MODELLING EXPRESSIVE MOVEMENT OF MUSICIANS

by

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Abstract

This thesis addresses the problem of modelling expressive movement in human figure animation. The domain of music is ideal for the study of expressive movement since there is often a relationship between the expression of music and the dynamics of a musician's body. The goal of this thesis is to provide control of kinematic expression in the animation of musical scores. Drumming movements in particular are appropriate to model because there is a wide range of movements to convey expression, and their physical quality makes them more readily observable than movements used with instruments such as the clarinet. Such a visualization is directly applicable to music education and score design, while the techniques to affect the expression could be used for other kinds of animated movement.

The proposed system is SMED, a system for modelling expressive drumming. SMED reads any MIDI-encoded drum score and in real-time renders a 3D animation of a drummer's performance of that score. It allows the user to modify the frequency and amplitude of joint rotations in order to affect the perceived expression of movement.

The quality of the generated movement was tested by having subjects interpret the kinematics of a number of performances. The effectiveness of SMED as a high-level tool for specifiying expressive movement was tested by having subjects manipulate the user interface to create drumming animations for several contrasting musical scores. The results of the study found that while there were a number of suggested refinements, subjects were able to recognize and interpret expressive aspects of performances and could manipulate the interface to create expressive performances with ease.

SMED represents an initial example of interactive specification of expressive movement in musical performance, and provides a solid foundation for future work.

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"The material of music is sound and bodily movement."

–Aristides Quintillianus (c.300AD) [52]

"Where MIDI falls short, and where I can always see it falling short, is in the embellishment and the personality that the animator can give an animation. You're not going to generate that from a program."

–Bob Munroe, technical director of Topix Computer Graphics and Animation Inc., creator of "Lifesavers: Good Times Roll," 1991 [44]

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Chapter 1

Introduction

Music is one medium for the expression of emotion and the movements seen in musical performance are part of that expression. The general goal of this work is to realistically model those movements for a given musical score and provide tools to allow users to personalize the kinematic expression. Such musical score visualization can be useful in music education for demonstrating performance techniques and in algorithmic composition for illustrating how a human performer could play a computer-generated score. Also, animators can benefit from the development of intuitive, high-level tools to effect the expression of an animation.

Recent research has given animators a higher level of control in creating animation. For example, an artist can create a "walk" animation by specifying gait parameters [11], as opposed to explicitly specifying joint angles in a traditional keyframe system. Alternatively, motion-captured walking data [35] could be used to drive an articulated figure and transformations could be applied to the captured data to customize the motion [3, 14].

Research has also addressed the modelling of emotion [3, 54], but the example activities have been limited to various gaits and "knocking" movements. The movement of musicians would be an ideal domain to study expressive movement; performance movements are inherently expressive, personalized, and varied.

1.1 Goals

The goals of this thesis are as follows:

1. to model the expressive movements of performing musicians, and

2. to create high-level tools to specify the kinematic animation of musical scores.

Within these goals is the secondary goal of learning how to specify the kinematic expression in the animation of musical scores.

While the implementation will be focused on modelling the expressive movement of musicians, it is hoped that insight will be gained into modelling other forms of human gestural expression. Eventually, this could lead to generalized high-level tools that would allow animators to specify and modify the expression and emotional behaviour of arbitrary articulated figures.

1.2 Why Drumming

Initially, the expressive nature of drumming will be studied. Drumming movements are particularly appropriate for this study because there is a wide range of movements to convey expression, and their physical quality makes them more readily observable than movements used with instruments such as the clarinet, for example. Also, it is more manageable to model the interaction of two arms and a seven-piece drum kit than to model the interaction ten fingers and an 88-key piano, for instance.

Another musical visualization program, SPAM [62], modelled hand movement for piano. Research in SPAM showed that modelling finger movement is a non-trivial task. Although finger placement and movement play an important role in stick-handling, they will not be addressed until the complexity of modelling the upper body and limb movements are determined.

Modelling drumming also presents the interesting problem of assigning hands to a sequence of drum hits. It is anticipated that this problem will be easier than the corresponding problem on the piano, that of assigning fingers to a sequence of notes. One could avoid this problem by modelling the performance for a "fixed-fingering" instrument such as the recorder, but the kinematics might not be as interesting.

Chapter 2

Literature Review

Before addressing the problem of modelling drummers, it will be helpful to review general approaches to human figure animation, including the way the animated body is represented and subsequently animated. Relevant research regarding expression in animation and music will also be discussed.

2.1 The Human Figure

The human body is most logically, and most commonly, represented as a hierarchical structure based on the skeleton (Figure 2.1).

Each joint is represented as a node in the tree. The bone between two joints defines an arc between the corresponding nodes in the tree. For example, the elbow and wrist nodes are connected by an arc designated by the lower arm. The tree structure is appropriate for human figure animation because body positions are typically described in terms of joint angles. One advantage is that transformations applied to nodes higher in the subtree will automatically affect all nodes in its subtrees. Thus, rotating the right shoulder will also position the elbow and wrist appropriately. Another advantage to the hierarchical approach is that each joint has its own local coordinate system so that rotations can be stored independently from other joints. Typically the pelvis is the root of the tree, with the back and legs as subtrees.

Associated with each joint is the number of *degrees of freedom*. A *pin joint* such as the elbow or knee has one degree of freedom. A *ball joint* such as the wrist has three degrees of freedom. It is necessary to store this information since each joint will require one rotational

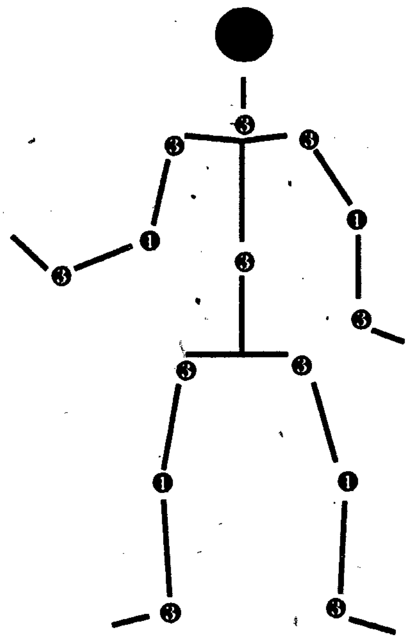


Figure 2.1: An example of a hierarchically-defined skeleton. The number at each joint indicates the associated number of degrees of freedom.

value for each animated degree of freedom.

The hierarchical approach is the de facto standard in articulated figure animation, used in animation systems such as LifeForms [16], Bruderlin's gait modelling program Gaitor [13], Perlin's computer-generated dancer [43], and synthetic actors such as those found in "Rendezvous à Montreal" [37].

2.2 Methods of Creating Movement

While there is one generally accepted approach to representing a given articulated body, there are a number of methods used to specify its movement.

2.2.1 Keyframe Systems

The most common method used by animators is *keyframing*. The animators position the body for important frames (called *keyframes*). The computer generates the intermediate frames (called the *inbetweens*) by interpolating the values at adjacent keyframes. An example of a keyframe animation system is LifeForms [16].

Keyframe systems provide users with detailed, low-level control of the animation. However, complex movements such as walking [13] and interactions with other figures can be tedious and time-consuming.

2.2.2 Procedural Animation

Procedural animation is created through the use of algorithms which calculate the appropriate joint angles for each keyframe. Typically certain aspects of the animation are parameterized so that the user can affect the animation. Bruderlin, Teo, and Calvert [13] describe Gaitor, a system which uses procedural techniques for modelling human locomotion. Step length and step frequency are two example parameters which can be changed by the user to create different walking animations.

Procedural animation provides higher-level control of animations, and given appropriate algorithms, very detailed, accurate movements can be created. However, the algorithms are specific to particular movements, and movements outside the program's (usually limited) scope simply cannot be generated.

2.2.3 Motion Capture

Motion capture involves the recording of live human movement. The recorded movement is used to drive the motion of the computer-generated character. Sensors placed on the body can monitor the flexion of limbs and/or the angle of joint rotation. Alternatively, markers (or transmitters) can be placed on the body and optically tracked (or by magnetic or radio-frequency). Maestri [36] provides an overview of various motion capture systems.

