X-System and deep content-based music recommendation

Discussion paper

August 2014

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Introduction

This is a commentary on a paper by van den Ord, Dieleman and Schrauwen entitled Deep content-based music recommendation (NIPS 2013) and on a report from a Spotify internship published in August 2014 by Sander Dieleman Recommending music on Spotify with deep learning (2014): http://benanne.github.io/2014/08/05/spotify-cnns.html

My own expertise is in music analysis rather than neural networks, so I comment on the implementation of deep convolutional networks with due caution and modesty. I nevertheless congratulate the authors on the clarity of their arguments and on the elegance of their design.

The purpose of the discussion paper is to demonstrate how X-System may be of relevance to the authors and to premium music subscription services in the further implementation of these ideas.

Overview

Deep content-based music recommendation

The authors address some of the shortcomings in collaborative filtering, in particular the "cold start" problem where insufficient user data is available for new or less popular repertoire. They identify a "semantic gap" between the physical nature of the audio signal and the psychological process of listener preference, and strive to bridge the gap by training deep convolutional neural networks to predict latent factors (likely listener preferences) from music audio.

X-System

X-System is based on the premise that there are two general aspects of response to music in the human brain. There are areas, largely in the neo-cortex, which are formed by experience and culture, and often account for explicit "preference". But there are also areas of the middle and lower brain concerned with universal neurophysiological responses to music, common to all human beings, which frequently over-ride cultural and other preferences (see Appendix One for an X-System bibliography).

X-System does not employ conventional signal processing. Rather it uses computational models of lower and mid- brain organs and systems - such as the brainstem, periaqueductal gray (PAG), Heschl's gyrus, the pre-motor cortex, the amygdala – to predict universal emotional response, in itself an important foundation for preference. For X-System there is no semantic gap. There are two systems working synergistically in parallel: individual, personalised responses to music and more dominant, universal responses.

X-System has verified its predictions using both autonomic sensors and psychometrics, feeding results back into the system through linear regression. In tests, X-System has proved more accurate in predicting collective emotional responses – an important foundation for preference – than any individual respondent (see Appendix Two for information on X-System experiments).

X-System predictive algorithms may be used on a standalone basis in music recommendation engines or may, when combined with autonomic sensors, enable real-time calculation of playlists in response to individual biofeedback in order to entrain the listener towards a desired state.

Discussion

The authors set out to extract characteristics of audio signals that may affect user preference and to evaluate these predictions in a music recommendation setting.

For the procedures described in the 2013 paper, they make use of the Million Song Dataset (Bertin-Mahieux, Ellis, Whitman, Lamere 2011). The analysis algorithms of the Dataset are based on the Echo Nest Analyzer API. Acoustic features, principally pitch, time and loudness, are extracted using traditional signal processing methods. In his 2014 report, Dieleman appears to streamline the process, focussing in particular on mel-spectrograms.

The problem here is that most traditional signal processing algorithms were developed for the purposes of telecommunications and audio broadcasting, and are concerned with issues such as compression, transmission, noise cancelation or equalisation. These procedures may be an effective digital/acoustic shorthand or surface level description, but they bear little relation to how the brain processes music emotionally.

Even more "musically" related aspects of signal processing, such as mel spectrograms, may model pitch perception, but at the same time fail to capture the subtleties of spectral energy distribution and structures of harmonicity and non-harmonicity which are detected by Heschl's gyrus and have a profound effect on emotional responses to music. Simple tempo induction alone will not predict emotional and motor responses to music. Rhythmicity, or the interaction of turbulence, tempo, rhythmic pattern and power, offers a more effective predictive model of brainstem and motor cortex activity.

The emotional power of music often depends on how one timbral or harmonic moment moves on to the next, and how this activates the amygdala and other systems. X-System provides this kind of neurophysiological data in both fine grain and generalised terms.

The X-System team submit that their predictive algorithms can provide useful input data for neural network processing, offering the opportunity to train systems and predict preference from musical features associated directly with musical emotion (and therefore preference) rather than simple, surface level descriptions which often omit or generalise psycho-biologically active data.

The 2013 NIPS paper compares bag-of-words representation with deep convolutional neural networks. The bag-of-words model derives from language processing, where words in a text are grouped together in a multiset, irrespective of word order or grammar. Convolutional networks derive from Hubel and Wiesel's work on the visual cortex of the cat and involve neurons tiled in a way that they may respond to overlapping regions in the visual field.

