearson Correlation Coefficients of $N = 960,000$ playlist paths by K value, measuring smoothness across mood and audio feature spaces.

9.3 K Values

In our third experiment, we evaluate different values for K, or the number of candidate points our algorithm extracts for a transition in the Valence-Arousal space. We examine the effects of extracting $K = [3, 7, 11, 15, 19, 23, 27, 31]$ points from our unsupervised KNN model in Stage 1 of our algorithm.

From Figures 20 and 21, we observe that as K increases, we generate playlists that travel more smoothly and evenly in audio feature spaces, at the expense of the smoothness and evenness in emotional travel. With a smaller K, recalling the K closest points means that these candidates are closer on average to the ideal Valence-Arousal transition. This enables our algorithm to create more precise emotional travel. However, yielding fewer songs in Stage 1 limits the optimization of our playlists' audio travel in Stage 2. A larger K reverses this effect, allowing the second stage to choose a song that provides the best audio travel, but this song could potentially be much farther than other candidates from the ideal emotional target. This effect is due to our algorithm's two-stage structure, first recalling a K songs based on mood transitions and re-scoring for audio similarity. These findings indicate that our algorithm gives designers and users the power to directly tune the balance between the emotional and genre transitions of their playlists using the recall, or K value, of its first stage.

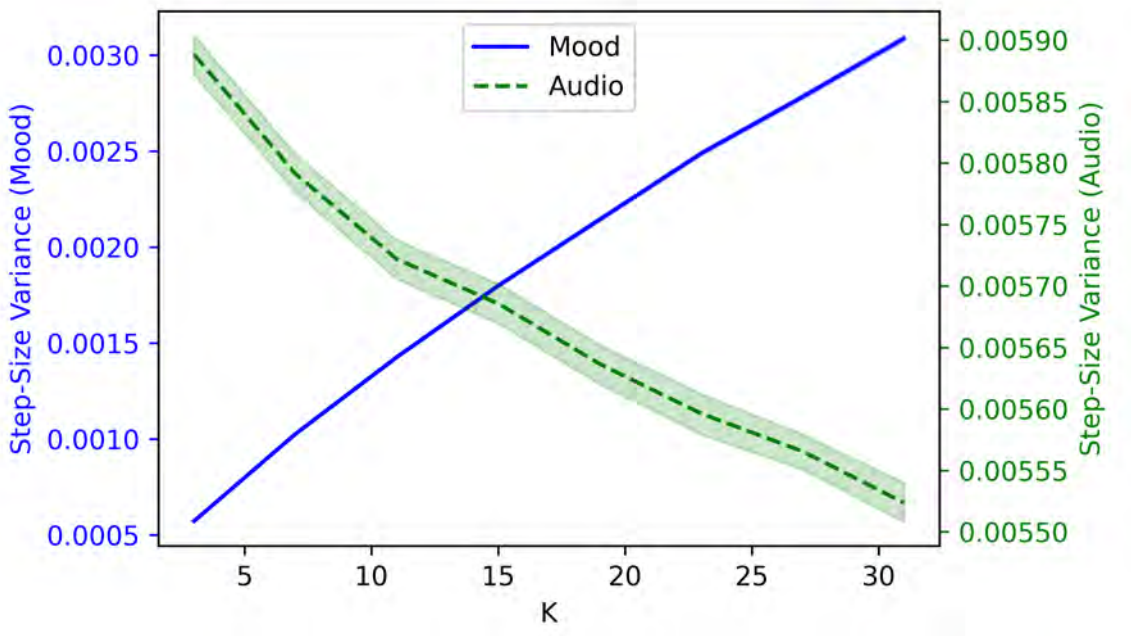

Figure 21: Step-Size Variances of $N = 960,000$ playlist paths by K value, measuring evenness across mood and audio feature spaces.

9.4 Playlist Lengths

We also examine the effect of requesting different lengths for playlists. Given the same origin and destination songs, as the length of the playlist between them increases, we expect the step sizes between songs to shrink. This enables us to study how the density of our dataset impacts playlists as the step size decreases. We generate playlists of $N = [3, 5, 7, 11, 13, 15, 17, 19]$ songs. Figure 22 and Table 17 show the effects of playlist lengths on theirs smoothness and evenness across both types of feature spaces.