Motion capture systems can deliver life-like movement, but obtaining the data is time-consuming and technically difficult. Often the data is riddled with noise, ambiguous readings, and false information and requires post-processing. Optical systems suffer when a marker is occluded. Magnetic systems can limit the freedom of the performer and hence the kinds of movement which can be recorded.

When the captured motion is mapped to the articulated figure, it is important that the computer-generated figure be of a similar physical mass and height as the recorded subject. Heavier individuals have more momentum and require more time to stop. Tricks such as tying sandbags to a performer's legs to get a "heavier" movement, or extending the performer's tracked limbs with sticks to obtain the movements of a taller individual have been used (at Electronic Arts, for example).

Sometimes, a precise recording of live movement is not what is required. Animations commonly use exaggerated movements [32] which bring characters more to life than if "realistic" movements were used.

2.3 Paradigms of Motion Control

Any system which automatically generates keyframes can use one (or both) of the following approaches: *kinematics* and *dynamics*.

Kinematic movement is determined by geometric characteristics of the figure, such as bone lengths and joint angles. The movement from dynamics is driven by forces and torques acting on the connected masses which define the figure. For example, a block which moves across the floor of a room from one side to another may be kinematically animated by specifying the positions of the block at the starting and ending times, and allowing the inbetweens to be generated. Animating using dynamics would involve specifying the mass of the block, its initial velocity, and forces acting on the block (such as the friction of the floor and the initial "pushing" of the block), and Newton's Laws can be applied to calculate the desired animation.

2.3.1 Kinematics

Often animators know where to place the hand of a figure, but find it tedious to position each parent joint in the hierarchy to achieve this hand placement. Instead, it would be easier to specify the *location* of the hand and have the joint angles automatically generated. This is known as the *inverse kinematic* problem. The object being positioned (in this case the hand) is known as the *end effector*.

Thus, given the geometry of an articulated figure and the location of the end effector, the joint angles are solved for using inverse kinematics. Conversely, given the geometry of an articulated figure and associated joint angles, and solving for the location of the end effector is called *forward kinematics*.

Kinematic techniques are used in keyframe animation systems such as LifeForms [16], Vertigo [22], and GIG 3DGO [22]. Perlin's computer-generated dancer [43], Bruderlin's walking figure [12], and Morowetz' goal-directed human animation [40] all employ a kinematic approach. Kinematics is an effective method because it allows direct control of the generated movement, and is computationally less expensive and simpler to implement than dynamic methods.

2.3.2 Dynamics

There is a parallel pair of problems in the dynamics paradigm. Given the forces and torques and the physical characteristics of an articulated figure, solving for the resulting joint angles (or their acceleration) is called the *forward dynamics* problem. Likewise, given the joint accelerations and solving for the applied forces is called the *inverse dynamics* problem.

Dynamic methods are desirable because the generated motion is quite realistic. The animation of situations such as colliding objects can be calculated automatically. However, the systems of equations to be solved (or more typically, approximated) require the use of computationally expensive numerical methods. Sometimes solutions can be unstable, resulting in nonsensical movement. Another major problem is user control. It can be difficult to specify particular motion paths or even points, and thus it is sometimes easier for the animator to specify motion kinematically [58, 27].

Wilhelms [58] discusses Virya, a system which allows users to specify motion using dynamics. Forces acting on each degree of freedom of an articulated figure can be described as a function over time. The created output is a series of keyframes representing the predicted movement. These keyframes can be kinematically tweaked if necessary.

Manikin and Kaya [59] are two dynamic-based systems which allow motion to be specified by forces or by goals. When a goal position is specified, the system determines the appropriate forces and torques necessary to reach the goal. Girard and Maciejewski [25] use inverse dynamics to model the locomotion of legged figures. Hodgins et al. [28] use springs and dampers to dynamically model the motion in pumping a swing, riding a seesaw, juggling, and riding a unicycle.

Dynamics are useful for scientific applications where the accuracy of a physical simulation is required. But dynamics, in being "natural" lack the expressive movement that can only be obtained by exaggeration [32]. This is likely one more reason why animators will continue to use kinematic specification, even when dynamic methods are computationally viable.

There are other mathematical techniques which take a physical approach of the problem. Witkin and Kass [61] solve for physically valid motions when given a set of user-chosen constraints and goals to be met by the motion. This technique, known as *constraint optimization*, works well for simple systems, such as a point mass which has internal power to accelerate, and must reach a positional goal. But as the system becomes more complex, such as a walking articulated figure with many degrees of freedom, it becomes extremely difficult to solve.

Badler et al. [7] use finite state machines and physical techniques to interpolate between two postures of a human figure. The figure in this goal-directed animation moves so as to be stable with respect to its centre of mass.

Overlapping movements such as waving and walking can be independently generated and later mixed in a kinematic system. However, in a dynamic system, the movements will need to be described and generated simultaneously because the forces of one motion affect the solution of forces in the other.

2.3.3 Interpolation

Keyframe systems use different kinds of interpolation to calculate "inbetween" values. Linear interpolation is the most simple method, but is easily criticized for its robotic look. One must look to curves of higher degrees to obtain smooth motion. *Interpolating* splines, such as Hermite and Bezier splines, travel through some of the control points which define the curve. However, motion created by adjacent spline segments may appear discontinuous without careful placement of the control points. CTB splines [30] are based on Hermite splines. But instead of manipulating tangent vectors, three parameters are used to affect the curve as it passes through the control points: continuity, tension, and bias. In particular, continuity is a valuable parameter for animation because both smooth and sudden movements can be easily specified. Bias controls of the amount of undershooting or overshooting of the spline through a control point. This is useful for providing anticipation or follow-through to a movement. Tension controls how straight the path is between two points.

Approximating splines such as B-splines and β-splines do not travel through the control points defining the curve, which makes control of the path more difficult. However, it is easy to achieve second-order continuity with these splines. Non-uniform rational B-splines (NURBS) interpolate between the first and last endpoints, but approximate among other control points. Also, points along the curve (called *knots*) can be used to edit the curve when control of the path is required.

In summary, splines allow the animator to add a variety of behavioural characteristics to keyframed motion.

2.4 Expression in Animation

Animation can be defined as the art of movement, or the art of moving with style [33]. By definition, it is the *movement* through which the artist communicates, whether the medium be clay or computer. Regardless of the human figure's representation or method of generating movement, *how* the figure will move aesthetically must be considered.

Expressive movement is important to bring personality to animated characters. *Believable agents* [9], computer-generated actors which algorithmically "behave" and interact with users or other agents, also require fundamental "knowledge" of the kinematics of expression so that their actions are believable. Lasseter's classic paper [32] describes how to apply the fundamental techniques of traditional animation to 3D computer animation. These techniques are applicable whether the animation is created manually or procedurally.

2.4.1 Exaggeration

Perhaps one of the most important techniques, as addressed by both Laybourne [33] and Lasseter [32], is *exaggeration*. Exaggeration manifests itself in a number of principles, such as the amount of squashing or stretching of a deformable (or even non-deformable) object, or the amount of anticipation or follow-through of a movement. Motion capture systems can only obtain exaggerated movements that can be humanly acted; if more exaggeration is required, the animation can be touched up frame by frame, or can be processed at a higher level. Bruderlin and Williams [14] propose a number of motion signal processing techniques to effect motion captured data at a high level. Changing high frequencies affected details of the movement, while changing low frequencies had a more coarse, general effect. Kinematic systems can simply change exaggeration by the manipulation of keyframe positions and values. This is not a problem if such changes can be done automatically, as in a procedural system, but may be tedious in a keyframe system.

2.4.2 Signal Processing

Researchers are interested in finding "emotional transformations" which can be applied to motion-captured data. For example, by applying an "angry transformation" to a neutral walking motion or knocking motion, the resulting motion would represent an angry walk or knock. Unuma et al. [54] and Amaya et al. [3] have researched this technique, but generalized results have not been obtained.

