Harmonious: An Emotion-Matching System for Intelligent Use of Players' Own Music Libraries with Game Soundtracks

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1.CONCEPT AND RATIONALE

In recent years it has been stated in numerous works, both scholarly [18, 22] and otherwise (for example [20]) that many video game players are eschewing the original musical soundtrack in games in favour of listening to their own music, either via music players built into the game platform or external music players, such as iPods. This phenomenon seems surprising considering the efforts made by game developers to create engaging musical soundtracks that can variously adapt to changing game conditions, interact with the player and otherwise aim to enhance the gameplay experience [3]. Indeed, many game composers expressed surprise and disbelief when discussing this phenomenon [7].

By replacing game music, players are deprived of any information or feedback on the game that is provided by such adaptive and dynamic soundtracks.

1.1The Prevalence of Replacing Game Music

None of the work discovered on this topic detailed specific figures on which and how many gamers were replacing game music. To this end a survey was carried out online that questioned gamers about their musical habits.

This survey was carried out with web-based software. The link to the survey was provided in forums and social networks focused on games and/or used by game players. Discussion forum messages were posted on these sites informing the members of the phenomenon being investigated, inviting members to take the survey and inviting any further discussion on the topic within the forum.

The headline result of the survey was this:

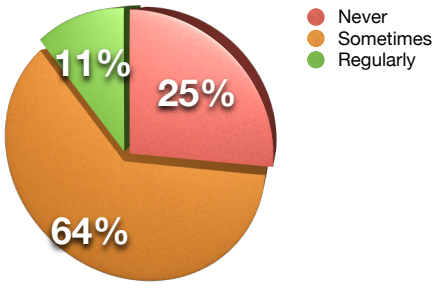

Figure 1: Percentage of players who turn off and replace game music

25% of the respondents never turn off game music, 64% sometimes turn off game music, and 11% turn it off regularly. Breaking this down by age, it was found that turning off game music is more common with younger players.

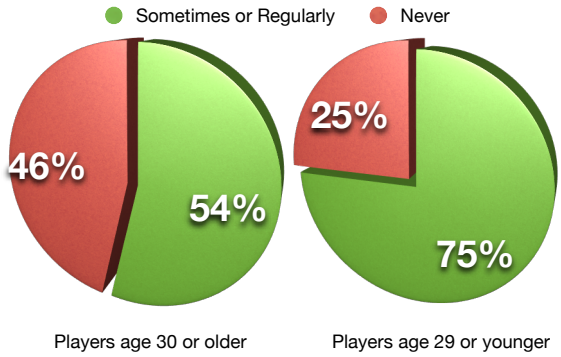

Figure 2: Percentage of players who turn off or replace music by age group

However, it must be noted that the older age group only accounted for 10% of the total number of respondents, so this result is not definitive. A greater difference can be seen from the perspective of how frequently the respondents play games, but again the less frequent group only accounts for just over 10% of the total respondents:

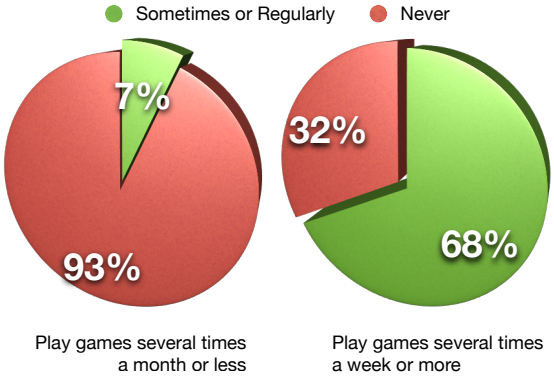

Figure 3: Percentage of players who turn off or replace music by play frequency

The survey asked respondents if there were particular genres of games in which they were more likely to turn off or replace music. The results were as shown in figure 4:

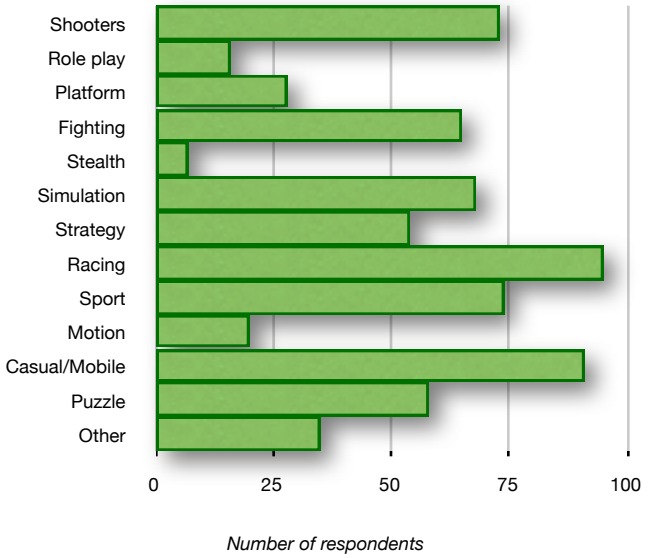

Figure 4: Genres in which players are more likely to turn off or replace music

Unsurprisingly casual/mobile games are frequently muted, which is very likely due to environmental factors. However Racing was the most commonly indicated genre, with 55% of the respondents choosing it. Similarly the survey asked if players were more likely to turn off music in single or multiplayer games. Multiplayer was the most common response.

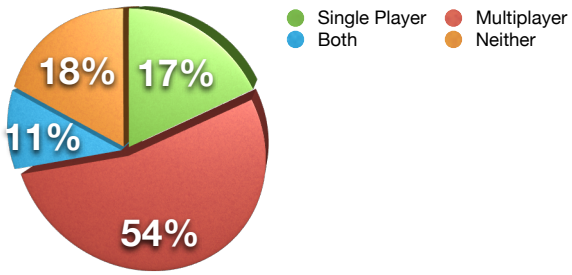

Figure 5: Game play types in which players are more likely to turn off or replace music

Discussions with the respondents started to indicate some common reasons why players turn off game music. A common opinion was that game music is too repetitive, or there simply isn't enough musical material to remain interesting over the course of gameplay. Racing games, shooters, role play and MMOs[1] were commonly charged with this complaint. Another frequent complaint was that music was not enhancing or reflecting gameplay. Multiplayer shooters, MMOs, puzzles and casual games were often cited with this viewpoint. Correspondingly many respondents said that if they felt the music was critical to a narrative they would always listen to it, though many noted that this was only the case on the first play through a game, and subsequent plays would often have the music replaced.

One surprising trend that emerged in discussion with the respondents was that a number of players who turn off game music replace it with spoken word material such as audiobooks or podcasts.

Given the forums used to invite survey participants, the respondent population shared many common demographic qualities - specifically most respondents were very interested in video games and were regular players. The majority of respondents were in their teens or twenties. Therefore, the survey results may potentially be skewed towards the opinions of the so called 'hard-core' gamer, and a wider population may be required to gather data which reflects attitudes of other types of player. Additionally, as discussion around the survey topic was invited in forums, the survey data may suffer from the "diffusion" effect [4]. However, the survey results can be seen as confirming the assertions in other works regarding players eschewing game music.

The complete survey data can be found in Appendix 1

1.2 Issues with Replacing Music

With the design of their XBox 360 game console, Microsoft built in technology that allows players to mute and replace music in games, without affecting the playback of other audio material, such as voice overs and sound effects [18]. Microsoft require that all games released for this console make use of this technology. Other game platform manufacturers, such as Sony, Nintendo and Apple, have similar technologies in place but do not currently enforce their use [1, 22]. Manufacturers are clearly aware of players' desires to replace game music, but the issue remains that information and feedback are being provided to players via game music through cueing, adaptive composition and other techniques. When the music is muted, this information is lost to the player.

2. PREVIOUS WORK

There has been no previous work found that directly addresses this issue, however, there exists a small amount of work that is relevant to understanding the music replacement phenomenon. The earliest such work was by Morris in 2003 [16], a conference paper proposing that multiplayer FPS[2] games should be considered as co-creative media, as the game experience can potentially be customized and personalized by players on each play. This customization could range from swapping out music, to creating new maps and mods[3] for games. As such the paper challenges the notion of a published game as final, complete work, similar to that of a film auteur - rather that it is the beginning of a co-creative

[1] Massively Multiplayer Online games

[2] First Person Shooter

[3] Mods are user/player made modifications of existing games that can range from the creation of new levels or scenarios to 'total conversions', where content and gameplay are completely replaced.

relationship between developer and player. From such a perspective original game music can be considered as a suggested soundtrack for a game, and that player-supplied replacement music can be considered as an equally valid part of the gameplay experience.

In 2005 Microsoft's XBox 360 was released, the first of the seventh generation of games consoles[4]. At the 2006 Game Developer Conference, Brain Schmidt, Architect of the XBox 360 audio system, claimed Microsoft's own research had shown that significant numbers of gamers replaced game soundtracks with their own music [18], though specific figures from this research were not revealed. Schmidt claimed that it was as a result of this research that the XBox 360 system features facilitating music replacement, and the QA requirement that games make use of these features, were developed.

In 2008 Jørgensen [10] did a study on playing games with the entire soundtrack muted: every sound produced by the game, including music, sound effects, and dialogue was removed. Unsurprisingly he found the experience was grossly crippled, as without audio cues, particularly UI and notification sounds, it was easy to miss details in the game.

However the only directly relevant work was a study by Wharton & Collins published in 2011 [22]. This study examined the experience of players when they had free choice over the music to accompany their gameplay. Players played a level from Fallout 3: Operation Anchorage on the XBox 360. At checkpoints in the game players were given the opportunity to choose music from their iPods, MP3 players or CDs.

The key finding of this study was that "players were unable to predict what music would improve their immersion, but were able to choose appropriate music to influence game playing tactics and anxiety levels" [22]. Significantly, the study also found that players still considered the 'replacement' music as an integral part of the game experience, reinforcing Morris' thesis.

3.OVERVIEW

The Harmonious system is a piece of software which can be integrated into video games to facilitate the replacement of game music with players' own music, whilst addressing the issue of loss of information. To this end the objectives of the system design were as follows:

- Allow players to listen to music in their own libraries whilst playing games
- Automate the choice of music from the player's library by matching gameplay mood with the emotional content of the music, thereby:
- Retaining some of the information and feedback provided by the original game music

In order the meet these objectives, the Harmonious system has been designed as shown below:

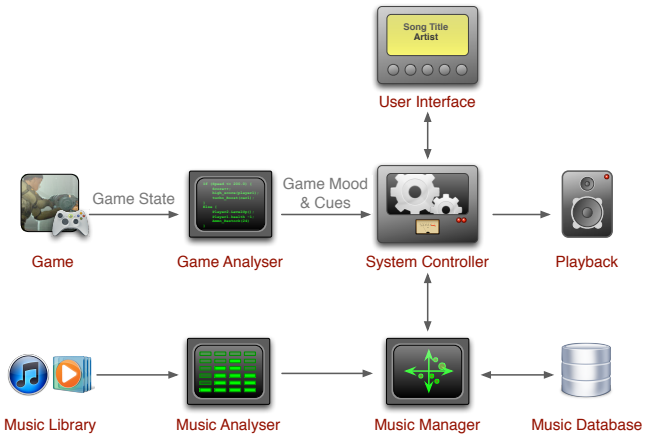

Figure 6: Harmonious system diagram

In this system, a music analyser iterates through the player's music library and determines the emotional content of each piece of music, along with supplementary data, such as key, tempo, bar and section locations, and metadata, such as title, artist and duration. The results of this analysis are stored in a database. Access to this data from the rest of the system is provided via a music manager object.

The system controller object presents both the programmer's API[5] to the game developer and the user interface to the player. The system controller receives cues for music to start, stop and change, and a representation of the current mood of gameplay from a game analyser object. When a new musical selection is required the system controller passes this mood value to the music manager, which determines the best matching music from the player's library. The system controller then plays back this piece of music.

The only component of the system that is game-specific is the game analyser object. This object examines the game's state and determines the current mood of the game, therefore this requires a game-specific implementation. However, a standard interface between a game analyser object and the system controller has been defined.

The controls exposed to the player include standard play/pause and skip controls, as well as controls that can fine tune the mood-matching process and 'teach' the database about the player's preferences.

4.REPRESENTATION OF EMOTIONS

The system relies on having a means of representing emotions in the digital realm. Models for representing emotions can be separated into two types: categorical and dimensional [11]. In a categorical system, analysis of music would result in each piece being allocated to a particular category or categories. The resolution of the system is therefore dependent on the number and type of categories. The model used by the annual MIREX[6] music emotion recognition competition is a typical categorical system and is shown in table 1 below.

[4] The others being the Sony Playstation 3 and the Nintendo Wii, both released in the following year

[5] Application Programming Interface

[6] The Music Information Retrieval Evaluation eXchange, details can be found at http://www.music-ir.org/?q=node/13

Clusters	Mood Adjectives
1	passionate, rousing, confident, boisterous, rowdy
2	rollicking, cheerful, fun, sweet, amiable/good natured
3	literate, poignant, wistful, bittersweet, autumnal, brooding
4	humorous, silly, campy, quirky, whimsical, witty, wry
5	aggressive, fiery, tense/anxious, intense, volatile, visceral

Table 1: MIREX categories from [11]

This approach may be useful in applications such as music streaming services, where the primary concern is the relationship between pieces of music. However, it is limiting in the context of this project, where emotional content of music is matched with emotional content of gameplay, as there is no way to distinguish between different pieces of music in the same category - which song in the 'happy' category is the happiest?

The dimensional approach to emotional modeling maps emotions on a plane, where the axes represent various emotional characteristics, and the continuous nature of the plane eliminates ambiguity as each point represents a unique emotion or level of emotion. The 2-dimensional Thayer/Arousal-Valence model is a simple and effective example of a dimensional model [17, 19]

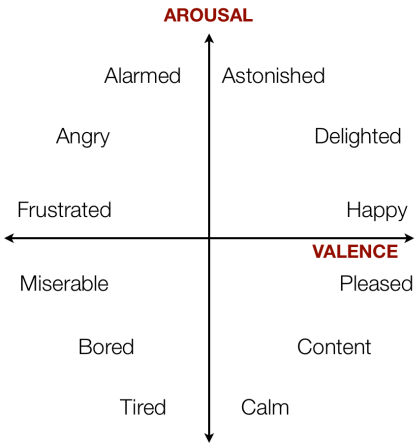

Figure 7: Locations of emotions on a 2-dimensional Aoursal/Valence plane

Though models with larger numbers of dimensions also exist, this 2-dimensional model has proven very effective in musical applications (see [11, 17, 23]).

In this model emotions are represented on a two-dimensional plane, where the axes represent *arousal* (level of energy) and *valence* (positive or negative feeling). Individual emotions are therefore represented as locations or areas on this plane. In the context of the Harmonious system this model offers a significant advantage: it removes the need for the use of subjective language. Gameplay is evaluated in terms of its arousal and valence; likewise music is also evaluated in terms of its arousal and valence. With such data, matching and refinement remains within the mathematical domain, and is not hampered by the translation of such data into subjective language terms, such as 'happy'.

