Words as block of notes and Zipf law in music using visibility algorithm.

Miguel Sanchez Islas.

December 11, 2017

Abstract

In this work we were aimed to study music using visibility algorithms. This algorithms are used as a way to get a network, from a time series. However the main idea of this paper was not to study music from the perspective of complex networks, but to studying it as a language, basically the changes in what we call words, between different ages in music. The visibility algorithm provide us a way to cut time series and generate the words, of the composers we were studying. We study classical music composers from different ages, from Bach to Schostakovish. Time series in this work came from MIDI archives and the series were generated by, the absolute difference between two adjacent notes, in the first voice in the MIDI archive. Once we had our series we apply the algorithm to generate words. The visibility algorithm was used also, as a way to get Zipf law because at first what we found was that when we used visibility algorithm we create a free-scale network, so we decided to take subgroup of this network that is going to be also free of scale, and make the musical words.

Introduction

Music has been studied in several ways long ago. One of the first studies trying to see music behavior were made by, Voss and Clarke[10]. They observe a 1/f behavior in music pitch. Since then there exist a number of works trying to study music, some from time series measuring hurst exponent[9,7,8], treating music like a fractional Brownian motion (fBm), seeing and searching fractality and a lot of research related. Recently a new perspective has been used, transforming music into a complex networks in order to studying music, from the tools of complex networks[4,3]. In contrast, in this work we try to see music in a different way, we are interested in see if music can be treated as a language, from the point of view of a language we need to define what our words are going to be. In order to form what we are going to call a word, we used the so called visibility algorithm[2]. Next what we are concerned, is to seeing if this words follow the Zipf’s law, like the rest of languages.

Visibility Algorithm

One algorithm that transform a time series into a network, is the Visibility Algorithms [2,3,6]. The natural visibility algorithm is a really easy way to transform a time series into a network. The main idea of the algorithm, is comparing two different points (A,B) in the time series. In order to decide, if this two are going to be connected in the network, what visibility does is to compare the straight line that can be draw between this points and then check if all the points that lie between (A,B) are below the straight line, if does, then the algorithm says that the points A and B are connected in the network.

The Visibility Algorithm, is often written as the following inequality:

\[ y_c < y_b + \frac{(y_a - y_b)}{t_b - t_a} (t_b - t_c) \]  

(1)

As we can see in figure ??.

Recently it has been shown that the visibility algorithm is a way to find motifs in time series [1].
Zipff Law.

In 1932 George Kingsley Zipf discover a new law concerning, the statistics properties of languages[11]. From this point it has been seen that humans language follow the distribit

The zipff law was discover in ...

Method.

In order to analyze music from different composers, we use MIDI files. In this files, we have information about duration and the note. Instead of having this information pictorially, as is often seeing in music scores, in our case is displayed with numerical values. So its relatively easy to extract the information and generate time series. Also we have the information related to the voices, all the pieces analyzed correspondo to piano works, and are from different composers.

Is good to clarify that, we only use the first voice in this study. Some times a chord comes out in the voice we are analyzing, in which case we only used the highest note. Having extracted the information, its easy to made a time series from adjacent notes. In this work we were no worry about the duration of notes. We put every note the same duration in the time series.

![Figure 1](image1.png)

Figure 1: In this picture we can see the notes, as they are in the pentagram. In this work we aren’t worry in time series of notes, instead we introduce a new time series that is going to be formed by the difference in semitones between adjacent pair of notes.

What we see in the picture above, is the representation of notes as they are in a pentagram, normally one way of doing a time series of music notes, is to put the values of the notes according to their corresponding value of the midi coding. Nevertheless, in this study we were aimed to do the semitone difference between adjacent notes. We can think that we are studying the discrete derivate of the original time series, because the difference in time is always one. So what we have pictorically in figure 1, once the difference in semitones between adjacent notes is done, is the next time series:

![Figure 2](image2.png)

Figure 2: What we have in the pentagram is now reduced to a time series, in which the high is the differences in semitones between notes. For example if in figure 1 is used G clef, then the first note is a G and the second one is also a G but an octave higher. Which means that between the first and the second notes there are 12 semitones of difference. Between the second and the third there is no difference so it appears as a zero, and so on.
Once we have the rate of change series between adjacent semitones, then we apply the visibility algorithm. In spite of using the visibility rule we made some changes, instead of checking visibility between point A and the following points in the series, we stop once the visibility criteria isn’t satisfy between A and some other point C in the time series. In this point once we have stop the algorithm, a block is formed, this block contain information of the semintones in the interval [A,C), and the information is going to be codified using letters. For example in figure , is the time series we are studying under visibility. We start at event one in the series, we apply the algorithm rules. Then we find that under this rules we are unable to see event number five in the series, so we jump and restart the algorithm in event number 4, always one before the visibility being cutten. Once the the visibility criterion is not satisfy we do not check for other events, this mean that we do not check if the visibility criterion is true or false for event number six we simple move forward in the time series.