2.4.3 Secondary Movements

Primary movements are those which contribute to the accomplishment of a specific goal. *Secondary movements* do not contribute directly to achieving the goal, but can add expression and meaning to the primary movements. A walking motion may be complemented with a secondary movement of looking around. Quick, frequent turns of the neck may imply paranoia, whereas slow, infrequent turns may suggest a casual interest in one's surroundings. Morowetz incorporates secondary movements in a script-based, goal-directed animation system [40]. It was found that adding such movements can change the expression of otherwise identical animations without requiring extensive work from the animator.

2.4.4 Repetition

Procedurally modelled animations may create cyclical motion more efficiently than an animator, but exact repetition in the movements may not convince the viewer of an expressive character [28]. Different techniques can be used to alleviate this problem. The use of different secondary movements can make for visually interesting sequences with the same primary movements [40].

Bates [9], referring to a discussion with animator Chuck Jones (co-creator of Bugs Bunny, Warner Brothers), states that it is the oddities, or "quirks" that give personality and life to characters. A quirk basically implies a break from the regular behaviour of the character, and could take place in either primary or secondary movements. To achieve a positional goal, a character may skip part of the way instead of walking the entire distance. Or a character may gesturally exclaim, "Eureka!" while walking.

Randomization is a common method for automatically introducing variation into movement. A quirk would typically be set off by some random function. Perlin [43] uses randomization so that various dance movements look similar, but are never exactly the same. Unuma et al. [54] use randomization at high frequencies to change a neutral walk into a shivering walk. Hodgins et al. [28] propose the use of noise to improve the various motions modelled by their dynamic system.

Variation in the movements of musicians are well known to researchers of musical input devices. Vertegaal and Ungvary [55] have an isometric device which allows for minor variations in the input to create the same basic musical output. They claim that it is this accommodating characteristic which makes their instrument a viable music controller. This suggests that musicians can use slightly different movements and achieve the same musical result. Thus an animator would have some latitude as to how a particular score could be visualized.

2.5 Summary

From the review of computer animation literature it can be seen that there are a number of ways to construct a system to model musical performance. Consideration must be given to the range of producible movements, the ease of adding new features to the system, and available processing power for interactivity. Also, the ability to exaggerate, produce secondary movements, and introduce variation in the motion will play an important role in creating expressive performances.

Chapter 3

Background

An awareness of the various levels of expression and communication in musical performance is helpful in order to model gestural musical expression. This chapter provides a musicological discussion of expression, cites specific examples of gestural expression and technique in drumming, and explains how musical performance is an appropriate domain for the study of kinematic expression in human figure animation.

3.1 Expression in Music

Music is one of the oldest media for human artistic expression. Interestingly, musicologists debate over what exactly that "expression" is.

Todd [52] states that "... during a performance the performer adds something not contained or explicitly in the score, this we often refer to as *expression*."

Budd [15] is careful to point out the difference between the *arousal* of emotion and the *expression* of emotion. The expression of the emotion would be that which the writer or performer contributes to the music. The aroused emotion is that which the listener experiences while listening to the music. Budd notes that these are not necessarily the same thing. For example, a "sad" piece of music may make one feel sad; alternatively, the piece may be played so poorly as to make the listener angry for wasting their time listening to it.

Allen [2] breaks down the expression of emotion in a different manner, believing that arousal theory fails to distinguish between emotions which are *evoked*, *provoked*, and *communicated*. Emotion embedded in the music which makes the listener feel the same emotion is considered to be *communicated*, as in feeling sad when listening to a sad song. Emotion embedded in the music which makes the listener feel a counterpart emotion is considered to be *evoked.* Allen provides the example that a piece of film music may arouse apprehension or fear in him, but the music would not be perceived to be apprehensive or fearful itself. Finally, emotion which the listener experiences *about* the attempt at evoking or communicating emotion is considered to be *provoked.* Feeling "disenchanted" by a poor musical performance would be a provoked emotion.

The issue of expression is fairly complex, and this thesis certainly does not seek to resolve it; that will be for musicologists [26, 29, 45, 50]. However, a review of the literature is helpful to understand some of the underlying aspects of acoustic expression in music. Further literary research revealed some interesting findings with respect to gestural expression in music.

Clarke [17] looks at how music is cognitively represented as input to a motor system. He also identifies generative principles for musical expression during performance. Clarke states that using timing, dynamics, and articulation, "... expressive gestures can perform a number of different functions: these include altering the relative proportions of events within a rhythmic group, indicating the position of a group boundary, marking a metrical accent, and creating an expressive gradient towards a focal point (that is, a pattern of directed motion)." The fact that gestures play a number of different roles in musical performance provides some explanation why there are commonly several interpretations among observers. Note that if the mentioned musical elements are inferrable from the encoded score, they can provide cues for algorithmically adding secondary movements.

Todd [52] proposes that an observer of an expressive musical performance can be made to feel as though he/she were actually moving, a condition known as *vection.* When performing musicians sway, rock, or bounce, they are engaging in what is known as *vestibular self-stimulation.* This movement affects the expression of the music (with respect to timing), which causes the audience to experience audio-kinetic vection. The end effect is that the musician is "moving" the audience.

Todd discusses evidence that the amount of swaying is dependent on the amount of expression, and that "... viewers can reliably distinguish expressive from deadpan performances on the basis of visual information alone" [19].

With respect to modelling musical performance, where the expression is embedded in the music, it should be quantifiable and encodable so that appropriate performances can be interpreted and generated. Where the expression is something that is motivated by the performer, then the user should be allowed to control the kinematics of the performance so that the piece is, in fact, "expressed" by someone. Lastly, where the expression is that which is interpreted by the audience, the quality of the movement should be sufficient to allow the animator to communicate through the movement.

3.2 Encodings of Music

How a musical score is represented forms an integral aspect of modelling a musical performance. The representation dictates what kind of information can be stored, thereby indicating what gestures can be generated directly from the score and what gestures must be controlled by the user.

MIDI (Musical Instrument Digital Interface) [6] was designed for different electronic instruments and computers to communicate among one another. The MIDI software specification includes file formats and real-time performance messages. Essentials such as pitch, volume, and duration for each onset are discretely represented. Continuous controllers are added to represent performance elements as pitch bending and tremolo. MIDI is the industry standard for musical hardware communication and musical score portability. Music archives throughout the Internet are MIDI-based.

Other digital music representations exist such as *Finale* (Phil Farrand), *Darms* (Bauer-Medgelberg, Erickson, McLean), *Score* (Leland Smith), and *Mustran* (Wnker, Byrd) [42].

SMDL (Standard Music Description Language) [42] is likely the most comprehensive musical representation system, covering aspects from the printed score to musicological discussion. SMDL covers four domains of information: *visual*, *analytical*, *logical*, and *gestural*. The visual domain contains information about the printable score, or scores, for a single piece of music. The analytical domain contains theoretical and musicological information about the piece. The logical domain contains the the actual pitches, timings, and durations which comprise the musical cantus. The gestural domain contains performance information for an arbitrary number of performances. The gestural information could be very useful for a performance modelling program. Here, qualitative and quantitative descriptions of the score can change over time and help automate the modelling process.

3.3 A Video Review of Drumming

Before modelling the movement of drummers, it is important to carefully observe and analyse their kinematics. Music instruction and performance videos provide a rich source of drumming examples and explanations from professional musicians.

The performances of eight professional drummers were analysed in order to determine what is necessary to model the kinematics of drumming. Both common elements and differences were determined. Common elements can then be automated into the modelling process. Biases or differences can be parameterized, encoded by script, or represented in some other manner for user control.

Performances of following artists were analysed: Kenny Aronoff (rock) [5], Louie Bellson (big band/jazz) [10], Jack Dejonette (rock/jazz) [20], Peter Erskine (jazz) [21], Steve Gadd (rock/latin) [23], Steve Smith (rock/jazz) [48, 49], Ed Thigpen (jazz) [51], and Dave Weckl (rock) [56].

3.3.1 Commonalities

Most of the common movements deal with the hardware of the drum kit, such as the kick pedal, hihat pedal, opening and closure of the hihat, and vibrations of the various cymbals (see Figure 3.1). The amplitudes and durations of the cymbals' vibrations are determined in part by the size of the cymbal and how hard the cymbal was struck. The surfaces of the drums sometimes reflected light differently when hit. Another very subtle motion was the vibration of a struck high or mid tom.