A potential downside to this approach is that various studies have reported that valence is much more difficult for automated systems measure/evaluate than arousal, giving courser grained results. But given the widespread adoption of this approach it is quite likely that improvements will continue to be made in this area.

To maintain a simple and consistent reference throughout this project, the arousal-valence plane is considered to have axes extending 2 units in length, from -1 to 1. The application of unit length to such a dimensional representation is, of course, arbitrary. This range was chosen for simplicity and clarity in calculations.

5.MUSIC ANALYSIS

Several approaches to music analysis were examined for suitability with this project. Many researchers are taking a computational approach to MER[7], making use of custom processes built with lower level MIR[8] tools such as Marsyas[9], LibXtract[10] and the MIR Toolbox[11], or by constructing completely bespoke systems (for examples see [15, 17, 23]). The accuracy of such systems is typically between 45-80% for dimensional emotion representations [11]. However such systems can be extremely computationally expensive and as such the time taken to analyse several thousand tracks on a desktop-class computer system would be prohibitive for a project such as this.

A second approach is mining a pre-existing database of human created descriptions of music. Such databases come in two types: expert and crowd. Projects such as the Music Genome Project[12] and the All Music Guide[13] have databases of tags applied to pieces of music that have been carefully determined by music experts, and present a valuable source of data. However, these expert databases generally remain private or accessible only via commercial

[7] Music Emotion Recognition

[8] Music Information Retrieval

[9] http://marsyas.info

[10] http://libxtract.sourceforge.net

[11] https://www.jyu.fi/hum/laitokset/musiikki/en/research/coe/materials/mirtoolbox

[12] http://www.pandora.com/mgp.shtml

[13] http://www.allmusic.com

contract, due to the cost and effort of producing them. Crowd-based music databases, such as last.fm[14] are usually more open and accessible. Laurier et al recently proved that for basic emotional tags, such as happy, sad, angry and tender, crowd- or social-based music databases can be reliable sources [12]. However, two issues remain with both expert- and crowd-based databases: No database can contain data on every piece of music that the Harmonious system (or any other) is likely to encounter; and using language tags as a datasource for a geometry-based system requires a subjective mapping between language and numeric values. Such a mapping can only be as accurate as the values shared between the mapper and the tagger. For the Harmonious system it would be preferable to determine arousal and valence values by direct audio analysis.

5.1 Echo Nest

It was therefore found that Echo Nest would provide a effective analysis platform for this project. Echo Nest is a music information system that provides a backend for online music services and is used by organizations such as the BBC and MTV. The Echo Nest system is available free of charge for non-commercial uses. The platform combines a server-based music analyser that mixes computational and textual approaches, and a database of "tens of millions" [5] of pre-analysed pieces of music. This gives a large set of existing analysis data that can quickly be retrieved and should hopefully cover a high percentage of the music encountered by the Harmonious system. For music that has not already been analysed by Echo Nest, the system can fall back on using the server-based analyser. This analyser has the advantage of running on dedicated, powerful hardware, and can typically analyse a 3 minute piece of music in under 5 seconds. The analysis time is therefore only limited by the time taken to upload the music to the server.

5.2 Harmonious Analysis Workflow

The process by which the Harmonious system analyses a player's digital music collection consists of three stages:

1. Correctly identifying the music contained in each audio file
2. Fetching Echo Nest's analysis data for that music
3. Parsing the analysis data to create mood shapes (areas of the arousal/valence plane indicating the emotional content of the music) for inclusion in the system database

The first stage is crucial to the entire system. If a piece of music is incorrectly identified, the wrong analysis data will be associated with the audio file, defeating the ability of the system to correctly match music with gameplay. Even the differences between two versions of the same piece of music (for example, and album version and a radio edit) can be significant enough to spoil the data, due to timing differences and other factors.

Harmonious makes use of three methods of identifying a track, starting with the most efficient, and incrementally falling back to the least efficient when necessary (here efficiency refers to the processing time taken by each method). The first method is audio fingerprinting. An audio fingerprint (sometimes referred to as an acoustic fingerprint) is a content-based 'signature' that summarizes the audio content of a digital recording [2]. Identifiable fingerprints can be created from highly compressed audio files, and fingerprinting algorithms are tolerant of audio distortion. Harmonious makes use of an open-source fingerprinting implementation called EchoPrint. As the name suggests, this implementation creates fingerprint codes that are compatible with the Echo Nest platform, and can be used as queries against the Echo Nest database.

Specifically, the Harmonious fingerprint identification process is as follows:

1. 60 seconds of the audio file are read into memory as PCM[15] samples
2. The array of samples is passed to the EchoPrint code to create a fingerprint.
3. The fingerprint code is send to the Echo Nest server to query its database
4. If a match if found for the fingerprint in the database, the matched metadata (artist, title, etc) is retrieved
5. The retrieved metadata is tested against metadata from the local audio file to prevent false positive matches. If the metadata matches to within a fine tolerance, the identification is considered a success.

It was through experimentation that the duration of 60 seconds was found to be the most effective. Counter-intuitively, longer audio segments do not lead to increased accuracy in matches. It was found that for durations of up to 60 seconds, increased duration led to a greater number positive matches. However, with durations over 60 seconds the number of false positives increased greatly with longer durations. 60 seconds was found to give the best balance.

If identification by fingerprinting fails, the system falls back on identification by metadata. In this case the system extracts artist, title and duration data from the audio file (if available). The artist and title strings are used as a search query against the Echo Nest database. This often results in multiple results, as the search engine uses very loose string matching (for example, an artist search for the string "Elvis" may return both "Elvis Presley" and "Elvis Costello" as possible matches).

To make the correct identification amongst the returned possibilities, the artist, title and duration values for each potential match are compared against those from the local audio file. Duration is simply compared numerically, and the difference, in seconds, is noted. The artist and title strings are each compared with fuzzy string matching using the Levenshtein Distance Algorithm [24]. This approach is used to allow the system to correctly identify a pair of strings such as "nick cave & bad seeds" and "Nick Cave And The Bad Seeds" as a positive match. The sum of the two string matching scores and the duration difference is taken as an overall match score, where a lower score indicates a closer match. The system defines a minimum tolerance, and a match score below this tolerance is considered to be a positive identification.

If identification by metadata fails, the system falls back on uploading the audio file and having Echo Nest perform a bespoke analysis. This approach is the most time consuming of the three

[14] http://last.fm

[15] Pulse Code Modulation: uncompressed digital audio

identification methods, but the system can be assured of the accuracy of the analysis results.

After a track has been identified (or uploaded for analysis) Harmonious fetches the full analysis data for the track from the Echo Nest database. This data contains the following information:

- •Track Metadata
- •Duration
- •Time Signature
- •Key
- •Mode (Major or Minor)
- •End of Initial Fade In
- •Start or Final Fade Out
- •Beat Locations
- •Bar Locations
- •Section Locations (sections being high-level divisions, such as verse, chorus, bridge, etc)
- •Segment Locations (segments being short divisions of relatively uniform timbre and harmony, typically less than 1 second)

Included with each segment location are the following:

- •Loudness (in dB)
- •Timbre (as an array of 12 values, each representing a sonic property)
- •Pitch (as an array of 12 values representing the relative dominance of each pitch in the chromatic scale)

(Full descriptions of the analysis data can be found in [6], from which the foregoing list information is summarized).

The first operation carried out with this data is to split tracks into segments of potentially differing emotional content. ('Segments' seemed the most appropriate term for these divisions, and throughout the Harmonious system, in source code and descriptions, these divisions are referred to 'music segments'. However, this clashes slightly with Echo Nest's use of the term 'segment' for the very short tonal based divisions it identifies. To limit confusion, throughout this text the term 'Echo Nest segment' is used when referring to the latter). Echo Nest's section divisions (high-level divisions, such as verse, chorus, etc) provide a convenient framework in which to search for potential significant changes in emotional content.

For each high-level section identified by Echo Nest, the average loudness and timbre values are calculated by iterating through that section's component Echo Nest segment data. Once this data has been collected for each section, each section's averages are compared with those of the sections immediately preceding and following. Experimentation with several known pieces of music revealed that a difference greater than 6.0 in both average loudness and average timbre was a signifier of a potential difference in emotional content. Harmonious then splits the track into music segments at such points of change.

Harmonious then makes a pass through the assembled music segments whilst examining the bar location information for the track. The segment boundaries are each adjusted to lie on bar boundaries, to allow for cleaner transitions at playback time.

After further testing, however, it was found that the criteria used to determine segment breaks would often identify occurrences such as a long sustained chord or note at the beginning or end of a track as a music segment. During gameplay, this would issue manifest itself as playback of several very short pieces of music (often under 10 seconds) amongst the longer musical segments. This was found to be distracting and confusing. Therefore the system limits segments to a minimum of 30 seconds in duration to prevent this.

After each music segment has been identified, an initial circular representation of the segment's emotional content on the arousal/valence plane is created. (These circular shapes are referred to in the source code as 'mood shapes'). The valence value is determined by the mode and mode confidence analysis data. Mode is represented as either major or minor, in the musical sense. Mode confidence is represented as a value between 0.0 and 1.0, with 1.0 indicating complete confidence in the analyser's assessment of the music's mode. If a segment's mode is major, it's valence value is set equal to the confidence value. If a segment's mode is minor, its valence value is set to zero minus the confidence value. This causes clearly major or minor music to be placed towards the extremes of the valence axis, while more ambivalent music tends towards the neutral centre.

The arousal value is determined by the segment's loudness and energy values (energy is a value between 0.0 and 1.0 representing Echo Nests determination of how energetic the music is. This data is provided in the summary information received the point of track identification, rather than in the full analysis data). The energy value is used as the basis for the arousal value, and then modified based on the variation in the segment's loudness values from the overall average loudness of the complete track.

The arousal and valence values are used as the co-ordinate of the centre of a circular mood shape, the radius of which is set to 1 minus the mode confidence, giving segments with lesser confidence a larger scope to be fine-tuned by the user/player (the fine tuning process is discussed in section 5).

All music analysis operations are carried out in the background of the host game's process, allowing the game to be played and to make use of the Harmonious system while analysis is taking place. Analysis operations can also be suspended and resumed when the host game is quit and restarted. The most time consuming aspect of the analysis workflow is the uploading of unidentified tracks for bespoke analysis by Echo Nest, therefore the overall time taken to analyse a music collection depends predominantly on the number of files that require uploading. During testing it was found that an average of 11% of the music encountered by the analysis system required uploading, with 39% being matched with fingerprints and 50% being matched with metadata. Typical time taken to analyse one thousand songs is around 6 hours.

Appendix 2 shows the analysis workflow summarized in a flowchart.

5.3 Measuring Analysis Accuracy

The accuracy of the mood shape analysis is dependent on the accuracy of the Echo Nest analyser. However, the means by which the Echo Nest analyser operates and determines the output values it produces is proprietary and kept in confidence by the company operating the service. There is therefore no means to validate the analyser's methods against other work in the field. However, the analysis results can be validated by measuring them against standard reference sets used in other MIR[16] and MER[17] studies.

A test was devised making use of the CAL500 dataset as a reference. This is a set of 500 pieces of popular western music from the last half-century with human-applied descriptive tags, created by Turnbull et al in 2008 at the Computer Audition Laboratory, University of California San Diego [21]. The set has been used by its authors and third parties as a reference set for various MIR experiments.

Of the 174 possible tags that may be applied to a piece of music in the CAL500 dataset, there are 36 tags describing emotional content. As an initial test of the Echo Nest platform, a comparison between these tags and Echo Nest's mood search was carried out. For each track in the CAL500 dataset the corresponding emotion tags were collected into a set. A dictionary was created mapping the terminology used by Echo Nest's mood search to the corresponding emotion tags from CAL500. A mood search operation was carried out for each Echo Nest mood and limited to music that appears in the CAL500. The results were used to create a second set of emotion tags for each track, representing the emotional content of the track as determined by Echo Nest. Comparing the two sets for each track, the results were as follows:

- 80.07% of the set pairs intersected
- The average complete match between set pairs was 28.74%
- The average complete match between intersecting pairs was 35.89%

This high rate of intersection was encouraging, so so a further test was carried out to compare arousal/valence mood shape representations between CAL500 and Echo Nest. However, as the CAL500 dataset only has textual representations, a means by which to translate these into shapes on the arousal/valence plane was required. To this end a vector was assigned to each of the 36 emotion tags representing the position of the emotion tag on the arousal/valence plane, where the vector origin lies at the origin of the plane, as shown in figure 8 below.

For each track in the dataset the emotion tags were extracted and the average of the corresponding vectors was calculated. The position indicated by this average vector was taken as the centre of a circle. The radius of the circle was based on a confidence value derived from the number of emotion tags applied to that track. This circle then represented the emotional content of track in arousal/valence terms.

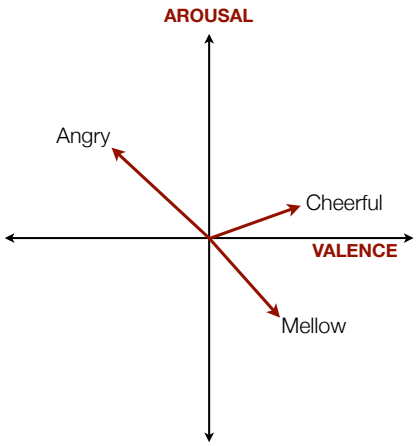

Figure 8: Example mood vectors

The mapping of textual emotion tags to vectors is, of course, a subjective process, as any translation of emotions between categorical and dimensional representations must be. However, the mapping used in this test was based on Thayer's descriptions of the two dimensional properties [19] and the indicative locations of moods on the arousal/valence plane adhered to by many MIR and MER works that derive from Thayer's thesis (for example see [11, 17, 23]). Therefore, while subjective, it can be said that the mapping of textual emotion tags to arousal/valence vectors is at least consistent with other MER work.

A second set of arousal/valence shapes for the tracks in the CAL500 set was collected by parsing the analysis data for each track from Echo Nest, by the same process used by the harmonious system. Comparing the two sets of circular shapes had the following results:

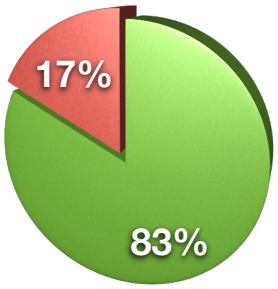

Figure 9: Percentage of circular mood representations overlapping between CAL500 and Echo Nest

- 82.67% of the circle pairs overlapped.
- The average distance between pairs that did not overlap was 10.5% the width of the plane.

These results sit quite favourably with results gained in various recent automated emotion recognition systems, which typically

[16] Music Information Retrieval

[17] Music Emotion Recognition

achieve 45-80% accuracy for dimensional emotion representation [11].

However, the Echo Nest analysis data suffers from the same difficulty found in other MER projects, that valence data is much courser grained than arousal data. Echo Nest data gives musical mode as a binary value with a floating point confidence rating, whereas data contributing to arousal (energy and loudness) are provided as fine grained floating point values. This issue manifests itself in the Harmonious system as a tendency for mood shapes to cluster towards the middle of the valence axis. However, the Echo Nest analyser is under ongoing development, and as many researchers have adopted the arousal/valence model for MER work, it is expected that improvements will be made in this area.