As a playlist's length increases, its smoothness over both mood and audio spaces decreases. This effect is strongest when increasing from three songs to five, but weakens as playlists get longer, especially for the audio features in Stage 2. With larger playlists, the number of songs in between a fixed origin and destination increases, and so the step size for choosing the next song decreases. In this smaller scale, the distances between candidate song points in both feature spaces is much larger relative to the step size, and some regions may be sparse in their song points.

Since our algorithm recalculates the trajectory to the destination point when choosing each song, the choice of a song far from the direct line between the origin and destination has a disproportionate impact on the shape of the playlist path. In this scenario, the playlist will create a new line to the destination instead of returning to the direct line from the origin, and subsequent points will continue to be far from

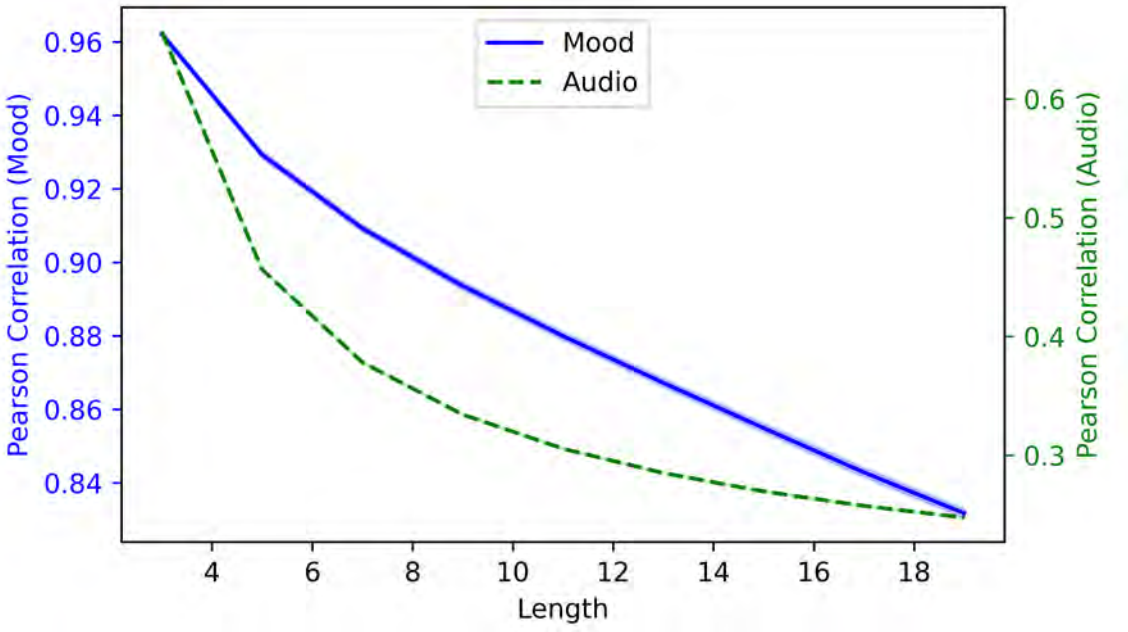

Figure 22: Pearson Correlations of $N = 960,000$ playlists of different lengths, measuring smoothness across mood and audio spaces.

the ideal line. A longer playlist can lead to more opportunities for such behavior from our algorithm, potentially resulting in curved or jagged playlist paths that are not smooth in a linear sense.

Each subsequent song added to the playlist seems to consistently impact the smoothness of playlists, as seen in the linear decay in the mood-based PCC score in Figure 22. Over audio feature spaces, longer playlists experience a sharp decline, as their PCC score drops from over 0.6 with a three-song playlist to well below 0.3 for a 19-song playlist in Figure 22. However, this decay seems exponential, and seems to stabilize as the playlist continues to get larger.

Table 17 shows that three-song playlists are much more evenly-spaced than longer playlists, since their median step size variance is far smaller than all longer playlists. This is an interesting edge case of our algorithm, since a three-song playlist only runs the algorithm once to choose a single song between the origin and destination. These playlists also have a denser pool of candidate points relative to their large step size. However, the standard deviations of their step size variances, especially in audio features, is much larger than with longer playlists. This suggests that three-song playlists may often have more evenly-spaced playlists, but that this is highly dependent on the uneven density of the Valence-Arousal space in the Deezer dataset.