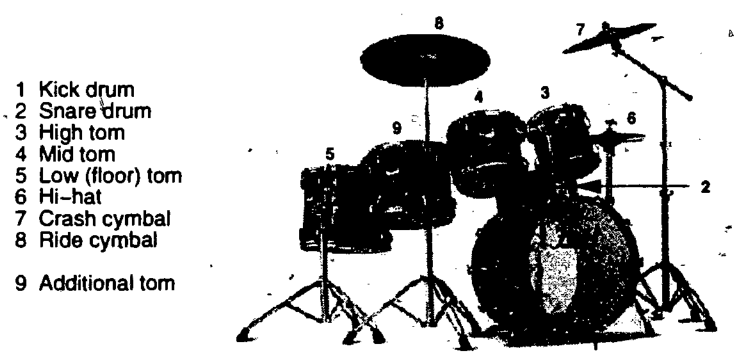


Figure 3.1: Components of a drum kit. (Photo courtesy of UBG Digital Media.)

3.3.2 Differences

Most of the differences of movement occurred in the kinematics and basic technique of each drummer. In the following discussion, it is unlikely that a professional drummer is limited to using a single technique. The point is to show that such differences do in fact exist.

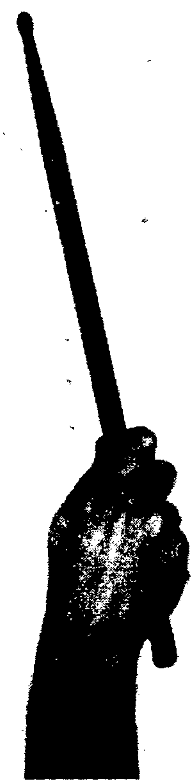


Figure 3.2: How to hold stick for matched grip or for right hand of traditional grip.

One difference is the way in which drummers hold their sticks. In the *matched* grip, each hand holds the stick "palms down." The sticks tend to point out as an extension of the forearm. With the *traditional* grip, the right stick is held as it is for the matched grip, but the left stick crosses the left hand, with the palms facing upwards. Here, the stick is more at a right angle with the forearm (see Figures 3.2 and 3.3). A different axis of rotation is used to strike with the left hand. Erskine [21], Weckl [56], use a traditional grip; Dejonette [20] and Aronoff [5], matched. Smith and Gadd gave performances with both grips.

The traditional way to play the hihat is with the right hand, as Smith, Thigpen, and Erskine do, but using the left hand has some advantages [38]. Playing the hihat or ride with the left hand avoids crossing and hitting the other hand playing the snare and leaves

Figure 3.3: How to hold stick for left hand of traditional grip.

the right hand free to play the toms while the left hand is busy. Aronoff, for example, plays this way. Gadd stated that he was so bored with the same patterns, performance after performance, that he sometimes switched and played left-handed hihats to "avoid going insane" [23]. Drummers like Aronoff typically move their ride cymbals from the right to the left of the kit to facilitate its playing with the left hand.

When playing the kick drum, music instructors will often tell students to play with the heel of the foot in contact with the ground. It is easier to control the dynamics with heels down, but many artists, including Smith and Weckl, play heels up when power is needed.

More distinguishing than particular techniques are the different kinematic styles of drummers. The movements can fall under two categories: *primary* and *secondary* movements. The primary movements are those which contribute directly to the drum stroke, such as those in the fingers, wrist, elbow, and shoulder. The secondary movements are those which do not directly contribute to the stroke, but are nonetheless an integral part of the playing style. Head bobbing and lower torso swaying are examples of secondary movement in drumming.

The difference between the kinematics of Smith and Dejonette can be readily observed. Smith keeps his sticks closer to the drums, whereas Dejonette has a higher backswing and rebound. Distinctions in secondary movements can be seen among Aronoff, Weckl, Bellson, and Thigpen. Weckl moves his head and back smoothly with the rhythm. Aronoff moves his head as well, but pulls back when playing the snare drum on beats 2 and 4. Sometimes he moves his head erratically from side to side. While commanding the drum set, Thigpen does not move his head much at all. At some points, he simply has his head lowered, completely focused on the snare drum. Bellson sometimes leans over his drums to zig zag over the ride and crash cymbals with showmanship.

Instead of playing with sticks, alternative techniques can be used. Most of the viewed drummers demonstrated the use of brushes. Thigpen additionally played the kit with his bare hands. Dejonette and Thigpen demonstrated playing with mallets, while Bellson sometimes held two sticks in each hand. Each striking method requires a different playing technique, which requires a distinct kinematic specification.

3.4 Computer Visualization in Music

Computers and music have a long-standing relationship, particularly in sound synthesis and algorithmic composition [4, 18]. Various kinds of visualization have been studied as well.

Mitroo et al. [39] map musical pitches to colours. The temporal proximities of notes in the musical score are mapped to spatial proximities of colours. Their system artistically serves to create a "visual experience" of a musical score. They were also interested in visually comparing the pieces of composers using this pitch-colour mapping.

Lamb [31] visualizes the timings and velocities of a performing student musician to analyse the accuracy of cross-rhythms. Lamb claims the program is useful because "students tend to hear the sounds they *intend* to produce, rather than what is actually played."

Software MIDI studios and music education software are examples of music visualization in widespread use [46, 63].

Music has played an integral part in traditional animation, and MIDI has facilitated even more strict ties to computer animation. The first MIDI-driven animation was "Beat Dedication," by Bob Sabiston [44, 47]. (Interestingly, this animation featured a drummer.) Brian Anderson created a more abstract MIDI-driven animation called "Alea."

Wayne Lytle [34], creator of the award-winning animation "More Bells and Whistles," used a MIDI score to drive the motion of various musical instruments. Lytle used CGEMS (Computer Graphics/Electronic Music System) to map aspects of the MIDI score to animated parameters. Some of the instruments were abstract and quite novel, such as mouth-like green pods, and circular chimes played by a shower of ball bearings. Motion was smooth, but simple. When percussive instruments such as the xylophone or drum kit were played, only the sticks or mallets were animated, without the musician.

"Lifesavers: Good Times Roll," a computer animation created by Topix Computer Graphics and Animation Inc., is an example of a successful use of MIDI-driven animation in a commercial application [44]. This television commercial shows an animated Lifesavers candy package dancing and playing a number of musical instruments. Topix was careful not to use "too much" synchronization. While the motion of the piano was MIDI-driven, the Lifesavers package which played the piano was not. Pfitzer talked to Bob Munroe, technical director at Topix. Munroe claimed that if the candy package were MIDI-driven, "... the bouncing pack would have ended up with less energy, fluidity, and character than when animated more traditionally." The intricities of the musical score would likely have caused the candy to ungracefully vibrate and would make the Lifesavers logo more difficult to read for the viewer.

3.5 Why music

Music provides an appropriate domain for expressive modelling for a number of reasons:

- Musical expression, like kinematic expression, has a number of levels of interpretation. Each can be described in terms of single events, such as a loud middle C, or a violent kick on a door (which is not necessarily the lowest level of analysis). Each can be described at a phrase or sequence level (or higher), such as a legato scale, or smoothly skating. Because the interpretation of both musical and kinematic events depend on neighbouring events, both domains are (by definition) context-sensitive.

- The domain of music is rich in expression, and the spectrum of movement in gestures of musical performance is very wide. Both subtle and strong movements (and later discovered, primary and secondary movements) are important to the modelling of musicians, just as they are to other forms of human figure animation.

- Simple elements of a musical score, such as pitch and timing information, allow for an event-driven system to be readily constructed. At the same time, complex musical scores can be created to provide interesting and challenging scores to be kinematically interpreted (either automatically, or by the user).

- With reliable, standardized representations such as MIDI, data sets are easy to create manually and are readily found in music archives such as those on the Internet.