The tag matching dictionary, the mood vector assignments and the code used to carry out the testing are provided in appendix 3.

6.REFINING MUSIC ANALYSIS AND MATCHING MUSIC WITH GAME MOODS

When the Harmonious system is in use with a game, the game analyser object monitors game conditions and sends cues for music to start, transition and stop to the system controller. The system uses gameplay mood information from the game analyser and the music analysis data (music segments and mood shapes) in the database to find an appropriate match between music and gameplay.

The initial musical analysis and mood shape representations for music segments are merely the starting point for the Harmonious system's capability to match music with gameplay. Whenever the system is in use by a game, each music segment's emotional representation can be refined by the user/player, which in turn improves the accuracy the process by which music is matched to gameplay.

Each music segment entry in the database includes two sets of mood shapes, one set for 'included' shapes and one for 'excluded' shapes. The initial shape created by the analysis workflow is added to the included shapes set. During gameplay a player can indicate to the system that the music segment currently playing is particularly appropriate match to the current gameplay. The system then creates a new circular mood shape and adds it to the segment's included shapes set. The location of centre of the new circle is located at the point on the arousal/valence plane that represents the current game mood (this is provided by the game analyser object) The radius of the circle is fixed at 0.2 units, a value found via experimentation. Having additional mood shapes in a segment's included shapes set gives the segment a higher chance of being chosen for the given gameplay mood, as discussed below.

Similarly a player can indicate that the currently playing music segment is a poor or inappropriate match to the current gameplay. In this circumstance, the system creates a new mood shape in the same manner as outlined above and adds this to the segment's excluded shapes set. This prevents the segment from being chosen for the given gameplay mood, as discussed below.

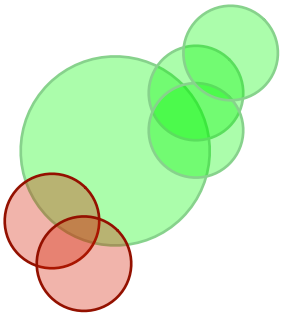

Figure 10: Example representation of a music segment's mood shapes, 'included' shapes in green and 'excluded' shapes in red

When the Harmonious system is required to select a new music segment for playback (due to receiving a cue from the game, or from the currently playing segment coming to an end without a cue to stop music playback), the current gameplay mood, represented as a set of co-ordinates in the arousal/valence plane, is fetched from the game analyser object. This in turn is passed to the music manager object to find an appropriate match in the music segments database. To avoid excessive repetition, the music manager maintains a record of the previous fifteen audio files played, and excludes these from its matching process.

The music manager queries each music segment in the database for a match score against the supplied arousal valence coordinates. A music segment calculates its match score by starting from zero and incrementing the score by one for each shape in its included shapes set which encloses the given co-ordinate, then decrementing the score by one for each shape in its excluded shapes set which encloses the current co-ordinate. A positive match score therefore indicates a possible match between music and gameplay, with a higher score indicating a better match.

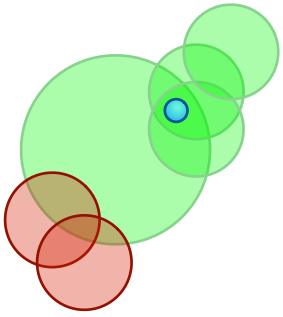

Figure 11: The match score between this music segment and the mood location indicated by the blue dot would be 3

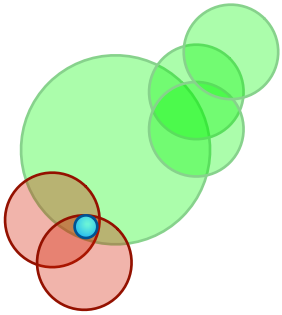

Figure 12: The match score between this music segment and the mood location indicated by the blue dot would be -1

The music manager collects each of the music segments with a positive match score, and assigns them a weighting equal to their score. The weightings are used to influence a pseudo random choice where a segment with a match score of two is twice as likely to be chosen as a segment with a match score of one.

Allowing for the possibility of lower scored matches to be chosen (albeit with a lower likelihood) may seem counterintuitive, and early in development the music manager used a selection system focused entirely on the top scored matches. Here the music manager would collect all the joint top matches for the game mood (i.e. if there existed ten segments with a match score of 1, five with a match score of 2 and four with a match score of 3, only those last four would be collected), and from this smaller collection it would choose a segment at random. However, this raised a serious issue when a user/player would begin to use the system for the first few times. In the early levels of the host game used for testing and development, the game mood could be consistently predicted to remain within a small area of the lower right quadrant of the arousal/valence plane. During a player's first attempt at the game, if the player indicated a 'like' of the music chosen at this point in gameplay, that piece of music's score would increase to 2 for that arousal/valence point. On the player's second attempt at the game, this piece of music would always be chosen, as it would be the only highest scored match. Players found that when having multiple attempts at the game in a short timeframe, hearing the exact same music at such points was too repetitive and would often start to mark choices they had previously 'liked' with a 'dislike' for the same gameplay mood just to overcome this repetitiveness. Therefore the weighted choice system was developed and has proven more robust.

In the circumstance where no music segment in the database has a positive match score for the given gameplay mood co-ordinate, the music manager makes a nearest match. This is done by requesting each segment in the database to return a value indicating distance between the given co-ordinate and the nearest edge of a composite shape created from the union of the areas all the circles in the segment's included shapes set with the subtraction of the areas of all the circles in the segment's excluded shapes set. Any segments with an excluded shape enclosing the current gameplay mood point are discarded. From the remaining segments, the one which returns the shortest distance is chosen.

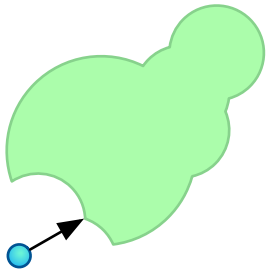

Figure 13: The minimum distance between a mood location and a composite shape

7.THE USER INTERFACE (UI)

The user interface displayed when Harmonious is in use with a game is shown below.

Figure 14: The Harmonious user interface

A text display shows the title and artist of the currently playing music segment and, when appropriate, the status of the music analyser.

As mentioned above, the player has the ability to refine the system and improve the matches between gameplay mood and music. Early in the development of the Harmonious system, this was carried out via the only two controls available to the player, a 'like' button and a 'skip' button. The 'like' button would indicate approval to the system; the 'skip' button would indicate disapproval and cause the system to select an alternate music match. However feedback from early demonstration and testing indicated a need to separate 'dislike' and 'skip' into individual controls, as players may wish to skip a piece of music for reasons other than disapproving of the match with the current gameplay.

This led to the development of a four control system: 'like', 'dislike', 'play/pause' and 'skip'. The former two send the approval and disapproval signals to the system respectively, with the 'dislike' control then triggering a transition to an alternate music segment. The latter two controls act like those on any music player, and have no effect on the system's database.

Feedback from players also indicated the need for a control that would indicate to the system that a particular piece of music should not be used at all by the system. Many of those players' digital music collections contained music acquired by spouses and/or children, and other music that for various reasons they would not normally listen to and did not wish to hear when playing a game.

To meet this issue a fifth control was added, the 'ban' control. This control causes the currently playing music never to be chosen for playback.

Though the Echo Nest music analyser scored very favourably when tested against the CAL500 dataset, 82.67% accuracy still left the potential for almost 1 in 5 tracks to have inaccurate mood shapes at the end of the analysis process. It therefore seemed prudent to include a means to directly manipulate mood shapes. To this end a 'fine tune' interface was added, which normally remains hidden, but can be revealed by clicking a button. This interface consists of two sliders, one labelled Sad/Happy, the other Laid Back/Energetic. The values of these sliders would be set to the valence and arousal values of the segment's original mood shape, and adjusting them would reposition that mood shape on the arousal/valence plane accordingly.

Figure 6: The Harmonious 'fine-tuning' interface

However, during player testing this 'fine tune' control was never used. The reasons for this were twofold. Firstly, a clear understanding of the function of this control required a deeper understanding of the internal operation of the Harmonious system than is necessary for its normal use. Secondly, manipulating this control would typically require pausing the game. This clearly breaks a player's immersion in the game, and as such diminishes the experience and violates the objectives of the project. Additionally, players were content with the results of using the 'like', 'skip' and 'ban' controls to fine tune the music matching process. It therefore seems that the 'fine tune' control may not be required as part of the standard user interface, and further testing and evaluation may indicate that it can safely be removed (the testing and evaluation carried out to-date is discussed in section 7).

Each of the player controls can be activate with the mouse, but this would often prove inappropriate during gameplay, so each is also mapped to a key on the keyboard, and could also be mapped to specific buttons on a game pad controller.

The default keys are:

1 = Like
2 = Dislike
3 = Ban
4 = Play/Pause
5 = Skip

8. THE PROGRAMMER INTERFACE (API)

The Harmonious music system is written in Objective-C and makes use of the FMOD Ex[18] C/C++ library for music playback, the Core Data Framework[19] for the music segments database, and the Cocoa Framework[20] for general operations (such as querying the Echo Nest server) and the user interface. Each of these libraries and frameworks are high-level and general function, and could be substituted for others with similar functionality should the Harmonious system be ported to a platform for which these were unavailable. Similarly, the API provided by the Harmonious system to integrate it into a game is in the Objective-C language, but could easily be adapted to C or C++ if necessary.

Implementing the Harmonious system within a game involves incorporating the system's code into the game, and causing an instance of the HarmoniousSystemController class to be created when the game is launched. The programmer must also create a GameAnalyser object specific to the game.

Though the GameAnalyser must be created for each game, the Harmonious system provides a template API so that it may be easily incorporated into the system. The template API requires the programmer to implement the following methods[21] in the GameAnalyser class:

```
-(id)initWithGameController:(id)theGameController;
```

This method is the designated initialization method for the GameAnalyser class, in which it receives a reference to an object referred to as theGameController. The type and nature of the object is unspecified, and would be an object which the game specific implementation code can communicate with to receive the current game state and any required game variables.

```
-(void)activate;
-(void)deactivate;
-(BOOL)isActive;
```

The first two of the above three methods indicate that to the GameAnalyser that it should start and stop sending cues to the Harmonious system controller. They would typically be invoked when the user/player switches between the game's original soundtrack and the Harmonious system. The third method is simply a means by with other objects can query the active state of

[18] http://www.fmod.org/index.php/products/fmodex

[19] https://developer.apple.com/library/mac/#documentation/Cocoa/Conceptual/CoreData/cdProgrammingGuide.html

[20] https://developer.apple.com/technologies/mac/cocoa.html

[21] In object-oriented programming, methods are programmatic routines, similar to functions, that are carried out by objects of a specific class

the GameAnalyser. This method should return a boolean value of *true* when the GameAnalyser is active and *false* when it is inactive.

```
-(NSPoint)currentGameplayMoodInArousalValenceCoordinates
```

This method is the means by which other components of the Harmonious system can discover the current gameplay mood in arousal/valence co-ordinates, as determined by the game analyser. The return type, *NSPoint*, is a structure containing two floating point values, labelled 'x' and 'y'. The x value should represent valence, the y value arousal.

```
@property id delegate;
```

Finally, the GameAnalyser must implement this *delegate* property[22] in order to receive a reference to the HarmoniousSystemController object. This reference is the means by which the GameAnalyser can send cues to the system. Two methods are defined in the HarmoniousSystemController class to facilitate these cues. These are:

```
-(void)playNewTrackForArousalValencePoint:(NSPoint)avPt;
-(void)fadeOutAndStopCurrentTrack;
```

The former is used to start music playback and transition to a different piece of music, the latter is used to stop music playback.

As the programmer has free reign over the implementation of the GameAnalyser class, the arousal/valence point it sends to the Harmonious system can be based on any factors appropriate to the game. These may be simple analyses of the number of enemies and the player character's health, through to more sophisticated processes, based on the game's narrative which, for example, could cause the arousal/valence point to indicate tension over a forthcoming event.

The remainder of the programmer's interaction with the Harmonious system is via the API presented by the HarmoniousSystemController class. This class implements three methods:

```
-(id)initWithGameController:(id)gameController;
-(void)startMusicPlayback;
-(void)stopMusicPlaybackWithFade:(BOOL)fadeOut;
```

The first method is the designated initializer for the class. The gameController parameter should be a reference to the object that is in turn passed to the GameAnalyser object upon its initialization. The second method should be called when the user/player has elected to listen to music via the Harmonious system. It in turn causes the GameAnalyser object to activate. The third method should be called when the user/player elects to stop listening to music with the system. This method stops playback and deactivates the GameAnalyser. The boolean *fadeOut* parameter is used to indicate whether the system should fade out any currently playing music, or stop it immediately.

The HarmoniousSystemController class also exposes the methods used by the user interface. These are:

```
-(void)showHarmoniousUIWindow;
-(IBAction)likeMusic:(id)sender;
-(IBAction)dislikeMusic:(id)sender;
-(IBAction)banMusic:(id)sender;
-(IBAction)pauseMusic:(id)sender;
-(IBAction)skipTrack:(id) sender;
```

Should the programmer wish to use an alternate user interface for the system, its controls can call these methods to gain the same functionality as the original interface.

The full interface declarations (header files) for the HarmoniousSystemController class and the GameAnalyser template can be found in Appendix 4.

9.GAME ANALYSER IMPLEMENTATION IN THE SPACE DEFENDER GAME

A small game was created specifically for testing, evaluation and development of the Harmonious system. This game, called '*Space Defender*', is a simple, two dimensional arcade-style game, where the player controls a space craft and must fend off waves of attacking alien craft. The attackers increase in numbers with each new wave, and waves are broken up with 'boss' levels, where a single, large and very strong enemy attacks.

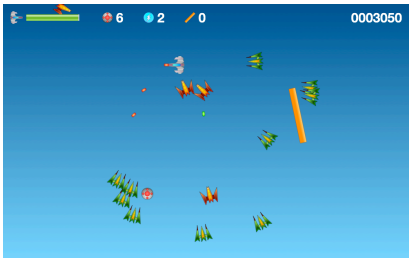

Figure 7: The *Space Defender* game

To create a reference against which the Harmonious system could be compared, a dynamic music system was created for the game using FMOD Designer and implemented using the FMOD Event library/API[23]. The music begins as an ambient synth pad and increases in complexity and intensity by adding further instrument tracks and layers in response to increasing intensity in the game. For the implementation of this music, game intensity is considered a one-dimensional property, defined by the formula:

$$\left(\frac{en}{100}\right)+\left(\frac{100\text{-}h}{100}\right)$$

[22] In the Objective-C language, a property is simply a shortcut for defining a combination of a variable, in this case called 'delegate', and a pair of methods to get and set the value of that variable.

[23] http://www.fmod.org/index.php/products

Where *en* is the maximum number of enemies in the current attack wave, and *h* is the player's level of health (a value between 0 and 100). This intensity value is then halved in the short intervals between a player defeating an attack wave and the beginning of the next wave. The intensity value is therefore a value between 0.0 and 1.0, and this is mapped to a parameter of the same scale in an FMOD event. This event contains a single sound instance of a 12-channel wave file containing each of the music layers. The FMOD event mixes these layers according to the parameter value.

