From White Noise to Für Elise: What makes music beautiful?

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December 15, 2011

Abstract

Can an entire symphony be predicted by just one note from just a single instrument in the orchestra? It seems absurd to even ask this question. The power of an orchestral piece is in how the flutes harmonize with the viola, and how the hardness of percussion counters the softness of the winds. The manner in which all of the notes from all of the instruments come together to produce a collective piece that evokes an emotional response from listeners is a very difficult subject to investigate. This is due to the complex interactions between the sounds produced and how humans perceive these sounds. In an attempt to describe these processes, current research in music theory has drifted from the traditional interpretation of music in terms of its properties (such as pitch, rhythm, tempo) to a more contemporary approach which tries to involve the neurological aspects of listening and composing. The complex and emergent behavior of music will be investigated with focus on how research has shifted over the past few decades. Emphasis will be placed on the hierarchal structure of interpreting music, and how views of this structure has shifted recently.

Other than language, music seems to be one of the most fundamental aspects of human nature. It is found in every culture and plays a role in the daily life of every person on this planet. Despite the wide variety of music around the world, there is still a universality; all music tends to evoke an emotional response. Whether it be a score for a movie dictating how to respond to a scene, or a tribal song celebrating the harvest season, all music has this power to make us feel. What is it in music that causes this response? What is it that makes a song beautiful to some people but not to others?

At its heart music is simply a collection of vibrating air molecules which are then detected by our ears. Even these vibrations can be reduced further to a collection of plane waves by means of a Fourier expansion. So its seems that any question about music can be answered by simply analyzing the Fourier components of the piece. This cannot be farther from the truth. Music cannot be understood as a sum of its parts. There are many collective effects and temporal dynamics which lead to the complex nature of music. In addition to this is the inherent fact that the complexity of music is intricately tied to the complexity of human cognition.

In order to achieve a basic understanding of the nature of music, first some historical context is necessary. For this context it seems appropriate to shed some light on how experts in music theory study their own topic. For this reason, Sections I & II of this paper will focus on traditional aspects of music theory and how these aspects have evolved in recent years. With this base to build on, the remaining sections will focus on what makes music a complex and emergent phenomenon.

I Rhythm, Pitch, Timbre: The Players of Music Theory

Music has been study by humans since the time of the Ancient Greeks when the concept of harmonies was used to describe the universe. This study of music is quite different from modern music theory and is often thought to be more philosophy in the modern sense of the words. It was not until the Medieval times that music was studied in the sense it is today. During this period, study of the liberal arts was broken up into three levels. The first level, called the trivium, included grammar, logic, and rhetoric. It was considered to be the basis need to study the liberal arts. After the trivium was studied, academics could progress to studying the quadrivium where music, astronomy, geometry and arithmetic were studied. Only after studying both the trivium and quadrivium could someone begin to study philosophy. In this sense music was considered one of the fundamental liberal arts during the Medieval times [1].

Music was studied further through the Renaissance and Baroque periods, but did not become what is know as Western music theory until the 18^{th} and 19^{th} centuries. During this time, classical western music was flourishing and music theory began to take a form that would last for hundreds of years. This is when people started to dissect music into its many elements (such as pitch, rhythm, melody, key, etc.) and look at reasons why composers choose certain arrangements over others. This being said, many of these ideas were know to musicians and composers before this time. They were simply formalized into theory at this stage. Since much of modern music theory builds off these ideas, it is imperative to get a sense of who these *players* of music theory actually are.

Music theory is broken up into a set of basic elements which then combine to form higher level elements. For the sake of brevity, only a few of the important aspects of this structure will be discussed here. Beginning with the basic elements of music, we have aspects such as pitch, rhythm, tempo, and timbre (pronounced tam-ber). Pitch in essence refers to the frequency of the note being played. This is somewhat misleading as pitch is actually a property of listening (see section IV) and not simply the Fourier component heard. In contract to pitch, which is a static property, rhythm and tempo both refer to temporal properties. Rhythm is how long a single note is to be played, while tempo is the overall speed of the piece. Finally timbre refers to the distinct sound an instrument gives compared to other instruments, voices, etc. Timbre is why a trumpet sounds like a trumpet and why we can differentiate people by their voices. These basic elements with several others can then be combined to produce higher level elements in music such as meter, key, harmony, and melody (see section III) [2].

With this basic structure, theorists believed that music could be described simply by studying the interplay of these aspects. This worked extremely well for classical western music and was used for a few hundred years. In the 20$^{\text{th}}$ century, these principles began to lose strength when people tried to apply the results to a wider variety of music. This eventually led to a divide in music theory.

