

Reading a Reed
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Motivation and Goal:

The clarinet reed plays a vital role in a clarinetist's performance, not only affecting his control over the instrument, but also the color of his sound. Even the most trained, consistent professionals will sound different on slightly different reeds. Furthermore, it is impossible to predict the quality of a reed's sound without playing on it, making reed selection an exhaustive and time-intensive process. Even after playing a reed, the clarinetist must spend up to a week customizing it. The manipulation of reeds is not an exact science and there does not exist a quantitative way to justify a particular action taken on a reed, making the customization period tedious.

The goal of my project is to discover a mapping between a reed's attributes to the subjective quality of the reed's sound. This goal can be divided into two sub-tasks:

1. Find the relationship between a reed's attributes (yet to be determined) to the following aspects of the reed's sound (not finalized):
 - a. The distribution of overtones and partials (i.e. the spectral envelope)
 - b. Amount of inharmonic noise in the sound
 - c. Timing of attack and decay.
2. Develop a model that will map the aforementioned sound characteristics to subjective tone colors, such as "dark", "bright", "clean", "pure", "shrill", "noisy"...etc.

Once the project is complete, when given a reed with particular attributes, the algorithm can predict its spectral envelope, inharmonic noise etc...and use this prediction to arrive at a subjective adjective to describe the reed's sound.

If the project is successful, the algorithm will greatly help the clarinet community. It provides the basis for a machine that can predict the sound quality of a set of reeds, rejecting ones that do not satisfy a clarinetist's tone preference. The machine will eliminate the need for clarinetists to waste time playing on reeds that they will eventually throw away. The project also lays foundations for a suggestion mechanism that can guide how clarinetists change their reeds.

Problem Background and Related Work:

I will describe prior work done on the two sub-tasks described above:

1.
 - a. David George et. al, in his paper *The clarinet: How blowing pressure, lip force, lip position and reed "hardness" affect pitch, sound level and spectrum*, describes how changing the reed "hardness" affects the spectral center. This research is limited in that it only considers the size of the tip and none of the other reed's attributes. Furthermore other aspects of sound such as inharmonic noise and the timing of attack and decay are not measured.
 - a. John Backus, in his classic paper, *Small Vibration Theory of the Clarinet*, rigorously studies the *physical* vibrations of the reed and its relation to the air

- column, mouthpiece and clarinet. Understanding the physics behind the reed's vibrations may lead to a more complete prediction model for the reed's sound.
2. Attempts have been made to characterize sound by condensing its infinite degrees of freedom to a few important, defining features:
 - a. Helmholtz, in his seminal work "On the Sensations of Tone as a Physiological Basis for the Theory of Music", claimed that to categorize the quality of a sound, all that is needed is the spectral envelope, the profile of the Fourier series.
 - b. Grey, in his dissertation at Stanford claimed that timbre can be described in a 3-dimensional space with the axes being the spectral energy distribution, timing of attack and decay, and amount of inharmonic noise.
 - c. Since Grey and Helmholtz, there has been considerable research done on the temporal aspect of sound and how the spectral envelope changes rapidly over the duration of a note.

Despite these rather complex sound models, researchers never attempted to map their models to subjective tone colors such as "dark", "bright"...etc, in part because such a list of adjectives would be overwhelmingly expansive and disparate across different instrument groups. Nevertheless, the research on sound models will be of tremendous importance as an erroneous sound model, or one that does not fully capture the aspects the clarinet sound, will create meaningless or incorrect mappings to subjective adjectives.

Approach:

The key idea underlying my approach is to have two stages of machine learning, the first to map a reed's attributes to a list of sound qualities and the second to map these sound qualities to a subjective tone color.

The first stage will be completely novel. In the past there was not a strong demand for researchers to study the inharmonic noise that a reed makes or the time of attack and decay. What was important was the Fourier analysis and spectral center. Yet, because the measurements we make in the first stage directly affect the second stage, there is a new demand for the study of different reed sound qualities.

In the second stage, there has been little attempt to map sound qualities to subjective adjectives because compiling such a list would be incredibly expansive. I believe that the expansiveness of this list results from researchers dealing with every instrument group. The adjectives that a trumpet player would use would be drastically different from those that a violinist would use. Because my research deals primarily with the B-flat clarinet, I believe that compiling a list of adjectives that clarinetists' use will be easier. From experience, I know that there are certain words that *all* clarinetists use to describe a tone. For example "dark", "bright", "focused", "pure", "noisy", "spready", "responsive" are all words that I have heard from teachers throughout the nation.

Plan:

1. Compile list of reed attributes to measure and how to measure them. E.g. Use a scanner to find contour of reed.
2. Make apparatus to artificially play clarinet so that specific variables can be kept constant (e.g. air pressure, lip pressure).
 - a. This may potentially be the hardest part. If such an apparatus is not possible I may need to play my own instrument and measure my own lip pressure, air

pressure...John Backus does however have an apparatus that I will experiment with.

3. Get funding to order reeds. A box of 10 reeds cost \$20 – 30; making a bulk purchase of reeds may be very expensive. I can also ask to be sponsored by reaching out to reed companies like Vandoren, that may give me reeds at a discounted price.
4. Find accurate way to measure the spectral envelope, the inharmonic noise and the timing of attack and delay. E.g. should I make a recording and then analyze it? Is there a way to analyze in real time?
5. (Artificially) play on ~1000 reeds and measure its sound qualities. Let us call this data set D1.
6. Create algorithm that will map a clarinet reed attributes to the various sound qualities using D1.
7. Compile list of adjectives that clarinetists use:
 - a. This may be quite difficult, but I am thinking about using some sort of survey and sending it out to all of my clarinet friends at music conservatory.
8. Send out audio files to the clarinet community asking them to match the clarinet sound to an adjective. Let us call this data set D2.
9. Create algorithm that will map sound qualities to subjective adjectives using D2.

Evaluation:

Splitting Data Sets:

One obvious testing that we can do on our 2 algorithms is to split D1 and D2 into training and testing data sets. We create our algorithm using the training set and test the accuracy of our model using the testing set. The limitation with this approach however, is that D1 and D2 are generated from the same clarinet and same constraints. Splitting the data does not give a realistic error term because all clarinetists exert different sorts of air/lip pressure. Hence real-life testing is essential in ensuring robustness of our model.

Real-time testing:

One possible scenario that I can run is to gather all the clarinetists at Princeton (~20 people). I will measure and predict on about 100 reeds before this gathering. During the meeting, I will ask each of these players to play on 5 reeds, assigning each reed to an adjective that I have given them. I will calculate a new error term comparing my predictions to their assignments. Another testing scenario is to tell each player how to change the sound of their reeds (e.g. make it darker, brighter...etc by shaving the tip of their reed) and ask them if the change was achieved.

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