In the 2013 paper the authors describe a training process involving short audio fragments, and the averaging of outputs across windows for longer segments. In the 2014 report, Dieleman proposes an additional convolutional, global temporal pooling layer, pooling across the whole time axis and computing statistics of learned features across time. It is important to note that X-System output data could easily be adapted to all of these systems and approaches.

Conclusions

1. X-System data input could improve the quality of prediction, through convolutional neural networks, of latent factors from audio. X-system is in the process of analysing a 35 million song/composition dynamic platform, which will provide ready-processed data for new songs and existing repertoire. The analysis could easily be implemented on other platforms.

2. X-System may be used to replace conventional, descriptive measures of audio features, bringing real bio-intelligence to music recommendation engines. The technology is capable of delivering "emotional" journeys in music, starting from a seed song and/or constrained by conventional metadata filters such as genre, selection of genres, artist, popularity etc. Playlists may thus be constructed in order to facilitate concentration, relaxation or motivation. The cohesion of these playlists lies in the integrity of the overall emotional experience, rather than individual song preference, and as such is a way to discover new repertoire and release the full power of music to global audiences. This represents a major breakthrough for music recommendation engines: collaborative filtering systems, as the authors point out, suffer from the cold-start problem, while in addition to the "semantic gap" identified by the authors, content-based filters that use conventional "soundalike" audio feature analysis tend to narrow the song recommendations, becoming repetitive. X-System, on the other hand, uses what may be described as "makes you feel alike" technology, which opens up the range of repertoire that may be recommended, producing a more varied set of song recommendations while ensuring their emotional consistency.

As an optional feature, X-System's design can incorporate wearable biofeedback sensors to monitor the emotional journey, correct if necessary and output data to advance and improve the system's performance. Thus a series of Apps may link next-generation wearable sensors to premium subscription services, enabling users to experience music that is always appropriate to their desired state of relaxation or activity.

X-System is also embarking on research in a number of areas of sports and medicine (e.g. potentiation and regulation of movement, stress management, Parkinsons, post traumatic stress disorder (PTSD), epilepsy etc.) where future outcomes will inevitably overlap with music for entertainment and leisure.

In other words, X-System promises an entirely new and consistent emotional experience in music search and discovery, as well as in practical consumer and healthcare applications.

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APPENDIX ONE: AN X-SYSTEM BIBLIOGRAPHY

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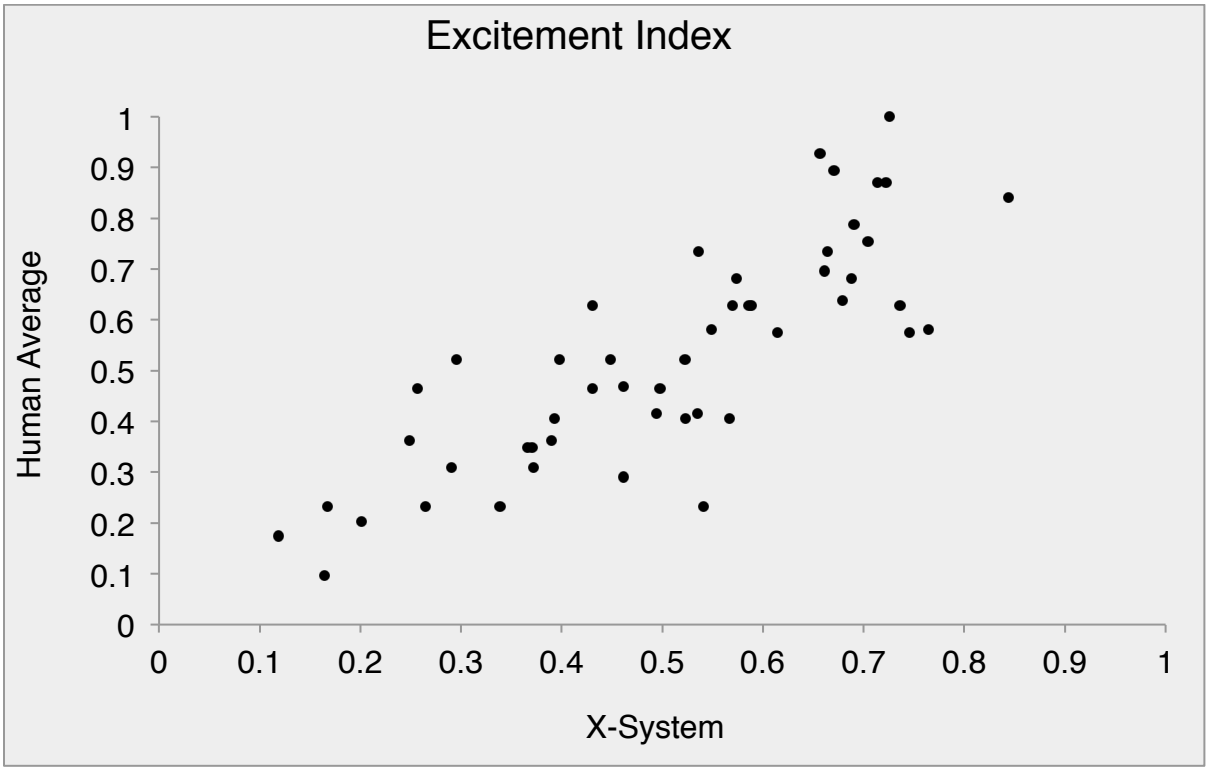
APPENDIX TWO: EVALUATION OF X-SYSTEM EXPERIMENTS