II The Cognitive Reformation: Music Theory's Modern Schism

In the latter half of the 20$^{\text{th}}$ century there were many changes in musical and social culture which led to an ever evolving music theory. With the ongoing Vietnam War and the rise of music radio, the 1970's provided a backdrop where music began to diversify. As more and more people could regularly access music, more musical styles developed. Included in this development was the shift to make atonal music; music which has no key (dominant note). Some famous examples of this come in Anton Webern's "pointilism" and John Cage's "chance music". Both of these composer strived to use experimental techniques to develop a new kind of music. To adapt to these new atonal musics and also in an attempt to describe the new popular and rock and roll music, some theorists began to take a more post modernist view. Instead of just decomposing music into its parts, they took a more holistic view of musical pieces. Additionally, with the post modernist idea of knowledge being relative to the observer, music theory began its shift to incorporate the human element into the picture [3].

Around the same time, the personal computer came into light, allowing more in depth analysis into pieces of music. Whether it be an analysis of the static structure of a piece or an analysis of the sound produced when a piece was played, it was clear that the computer would be an important tool in music studies. At first much of the work using computers involved strides toward developing a grammar for musical pieces (see section III). That is efforts were made to decompose music into small and smaller parts as is done in language. As time progressed and post modernist view crept into music theory, the computer's role in music theory shifted to incorporate human action as well [4].

One of the pioneers in incorporating cognitive analysis into music theory was Otto Laske [4]. Building off the ideas of a music grammar he tried to develop a grammar which incorporated listening and composing instead of simply the static structure. He was also one of the first people to incorporate artificial intelligences into the study of music. This work paved the way for many other computer aided studies using A.I. and eventually to the use of neural based networks in music analysis.

With the increase in computer use and the social changes in the late 20^{th} century, music theory began to experience some tension. The subject had become dichotomous. One crowd of people remained in the traditionalist camp; they analyzed the structure of pieces and tried to interpret them on the basis of separate properties. On the other hand their was a camp breaking off from this traditional point of view to investigate music on a more cognitive approach. They tended to interpret pieces based on how people perceive the music, hence taking a more post modern point of view. This eventually led to a split of the subject of music theory into two parts: music theory and cognitive music theory [3]. This division is evident not only in the subject matter but also in the fact that journals even began to develop dedicated to each field.

While there is still some debate over which viewpoint is the better one to take when interpreting music, most people agree that there is necessity and merit in both. Just by looking at this history and the different ways to interpret musical pieces, it is clear that music is a complex phenomenon. Not even the experts in the field can agree to one prescribed method of analyzing music. With this historical context in mind, it is now possible to delve further into what causes this complexity. By examining both viewpoints, a better idea of how the parts meld together to evoke emotional response can be found. Perhaps progress can be made toward answering the question of how beauty emerges from a collection of vibrations, as well.

III Hierarchical Structure and Musical Grammar

One aspect in any complex system is a sense of hierarchical structure in the system. The basic idea of hierarchy is that there are multiple levels of description for the same phenomenon. These levels are organized in a systematic manner such that the lower levels correspond to a more detailed description while the higher levels correspond to a broader description of the system. The different levels are then connected in how the *players* on that level interact with each other to form a collective effect on a higher level. We can think of this broadly in the sense of an everyday object, take a coffee cup. On the level of everyday use, the mug is one object. If it is observed more closely however, it becomes apparent that the mug is formed of atoms which interact via the electromagnetic force. The atoms can then be observed and it is clear that they too are made of pieces called the proton, neutron, and electron. This can be continued on to lower and lower levels. The beauty of this hierarchal structure is that it does not matter what happens on the lower levels, ie- one does not need to know about atoms to claim the mug will hold coffee.

Now consider how music exhibits aspects of this hierarchical structure. As a first example, consider the basic structure of the traditional music theory described in section I. In the described analysis, theorists break music into its fundamental elements (pitch, tempo, loudness, etc.) and then these pieces come together to form a higher level. This higher level is where aspects of music such as key and harmony are represented. Take key for instance, which describes the importance of a note in a piece. It is formed by the interplay of all of the pitches in a piece and also the timing/order the pitches are played in. This is some kind of effect arising from the many interactions of the lower level *players* and hence is a collective behavior of the system [2]. In addition to this, these levels are even isolated from each other, in the sense that key, melody and harmony can be discussed in terms of how the music sounds, without really knowing exactly what pitches are being played when [5]. It is then apparent that even this traditionalistic approach has aspects of complexity built into it.