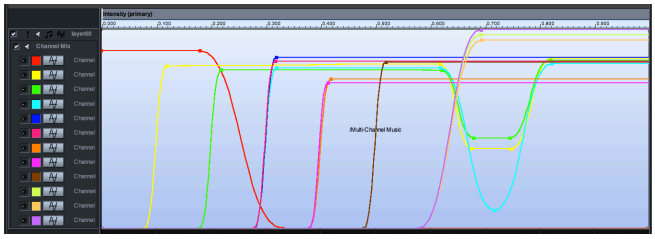

Figure 15: The Music event in the FMOD Designer application

The Harmonious system code was also added to the game, and a GameAnalyser object was created to link the game to the system. The GameAnalyser creates and arousal valence co-ordinate representation of the gameplay mood by the formula:

$$arousal = \left(\frac{en}{35}\right)\text{-}1 \quad valence = \left(\frac{h}{50}\right)\text{-}1$$

which constrain the arousal/valence values between -1 and 1.

A preference option is provided in the game to allow the player to switch between listening to the game's original music and music from the Harmonious system.

10.PLAYER FEEDBACK

The *Space Defender* game was made available to a small group of five players to gather feedback. Players were asked to use the original music whilst playing their first few attempts at the game and becoming familiar with the controls. Once they became comfortable with the game, they would switch to playing with the Harmonious system. The nature of the Harmonious system and its controls were explained to each player beforehand.

The method used to gather this feedback was modeled on that used by Wharton and Collins in a study examining the experience of players given free choice over the music heard during gameplay [22]. In this study, players played the game in the presence of the researcher and used the Think-Aloud method [13] during play. This method is common in user interface testing and evaluation [14] and encourages testers to say out loud what they are thinking as they use and test a device or interface. In the Wharton and Collins study, players were also asked to pause at checkpoints in the game and reflect on their choices of music with the researcher.

Such an approach allows the researcher to gain first hand experience with the participants and allows for any unusual or unexpected occurrences to be observed directly [4]. This approach seemed particularly suitable for early testing of the Harmonious system as it allowed for the gathering of feedback on music choices by the system and their effect on the player as they were happening, and before those effects could be diminished or forgotten by subsequent music choices and game events.

Players were asked to play the *Space Defender* game with the Harmonious system (which had previously analysed the player's music library) and asked to think-aloud on their interactions with the system and the effects of the music on their gameplay. Specifically, players were asked to reveal their thoughts when they made use of any of the harmonious systems controls ('like', 'ban', etc) to make clear their desires and intentions; and to comment of the results of using those controls to reveal whether the system responded as expected. Additionally, players were asked to comment on the matches between music and gameplay and were encouraged to speak any other thoughts they had about the game and the music.

Two players seemed comfortable with the description of the controls before playing, but early in the gameplay they expressed confusion over the 'dislike' and 'ban' controls, saying they were unsure of the difference between the two actions, and therefore unsure of which to use in a particular circumstance. After a further, short explanation of these controls, each of these players' think-aloud comments revealed their understanding. Of the remaining players, one had been involved in earlier testing during the development of the user interface, and therefore found it clear. The remaining two also found the distinction between these two controls clear, as revealed by comments such as 'this song is too slow' before using the 'dislike' control and 'this is one of [my spouse]'s songs' before using the 'ban' control.

One player seemed to make use of the 'like' control to indicate enjoyment of a particular piece of music, rather than approval of the match between music and gameplay, as revealed by think-aloud comments such as 'this is a great song', 'I like this one' and 'this is my kind of music'. When asked about the function of the 'like' control, this player revealed that he was indicating approval of the match between gameplay and music genre, rather than music mood (unfortunately the long term results of using the system in such a manner cannot be yet determined from the amount of testing carried out to-date). The other players showed use of the 'like' control for mood match approval, as revealed by think-aloud comments such as 'this is a better tempo' and 'this is a good fit'.

In later attempts at the game each player's think-aloud comments were less in regard to the use of the controls and more on the music and gameplay in general, seeming to indicate increased confidence and comfort with the controls.

In summary, some players showed some initial misunderstanding of the system's five basic controls, but through coaching and experience they achieved suitable understanding and familiarity. It would seem therefore that this control system is reasonably understandable, but that some initial player induction would be beneficial. Such an induction could perhaps take place in the form of a short in-game tutorial when the system is used for the first time, in a similar manner to gameplay tutorials offered at the beginning of games.

Between attempts at the game (when the player had 'died') players were asked to reflect on how well they felt the Harmonious system was refining itself to their preferences. All players reported that they found they system's music choices had improved on each attempt. Two players had made heavy use of the 'like, 'dislike', and 'ban' controls during their first two attempts at the game, and by the third attempt they reported that they felt the system was making accurate music choices. In later attempts these players made only occasional use of these controls. These players seemed to treat their initial attempts as simply system training and the latter attempts as actual gameplay. The remainder of the players focused

more consistently on gameplay throughout their attempts, and correspondingly made slightly lighter use of the system controls. These players reported a similar satisfaction with match accuracy by their fourth and fifth attempts. An interesting phenomenon was that when Harmonious played music of a player's favourite genre, most players claimed that this type of music was a perfect match to the Space Defender game's style of gameplay.

Based on this mid-game feedback, it would seem that the Harmonious system is meeting the project's objective of automating music choices with mood matching. Players found that, after some refinement of the system, the music choices were accurate and effective. However, further research and testing could prove that the requirement for refinement is discouraging to potential users. As discussed above, the initial matching has an accuracy of around 83%, giving the potential for almost 1 in 5 matches to be inappropriate when a player is using the system for the first time. Should this be the case, the tutorial system suggested above may help mitigate this discouragement.

After playing for around 45 minutes players were asked for feedback relating to the project objectives: how informative the music selections were and how their enjoyment of game and focus on gameplay compared against playing with the original music. Players were asked what they understood the role of the game's original music to be. Every player responded that the link to game intensity was clear, particularly in the later, more intense stages of gameplay where health is low and/or enemies are overwhelming. Players were then asked if they felt the music played by the Harmonious system fulfilled the same role. Again, every player reported that they felt that the music played by Harmonious followed a similar pattern of intensity throughout the game. Players were asked if they felt more or less focused on and engaged with the game when playing with the Harmonious system. Four players reported that they found the higher intensity portions of gameplay were particularly effective with the Harmonious system, where the intensity of the music heightened the gameplay experience and increased their focus on the game. Comments were sparser and more neutral for the lower intensity waves at the beginning of the game. Two players noted that they found themselves firing their weapons in time to the music during medium-high intensity gameplay, which would typically be accompanied by up-beat music. One player however, reported that he was less concerned with matches between music and gameplay, and more with hearing his current favourite tracks. During periods of low activity between attack waves, he would concentrate on skipping through several tracks in the Harmonious UI to find one of his favourites (this being the same player that had used the 'like' control to match gameplay with genre, described above).

This post-game player feedback would seem to indicate that the Harmonious system is capable of meeting the project objective of retaining information and feedback provided by original game music. However, the test game is limited in terms of the emotions it provokes in players, and therefore the gameplay moods which the system is matching music against are also limited. It remains to be seen how effective the system would be with a more emotionally complex game.

During the evaluation, players gave a few further interesting comments. One player noted that he had tried listening to alternate music whilst playing games by playing music on a hi-fi system and a portable music player. He had liked the idea of hearing his own music, but these methods typically made the game's sound effects difficult to hear, and he felt hearing these effects was crucial in the games he played (primarily motor racing and FPS games). He felt the Harmonious system was a better solution as the music playback was integrated within to the game, and could be controlled with the game's own relative volume controls. Two players raised a concern that having to refine the system (via 'like' and 'dislike') multiple times for multiple games would be tedious and likely to discourage their use of the system. Having refinements shared amongst all games using the system would be more appealing. One player also had the concern that without a large and varied music collection, the system would be ineffective.

From this player testing and evaluation, it can be concluded that the Harmonious system has the potential to meet the project's objectives. However, the feedback gathered was from only a small number of players and with a very simple game. Therefore it can only be taken as an early indication. Additionally, the data gathering approach used in this evaluation is known to have drawbacks, specifically that subjects may find the presence of the researcher to be intrusive and that the researcher's presence may bias the subject's feedback [4].

Conclusive proof of the system meeting the project's objectives will require testing with larger numbers of players and games of differing styles, genres and complexity. In such testing, the potential limitations of a researcher-in-attendance approach could be mitigated by the establishment of an Observational Protocol [4] which would allow for the observations and interviewing to be carried out effectively by a third party. Such a protocol could include the gathering of demographic and biographic data on participants to provide a richer data set from which a deeper analysis could be carried out [4]. The feedback gathered to date indicates that such further testing would be worthwhile.

11. FURTHER DEVELOPMENT

11.1 Social Playlist Sharing

At the outset of this project it was envisioned that the system would include a social component, whereby user/players could share playlists amongst their friends[24]. To facilitate this the Harmonious system would keep a record of music that a player 'likes' on a game-by-game basis. These 'liked' tracks would be collected into a playlist entity in the Harmonious database. When a game had a sufficient number of tracks in it's playlist (the number would have to be defined via testing, but is estimated to be at least 50) the playlist would be uploaded to an online database server. When another player begins playing a game with the Harmonious system, that player's system would check the online database for any updated playlists associated with that particular game from any of the player's friends. The player could then be offered the option to play the game with the music that their friends preferred. Should the player not have the playlist's complete set of songs in their music library, they could be presented with an option to purchase the remaining music from an online service appropriate to the game platform. By use of affiliate programmes, this could present a revenue opportunity for the Harmonious project.

[24] The term 'friend' is used here in the social networking sense, indicating a fellow user of an online service with whom a given user has agreed to share information and communications through the service. Popular services in the video game market include Microsoft's XBox Live and Games for Windows Live, and Sony's Playstation Network

Implementing a social playlist sharing component to Harmonious would not be a technically complex undertaking, it was just not possible to complete within the timeframe of the project. As the Harmonious system already makes use of a local database and is processing player 'likes' during gameplay, it would be trivial to have the system build playlist by noting the track (with metadata) associated with the music being 'liked' and add this to a collection in the database labelled with the game title. As each track is added to this collection, the system can check for reaching the number of entries that would signify a 'full' playlist. At this point the playlist would be uploaded to an online database, including track metadata, segment locations and arousal-valence mood shapes.

Creating an online database could be achieved quite simply by using existing technologies, such as Ruby-on-Rails[25] and mySQL[26], which are commonly used for web applications [8]. These technologies would allow for an online database access application with user/password authentication to be created in a very short timeframe [8]. New playlist entries could be uploaded to such a server by encoding the contents of the playlist into the parameters of an HTML POST request[27]. A similar request could be used as the means by which checking for and downloading playlists are achieved.

The Harmonious system would check with the server when gameplay was about to begin, download any new playlists from friends and offer these to the player. Should the player accept, the music matching system would temporarily favour the music segments in the playlist and use the arousal/valence mood shapes from that playlist, rather than those that exist in the local database. Should the player make any 'likes' or 'dislikes' during gameplay with the playlist, these would be merged into the local database for future play.

Sharing features could be activated or deactivated by a local preference setting in the Harmonious system.

11.2 Platform Level Integration

Whilst integrating the Harmonious system into a game is a reasonably simple process, the system could prove more effective if implemented at a platform level as a platform-wide service. As such, music analysis data and user refinement of mood shapes could be easily shared amongst any games played on the platform (player feedback indicated that having to 're-train' the system multiple times for multiple games would be unappealing).

Platform level integration was also allow for simpler access to the platform's online music sales service (if available) and would allow Harmonious to play music files that are subject to any digital rights management restrictions enforced on the platform, a feature that is not currently available to Harmonious as a stand-alone technology.

12. CONCLUSIONS

This project aimed to create a means by which video game players could listen to their own music libraries during gameplay instead of the game's original music, in an integrated, intelligent manner which would help preserve the information and feedback contained in the original music. To this end, the project's stated objectives were:

- Allow players to listen to music in their own libraries whilst playing games
- Automate the choice of music from the player's library by matching gameplay mood with the emotional content of the music, thereby:
- Retaining some of the information and feedback provided by the original game music

The Harmonious system was developed to meet these objectives, and operates around a central principle of emotional analysis of music and gameplay resulting in two-dimensional geometric representations of emotions on a plane where arousal and valence properties form the axes.

The Echo Nest platform is used to perform the bulk of the music analysis operations, and this proved effective. The efficiency of this approach was very high when compared to other efforts in the field of music emotion recognition. However, as found in other studies, valence remains a more difficult property of music to resolve at fine-grained level compared to the evaluation of arousal.

The means by which players could refine the music analysis data during gameplay were developed and fine-tuned with player feedback and have proven effective in quickly and unobtrusively improving the system's matching to the player's tastes. Initial evaluations have shown that the advanced refinement features may be unnecessary, but they remain in place until such time as more comprehensive player testing can take place.

Initial player testing has shown that the Harmonious system operates at a suitable level of efficiency and that players feel the music chosen by Harmonious during gameplay provides an effective means of communicating the information provided by the game's original music. Players found the experience of playing with the Harmonious system pleasurable and found that it contributed to their immersion in the gameplay. However, this initial testing was limited to a small number of players playing a very simple game. Further and more rigorous testing with more involved games and greater numbers of players is required to draw definitive conclusions.