Three experiments are described below. The first sought to demonstrate that X-System predictions correspond closely to overall human appreciation of the arousal/counter arousal effect of music as measured by an "excitement index". The second sought to establish that music has a common, predictable, physical effect on people under controlled listening conditions and the third sought to demonstrate that calming music may facilitate relaxation.

Experiment 1:

The first experiment tests whether X-System predictions of the excitement effect of different pieces of music of a wide range of genres accord with human assessment. 15-second excerpts from 100 pieces of music were selected from 12 genres by music expert Nigel Osborne, aiming to cover the full range of the world's musical styles and emotions. A web-based comparison app was used to repeatedly ask users to compare pairs of excerpts to each other in terms of excitation. In the initial version of the experiment, five listeners performed about 100 comparisons each, and the results were used to produce an overall list of all 100 excerpts ordered from most relaxing to most exciting. 50 of the excerpts were then used to train the analyser, and the other 50 (shown in the graph) were used as independent test data.



X-System predicts only the human universal vector of excitement; in each case the listener will also respond individually to the music according to preference, association and other conscious factors. Despite any variability this may introduce, this experiment provides an early indication of the efficacy of X-System in predicting the subjective human assessment of the excitement index of pieces of music across a wide variety of genres. Confidence in this prediction will be enhanced by broadening the test to a greater number of participants.

Experiment 2:

While Experiment 1 was conducted to demonstrate how closely X-System predictions match human assessment of musical arousal, Experiment 2 aimed to establish the relationship between increased heart rates in people while they listened to arousing music.

It was hypothesised that the overall heart rate of participants would be higher while they were listening to high arousal music than when listening to low arousal music.

Experiment Design: 148 participants were played 40 minutes worth of both music, with 20 minutes of high arousal and 20 minutes of low arousal music. Each participant listened to the music while sitting down in a quiet room, while wearing headphones and with their eyes closed. They wore a wrist pulse oximeter to measure their heart rate. Whether the participant listened to the Low category or High category first was alternated to ensure a random distribution.