3.6 The Challenge of Animating Musical Performance

Munroe [44] had more general comments about MIDI-driven animation: "Where MIDI falls short, and where I can always see it falling short, is in the embellishment and the personality that the animator can given an animation. You're not going to generate that from a program." Certainly no program, MIDI-driven or otherwise, can compete with the intelligence and creativity of a human animator. However, it is the claim of this thesis that expressive musical performance can be generated with careful design of the kinematic and aesthetic range of a MIDI-driven, modelled performance, combined with useful user-controllable parameters. This way, the unwieldy task of accurately animating a musical score is done automatically and instead of relinquishing control of the expression to the program, the animator has higher-level tools to effect the expression.

Chapter 4

SMED: Proposal and Approach

This chapter describes a system for specifying kinematic expression in drumming scores: SMED, system for modelling expressive drumming. SMED reads any MIDI-encoded drum score and in real-time renders a 3D animation of a drummer's performance of that score. It allows the user to modify the frequency and amplitude of wrist, elbow, and shoulder rotations in order to affect the perceived expression of movement.

4.1 Features

4.1.1 Interface

Upon running SMED, the user is presented with a viewer window and a column of buttons (Figure 4.1). Each button opens up a new window with a set of related controls. The interface was designed so that the user could see as few or as many controls as desired.

The main rendering area is an Inventor Examiner Viewer [57]. This viewer displays the animated drummer and drum kit and provides complete viewpoint control for the user with zoom, pan, and rotation controls. Up to eight individual viewpoint settings can be stored and recalled in the View Flags window.

The transport button displays a window with a time counter and standard playback controls: play, stop, beginning of song, end of song, fastforward, and rewind (Figure 4.2). Additional forward/reverse step controls are provided to allow the user to view the animation in step-time. The size of the step is changeable as well. A reverse playback toggle and playback speed slider help the user to analyse the animation. The song flags button controls

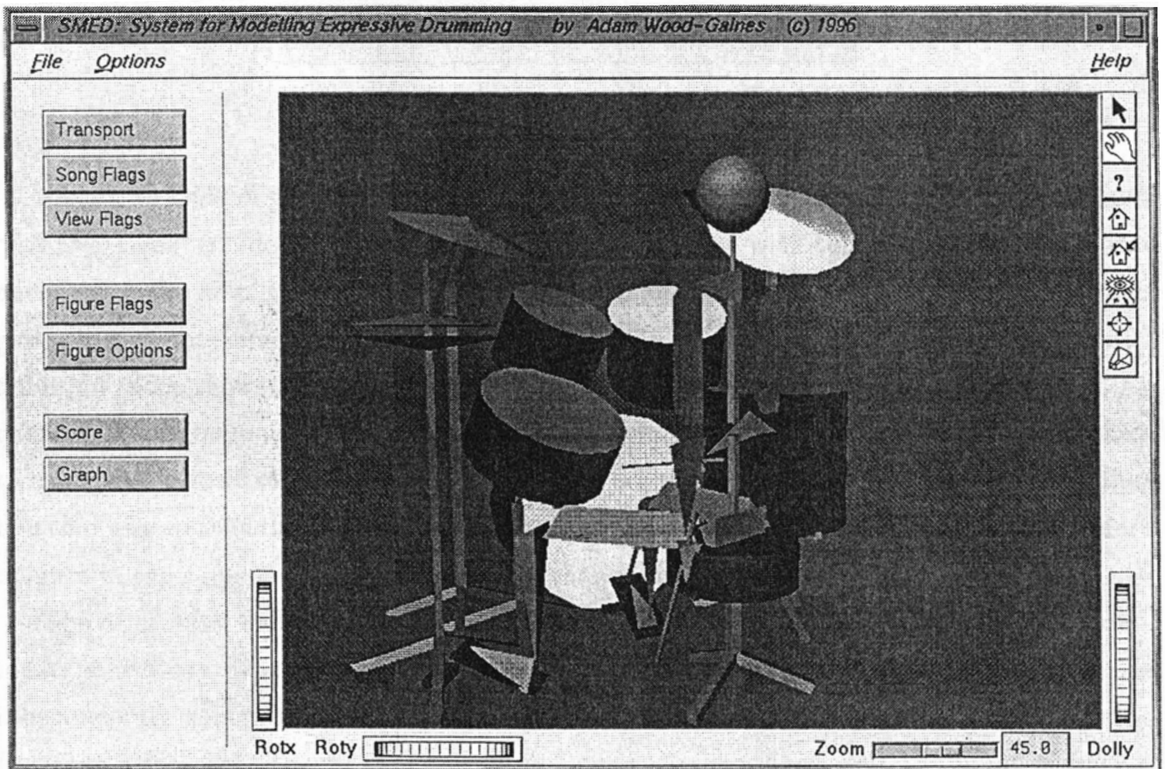


Figure 4.1: Main window and viewer of SMED.

a window to store up to eight key song positions to be set for quick absolute positioning in a song.

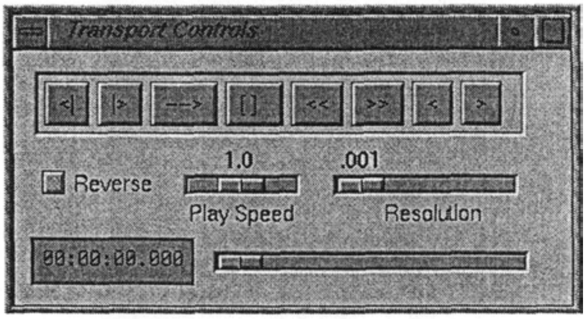


Figure 4.2: Transport control window of SMED.

Sliders to control the kinematic expression of the drummer are grouped in a separate "figure options" window (Figure 4.3). The user is provided with controls to modify the frequency and the amplitude of the wrist, elbow, and shoulder joint rotations. The amplitude gain slider proportionally changes the amplitudes in all three joints. Each amplitude distribution slider shows the percentage of the amplitude gain attributed to the corresponding channel. Changing one channel's distribution by an amount A causes the other two channels to change by a total of $-A$. This inverse change is shared proportionally between the other two channels so that the ratio between these two channels is constant. The frequency sliders operate in the same manner, but affect the channel frequencies.

The drumming movements are complemented with head bobbing and lower back movements which are synchronized with the beat. The amplitudes of these movements are independently controllable. The beat length and number of beats per bar can be inferred from the MIDI file. Tempo changes are not currently processed, but the point of having these movements is to illustrate the effectiveness of incorporating secondary movements into the animation. SMED could be readily modified to accommodate tempo changes, but most MIDI scores (at least the ones tested) tend to be free of tempo changes. A separate window allows eight different kinematic settings to be stored, which can additionally be saved to file.

SMED has two other windows which are animated. The score window displays the drum score scrolling across the screen as it is played (Figure 4.4). This feature helps users to correlate between the score and the animation. To reduce rendering time, notes are represented by simple geometric shapes such as rectangles and diamonds. The glyphs are

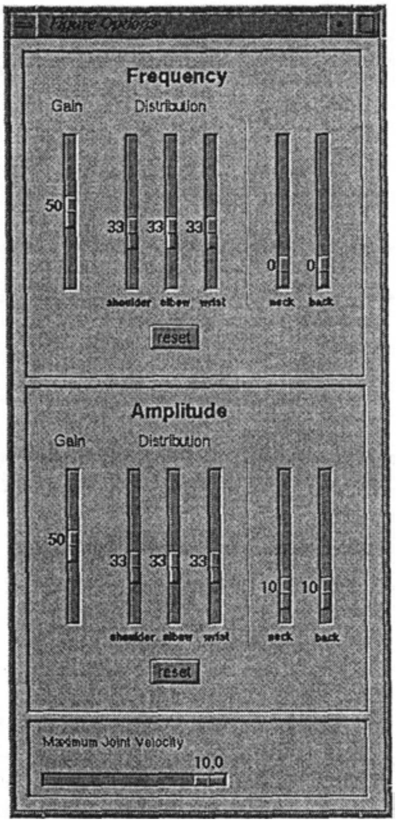


Figure 4.3: Figure options window of SMED.

placed on their proper place on the musical staff and are coloured to help visualize the score. A four second lookahead and four second history is divided by a red bar to indicate the currently played notes.