N	Mood-Based Evenness			Audio-Based Evenness		
	Mean	*St.Dev.*	*Median*	*Mean*	*St.Dev.*	*Median*
3	0.000873	0.001489	0.000388	0.003130	0.004302	0.001458
5	0.001142	0.001302	0.000750	0.003424	0.002799	0.002705
7	0.001158	0.001170	0.000818	0.003464	0.002244	0.002992
9	0.001112	0.001028	0.000824	0.003477	0.001910	0.003127
11	0.001061	0.000924	0.000804	0.003490	0.001706	0.003214
13	0.001011	0.000834	0.000785	0.003514	0.001559	0.003276
15	0.000965	0.000763	0.000765	0.003520	0.001443	0.003318
17	0.000925	0.000711	0.000743	0.003528	0.001341	0.003353
19	0.000888	0.000668	0.000722	0.003536	0.001264	0.003379

Table 17: Evenness of playlists by length across both mood and audio spaces.

Outside of this edge case, Table 17 shows that playlist songs are less evenly spaced in their audio features as their length increases. This behavior is also consistent with mood-based evenness, though this effect reverses with playlists longer than seven or nine songs. Due to the inclusion of discretization for some audio features in our data cleaning process, some features have a step size of 0.1 between their 20 bins with values ranging from -1 to $+1$. For a longer playlist, this step in a feature becomes quite large relative to the ideal step size between songs, and may have an undue weight in song selection. The Valence-Arousal features from the Deezer dataset do not face this issue, as they were not discretized during the cleaning process. This suggests that discrete features should be avoided in audio datasets for dynamic playlist generation.

9.5 Dataset Segment Durations

The number of segments from the start and end of a song to include is configurable when compiling the weighted average of features for a segment-based dataset. Since these segments correspond to a single note or sound in a song, they do not have consistent duration. We account for this when we collect our segment datasets, so each song's features are a weighted average of a different number of segments at its head and tail. As a result, we compare nine datasets that are created from each song's first and last $D = [1, 2, 5, 10, 20, 30, 40, 50, 60]$ seconds. Each playlist is evaluated against the audio feature space of the segment dataset collected with $D = 30$ seconds, with results for both mood and audio in Figures 23 and 24.

In the Valence-Arousal space, there is no observable improvement with segment-based datasets of various durations. This is consistent with other audio datasets, as seen in Section 9.2. For a segment-based audio feature space, playlist smoothness increases with segment duration up until 10 seconds, after which it decreases. This

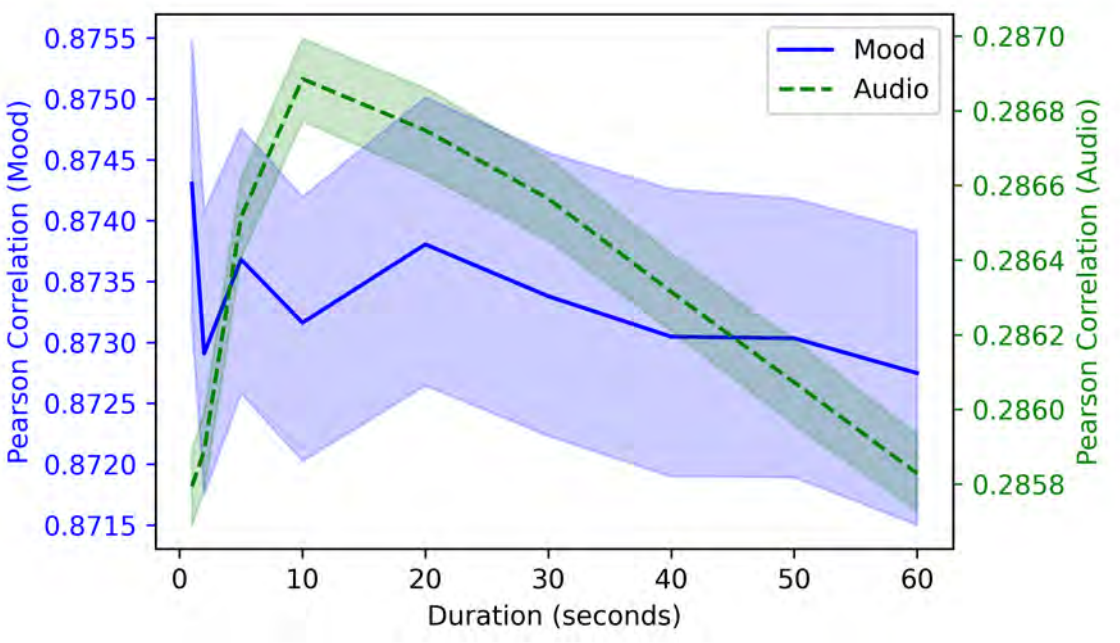

Figure 23: Pearson Correlation Coefficients of $N = 1,080,000$ playlists generated from the first and last D seconds of songs across both mood and audio spaces.