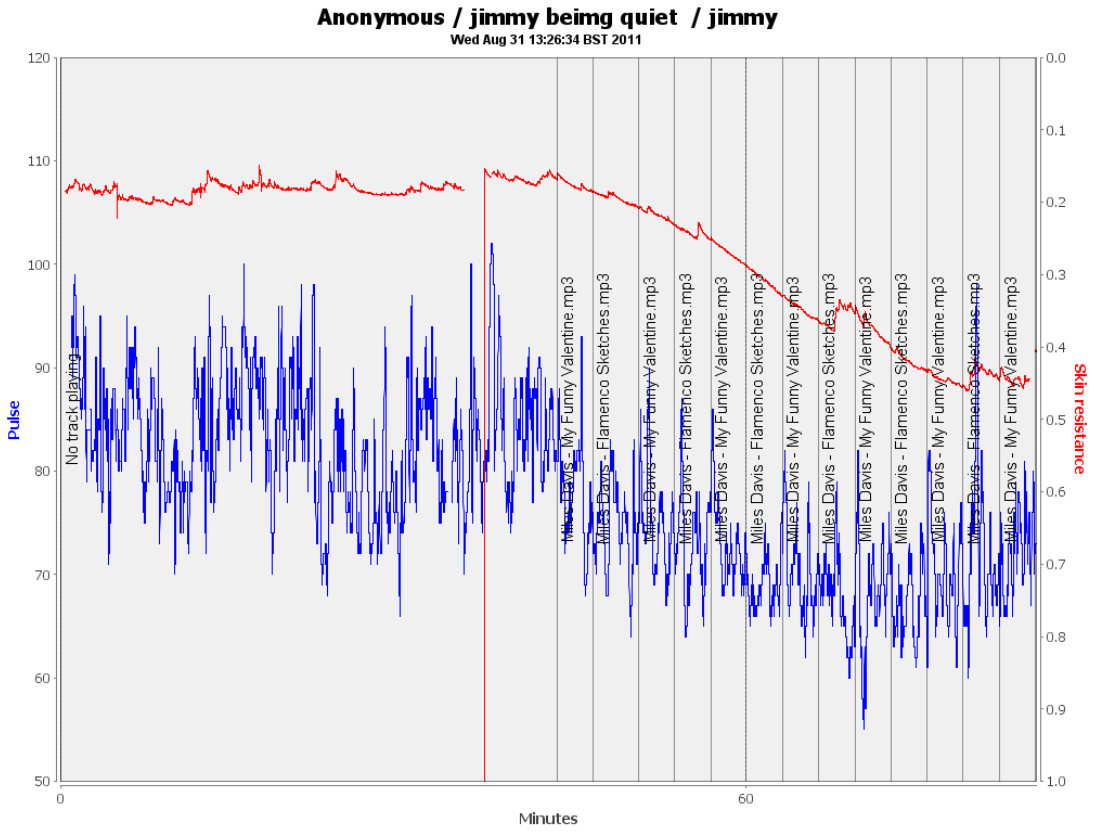
A selection of 47 songs was used, that had previously been ordered from "most calming" to "most arousing" by 5 people in January 2012. The means of these subjective orderings were then used to rank the songs and separate them into 3 categories: Low, Medium and High. Three genres were used: Bengali Folk, Western Classical and Pop.

A One-Factor Repeated Measures ANOVA test was carried out on the results, comparing heart rates of the 148 participants during high arousal music and low arousal music. The calculated F value was 10, which is higher than the table value of F (1,120), which is 3.92. Thus, the null hypothesis was rejected at a significance level of 0.05. This means that the probability that the difference between the two samples occurred due to random error is less than 5%. Even at a 0.01 level of significance, where the table value of F (1,120) is 6.85, the calculated value of F remains significant (arrows indicate sample size at each point)

Thus, the experiment results show that heart rate most likely increases when people listen to high arousal music, suggesting that listening to music can affect a person physically.

Experiment 3:

Experiment 2 demonstrates that the effect of music can be measured in average pulse rates across a population of individuals listening to the same pieces of music under controlled conditions. Can the relaxing effect of music on an individual be measured biometrically over time? In Experiment 3 the subject was asked to relax without the aid of music. Once a cycle of music, predicted by X-System to be relaxing, was played over an extended period of time, both pulse rate and galvanic skin conductance showed the predicted effect.



Of particular interest in this graph is the relatively elevated resting pulse rate of the subject, a healthy male in his mid twenties. As he relaxes pulse rate and skin resistance move together, but once heart rate has reached a more normal level, the absolute relationship between the two indicators is broken; clearly there is a base level of heart activity below which it will not fall and this may be expected to vary from subject to subject.

While these three experiments confirm that music has a measurable effect on the autonomic nervous system, until X-System there has been no reliable, algorithmic means of predicting this effect. There have been attempts to use tempo, and sometimes energy, to match music to activity, to motivate, or to control mood, but the entrainment effect on which this depends works only weakly and within a narrow range in the Huygens sense. Other initiatives have modulated beats per minute to extend the entrainment range, or composed "psycho-acoustically correct" music to elicit desired response, as well as attempts to measure the inherent mood of music analytically with reference to Robert Thayer's work: *The biopsychology of mood and arousal* (Oxford University Press, 1989) [1], but only X-System has modelled the brain's response to music to predict the effect of the repertoire at large.

X-System does not suffer from the limitations of other technologies because it models the way in which the primitive brain processes sounds; it is proven to predict reliably the effect of music from a wide variety of genres on the autonomic nervous system, opening the way for X-System to enable the systematic use of music in medical applications as either a low cost, practical alternative to, or complement to, professional music therapists.