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Appendix 1: Game Music Survey Results

ID	7	6	1	2	3 In which genres of games would you be more likely to turn off music or listen to your own music?													
	Age	How often to you play video games?	Do you turn off video game music when playing and/or replace it with your own music?	Are you more likely to turn off game music or listen to your own music when playing single player or multiplayer?	*First/ Third person shooters*	Role play games	Platform games	Fighting games	Stealth games	Sim games	Strategy games	Racing games	Sport games	Motion games	Casual/ Mobile games	Puzzle games	Other
fb4	Teens or younger	Hardly ever or not at all	Never	Neither												1	
fb5	30's	Several times a month	Sometimes	Single Player											1	1	
fb9	40's	Several times a month	Sometimes	Single Player								1					
fb10	20's	Several times a month	Sometimes	Neither						1	1	1			1		
fb11	30's	Several times a month	Sometimes	Single Player						1					1	1	
fb12	Teens or younger	Several times a month	Sometimes	Single Player	*1*	1	1	1			1				1		
fb14	30's	Several times a month	Sometimes	Multiplayer	*1*					1					1	1	
fb15	40's	Several times a month	Regularly	Single Player			1	1	1	1	1		1	1	1	1	
fb16	30's	Several times a month	Never	Neither								1		1	1	1	
6663956	20's	Several times a month	Never	Neither											1		
6657510	20's	Several times a month	Sometimes	Multiplayer								1	1				
6654826	20's	Several times a month	Never	Neither				1				1					
6686062	20's	Several times a month	Never	Neither						1							
6657275	20's	Several times a month	Sometimes	Both	*1*												
6658049	20's	Several times a month	Never	Multiplayer	*1*												
6685660	Teens or younger	Several times a month	Sometimes	Single Player								1	1		1	1	
fb1	40's	Several times a week or more	Regularly	Multiplayer	*1*		1								1		
fb2	20's	Several times a week or more	Sometimes	Multiplayer								1	1		1	1	
fb3	40's	Several times a week or more	Regularly	Single Player									1				
fb7	Teens or younger	Several times a week or more	Regularly	Multiplayer	*1*												
fb8	Teens or younger	Several times a week or more	Never	Neither				1		1		1				1	
fb13	20's	Several times a week or more	Sometimes	Multiplayer	*1*			1			1	1	1				
fb17	20's	Several times a week or more	Sometimes	Single Player													1
6658383	30's	Several times a week or more	Sometimes	Multiplayer								1			1		1
6656765	30's	Several times a week or more	Sometimes	Both													1
6654967	30's	Several times a week or more	Sometimes	Single Player													1
6657821	30's	Several times a week or more	Never	Neither													1
6685675	30's	Several times a week or more	Regularly	Both		1	1	1	1	1	1	1	1	1	1	1	1
6655191	30's	Several times a week or more	Sometimes	Single Player			1	1		1	1	1	1	1	1	1	
6656830	30's	Several times a week or more	Sometimes	Multiplayer								1	1		1		
6655307	30's	Several times a week or more	Regularly	Single Player								1	1				
6657202	20's	Several times a week or more	Regularly	Both	*1*	1	1	1		1	1	1	1		1	1	1
6667841	20's	Several times a week or more	Sometimes	Both						1	1	1			1	1	1
6656809	20's	Several times a week or more	Sometimes	Single Player											1		1
6663921	20's	Several times a week or more	Never	Neither											1	1	1
6663931	20's	Several times a week or more	Sometimes	Multiplayer									1				1
6657075	20's	Several times a week or more	Sometimes	Both	*1*					1	1	1					1
6654757	20's	Several times a week or more	Never	Multiplayer													1
6661363	20's	Several times a week or more	Never	Multiplayer													1
6684423	20's	Several times a week or more	Never	Multiplayer													1
6654685	20's	Several times a week or more	Sometimes	Multiplayer													1
6655490	20's	Several times a week or more	Sometimes	Multiplayer													1
6658446	20's	Several times a week or more	Sometimes	Multiplayer													1
6657690	20's	Several times a week or more	Never	Neither													1
6686089	20's	Several times a week or more	Never	Neither													1
6664107	20's	Several times a week or more	Sometimes	Neither													1
6684444	20's	Several times a week or more	Sometimes	Neither	*1*												1
6654969	20's	Several times a week or more	Regularly	Multiplayer	*1*		1	1		1	1	1	1	1	1	1	1
6664069	20's	Several times a week or more	Never	Multiplayer				1		1	1	1	1	1	1		1
6654760	20's	Several times a week or more	Sometimes	Both	*1*			1		1		1		1	1	1	1
6654635	20's	Several times a week or more	Sometimes	Multiplayer						1	1			1	1	1	1
6664374	20's	Several times a week or more	Regularly	Both	*1*		1	1		1	1	1	1		1	1	1

	7	6	1	2	3 In which genres of games would you be more likely to turn off music or listen to your own music?												
ID	Age	How often to you play video games?	Do you turn off video game music when playing and/or replace it with your own music?	Are you more likely to turn off game music or listen to your own music when playing single player or multiplayer?	*First/ Third person shooters*	Role play games	Platform games	Fighting games	Stealth games	Sim games	Strategy games	Racing games	Sport games	Motion games	Casual/ Mobile games	Puzzle games	Other
6654301	20's	Several times a week or more	Regularly	Multiplayer	*1*		1	1		1	1	1	1	1	1		
6684158	20's	Several times a week or more	Never	Neither						1		1	1	1	1	1	
6663858	20's	Several times a week or more	Sometimes	Multiplayer	*1*	1	1		1			1	1	1	1	1	
6686692	20's	Several times a week or more	Sometimes	Multiplayer				1				1	1	1	1	1	
6684403	20's	Several times a week or more	Sometimes	Multiplayer						1			1	1	1		
6658385	20's	Several times a week or more	Never	Multiplayer		1	1	1		1	1	1	1		1	1	
6655160	20's	Several times a week or more	Sometimes	Multiplayer	*1*		1	1		1	1	1	1		1		
6654396	20's	Several times a week or more	Regularly	Multiplayer	*1*		1	1		1	1	1	1		1	1	
6668530	20's	Several times a week or more	Never	Multiplayer	*1*			1		1	1	1	1		1		
6656354	20's	Several times a week or more	Sometimes	Multiplayer				1		1	1	1	1		1		
6664194	20's	Several times a week or more	Sometimes	Multiplayer	*1*			1		1	1	1	1		1	1	
6684234	20's	Several times a week or more	Sometimes	Multiplayer				1		1	1	1	1		1	1	
6663990	20's	Several times a week or more	Regularly	Multiplayer	*1*			1		1	1	1	1		1		
6663922	20's	Several times a week or more	Never	Multiplayer						1	1	1	1		1	1	
6657938	20's	Several times a week or more	Sometimes	Multiplayer	*1*					1	1	1	1		1		
6661409	20's	Several times a week or more	Sometimes	Multiplayer	*1*					1	1	1	1		1		
6686584	20's	Several times a week or more	Sometimes	Multiplayer	*1*	1		1			1	1	1		1	1	
6664004	20's	Several times a week or more	Sometimes	Multiplayer	*1*			1			1	1	1		1		
6664041	20's	Several times a week or more	Sometimes	Single Player			1	1	1	1		1	1		1	1	
6686652	20's	Several times a week or more	Regularly	Both			1	1		1		1	1		1		
6685727	20's	Several times a week or more	Sometimes	Multiplayer	*1*			1		1		1	1		1		
6659813	20's	Several times a week or more	Sometimes	Single Player						1		1	1		1		
6655010	20's	Several times a week or more	Sometimes	Multiplayer				1				1	1		1	1	
6655559	20's	Several times a week or more	Sometimes	Multiplayer	*1*			1				1	1		1	1	
6656292	20's	Several times a week or more	Sometimes	Multiplayer				1		1			1		1		
6667041	20's	Several times a week or more	Sometimes	Multiplayer	*1*					1			1		1		
6663853	20's	Several times a week or more	Never	Neither						1			1		1	1	
6663812	20's	Several times a week or more	Never	Neither						1	1	1			1	1	
6654494	20's	Several times a week or more	Sometimes	Both	*1*		1				1	1			1	1	
6686600	20's	Several times a week or more	Sometimes	Multiplayer	*1*						1	1			1		
6684274	20's	Several times a week or more	Regularly	Multiplayer	*1*			1		1		1			1	1	
6656226	20's	Several times a week or more	Sometimes	Both			1	1				1			1		
6655597	20's	Several times a week or more	Sometimes	Multiplayer				1				1			1		
6685781	20's	Several times a week or more	Sometimes	Multiplayer	*1*			1				1			1		
6657389	20's	Several times a week or more	Regularly	Single Player	*1*			1				1			1	1	
6655031	20's	Several times a week or more	Regularly	Single Player		1	1			1					1	1	
6658500	20's	Several times a week or more	Sometimes	Multiplayer		1		1							1	1	
6657933	20's	Several times a week or more	Never	Multiplayer	*1*	1									1		
6667306	20's	Several times a week or more	Sometimes	Both											1	1	
6661459	20's	Several times a week or more	Sometimes	Multiplayer	*1*										1		
6657776	20's	Several times a week or more	Sometimes	Single Player											1	1	
6686562	20's	Several times a week or more	Sometimes	Single Player											1	1	
6655017	20's	Several times a week or more	Never	Neither											1	1	
6656763	20's	Several times a week or more	Never	Neither											1		
6663974	20's	Several times a week or more	Never	Neither											1		
6684037	20's	Several times a week or more	Never	Neither											1		
6685630	20's	Several times a week or more	Never	Neither											1		
6657349	20's	Several times a week or more	Sometimes	Both	*1*		1	1		1	1	1	1				
6656815	20's	Several times a week or more	Never	Multiplayer						1	1	1	1				
6663989	20's	Several times a week or more	Never	Multiplayer				1		1		1	1				
6684192	20's	Several times a week or more	Sometimes	Multiplayer	*1*			1		1		1	1				
6660506	20's	Several times a week or more	Sometimes	Single Player						1		1	1				

	7	6	1	2	3 In which genres of games would you be more likely to turn off music or listen to your own music?												
ID	Age	How often to you play video games?	Do you turn off video game music when playing and/or replace it with your own music?	Are you more likely to turn off game music or listen to your own music when playing single player or multiplayer?	*First/ Third person shooters*	Role play games	Platform games	Fighting games	Stealth games	Sim games	Strategy games	Racing games	Sport games	Motion games	Casual/ Mobile games	Puzzle games	Other
6663839	20's	Several times a week or more	Sometimes	Multiplayer	*1*			1				1	1				
6654418	20's	Several times a week or more	Sometimes	Multiplayer								1	1				
6655310	20's	Several times a week or more	Sometimes	Multiplayer								1	1				
6686596	20's	Several times a week or more	Sometimes	Multiplayer	*1*							1	1				
6663953	20's	Several times a week or more	Sometimes	Single Player								1	1				
6656679	20's	Several times a week or more	Never	Multiplayer							1		1				
6658315	20's	Several times a week or more	Never	Multiplayer				1					1				
6658120	20's	Several times a week or more	Sometimes	Both				1			1	1				1	
6654409	20's	Several times a week or more	Sometimes	Multiplayer	*1*						1	1					
6656421	20's	Several times a week or more	Sometimes	Multiplayer	*1*		1	1		1		1					
6684100	20's	Several times a week or more	Sometimes	Multiplayer				1		1		1					
6654954	20's	Several times a week or more	Sometimes	Multiplayer						1		1					
6655041	20's	Several times a week or more	Sometimes	Multiplayer	*1*					1		1					
6657899	20's	Several times a week or more	Sometimes	Both		1		1				1				1	
6686056	20's	Several times a week or more	Sometimes	Multiplayer	*1*			1				1					
6657546	20's	Several times a week or more	Sometimes	Multiplayer	*1*							1					
6654394	20's	Several times a week or more	Never	Neither								1					
6654935	20's	Several times a week or more	Sometimes	Single Player		1				1	1						
6663886	20's	Several times a week or more	Sometimes	Multiplayer							1						
6658450	20's	Several times a week or more	Never	Neither						1							
6663875	20's	Several times a week or more	Sometimes	Single Player	*1*	1			1								
6656798	20's	Several times a week or more	Sometimes	Multiplayer	*1*												
6663978	20's	Several times a week or more	Sometimes	Multiplayer	*1*												
6686019	20's	Several times a week or more	Never	Neither	*1*												
6685344	Teens or younger	Several times a week or more	Sometimes	Multiplayer	*1*			1		1	1				1		1
6684691	Teens or younger	Several times a week or more	Never	Neither								1					1
6657249	Teens or younger	Several times a week or more	Sometimes	Single Player						1							1
6657607	Teens or younger	Several times a week or more	Sometimes	Single Player		1											1
6684333	Teens or younger	Several times a week or more	Sometimes	Multiplayer				1		1		1	1	1	1		1
6685609	Teens or younger	Several times a week or more	Sometimes	Both	*1*		1	1				1	1	1	1	1	1
6656529	Teens or younger	Several times a week or more	Sometimes	Multiplayer						1	1	1	1		1		1
6686090	Teens or younger	Several times a week or more	Sometimes	Multiplayer	*1*			1		1		1	1	1	1		
6661327	Teens or younger	Several times a week or more	Sometimes	Multiplayer						1			1	1	1	1	
6684284	Teens or younger	Several times a week or more	Sometimes	Multiplayer	*1*			1			1	1		1	1		
6654744	Teens or younger	Several times a week or more	Never	Neither								1		1	1		
6684056	Teens or younger	Several times a week or more	Sometimes	Single Player	*1*		1	1	1	1	1	1	1		1		
6654738	Teens or younger	Several times a week or more	Sometimes	Multiplayer			1	1		1	1	1	1		1	1	
6669177	Teens or younger	Several times a week or more	Sometimes	Multiplayer				1				1	1		1		
6684286	Teens or younger	Several times a week or more	Sometimes	Single Player							1		1		1		
6654389	Teens or younger	Several times a week or more	Sometimes	Both	*1*		1			1	1	1			1	1	
6658453	Teens or younger	Several times a week or more	Sometimes	Multiplayer	*1*			1		1		1			1	1	
6654168	Teens or younger	Several times a week or more	Sometimes	Multiplayer				1		1	1				1	1	
6657773	Teens or younger	Several times a week or more	Sometimes	Multiplayer	*1*			1		1	1				1	1	
6667650	Teens or younger	Several times a week or more	Sometimes	Multiplayer	*1*			1			1				1		
6657404	Teens or younger	Several times a week or more	Sometimes	Single Player	*1*						1				1	1	
6654709	Teens or younger	Several times a week or more	Never	Neither											1		
6663859	Teens or younger	Several times a week or more	Sometimes	Multiplayer	*1*		1	1		1		1	1				
6657736	Teens or younger	Several times a week or more	Never	Neither	*1*					1		1	1				
6684462	Teens or younger	Several times a week or more	Sometimes	Multiplayer	*1*		1	1				1	1			1	
6655248	Teens or younger	Several times a week or more	Never	Multiplayer	*1*			1				1	1				
6654222	Teens or younger	Several times a week or more	Sometimes	Multiplayer								1	1			1	
6655406	Teens or younger	Several times a week or more	Sometimes	Multiplayer	*1*							1	1				