On top of the more traditional hierarchy, there is also a leveled structure found in cognitive music theory, in the study of musical grammars. This area of research attempts to relate the ideas of language analysis to music analysis. In linguistics, the structure of spoken and written words are broken into various parts (sentences, paragraphs, nouns, verbs). Then the rules for piecing these parts together are investigated. In a similar manner, people who study music grammar, try and find ways to naturally break apart the music forming different levels of description. Two examples of purposed musical grammars will be presented below.

As a first example of a musical grammar, consider the work of Lerdahl and Jackendoff [6]. Instead of simply breaking apart the notes as written on sheet music, they purpose a decomposition using heard structure. Their constructed grammar, in turn, inherently incorporates aspects of human listening. Their work was ground breaking in a sense that it tried to predict musical intuition that a listener has when hearing a piece. By examining four aspects of heard music and establishing rules for the formed structures, they were able to decompose the music into a few general feelings a listener has. As an example of this one structure they formed, called time span reduction, used the temporal aspects of the music to investigate whether the music was tensing up or relaxing. They could then take this structure and form a hierarchy. So on the most general level a piece may tense to a certain point and then relax for the rest of the piece. When looked at more closely, however, there is a much more intricate pattern of tensing and relaxing. This leveled organization is seen throughout the other properties they investigate as well.

Another musical grammar with multiple levels of description was purposed by Baroni, et. al. [5]. Here it is suggested that in order for a grammar to be effective, the grammar must be applicable to many different types of music. With this strive for a more universal theory, Baroni develops a grammar through comparison of many different pieces. By using this comparative measure they attempt to test for statistical likelihoods of certain rules in their ensemble of musical pieces. This is then used to extract very general, broad statements about the different musical pieces. While it seems their grammar only focuses the top levels of the hierarchy they can be adapted to more and more detailed views.

It is clear that in both a highly cognitive setting and in a more traditional setting, that music theory contains many hierarchical structures. These structures at heart represent the complex nature of the interaction of all of the different aspects of music. While some aspects of human perception are involved in these theories, they do not yet fully delve into why music seems to be so universal in human culture. They also greatly simplify the model of a listener's emotional response. In order to more fully understand what makes music so special, it is necessary to tackle the human element straight on.

IV The Listener and The Composer: How Humans Couple to Music

The basic tenet of the post modern view was that knowledge could not be decoupled from the observer. That is the social and historical context a person has must affect how they perceive a piece of knowledge. While some of these ideas are highly debated in the sciences, when speaking about music, they most definitely apply. It is not possible to remove human involvement in music. Whether it be a the level of composing, playing, or listening, humans are involved in every aspect of music. For this reason much of music theory has begun to approach the situation from a neuroscience point of view.

With this being said their is still merit in studying the traditional music theory. Even though the human element is not explicitly approached in these studies, it is very much there. For example consider the concept of pitch presented before. As first introduced, pitch is just the frequency of the sound being produced. This is a perfectly good definition to a physicist, however to a musician this definition doesn't have much weight. Instead pitch is defined in terms of a perceived frequency; a heard frequency. As a consequence of this frequencies that are logarithmic multiples of each other are considered to be the same pitch because they are heard to be the same [2]. This is where the A-G, or "*do, re, mi*" notes come from. As Levitin suggests, for this reason pitch cannot be separated from the human mind [2]. It is at its essence a construct the human brain makes out of the physical quantity of frequency. In addition to this, the higher level aspects to traditional music theory (like melody) are also constructs of human perception. Hence while they try and ignore the human aspect in traditional music theory, it is inherently present.

As opposed to this passive approach of incorporating human complexity into music theory, a much more active approach is taken in the cognitive music theories. These theories immediately recognize that human involvement must be incorporated to completely understand the power of music. One example of such development was done by Gill and Purves, where they purposed a biologically rooted reason for the seemingly universal use of scales in music [7]. By investigating many different cultures and musical styles, and by developing a library of commonly used scales, they noticed that 5 or 7 notes scales were commonly used. As an explanation of this they purposed the scales most often used match the closest with higher harmonics of a common tone. They found that this was in most cases true and so confirmed their hypothesis. To tie in the human aspect they then suggested that this may come from the evolutionary fact that vocalization and many natural sounds tend to happen at harmonics. While there were some caveats to this theory, it was a step toward combining the ideas of music theory to those of evolutionary and nuero biology.