![Absolute changes between adjacent notes](image)

**Figure 3:** We analyze figure with visibility, we changed that once visibility is cutted we stop and re-start one event before. In this case we start in event number one and the visibility is lost when we analyzed the first event in the series with number 5 so we re-start in event number 4, and we start visibility algorithm again. Placing the algorithm one before the visibility is lost, is to being placed in an event with higer visibility.

We mencioned before that we are aimed to formed words, so when the visibility is lost we create a block wich is going, from the event in wich the algorithm has been started, to one before the visibility has ben cutted. Nevetereless in order to avoid confutions when reading the blocks, we put a labels to the diference in semitones, and obtaining a string of characters. Each caracter contain the information of the diference in semitones, acording to the following table.

| Number of semitones | Letter representation |
|---------------------|-----------------------|
| 0                   | A                     |
| 1                   | B                     |
| 2                   | C                     |
| 3                   | D                     |
| 4                   | E                     |

Table 1: Semitone Coding, using words instead of numbers in order to generate blocks

With this, the information in figure once is splitted is going to be coded as the next blocks: MAAL-LAAL. Also is worth it to mention, that if there is a difference above 25 semitones we put a d lowercase, re-starting the letters with the A. For example if there is a 26 diference in semitones then we put Ad. This
doesn’t occur to often however it can occur. Also an important thing is that we consider a block, the union of two consecutive blocks. So the final block above is going to be MAALAAL.

Results.

We analyzed pieces from different composers like Bach, Beethoven, Chopin, Scriabin, Satie among others. The majority of our files came from kunstderfuge web site, nearly 1300 pieces were analyzed. First we wanted to know if the difference series, transform as a scale free network. In order to know this we run the visibility algorithm with out any modification. What we saw was that the time series, was transformed into a scale free network. This can be seeing in the next graphs, we plot some of the results found. The degree distribution follow a power law on most cases and is approximated to this behavior.

Once we know that the networks are scale free. We take a subgroup of the network, using the modified algorithm. The blocks formed are contained in the network but possibly with less connections, because of the modifications that were made when the visibility is lost. This blocks is what we call musical words, and as we know, the languages tend to follow Zipf’s law. That’s why we wanted to know if the whole network was

Figure 4: In the figures above we can see that the networks that were formed by the visibility algorithm, follow a power law in the degree distribution of the network.
scale free, as a manner to ensure that the words formed also have this behavior and result in a Zipf’s law when they are ranked.

In order to study words, a data set was made. This data set contains the words used by a certain author, and how often are used by this composer. Thinking that every composer could be seen as a different musical language with his own words. Again we used the 1300 files, and when we plotted, rank of the words used by the composer vs the probability for a certain word, we find the following graph.

Figure 5: When the words formed are ranked and we do the graph of ranked word vs probability of each word formed per composer, we can see that it tent to follow a power law distribution, meaning that it has behavior in the majority, similar to Zipf’s law.
In the picture above we see that the blocks formed by the modified algorithm tend to follow a Zipf’s law, as languages does. With this result, we can think that every composer generate his own language. The words in the languages are going to depend on the variations of the nearest notes, remembering that every character in the block is a measure of the rate of change between adjacent notes in semitones. Having the words of the different composers, seems reasonable to find differences among composers in the words formed. Meaning that we can construct a time series based, on how a fixed word, is probable for every composer. Thinking that every composer represent a different time in the series.

Figure 6: First 100 blocks

Most used words by Bach
Figure 7: Time series above are formed with the words we found. We fix a word that happen with a high probability in a certain composer and then this word is compared among the composers. We note that for a fixed word, the probability change among composers get higher or lower.

As we see above the words provides us a way to see how change the music from different times. For example, in early ages often we see that the words begin with C or a D, and also is not so common to find letters that are the last ones in the alphabet, among early composer. So we can think is that in early ages of music the jump between adjacent notes was really short in the majority of the times. Also when we compare the most often words use by this early composer, we can see that this words are used by more contemporany composers. The exception it could be Couperin, in which we found words with higher alphabet letters. When we see the graph of Couperin, we can see that most of their words died soon or are not longer used, others are used later on.

Figure 8: CBBC it is frequent in Bach. Nevertheless as we only have information in adjacent notes we have multiple musical figures that can match in CBBC.

In contemporany composers we see that they like to introduce changes in adjacent notes that are above an octave, this make a contrast with early ages. Also among the most used words are some words that not were used before or after. This don’t occur with early composers.

Figure 9: PGXX it is frequent in Scriabin. We can see that the rate of change between adjacent nodes is different from Bach.

We can think that this most frequent words, are what makes the music composers different between them.
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