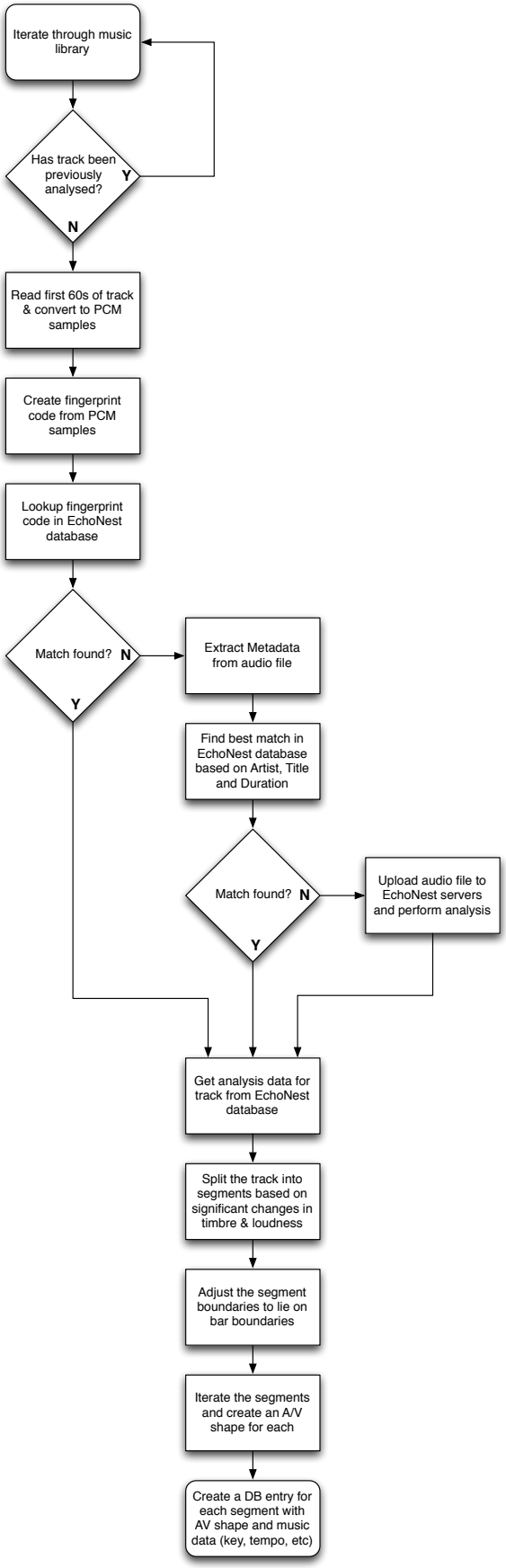
	7	6	1	2	3 In which genres of games would you be more likely to turn off music or listen to your own music?
	4				5
ID	Are there any games in particular that you would always turn off the music for? (optional)				Are there any games in particular that you think have such great music you could never imaging anyone not wanting
fb4	crash bandicoots, farmville				
fb5	Angry Birds				
fb9					
fb10	repetitive non story driven games, strategy games etc				Metal Gear Solid, Final Fantasy, Fallout- more soundscapey than music.
fb11					
fb12	Farmville				Wii
fb14	Farmville, Tetris				Gran Turismo
fb15					
fb16					Halo, Mass Effect 1 + 2, Arkham Asylum - all atmospheric and needed to play properly
6663956					
6657510					
6654826					Street Fighter III: 3rd Strike, Super Mario Galaxy
6686062	Pokemon				
6657275					Mass Effect 2, Super Meat Boy
6658049	Not one that I can think of.				Starcraft 2, Torchlight
6685660					
fb1	Call of Duty: Zombie Maps				Shadow of the Colossus
fb2	The only one that i didnt tick is Prototype, just because the music is pretty rubbish/doesn't add to the gameplay really.				La.Noir, Call of duty (single player), F.E.A.R & FEAR2
fb3					
fb7	pc games				call of duty moder wafer
fb8					
fb13	FIFA (In multiplayer), Unreal Tournament, Burnout				God of War (entire series), Super Mario Galaxy, Heavy Rain, Grand Theft Auto (although I also enjoy the 'User Tracks' option)
fb17					
6658383	games where the music was clearly an afterthought, or music that doesn't support the mood of the game (bullshit cash-in soundtracks)				Shatter, Kings Bounty: Armored Princess
6656765	MMOs.				
6654967	Basically, any genre of games that exceed 50 hours of total play, (grind heavy, endurance races etc)				Demon's Souls, Mass Effect 1&2, Red Dead Redemption for it's dynamic implementation of sound
6657821	none				CHRONO TRIGGER
6685675					Halo series and Gears of War series
6655191					
6656830					
6655307	NFS				FF
6657202	puzzle games				
6667841	MMOs after few weeks				Trine, Puzzle Quest, Super Meat Boy, VVVVVV
6656809	Super Meat Boy. It has great music, but now that I've heard it all, my own music/podcast distracts me from the grind of constant death.				Any sort of interactive experience where you are inhabiting a world.
6663921	Mobile games mostly				Metal Gear series, Silent Hill series, God of War series, Final Fantasy series
6663931					
6657075					Guild Wars, The Elder Scrolls, Final Fantasy, Super Meat Boy
6654757	Diablo 2				Braid
6661363					
6684423	World of Warcraft				Final Fantasy series
6654685	World Of Warcraft				Zelda Franchise
6655490	MMOs				Adventure Games
6658446	World of Warcraft				Persona 3, Persona 4, L.A. Noire, Red Dead Redemption
6657690					
6686089					Chrono Cross, any Zelda game, VVVVVV,
6664107					
6684444					The Witcher, Chrono Trigger, Castlevania: Symphony of the Night.
6654969					
6664069	Sports				

	4	5
ID	Are there any games in particular that you would always turn off the music for? (optional)	Are there any games in particular that you think have such great music you could never imaging anyone not wanting
6654760	Mount and Blade: Warband	
6654635		All the Final Fantasy and Metal Gear Solid games.
6664374	games with bad music	no, those people are stupid
6654301		The Final Fantasy series. And Mass Effect.
6684158		
6663858	Forza	Nope
6686692		
6684403	MMORPGs	Mass Effect 1 and 2, Metal Gear Solid 1, 2, 3, 4, Peace Walker
6658385	Oblivion	S.T.A.L.K.E.R.
6655160		
6654396	Street Fighter, MvC, Starcraft 2 (keep on FX though for warnings)	most RPGs, adventure games, and platformers (read: Final Fantasy, Mario, Zelda, etc.)
6668530		
6656354	Civilizaion because it has such long playsessions	Games where emotional connection is important or setpieces are integral to the design, I find is best experience with the original music on
6664194	I almost always prefer my own music for multiplayer games, games that I've already completed once, or grinding in RPGs.	
6684234		
6663990	Disgaea.	Rez, Fallout series.
6663922	Burnout	Metal Gear Solid
6657938	Starcraft 2 - multiplayer only, Call of Duty franchise - multiplayer only	Morrowind, despite the size and length of the game and the potential for the music to become tedious, I never got tired of listening to it.
6661409	Most MMOs (I listen to podcasts as I play)	Elder Scrolls IV: Oblivion, Fallout 3, Portal 2, Any Mario Game
6686584		
6664004		Super Meat Boy
6664041	If the soundtrack is predominantly death metal.	Anything in the Zelda series or Mario series.
6686652	All sports games after playing for about 20 hours	Final Fantasy games
6685727	FIFA	
6659813	Minecraft, most iOS games, Civilization games	
6655010	Games with bad music	Rhythm/Music games
6655559	World of Warcraft, Spiral Knights, Team Fortress 2 sometimes, etc. Multiplayer games where the focus is not on narrative.	
6656292	Ones with bad music. I rarely turn music off unless its annoying or just plain bad.	
6667041		
6663853		
6663812		
6654494		Rock Band
6686600	League of Legends, online FPS games...	Mass Effect 1 & 2, The Elder Scrolls series, Katamari Damacy, Shadow of the Colossus, Ocarina of Time, Deus Ex (if only for the title theme), Rez, Castlevania: Symphony of the Night
6684274	Halo, Any CoD game.	
6656226	Most PSN games come to mind since they are mostly arcade type games	RPG games, breath of fighter 4 has brilliant music.
6655597		
6685781	Call of Duty Black Ops Multiplayer	Metal gear Solid (1-4)
6657389	burnout paradise	
6655031		
6658500		
6657933		
6667306	Plants vs. Zombies, Peggle, Space Giraffe, Gridrunner Revolution	Bionic Commando Rearmed, Command and Conquer, Red Alert
6661459		
6657776	Tiny Tower	BlazBlue: Continuum Shift
6686562	Impossible Creatures	
6655017		
6656763		
6663974		
6684037		

	4	5
ID	Are there any games in particular that you would always turn off the music for? (optional)	Are there any games in particular that you think have such great music you could never imaging anyone not wanting
6685630		
6657349	World of Warcraft	
6656815		
6663989		
6684192		Anno 1404: Dawn Of Discovery
6660506		Katamari series
6663839		
6654418		
6655310		Child of Eden/Rez, Red Dead Redemption, Mass Effect 2, Assassin's Creed, VVVVVV
6686596	Less than average shooters	Super Meat Boy
6663953		
6656679		
6658315		
6658120	It's not so much as me caring for the music or not, but the storyline instead. If I don't care about the story line (ex. Vanquish), my music, or podcast, goes on.	Jet Set Radio Future, Chime, Elder Scrolls, Final Fantasy, Halo, Half-Life 2, GTA IV's radio stations
6654409	StarCraft II. I always have my own music or podcasts playing instead.	Burnout 3 has a great soundtrack.
6656421		
6684100	TrackMania Nations	Anything with music composed by Shoji Meguro, Koji Kondo, or Nobuo Uematsu
6654954		
6655041		
6657899		
6686056	Wipeout. But that's because you can make your own playlists for that game.	Persona 3&4
6657546	Black Ops multiplayer	Portal 2
6654394		
6654935		
6663886	Multiplayer PC games.	Shadow Of The Colossus
6658450		
6663875		
6656798	Depends on the soundtrack. If it's really generic, repetitive music, yes.	RPG soundtracks, usually.
6663978		
6686019		
6685344	League of Legends, RIFT, WoW	Mass Effect 2, Super Mario Galaxy 1+2, all of the Legend of Zelda games, Pokemon, Ace Attorney series
6684691		Bioshock, Dead Space
6657249	MMO's	
6657607	World of Warcraft	
6684333	Counter-Strike: Source,Garry's Mod,Trackmania Nations Forever	The Elder Scrolls: Morrowind,Batman: Arkham Asylum,Gemini Rue
6685609	Definitely racing games and multiplayer FPSs. Sometimes in long games like the Elder Scrolls, the music (though good) gets tired after a while so I'll put on the LOTR soundtrack.	Elder Scrolls has really appropriate music
6656529	Starcraft 2, trackmania, COD multiplayer.	The Witcher 2, Super Meat Boy, L.A. Noire, Red Dead Redemption.
6686090		Halo, Shadow of the Colossus, Zelda, Mario
6661327	Minecraft, Tetris	Most games
6684284	Street Fighter, Any Multiplayer Shooter. Games where atmosphere isn't a huge part or there is little dialogue.	Persona, Portal, Splinter Cell, Uncharted
6654744		
6684056		Super Meat Boy
6654738		Bioshock
6669177		Super Mario Bros., Scott Pilgrim, Super Meat Boy, Rhythm games of course.
6684286		Uncharted Series, Metal Gear
6654389		Zelda series, Metroid Prime series
6658453	Games that I play a whole lot of, since the music gets boring after a few hundred hours.	World of Warcraft, until you play it too much.
6654168		
6657773	Any type of MMO	
6667650	Only SC2 multiplayer.	The Persona series.
6657404		

	4	5
ID	Are there any games in particular that you would always turn off the music for? (optional)	Are there any games in particular that you think have such great music you could never imaging anyone not wanting
6654709		
6663859		
6657736		
6684462		
6655248		
6654222		
6655406	Gran Turismo 5	The Final Fantasy games.
6661457		
6661469		
6684236		
6658198	Borderlands	Mass Effect, Mass Effect 2, Super Mario Galaxy, Lost Odyssey, etc.
6663920	Dead or Alive 4	Shatter, Metal Gear Solid 3, Midnight Club: Los Angeles
6661435		Deus Ex
6658232		
6686916		
6657458		Motorstorm, Persona 4, Professor Layton
6663977	Team Fortress 2, Starcraft 2	Audiosurf :P
6661793	If I am playing a third person or first person shooter multiplayer, I will almost always turn the music off.	Bioshock has great atmospheric music that really helps set the game world up. Other games like Super Meat Boy just have cool music.
6656960		Super Smash Brothers Brawl, Super Mario Galaxy, Halo 3 ODST
6657229	Elder Scrolls Fallout	Halo 3: ODST
6658527	No, but I only ever turn music off while replaying a game for achievements/trophies so I can listen to my own music or podcasts	Flower, Pixeljunk Eden, Mirror's Edge, Silent Hill
6684399	Whatever I've already played through or where sound isn't integral to the experience (multiplayer for example)	Not unless the music is a focus of the game and plays a part in the mechanics
fb6	Turn off music for almost all games, cant stand the repetitive loop	Wip3out was the only one I can remember music being a critical part
6663971		

Appendix 2: Analysis Workflow



Appendix 3: Echo Nest/CAL500 Testing

3.1 Dictionary mapping CAL500 Emotion Tags to Echo Nest Moods

CAL500 Emotion Tags	Echo Nest Moods
Angry / Aggressive,	aggressive; angry; angst-ridden; harsh; industrial; rebellious;
Not Angry / Aggressive,	calming; fun; gentle; quiet; spiritual; warm;
Arousing / Awakening,	bouncy; dramatic; energetic; enthusiastic; epic; haunting; hypnotic; intense; lively; ominous; rebellious; rowdy; sexy;
Not Arousing / Awakening,	calming; gentle; mellow; quiet;
Bizarre / Weird,	complex; dark; disturbing; dreamy; eerie; harsh; haunting; manic; mystical; spacey; strange; trippy;
Not Bizarre / Weird,	carefree; cool; gentle;
Calming / Soothing,	ambient; calming; dreamy; gentle; cool; hypnotic; meditation; mellow; peaceful; relax; soothing; spiritual;
Not Calming / Soothing,	aggressive; angry; angst-ridden; cold; disturbing; dramatic; eerie; energetic; harsh; haunting; manic; ominous; rowdy;
Carefree / Lighthearted,	bouncy; carefree; dreamy; fun; funky; cool; humorous; light; playful; sweet; whimsical;
Not Carefree / Lighthearted,	aggressive; angst-ridden; complex; dark; eerie; industrial; intense; ominous; rebellious;
Cheerful / Festive,	cheerful; cool; fun; gleeful; groovy; humorous; joyous; lively; spiritual; sweet;
Not Cheerful / Festive,	cold; dark; gloomy; melancholia;
Emotional / Passionate,	dark; dramatic; energetic; enthusiastic; intense; lively; manic; passionate; poignant; rebellious; romantic; sexy; spiritual;
Not Emotional / Passionate,	cold; harsh; laid-back; mellow; peaceful;
Exciting / Thrilling,	complex; energetic; epic; dramatic; haunting; intense; lively; manic; sexy;
Not Exciting / Thrilling,	ambient; dreamy; gentle; laid-back; meditation; mellow; peaceful; quiet; relax;
Happy,	fun; gleeful; happy; joyous; warm;
Not Happy,	cold; cool; dark; disturbing; gloomy; harsh; dark; gloomy; melancholia; poignant; sad;
Laid-back / Mellow,	ambient; calming; cool; calming; laid-back; meditation; mellow; peaceful; reflective; relax; soothing; spacey; trippy;
Not Laid-back / Mellow,	aggressive; bouncy; complex; disturbing; dramatic; energetic; enthusiastic; harsh; intense; manic;
Light / Playful,	bouncy; fun; funky; groovy; carefree; light; playful; sweet; whimsical;
Not Light / Playful,	complex; dark; eerie; epic; industrial; intense; strange;
Loving / Romantic,	dramatic; elegant; intimate; mystical; passionate; poignant; romantic; sentimental; sexy; sweet; warm;
Not Loving / Romantic,	aggressive; angry; harsh; industrial;
Pleasant / Comfortable,	elegant; gleeful; happy; mellow; spacey; warm;
Not Pleasant / Comfortable,	cold; dark; disturbing; eerie; haunting; ominous;
Positive / Optimistic,	elegant; enthusiastic; funky; happy; warm;
Not Positive / Optimistic,	angst-ridden; gloomy; melancholia; strange;

```
Powerful / Strong,            complex; dramatic; energetic; epic; haunting; hypnotic; industrial;
                              intense; mystical; poignant; rebellious; rowdy; spiritual;

Not Powerful / Strong,        ambient; calming; gentle; laid-back; light; mellow; peaceful; quiet;

Sad,                          cold; cool; dark; disturbing; gloomy; harsh; dark; melancholia; sad;

Not Sad,                      fun; gleeful; happy; carefree; cheerful; joyous; warm;

Tender / Soft,                ambient; calming; gentle; dreamy; intimate; meditation; mellow; peaceful;
                              quiet; romantic; sentimental; soothing; sweet; warm;

Not Tender / Soft,            aggressive; angry; angst-ridden; complex; harsh; industrial; manic;

Touching / Loving,            dramatic; gentle; dreamy; intimate; passionate; poignant; reflective;
                              romantic; sentimental; sexy; spiritual; sweet; warm;

Not Touching / Loving,        aggressive; cold; dark; harsh;
```