The graph window displays a scrolling plot of the shoulder, elbow, and wrist angles (Figure 4.5). The primary purpose of the window is to show a user how the score and changes in the UI affect joint angles. The joint angles are colour coded and superimposed so that they can be visually compared.

4.1.2 Scripts

SMED can be tailored by editing particular script files. The body model is stored in a text Inventor file where limb lengths can be changed and geometric detail can be added where desired. The fundamental hierarchical structure of the figure must not change (Figure 4.6), otherwise assumptions about the structure of the drummer will be false, resulting in

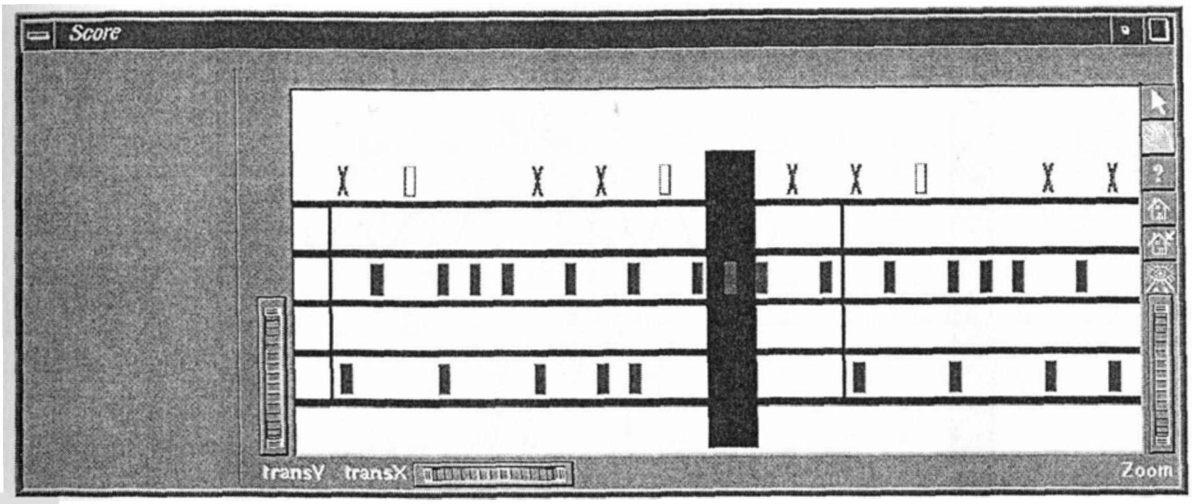


Figure 4.4: The score window of SMED shows a scrolling score during playback. The thick black vertical line in the middle shows the current position in the song.

incorrect movements.

The kit script contains information to specify the setup of the drum kit (Figure 4.7), such as the size, location, and orientation of each drum (Figure 4.8). The primary purpose of the kit script was to facilitate the kit specification during development. The script can be edited to generate other kits, but there are some limitations to what can be changed. A fixed number of animated channels was created to keep interactive speeds and high frame rates. These channels, such as cymbal vibration and skin highlighting, make assumptions about the existence of particular drums. Also, the hand assignment algorithm is based on a MIDI standard drum setup, so it will take some programming effort to dynamically allocate animated channels and create hand assignments for arbitrary kit setups.

The sample assigned to each drum can be changed by loading different audio kits. Each audio kit is a list of digital audio files which is stored in parallel with the list of drums in the kit script. Each drum can have a different number of *variations*. For example, a hihat has three variations: open, closed, and pedal. A floor tom may have only one variation. Each variation has a corresponding MIDI note number as well as a proper audio sample.

MIDI incorporates the velocity (volume) of each note, which can simply be sent to the MIDI port during the playback of the animation. However, a digital audio sample must first be scaled to achieve the proper volume. To do this, each word of the sample must be multiplied by some scalar. Samples of up to 200,000 words can be required for sustained

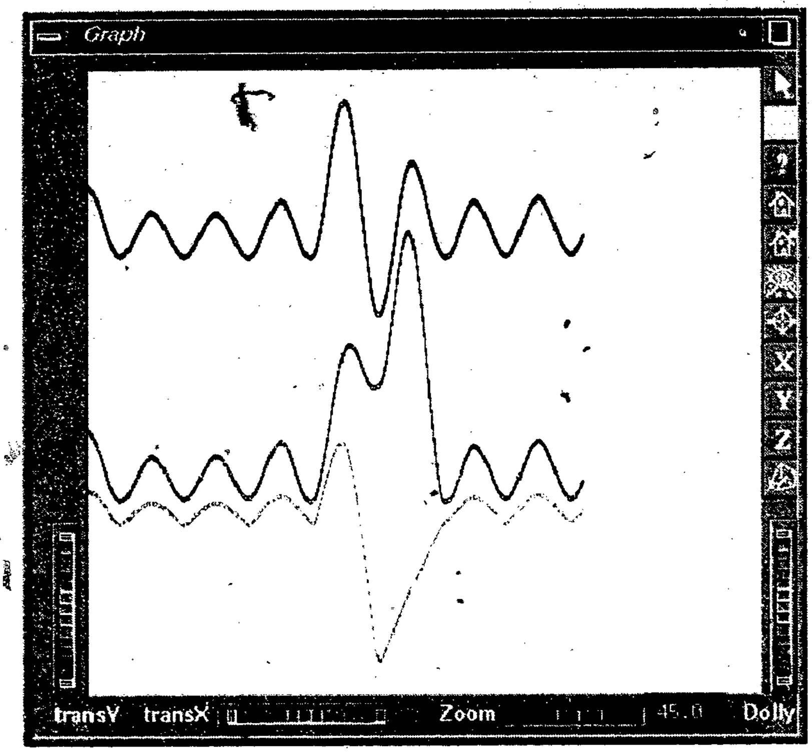


Figure 4.5: Graph window of SMED.

instruments like crash cymbals, and scaling these in real-time with acceptable frame rates is not possible. Therefore, samples are scaled and stored for quick recall during playback. This is a compromise between space and time, but is well worth the improvement in performance. To lessen the impact of the space requirements, each drum can have a different number of prescaled samples. This quantity will be called the audio *resolution* of a drum. Short samples like the snare drum can then have a high resolution to reflect sonic subtleties, while long samples like the crash cymbal can have fewer levels of dynamics to save memory. The resolution is specified with each drum in the kit script.

When changes in scripts violate programming assumptions, creating errors such as a limb not being able to reach a drum for a specific onset, error messages are displayed.

4.1.3 Automation

Several tasks are done for the user to facilitate the creation of data sets and to aid in the visualization of the scores.