peak at around 10 seconds of segments implies that the first and last 10 seconds are the most representative of a song's audio features, and including more seconds in the calculation with Equation (4) may hinder the smoothness of track transitions in dynamic playlists. This implies that studies in segment-based playlist generation can focus on optimizing the transitions between the last 10 seconds of one song and the first 10 seconds of the next to guarantee the smoothest playlists.

Datasets that collect the first and last 30 seconds of segments generated more even playlists when evaluated the same 30-second segment dataset. However, from the relatively similar evenness for playlists generated by datasets containing more than 30 seconds of segment data, we see further evidence of the stabilization effect of Equation (4). This shows that including more segment data yields diminishing returns in the evenness of dynamic playlists.

9.6 Regional Variances

Across all tests, the uneven distribution of points in the Valence-Arousal space has an effect on playlists' smoothness and evenness. Table 18 shows that opposite quadrant pairs, which induce diagonal travel, have the smoothest playlists overall. Within the same direction of travel, quadrant pairs with more unique points in the Valence-Arousal space had smoother playlists. These findings indicate that playlists which

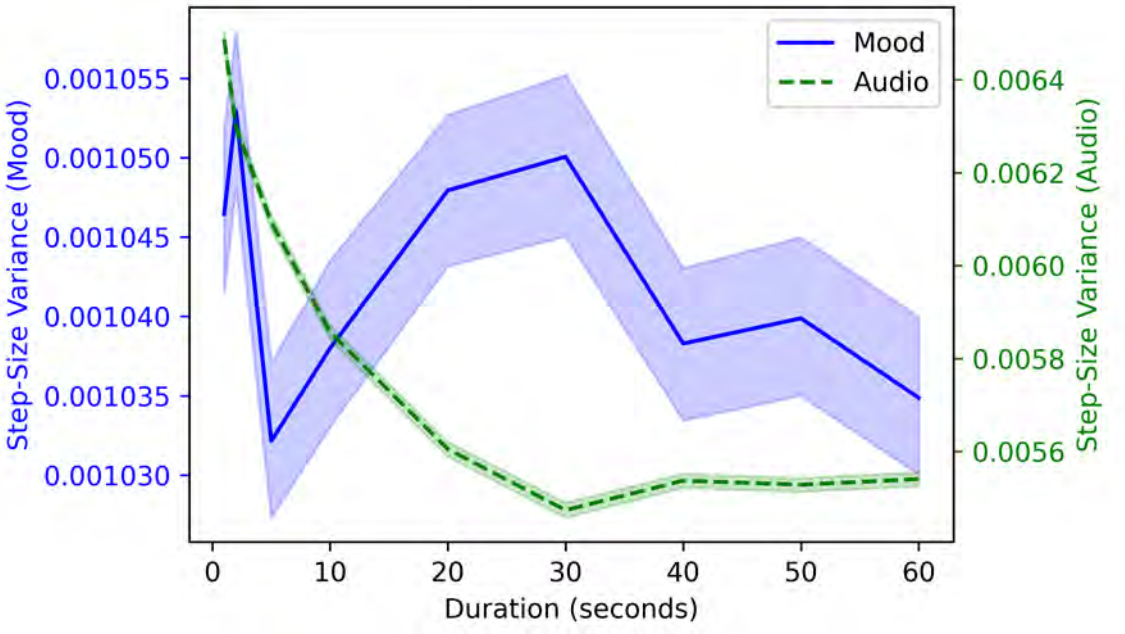

Figure 24: Step-Size Variances of playlists generated from the first and last D seconds of songs across both mood and audio spaces.

transition in both the Valence and Arousal of their songs are likely to provide a smoother listening experience for users. Transitioning in both emotion dimensions represents potentially the most common and effective use case of dynamic playlists, where a user may need to be cheered up after feeling sad and depressed, or perhaps to find calm after feeling tense and angry.