3.2 CAL500 to Echo Nest Emotion Tag Comparison Code

```
int main (int argc, const char * argv[])
{
    NSAutoreleasePool *pool = [[NSAutoreleasePool alloc] init];
    NSTimeInterval startTime = [[NSDate date] timeIntervalSinceReferenceDate];
    NSMutableDictionary *combinedSongInformationByID;

    // arg 1 is the csv file with the artist, title and echo nest IDs for each CAL500 song
    NSString *songsFilePath = [NSString stringWithUTF8String:argv[1]];
    NSString *songsList = [NSString stringWithContentsOfFile:songsFilePath
                                                    encoding:NSUTF8StringEncoding
                                                       error:nil];

    NSArray *songs = [songsList componentsSeparatedByCharactersInSet:
                                                        [NSCharacterSet newlineCharacterSet]];

    if ([(NSString *)[songs lastObject] length] == 0)
    {
        songs = [songs subarrayWithRange:NSMakeRange(0, [songs count] -1)];
    }

    combinedSongInformationByID = [NSMutableDictionary dictionaryWithCapacity:[songs count]];


    // arg 2 is the csv file with table of vocab annotations for the CAL500 set
    NSString *annotationsTablePath = [NSString stringWithUTF8String:argv[2]];
    NSString *annotationsTable = [NSString stringWithContentsOfFile:annotationsTablePath
                                                           encoding:NSUTF8StringEncoding
                                                              error:nil];

    NSArray *annotationRows = [annotationsTable componentsSeparatedByCharactersInSet:
                                                                [NSCharacterSet newlineCharacterSet]];
    if ([(NSString *)[annotationRows lastObject] length] == 0)
    {
        annotationRows = [annotationRows subarrayWithRange:NSMakeRange(0, [annotationRows count] -1)];
    }


    // arg 3 is the file with the list of emotion vocab terms
    NSString *calEmotionsTagsPath = [NSString stringWithUTF8String:argv[3]];
    NSString *calEmotionsTagsList = [NSString stringWithContentsOfFile:calEmotionsTagsPath
                                                              encoding:NSUTF8StringEncoding
                                                                 error:nil];

    NSArray *calEmotionTags = [calEmotionsTagsList componentsSeparatedByCharactersInSet:
                                                                [NSCharacterSet newlineCharacterSet]];
    if ([(NSString *)[calEmotionTags lastObject] length] == 0)
    {
        calEmotionTags = [calEmotionTags subarrayWithRange:NSMakeRange(0, [songs count] -1)];
    }
```

```
// iterate through the CAL500 annotations and extract emotion tags per song
NSUInteger rowIndex;
for(rowIndex = 0; rowIndex < [songs count]; rowIndex++)
{
    NSUInteger columnIndex;
    NSMutableSet *cal500tags = [NSMutableSet set];
    NSArray *columnValues = [(NSString *)[annotationRows objectAtIndex:rowIndex]
                                                componentsSeparatedByString:@","];

    for (columnIndex = 0; columnIndex < 36; columnIndex++)
    {
        if([[columnValues objectAtIndex:columnIndex] isEqualToString:@"1"])
        {
            [cal500tags addObject:[calEmotionTags objectAtIndex:columnIndex]];
        }
    }

    NSMutableDictionary *songInformationDictionary = [NSMutableDictionary dictionary];
    [songInformationDictionary setObject:cal500tags forKey:@"cal500tags"];

    [combinedSongInformationByID setObject:songInformationDictionary
                                    forKey:[[[songs objectAtIndex:rowIndex]
                                                componentsSeparatedByString:@","] lastObject]];
}



// arg 4 is the file mapping CAL500 mood tags to echonest mood tags
NSString *moodTagMatchesFilePath = [NSString stringWithUTF8String:argv[4]];
NSString *moodTagMatchesFileContents = [NSString stringWithContentsOfFile:moodTagMatchesFilePath
                                                                  encoding:NSUTF8StringEncoding
                                                                     error:nil];

NSMutableDictionary *enMoodToCAL500MoodTranslations = [NSMutableDictionary dictionary];

for (NSString *line in [moodTagMatchesFileContents componentsSeparatedByCharactersInSet:
                                                        [NSCharacterSet newlineCharacterSet]])
{
    if([line length] > 0)
    {
        NSString *cal500MoodTag = [[line componentsSeparatedByString:@", "] objectAtIndex:0];
        NSArray *echoNestTags = [[[line componentsSeparatedByString:@", "] objectAtIndex:1]
                                                componentsSeparatedByString:@";"];

        for (NSString *echoNestTag in echoNestTags)
        {
            if ([echoNestTag length] > 0)
            {

                if ([enMoodToCAL500MoodTranslations objectForKey:echoNestTag] == nil)
                {
                    [enMoodToCAL500MoodTranslations setObject:[NSMutableSet set]
                                                       forKey:echoNestTag];
                }
                NSMutableSet *matchingCAL500Tags = [enMoodToCAL500MoodTranslations
                                                                    objectForKey:echoNestTag];
                [matchingCAL500Tags addObject:cal500MoodTag];
            }
        }
    }
}


// iterate through the list of echonest moods and see which matches in the
// CAL500 songs set echonest finds
for(NSString *mood in [enMoodToCAL500MoodTranslations allKeys])
{
    NSUInteger serverResultsStartIndex = 0;
    NSUInteger resultsPerQuery = 15;
    BOOL moreResultsAvailable = YES;
```

```
        while (moreResultsAvailable)
        {
            NSString *urlString = [NSString stringWithFormat:@"http://developer.echonest.com/api/v4/
song/search?api_key=D3MKHMOAM5QLRCAT6&mood=%@&bucket=id:CADWAVJ130D48CB527&limit=true&results=%d&start=
%d", mood, resultsPerQuery, serverResultsStartIndex];
            NSData *serverResponse = [NSData dataWithContentsOfURL:[NSURL URLWithString:urlString]];

            NSArray *matchingSongDicts = [[[serverResponse yajl_JSON] valueForKey:@"response"]
                                                                      valueForKey:@"songs"];

            for(NSDictionary *matchingSongDict in matchingSongDicts)
            {
                NSString *songID = [matchingSongDict objectForKey:@"id"];
                NSMutableDictionary *songInfo = [combinedSongInformationByID objectForKey:songID];
                [songInfo setObject:[matchingSongDict objectForKey:@"title"] forKey:@"title"];
                [songInfo setObject:[matchingSongDict objectForKey:@"artist_name"] forKey:@"artist"];

                if ([songInfo objectForKey:@"echoNestTags"] == nil)
                {
                    [songInfo setObject:[NSMutableSet set] forKey:@"echoNestTags"];
                }

                NSMutableSet *echoNestTags = [songInfo objectForKey:@"echoNestTags"];
                [echoNestTags unionSet:[enMoodToCAL500MoodTranslations valueForKey:mood]];
            }

            if([matchingSongDicts count] == resultsPerQuery)
            {
                serverResultsStartIndex += resultsPerQuery;
                NSLog(@"More results available for %@", mood);
            }
            else
            {
                moreResultsAvailable = NO;
            }
        }
    }



    // iterate through the combined data and compare the CAL500 and Echonest tags,
    // prepare the data for output

    NSMutableString *csv = [NSMutableString string];
    [csv appendString:@"Song ID,Artist,Title,CAL500 Tags,Echonest Tags,Match\n"];

    for(NSString *songID in combinedSongInformationByID)
    {
        NSMutableDictionary *songInfo = [combinedSongInformationByID objectForKey:songID];

        [csv appendFormat:@"%@,\"%@\",\"%@\",", songID,
                                                [songInfo objectForKey:@"artist"],
                                                [songInfo objectForKey:@"title"]];

        [csv appendString:@"\""];
        for(NSString *tag in [songInfo objectForKey:@"cal500tags"])
        {
            [csv appendFormat:@"%@, ", tag];
        }
        [csv appendString:@"\","];

        [csv appendString:@"\""];
        for(NSString *tag in [songInfo objectForKey:@"echoNestTags"])
        {
            [csv appendFormat:@"%@, ", tag];
        }
        [csv appendString:@"\","];

        NSMutableSet *commonTags = [NSMutableSet setWithSet:[songInfo objectForKey:@"cal500tags"]];
        [commonTags intersectSet:[songInfo objectForKey:@"echoNestTags"]];
```

```
        double matchScore = (double)([commonTags count]/[[songInfo objectForKey:@"cal500tags"] count]);
        [csv appendFormat:@"%f", matchScore];

        [csv appendString:@"\n"];
    }


    [csv writeToFile:[@"~/Desktop/ComparisonResults.csv" stringByStandardizingPath]
          atomically:YES
            encoding:NSUTF8StringEncoding
               error:nil];


    NSLog(@"Completed in %3f seconds", [[NSDate date] timeIntervalSinceReferenceDate] - startTime);

    [pool drain];
    return 0;
}
```

3.3 CAL500 Emotion Tag Vector Mapping

CAL500 Emotion Tag	Vector Angle, Magnitude
Emotion-Angry_/_Agressive	: 315.0, 0.75
NOT-Emotion-Angry_/_Agressive	: 135.0, 0.5
Emotion-Arousing_/_Awakening	: 10.0, 0.75
NOT-Emotion-Arousing_/_Awakening	: 190.0, 0.5
Emotion-Bizarre_/_Weird	: 280.0, 0.3
NOT-Emotion-Bizarre_/_Weird	: 150.0, 0.3
Emotion-Calming_/_Soothing	: 155.0, 0.75
NOT-Emotion-Calming_/_Soothing	: 335.0, 0.5
Emotion-Carefree_/_Lighthearted	: 100.0, 0.5
NOT-Emotion-Carefree_/_Lighthearted	: 280.0, 0.5
Emotion-Cheerful_/_Festive	: 80.0, 0.5
NOT-Emotion-Cheerful_/_Festive	: 260.0, 0.5
Emotion-Emotional_/_Passionate	: 30.0, 0.75
NOT-Emotion-Emotional_/_Passionate	: 150.0, 0.5
Emotion-Exciting_/_Thrilling	: 0.0, 0.8
NOT-Emotion-Exciting_/_Thrilling	: 180.0, 0.5
Emotion-Happy	: 80.0, 0.9
NOT-Emotion-Happy	: 260.0, 0.5
Emotion-Laid-back_/_Mellow	: 135.0, 0.75
NOT-Emotion-Laid-back_/_Mellow	: 315.0, 0.5
Emotion-Light_/_Playful	: 80.0, 0.3,
NOT-Emotion-Light_/_Playful	: 260.0, 0.3
Emotion-Loving_/_Romantic	: 110.0, 0.5
NOT-Emotion-Loving_/_Romantic	: 290.0, 0.3
Emotion-Pleasant_/_Comfortable	: 130.0, 0.5

```
NOT-Emotion-Pleasant_/_Comfortable    : 310.0,  0.3
Emotion-Positive_/_Optimistic         : 90.0,   0.75
NOT-Emotion-Positive_/_Optimistic     : 270.0,  0.5
Emotion-Powerful_/_Strong             : 0.0     0.75
NOT-Emotion-Powerful_/_Strong         : 180.0,  0.5
Emotion-Sad                           : 270.0,  0.9
NOT-Emotion-Sad                       : 90.0,   0.5
Emotion-Tender_/_Soft                 : 130.0,  0.5
NOT-Emotion-Tender_/_Soft             : 320.0,  0.3
Emotion-Touching_/_Loving             : 120.0,  0.75
NOT-Emotion-Touching_/_Loving         : 330.0,  0.5
```