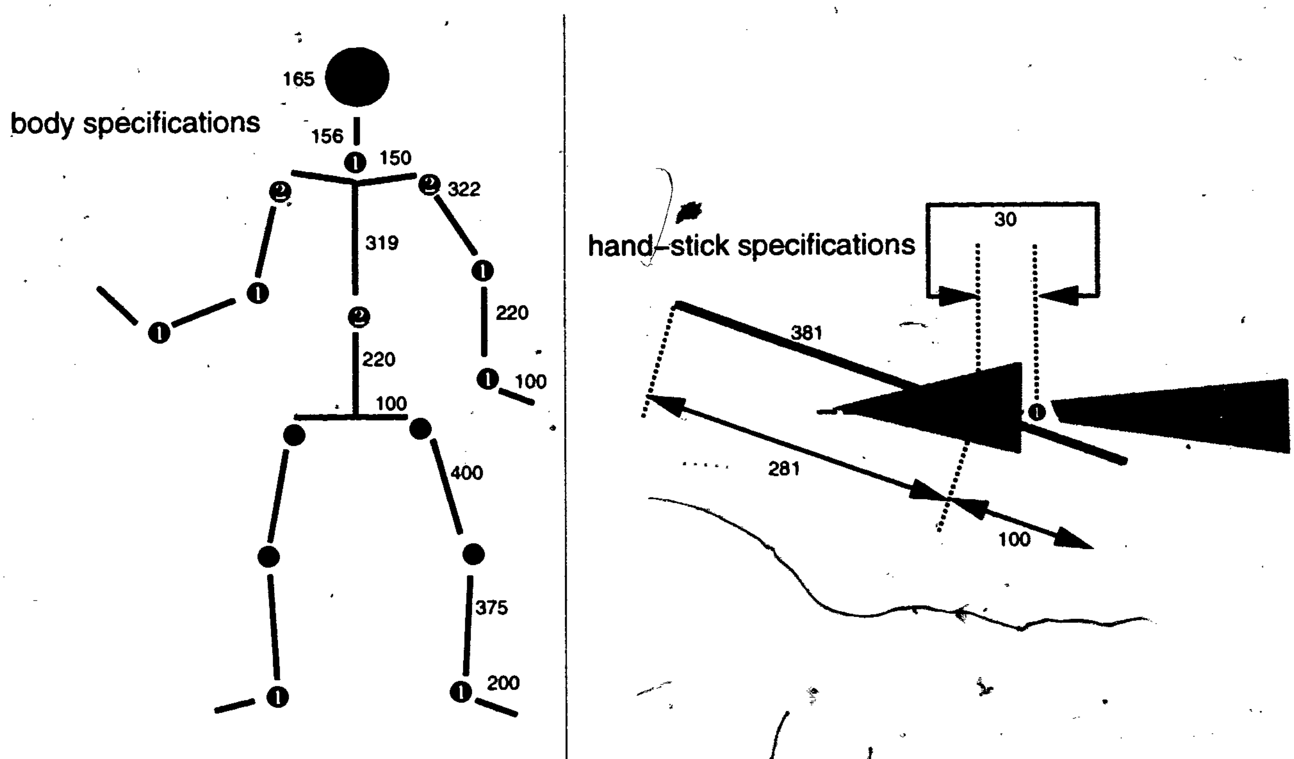


Figure 4.6: The segment lengths (in millimeters) of the used skeleton and number of animated degrees of freedom for each joint are shown. The body is symmetrical in the segment lengths and animated degrees of freedom.

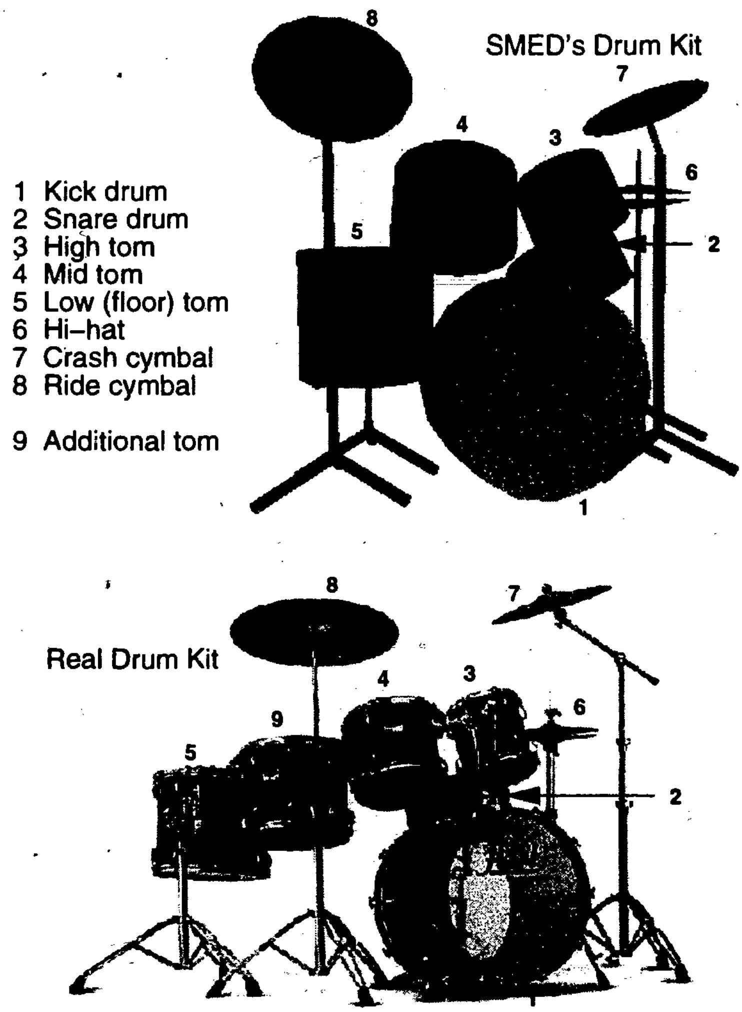


Figure 4.7: Components of SMED's 3D modelled drum kit and similar real drum kit. (Photo courtesy of of UBG Digital Media.)

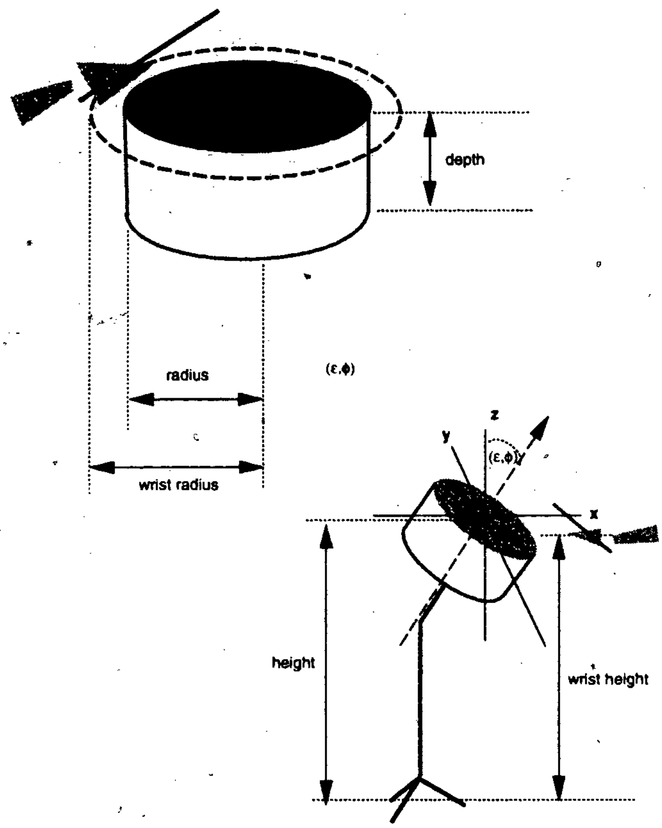


Figure 4.8: The depth, radius, height, orientation, wrist radius, and wrist height are defined for each drum in a kit definition file. The orientation of the drum is given by two angles, ϵ and ϕ, which describe the rotation of the drum about the x and y axes, respectively.

- A utility called *mid2scr* converts a MIDI file to SMED's score format. The score is in a text format so that hand assignments can be modified by the user, and test files can be created without a MIDI sequencing program.

- The limbs are animated so that notes encoded with higher velocities are played with greater stroke amplitude. Sequences of notes which occur very close together are played with attenuated amplitudes.

- Drum skin highlighting, cymbal vibration, foot pedal movement and hihat opening/closing provide visual cues to accompany the score being played. They also serve to simulate movements which occur in live performance.

- The amplitude of the head bobbing changes based on the velocity and density of the played notes. The head and back movements oscillate to the beat of the music and thus provide a visual cue for tempo.

4.2 Algorithms

A design goal for SMED was that the system could respond quickly to changes in the UI. SMED relies on an adaptation of keyframing where some keyframes are generated on the fly in response to user specifications and others are computed in advance to reduce run-time overhead.

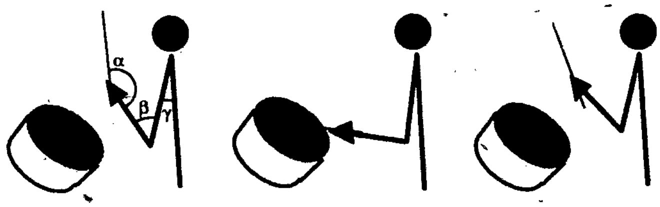


Figure 4.9: Illustration of limb positionings for calculated keyframes. The preparation keyframe (p) shows the considered angles of rotation: wrist, α; elbow, β; shoulder, γ.