Our results also indicate that more points in the origin and destination quadrants can also improve a playlist's evenness. In our algorithm, a denser region in the Valence-Arousal space means that the K nearest candidates to an ideal target point are closer than they would be in a sparser region. This means that the step size between subsequent songs will be closer to a consistent ideal, minimizing such variance. Thus, the distribution and density of Valence-Arousal points is a limitation of the Deezer dataset. To ensure playlists have evenly spaced songs and that the emotional transition is consistent for users in the listening experience, datasets should include a dense, even distribution of emotional points.

Quadrants				**Pearson Correlation**			**Step-Size Variance**		
Origin	*Destination*	**Direction**	**Points**	*Mean*	*St.Dev.*	*Median*	*Mean*	*St.Dev.*	*Median*
I	II	Horizontal	1069	0.794634	0.246256	0.907550	0.001454	0.001215	0.001115
I	III	**Diagonal**	1613	**0.971965**	**0.064516**	**0.987958**	0.000825	0.000606	0.000693
I	IV	Vertical	902	0.833396	0.227208	0.937148	0.001165	0.000860	0.000968
II	I	Horizontal	1069	0.796146	0.245712	0.908172	0.001443	0.001153	0.001129
II	III	Vertical	**1770**	0.888797	0.191275	0.968605	**0.000512**	**0.000362**	**0.000425**
II	IV	**Diagonal**	1059	**0.955230**	**0.106923**	**0.987342**	0.000928	0.000773	0.000728
III	I	**Diagonal**	1613	**0.974322**	**0.060475**	**0.989096**	0.000933	0.000720	0.000764
III	II	Vertical	**1770**	0.889705	0.193054	0.970080	**0.000569**	**0.000435**	**0.000450**
III	IV	Horizontal	1603	0.834496	0.231589	0.942602	0.000861	0.000867	0.000606
IV	I	Vertical	902	0.831887	0.229291	0.938066	0.001200	0.000897	0.000992
IV	II	**Diagonal**	1059	**0.953424**	**0.108653**	**0.987017**	0.000888	0.000657	0.000719
IV	III	Horizontal	1603	0.832887	0.230528	0.939457	0.000758	0.000692	0.000565

Table 18: Mood-based smoothness and evenness scores for $N = 1,080,000$ playlists generated during the dataset test in Section 9.2, separated by the origin and destination quadrants of the playlists.

10 Discussion

Previous studies have introduced methods to create playlists that are dynamic in either mood [10] or audio spaces [25]. We combine these aspects into a multi-stage algorithm that generates playlists which gradually travel through both spaces between origin and destination songs. Our novel approach creates a path through vector spaces of song features, and thus requires no personalized data on existing playlists or the status of the user. We define numerical metrics for a playlist's smoothness and evenness, and a novel testing methodology for mood-dynamic playlists which evaluates across several regions of a feature space. This is the first approach in the automatic playlist generation field that evaluates dynamic playlists as paths in a vector space of mood and audio.

10.1 Summary of Findings

We observe that our algorithm's input parameters have a strong effect on the performance characteristics of playlists. The balance of a playlist's performance between mood and audio characteristics can be easily tuned by adjusting the recall of its first stage. Our approach builds upon research into two-stage algorithms [76] by using the high recall of the first stage as an important parameter.

In the algorithm's second stage, using the Cosine distance metric and reducing the dimensionality of feature data can lead to slightly smoother travel through audio. This ensures that each song in a playlist moves the user on a linear emotional and acoustic journey. However, this comes at the expense of consistent steps through these spaces, potentially making these transitions more jarring for users.

In addition, the distribution of Valence-Arousal points in our dataset has a strong effect on a playlist's smoothness or evenness. Controlling for the first and final songs of the playlist, including more songs in between reduces the size of each emotional transition between tracks. Requesting shorter playlists, with a larger step between songs, leads to smoother playlists than a smaller step due to the relative sparsity of the data at a smaller scale.

Playlists that travel through sparser regions of our Valence-Arousal feature space tend to vary more in the magnitude of their emotional transitions from one song to the next. However, smoothness is more dependent on the direction of travel; playlists that transition heavily in both Valence and Arousal more likely to have their points lie on a linear path than those which only mainly travel in one dimension.

