ISE 575b - Computational Modeling of Expressive Performance

Todd, N. P. M. (1998). The kinematics of musical expression. Journal of the Acoustical Society of America, March 1995, Vol.97, Issue 3, pp.1940-1949.

Some classical Greek musical writings can be classified as belonging to the school of Aristoxenian. For Aristoxenians, notes are geometric points in a space and intervals are the distance between the notes. It is important to note that this idea of a connection between music and motion is much older than the Greeks. To summarize, the following has generally been suggested: musical movement has two degrees of freedom, tonal and rhythmic movement, this movement is similar to physical movement, and musical motion specifically relates to movements of the body or the limb.

Some previous work that this study relies on was conducted by Kronman and Sundberg. They used regression analysis to 'model the final ritardando in musical performances as a motion under constant negative acceleration.' The goals of this paper are to formulate the problem of substantiating the relationship between music and motion in a more mathematical form, to extend the studies of Sundberg et. al., and to show that the metrical grid originates from the way the auditory system processes rhythm.

In an attempt to meet the first goal, the author draws a parallel between expression in music and problems of kinematics in the theory of motor control. In both, one is concerned with a set of variables that describe the geometry of a motion and the time evolution of those variables. More specifically, a score is like a trajectory in a 2D space where the vertical axis contains the pitch space while the horizontal axis contains the metrical position. This study only considers the metrical position as a kinematic variable.

This study focuses on tempo in the abstract form. Therefore, the idea of tempo must be further developed. Since tempo is a fictitious variable, the actual measurement that is substituted for it is the onset time of an event. Because of this, tempo and acceleration may only be *estimated* numerically. The estimation of tempo is the change in metrical position over time. Similarly, the estimation of acceleration is the change in tempo over time.

As with the Sundberg study, this study uses regression analysis. For reasons explained above, the regression analysis uses a series of measured onset times instead of tempo. In general, a piece consists of a series of n connected segments. For each of these segments, the author proposes a regression equation with p parameters. The p value does not exceed 2, since the shortest segments are 2 onsets in length. Using this basis, two models are developed. The first is referred to as the piecewise liner tempo (PLT). This model is similar to that employed by Sundberg and has a $p = 2$. The second model is referred to as the piecewise constant tempo (PCT). This model assumes that the tempo is constant within a segment with a $p = 1$. Both of these models use time as the independent variable. The regression analysis was conducted using timing measurements of three performances of Chopin pieces by a single pianist. In all cases, the PCT model accounted for a high proportion of the variance. Also, in all cases, the PLT accounted for a higher proportion of the variance. What is interesting about these results is just how much of the variance is accounted for by PCT alone. As an explanation, the author points out that any performance with very shallow rubato could be approximated well using the PCT model. It would be interesting to see the results of the analysis from a larger and more varied data set. It is possible that the pieces tested had shallow rubato.

An interesting idea pointed out by the author is that the sensory motor process can be described mathematically by a dynamic system. This system has 'two degrees of freedom and can be modeled as two weakly coupled mass-spring-damper systems'. The first system is associated with an action like foot tapping or clapping. The second system is associated with whole body motion. The first system has a natural period (600 ms) which is much faster than the

second system (5 s). This idea is very intriguing because it seems to get to the heart of the connection between music and the physical world.