In this light many other people have presented evolutionary reasons for why humans respond to sounds in certain ways. For example, the idea that finger nails on a chalk board resemble predatory cats nails scratching rocks, is purposed to be the reason why many people find that sound unpleasant. While it is difficult to test some of these ideas, they are a start to a complete understanding of music cognition and perception. Studies like these begin to shed light on possible reason music has become such an important aspect of human life. They begin to answer the long sought after questions of what makes some music sound pleasant and other music sound wretched.

V The Variational Principle of Music

With an active incorporation of perception into music theories, many experiments can be performed using human subjects. On one hand, one can conceive neuroscience experiments, such as looking into what areas of the brain are stimulated when certain sounds are played. On the complete opposite side of this a social science perspective can be taken in which human subjects are studied through surveys and observations of their actions. Both cases yield insight into the intricate connections between the human brain and musical sounds. As an example of the latter, a psychological study was done by McAdams and Matzkin, in an attempt to discover what makes two pieces of music sound similar [8].

The main premise of the study was to investigate systematic variations on a theme, in an attempt to figure out what variations maintain the basic feeling of the original piece and which variations cause too much of a change. In traditional variational pieces, composers use many techniques to change their music. Almost all of these techniques can be decomposed into the following three categories: reordering of notes, changing of notes, or adjusting timing. When put together these variations can cause a sound which is similar to the original or one that is vastly different. In addition to the various ways a piece can be altered, there are also many ways similarity can be measured. In one sense a probabilistic, or a statistical analysis of correlations between the two pieces can be modeled. On the other hand, pattern and abstract structures found in the music can be compared between two pieces [8]. The issue is that neither of these measure how similarity between the two pieces are perceived; they are just mathematical constructs for something that tends to be more subjective.

McAdams and Matzkin get around this subjective nature of the problem by letting the listener decide what they consider to be similar instead of some arbitrarily constructed scale. In their study, they ran two experiments with essentially identical setups. They take several short pieces of music and have a composer create variations on the music. Most of the variations changed the pitch and rhythm to different degrees. They then asked listeners to listen to the original and one of the variations (including a control) and rate how similar the two pieces were. There were many different ideas tested in this study but the main purpose was to investigate what causes two pieces to sound different.

There were many unexpected results from these studies. First, they wanted to test whether there was a difference between a trained musician listening as opposed to a lay person listening. While they expected a difference because the trained musician is taught to listen in a special manner, there was no statistical difference between a trained versus an untrained ear. While surprising this result also brought the hope of some sort of universal aspect to variations of music. McAdams and Matzkin then went on to investigate whether different selections with similar variations would lead to similar similarity ratings. Again they were surprised and discovered that the results were highly dependent on the original piece. This implies that similarities in music are much more complex and cannot be characterized by similarities in one or two aspects of music theory.

VI Conclusion

By investigating the history of music theory and looking at several recent attempts to study the intricacies of music, it is clear that music is extremely complex. It is not enough to simply break music up into a bunch of different characteristics and think that these characteristics can accurately describe the motivations of composers or the response of listeners. It would be like trying to taste a peach pie by reading a list of ingredients; an impossible feat. While modern studies in cognitive neuroscience have made immense progress there is still a long trek ahead to understand why music is so special. So in an attempt to answer the purposed question, why is music beautiful? Music is beautiful because of the complex manner in which vibrating air molecules are produced, transmitted, detected, and perceived by human beings.

References

[1] R. Monelle, "What kind of theory is music theory?. epistemological exercises in music theory and analysis," *Music and Letters.*, vol. 90, no. 3, pp. 521–525, 2009.

[2] D. J. Levitin, *This is Your Brain on Music*, ch. 1. Penguin Group (USA) Inc., 1 ed., 2006.

[3] E. Narmour, "Our varying histories and future potential: Models and maps in science, the humanities, and in music theory," *Music Percept.*, vol. 29, no. 1, pp. 1–21, 2011.

[4] N. Schűler, "From musical grammars to music cognition in the 1980s and 1990s: Highlights of the history of computer-assisted music analysis," *Muzikoloski Zbornik*, vol. 43, no. 2, pp. 371–396, 2007.

[5] M. Baroni, S. Maguire, and W. Drabkin, "The concept of musical grammar," *Music Percept.*, vol. 2, pp. 175–208, 1983.

[6] F. Lerdahl and R. Jackendoff, "An overview of hierarchical structure in music," *Music Percept.*, vol. 1, pp. 229–252, 1984.

[7] K. Gill and D. Purves, "A biological rationale for musical scales," *PLoS One.*, vol. 4, no. 12, 2009.

[8] S. McAdams and D. Matzkin, "Similarity, invariance, and musical variation," *Ann NY Acad Sci*, vol. 930, pp. 62–76, 2001.