3.4 CAL500 to Echo Nest Arousal Valence Shape Comparison Code

```
typedef struct _MWVector {
    double angle;
    double magnitude;
} MWVector; // angle is in degrees

#define MWZeroVector MWMakeVector(0.0, 0.0)

MWVector MWMakeVector(double angle, double magnitude);
MWVector vectorForPoints(NSPoint startPoint, NSPoint endPoint);
NSPoint offsetForVector(MWVector vector);
MWVector averageVectors(MWVector *vectorsArray, NSUInteger arrayCount);

double degreesToRadians(double degreeValue);
double raidansToDegrees(double radianValue);


int main (int argc, const char * argv[])
{
    NSAutoreleasePool *pool = [[NSAutoreleasePool alloc] init];

    NSTimeInterval startTime = [[NSDate date] timeIntervalSinceReferenceDate];

    // arg 1 is file with vectors for each CAL500 Emotion Tag
    NSString *cal_emotionVectorsFilePath = [NSString stringWithUTF8String:argv[1]];
    NSString *cal_emotionVectorFileContents = [NSString stringWithContentsOfFile:emotionVectorsFilePath
                                                                         encoding:NSUTF8StringEncoding
                                                                            error:nil];

    NSArray *cal_emotionVectorFileLines =
                            [cal_emotionVectorFileContents componentsSeparatedByCharactersInSet:
                             [NSCharacterSet newlineCharacterSet]];

    if ([(NSString *)[cal_emotionVectorFileLines lastObject] length] == 0)
    {
        cal_emotionVectorFileLines = [cal_emotionVectorFileLines subarrayWithRange:
                                                    NSMakeRange(0, [cal_emotionVectorFileLines count] -1)];
    }

    NSUInteger cal_totalEmotionsCount = [cal_emotionVectorFileLines count];


    // Create a vector for each emotion tag
    MWVector *cal_emotionVectors = calloc(cal_totalEmotionsCount, sizeof(MWVector));

    NSUInteger lineNum = 0;
    for (NSString *line in cal_emotionVectorFileLines)
    {
```

```
        double angle, magnitude;

        NSScanner *scanner = [NSScanner scannerWithString:line];
        [scanner scanUpToString:@":" intoString:NULL];
        [scanner scanString:@":" intoString:NULL];
        [scanner scanDouble:&angle];
        [scanner scanString:@"," intoString:NULL];
        [scanner scanDouble:&magnitude];

        MWVector emotionVector = MWMakeVector(angle, magnitude);
        cal_emotionVectors[lineNum] = emotionVector;
        lineNum++;
    }


    // arg 2 is the file with the song names and IDs
    NSString *songNamesFilePath = [NSString stringWithUTF8String:argv[2]];
    NSString *songNamesFileContent = [NSString stringWithContentsOfFile:songNamesFilePath
                                                                encoding:NSUTF8StringEncoding
                                                                   error:nil];

    NSArray *songNamesAndIDs = [songNamesFileContent componentsSeparatedByCharactersInSet:
                                                            [NSCharacterSet newlineCharacterSet]];
    if ([(NSString *)[songNamesAndIDs lastObject] length] == 0)
    {
        songNamesAndIDs = [songNamesAndIDs subarrayWithRange:NSMakeRange(0,[songNamesAndIDs count] -1)];
    }



    // arg 3 is the CAL500 dataset csv
    NSString *cal500FilePath = [NSString stringWithUTF8String:argv[3]];
    NSString *cal500FileContents = [NSString stringWithContentsOfFile:cal500FilePath
                                                              encoding:NSUTF8StringEncoding
                                                                 error:nil];

    NSArray *cal500Rows = [cal500FileContents componentsSeparatedByCharactersInSet:
                                                          [NSCharacterSet newlineCharacterSet]];
    if ([(NSString *)[cal500Rows lastObject] length] == 0)
    {
        cal500Rows = [cal500Rows subarrayWithRange:NSMakeRange(0, [cal500Rows count] -1)];
    }



    // Iterate through the CAL500 set and create and average emotion vector based on the emotion tags
    // for each song.  Use the average vector to calculate an AV point and compare with AV points
    // derived from echonest analyses.

    NSMutableString *outputCSV = [NSMutableString string];
    [outputCSV appendString:@"Song,CAL500 average vector angle,CAL500 average vector magnitude,CAL500
valence,CAL500 arousal, CAL500 confidence,EN Valence,EN arousal,EN confidence,Difference between
centres,Difference between edges,Intersects\n"];

    MWVector *cal_songEmotionVectors = calloc(cal_totalEmotionsCount, sizeof(MWVector));
    NSUInteger rowIndex = 0;
    for (NSString *row in cal500Rows)
    {
        NSLog(@"Song %lu of %lu", rowIndex +1, [cal500Rows count]);

        // for each song iterate the tags and gather all the applicable emotion vectors
        NSArray *columns = [row componentsSeparatedByString:@","];
        NSUInteger columnIndex, cal_songEmotionsCount = 0;
        for (columnIndex = 0; columnIndex < cal_totalEmotionsCount; columnIndex++)
        {
            if([[columns objectAtIndex:columnIndex] integerValue] == 1)
            {
                cal_songEmotionVectors[cal_songEmotionsCount] = cal_emotionVectors[columnIndex];
                cal_songEmotionsCount++;
            }
        }
```

```
        // calculate the average vector for the song and convert to a point in AV space
        MWVector cal_songAverageEmotionVector = averageVectors(cal_songEmotionVectors,
                                                               cal_songEmotionsCount);
        NSPoint cal500AVLocation = offsetForVector(cal_songAverageEmotionVector);
        double cal500Confidence = (double)cal_songEmotionsCount /((double)cal_totalEmotionsCount / 2.0);


        // get the echonest anlysis results for the song
        NSString *songID = [[[songNamesAndIDs objectAtIndex:rowIndex]
                                componentsSeparatedByString:@","] lastObject];

        NSURL *en_audioSummaryURL = [NSURL URLWithString:[NSString stringWithFormat:@"http://
developer.echonest.com/api/v4/song/profile?api_key=D3MKHMOAM5QLRCAT6&format=json&id=
%@&bucket=audio_summary", songID]];

        NSDictionary *en_audioSummary = [[[[[[NSData dataWithContentsOfURL:en_audioSummaryURL]yajl_JSON]
                                          valueForKey:@"response"] valueForKey:@"songs"]
                                              objectAtIndex:0] valueForKey:@"audio_summary"];

        NSURL *en_fullAnalysisURL = [NSURL URLWithString:[en_audioSummary valueForKey:@"analysis_url"]];
        NSDictionary *en_fullAnalysis = [[NSData dataWithContentsOfURL:en_fullAnalysisURL] yajl_JSON];

        double enValenceValue;
        double enConfidence = [[[en_fullAnalysis valueForKey:@"track"] valueForKey:@"mode_confidence"]
                                doubleValue];
        if ([[en_audioSummary valueForKey:@"mode"] integerValue])
        {
            enValenceValue = enConfidence;
        }
        else
        {
            enValenceValue = 0.0 - enConfidence;
        }

        double enEnergyValue = ([[en_audioSummary valueForKey:@"energy"] doubleValue] * 2.0) - 1.0;

        NSPoint enAVLocation = NSMakePoint(enValenceValue, enEnergyValue);


        // compare the 2 AV locations
        // measure the distance between the 2 centres, between the 2 edges, and note overlaps

        double differenceBetweenCentres = vectorForPoints(cal500AVLocation, enAVLocation).magnitude;

        double calRadius = 1.0 - cal500Confidence, enRadius = 1.0 - enConfidence;
        double differenceBetweenEdges = differenceBetweenCentres - (calRadius + enRadius);

        NSInteger intersects = (differenceBetweenEdges <= 0.0) ? 1 : 0;


        // add the data to the output file
        [outputCSV appendFormat:@"%@,%f,%f,%f,%f,%f,%f,%f,%f,%f,%f,%d\n", songID,
cal_songAverageEmotionVector.angle, cal_songAverageEmotionVector.magnitude, cal500AVLocation.x,
cal500AVLocation.y, cal500Confidence, enAVLocation.x, enAVLocation.y, enConfidence,
differenceBetweenCentres,differenceBetweenEdges,intersects];

        rowIndex++;
    }

    NSLog(@"Finished in %2f seconds", [[NSDate date] timeIntervalSinceReferenceDate] - startTime);

    [outputCSV writeToFile:[@"~/Desktop/CAL500-EN AV Comparison.csv" stringByStandardizingPath]
                atomically:YES
                  encoding:NSUTF8StringEncoding
                     error:nil];

    free(cal_songEmotionVectors);
    free(cal_emotionVectors);

    [pool drain];
    return 0;
}
```

```
MWVector MWMakeVector(double angle, double magnitude)
{
    MWVector vector;
    vector.angle = angle;
    vector.magnitude = magnitude;
    return vector;
}


MWVector vectorForPoints(NSPoint startPoint, NSPoint endPoint)
{
    double xOffset = endPoint.x - startPoint.x;
    double yOffset = endPoint.y - startPoint.y;

    if( (xOffset == 0.0) && (yOffset == 0.0) )
    {
        return MWZeroVector;
    }

    if(xOffset == 0.0)
    {
        if (yOffset > 0.0)
        {
            return MWMakeVector(0.0, yOffset);
        }
        else
        {
            return MWMakeVector(180.0, yOffset);
        }
    }

    if(yOffset == 0.0)
    {
        if (xOffset > 0.0)
        {
            return MWMakeVector(90.0, xOffset);
        }
        else
        {
            return MWMakeVector(270, xOffset);
        }
    }


    NSInteger quadrant = 0;

    if( (xOffset > 0.0) && (yOffset < 0.0) )
    {
        quadrant = 1;
    }
    else if( (xOffset < 0.0) && (yOffset < 0.0) )
    {
        quadrant = 2;
    }
    else if( (xOffset < 0.0) && (yOffset > 0.0) )
    {
        quadrant = 3;
    }

    double hypotenuse, opposite, adjacent;
    switch (quadrant)
    {
        case 0:
        {
            adjacent = yOffset;
            opposite = xOffset;
            break;
        }
        case 1:
        {
```

```
            adjacent = xOffset;
            opposite = -yOffset;
            break;
        }
        case 2:
        {
            adjacent = -yOffset;
            opposite = -xOffset;
            break;
        }
        case 3:
        {
            adjacent = -xOffset;
            opposite = yOffset;
            break;
        }
        default:
            break;
    }

    hypotenuse = hypot(adjacent, opposite);

    double angleInRadians = asin(opposite / hypotenuse);
    double angleInDegrees = raidansToDegrees(angleInRadians);

    switch (quadrant)
    {
        case 1:
            angleInDegrees += 90.0;
            break;
        case 2:
            angleInDegrees += 180.0;
            break;
        case 3:
            angleInDegrees += 270.0;
            break;
        default:
            break;
    }

    return MWMakeVector(angleInDegrees, hypotenuse);
}


NSPoint offsetForVector(MWVector vector)
{
    double vAngle = vector.angle, vMagnitude = vector.magnitude;

    if( (vAngle < 0.0) || (vAngle > 360.0) )
    {
        NSLog(@"Invalid vector angle: %f", vAngle);
        return NSZeroPoint;
    }

    if(vAngle == 0.0)
    {
        return NSMakePoint(0.0, (CGFloat)vMagnitude);
    }

    if(vAngle == 90.0)
    {
        return NSMakePoint((CGFloat)vMagnitude, 0.0);
    }

    if(vAngle == 180.0)
    {
        return NSMakePoint(0.0, -(CGFloat)vMagnitude);
    }

    if(vAngle == 270.0)
    {
        return NSMakePoint(-(CGFloat)vMagnitude, 0.0);
```

```
    }

    double workingAngle = vAngle;
    NSInteger quadrant = 0;

    if( (vAngle > 90.0) && (vAngle < 180.0) )
    {
        workingAngle -= 90.0;
        quadrant = 1;
    }
    else if( (vAngle > 180.0) && (vAngle < 270.0) )
    {
        workingAngle -= 180.0;
        quadrant = 2;
    }
    else if( (vAngle > 270.0) && (vAngle < 360.0) )
    {
        workingAngle -= 270.0;
        quadrant = 3;
    }


    double adjacentHypotenuseRatio = cos(degreesToRadians(workingAngle));
    double oppositeHypotenuseRatio = sin(degreesToRadians(workingAngle));
    double hypotenuse = vMagnitude;
    double adjacent = hypotenuse * adjacentHypotenuseRatio;
    double opposite = hypotenuse * oppositeHypotenuseRatio;


    switch (quadrant)
    {
        case 0:
            return NSMakePoint((CGFloat)opposite, (CGFloat)adjacent);
            break;
        case 1:
            return NSMakePoint((CGFloat)adjacent, (CGFloat)-opposite);
            break;
        case 2:
            return NSMakePoint((CGFloat)-opposite, (CGFloat)-adjacent);
            break;
        case 3:
            return NSMakePoint((CGFloat)-adjacent, (CGFloat)opposite);
            break;
        default:
            return NSZeroPoint;
            break;
    }
}


MWVector averageVectors(MWVector *vectorsArray, NSUInteger arrayCount)
{
    if (arrayCount == 0)
    {
        return MWZeroVector;
    }

    NSPoint averageVectorTailPoint = NSZeroPoint;
    NSUInteger i;
    for (i = 0; i < arrayCount; i++)
    {
        averageVectorTailPoint.x += offsetForVector(vectorsArray[i]).x;
        averageVectorTailPoint.y += offsetForVector(vectorsArray[i]).y;
    }

    averageVectorTailPoint.x /= arrayCount;
    averageVectorTailPoint.y /= arrayCount;

    MWVector averageVector = vectorForPoints(NSZeroPoint, averageVectorTailPoint);

    return averageVector;
}
```

```
double degreesToRadians(double degreeValue)
{
    return degreeValue * (M_PI / 180.0);
}


double raidansToDegrees(double radianValue)
{
    return radianValue / (M_PI / 180.0);
}
```

Appendix 4: Harmonious API

4.1 System Controller Header

```
//
//  SystemController.h
//  Harmonious
//
//  Created by Jim McGowan on 16/07/2011.
//
//     This class is the main interface to the harmonious system.
//     It manages the Window with the system's UI and controls the music
//     database, analysis and playback systems.
//

@interface HarmoniousSystemController : NSWindowController <GameAnalyserDelegate>

// Initializing the system.  The system controller does not hold a reference to the game controller,
// it is just passed on to the game analyser
- (id)initWithGameController:(id)gameController;


// Showing the UI
- (void)showHarmoniousUIWindow;
- (IBAction)toggleFineTuneView:(id)sender;
@property (readonly) BOOL activateUIControls;


// starting and stopping music playback
- (void)startMusicPlayback;
- (void)stopMusicPlaybackWithFade:(BOOL)fadeOut;     // if fadeOut is NO, music stops immediately
- (IBAction)pauseMusic:(id)sender;
- (IBAction)skipTrack:(id)sender;


// triggering playback of a new music segment based on the game analyser's analysis
- (void)playNewTrackForArousalValencePoint:(NSPoint)avPoint;


// updating the arousal valence representation for a music segment
- (IBAction)likeMusic:(id)sender;
- (IBAction)dislikeMusic:(id)sender;
- (IBAction)banMusic:(id)sender;
- (IBAction)adjustHappySadSlider:(id)sender;
- (IBAction)adjustEnergeticLaidBackSlider:(id)sender;


@end
```

4.2 Game Analyser Header

```
//
//  GameAnalyser.h
//  Space Defender + Harmonious
//
//  Created by Jim McGowan on 12/8/11.
//
//     While the rest of the Harmonious system is generic and 'game-agnostic',
//     this game analyser class is written specifically to analyse the
//     host game.  The methods declared here are required by the system,
//     though the implementation details any other functionality are at the
//     programmer's discretion.
//


// These are the methods that the game analyser can call on its delegate (the system controller)
// to trigger cues
@protocol GameAnalyserDelegate <NSObject>
- (void)playNewTrackForArousalValencePoint:(NSPoint)avPoint;
- (void)fadeOutAndStopCurrentTrack;
@end



@interface GameAnalyser : NSObject

// Initializing the analyser and setting the controller & delegate
- (id)initWithGameController:(id)theGameController;
@property (assign) id <GameAnalyserDelegate> delegate;


// Activating the game analyser will cause it to start sending music trigger messages
// (-playNewTrackForArousalValencePoint: & -fadeOutAndStopCurrentTrack) to it's delegate
- (void)activate;
- (void)deactivate;
- (BOOL)isActive;


// Accessing the current gameplay mood as a point in Arousal/Valence space
// For Arousal/Valence locations represented as NSPoints, x = valence, y = arousal
- (NSPoint)currentGameplayMoodInArousalValenceCoordinates;

@end
```

Appendix 5: License Information for Third Party Software used by the Harmonious System

5.1 EchoPrint CodeGen

Whitening, SubbandAnalysis, Fingerprint
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libcodegen makes use of the following pieces of software:
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- Boost (Boost Software License)http://www.boost.org/users/license.html
- Base64.cpp and Base64.h, see source files for licenseCopyright (C) 2004-2008 Rene Nyffenegger

5.2 TagLib

Scott Wheeler <wheeler@kde.org>
Author, maintainer
Ismael Orenstein <orenstein@kde.org>
Xing header implementation
Allan Sandfeld Jensen <kde@carewolf.org>
FLAC metadata implementation
Teemu Tervo <teemu.tervo@gmx.net>
Numerous bug reports and fixes

Please send all patches and questions to taglib-devel@kde.org rather than toindividual developers!

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NSString-Levenshtein.h/m

Created by Rick Bourner on Sat Aug 09 2003.
rick@bourner.com
http://www.merriampark.com/ldobjc.htm

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