10.2 Limitations

The primary limitation of our work is the quantity and quality of music emotion datasets. Although the Deezer 2018 dataset [16] is a large repository of songs and their Valence-Arousal scores, the synthetic nature of its emotion annotations limits their effectiveness. As discussed earlier in Section 5.1, as many as 1700 songs share a Valence-Arousal point, and the number of unique points is only 15% of the total number of songs. This required us to implement additional structures that filter for unique points and handle them, as described in Section 6.3.

Datasets that collect Valence-Arousal readings from humans not only potentially serve as a more accurate reflection of a song's mood, but can avoid this problem due to the variance of multiple users labeling songs. However, existing datasets that employ these methods [1, 11, 77] are too small in size and sometimes consist of less popular songs for which it is more difficult to find other features from public datasets.

10.3 Future Work

Building on the contributions of this work, there are many opportunities for future improvements and extensions of our mood-dynamic playlist algorithm. Currently, we evaluate a purely linear trajectory from an origin to a destination song, but some approaches allow users to draw a curved path on the Valence-Arousal plane on which to generate playlists [10, 14]. Adding a curved trajectory for our playlist's song selection could potentially allow for more personalized transitions for users, but this requires testing to see if it creates a more satisfying listening experience.

In this experiment, we collect data on the segments of a song and demonstrate that they have little effect in improving playlists. However, our current evaluation methods only examine smoothness and evenness at the whole song level, treating each song as an acoustic and emotional monolith. Future studies can examine the change in mood throughout the duration of a song, and perhaps create a smoother listening experience for the user. Furthermore, this approach can be extended to personalized data, such as a user's ratings of songs or listening history, to create playlists that directly reflect their own specific taste in music.

This works presents an opportunity to test the effectiveness of mood-dynamic playlists on human subjects to measure the change in a user's emotion throughout the listening experience. Previous studies in dynamic playlists [10, 25] either do not evaluate their recommendations or use existing data to measure playlists which travel in genre, but not in mood. Our algorithm can power an application that recommends a playlist based on the user's current mood a state which they desire. During and after listening to the playlist, the user's mood can be measured to examine if the desired emotional transition from the playlist was achieved.

10.4 Applications

Researchers could potentially integrate this algorithm with a human-in-the-loop system that collects the user's current mood. A few studies [19, 67] explore systems for recognizing emotions in facial expressions, and recommending music that matches the user's mood. Other studies use data from accelerometers [21, 35] or electrocardiograms [29] to choose songs related to a user's present state. However, such systems can also factor context-related data such as foreground computer processes [66] and the current climate [29, 60] when recommending songs to users.

However, with the exception of Liu et al. [40] whose approach seeks to lower a user's high heart rate with calming music and vice versa, most studies seek to keep the user in the same mood. Future studies might integrate these methods for emotion recognition with our work in experiments that examine the change in a listener's mood after listening to a mood-dynamic playlist generated by our algorithm.

This playlist algorithm could also be integrated into continuous systems which recommend the next song to play based on user preferences and a desired target mood. Studies from Chi [13] and Liebman [39] use reinforcement learning techniques that repeatedly adjust recommendations based on whether a user replayed, skipped, or rated the current song. With our algorithm, such a system could change recommendations based on the user's current mood, perhaps as an extension to recent studies such as Rumiantcev [62] which allow users to report their current mood and environment to deliver them their next song. We show that a three-song playlist, where the algorithm just chooses a single step towards a desired mood, has strong performance. However, this requires more thorough examination on the proper step size to use for the algorithm, and user testing to evaluate the true emotional impact of such playlists.

10.5 Conclusion

This work presents a novel and efficient exemplar-based learning algorithm, leveraging existing public datasets of songs to create musical playlists that travel in mood while maintaining similarity in audio. We define and measure two key qualities in evaluating a playlist's effectiveness, utilizing the Pearson Correlation Coefficient and Root Mean Square Error to measure smoothness and evenness in continuous mood and audio spaces. Our experiments indicate that this algorithm can be tuned through several parameters to adjust the effectiveness of a playlist's track transitions. To our knowledge, this is the first study that uses a nearest-neighbor approach to construct and evaluate mood-dynamic playlists that also smoothly transitions by acoustic similarity. Such an interactive tool could serve as an aid to music therapy, gently nudging users from their current mood towards more happy, focused, or content state of mind.

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