The basic drumming stroke can be defined using three keyframes: a *preparation* keyframe that readies the arm, a *strike* keyframe for when the stick is in contact with the drum, and a *rebound* keyframe that defines how far back the arm moves at the end of the stroke (Figure 4.9). Intermediate joint values are calculated using CTB spline interpolation [30]. By manipulating the continuity, one may readily obtain desirably smooth motion, as well as model stick-drum impacts.

SMED creates the preparation and rebound keyframes at run-time, and these are processed with adjacent strike keyframes for interpolation. Changing the amplitude sliders affects the rotational values stored at the preparation and rebound keyframes, whereas changing the frequency sliders affects the relative locations of the keyframes. Increasing the amplitude increases the range of movement during both the preparation and rebound phases. Increasing the frequency reduces the time between the preparation and strike frames and that between the strike and rebound frames, adding a "snap" to the strike motion.

Neighbouring strike frames, which are time-stamped according to the score, may be so close that the keyframing algorithm will combine the rebound and preparation keyframes into a single keyframe. If strike frames are even closer, amplitudes are attenuated (Figure 4.10). This reflects an observation (and personal musical experience) that drummers tend

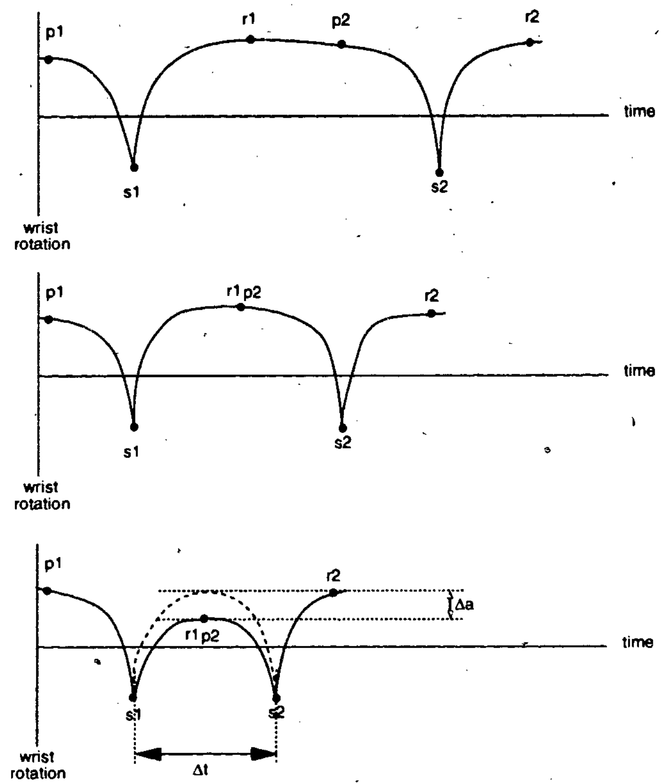


Figure 4.10: Due to the proximity of strike keyframes s1 and s2, rebound frame r1 and preparation frame p2 are represented by a single keyframe. Continuing to move s1 and s2 together causes attenuation in the rotation. The amount of attenuation Δa increases as Δt decreases.

to shorten stroke lengths for quick sequences of notes.

All of the strike keyframes are precomputed and stored since they are independent of the frequency and amplitude settings. This avoids numerous trigonometric calculations at run-time.

4.2.1 Kinematic Computations

Once the MIDI file has been converted to SMED's score format (discussed later), a number of passes is made of the score to calculate joint angles. Figure C.1 serves as a reference for trigonometric calculations.

Torso Twist and Swaying

The movements of the back rocking and twisting affect the position of the shoulder and hence other joints in the heirarchy (Figures 4.11 and 4.12). For this reason the keyframes of the lower back are calculated first.

The torso twist angles (those about the z-axis) are calculated to face the drummer in the general direction of drumming activity. The drummer attempts to face each hit drum head-on (Figure 4.11). The angular velocity of the back has a ceiling so that unnatural, abrupt motions are not produced.

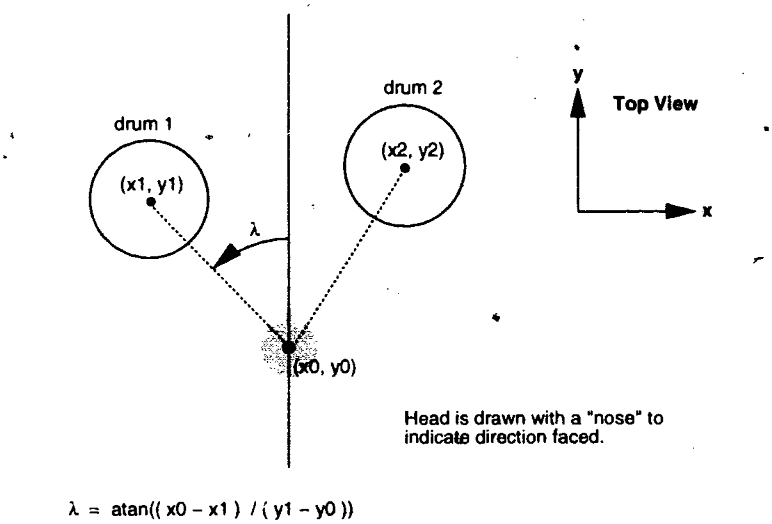


Figure 4.11: The drummer attempts to face each drum at the point of stick impact. To play drum 1, the drummer attempts to face it at an angle of λ. Calculations shown are precomputed.

The oscillation of the lower back (rotation about the x-axis) is created by using two keyframes for each beat of a score. One keyframe brings the upper torso down on the beat, the other puts the upper torso upright between beats. For the swaying movement of the back (and neck), frequency is *simulated* by manipulating the control, tension, and bias of the interpolating CTB spline.

Head Bobbing

Although the neck keyframes do not affect other joint positions, they are calculated at the same time since the logic is similar to that of the back. Two keyframes are used for the

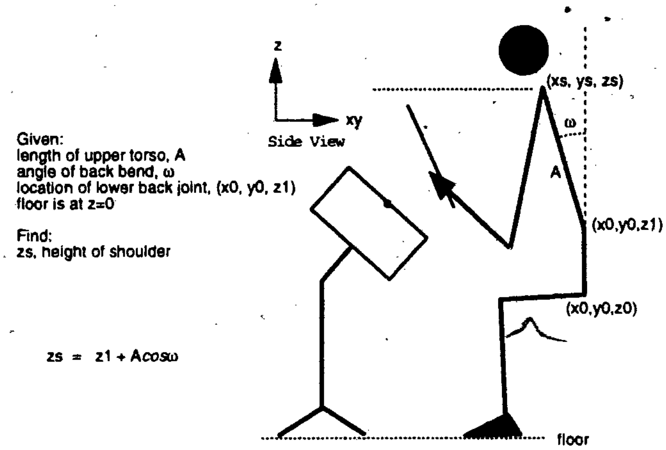


Figure 4.12: Formula for determining the height of the shoulder. ω changes over time as the back oscillates to the beat.

neck for each beat of the score, and frequency is simulated as it is for the lower torso. But the amplitude of the neck is not completely controlled by the user as it is for the back. The amplitude of the head is algorithmically determined based on the MIDI velocity of the notes at the head bob and the number of surrounding notes.

At the neck keyframe on the beat, a *bobbing factor* is stored to scale the user-selected amplitude. The bobbing factor is composed of two cofactors: the *velocity* cofactor and the *density* cofactor.

The velocity cofactor considers the onsets of the kick, snare, toms, and crash cymbal within a narrow time interval of the downbeat. The ride cymbal and hihat are not considered since their contribution to the musical dynamics is more subtle. The currently used strike range has a radius of 25 milliseconds. The average velocity of all onsets within the interval is calculated. This way, two loud onsets will give a higher cofactor, and hence a greater head swing, than one loud and one soft onset. Ten percent is added to the cofactor for each note in the strike range. This way, two loud onsets will produce a higher cofactor than one loud onset, and the overall dynamics of the score is reflected by the bob of the neck.

The density cofactor considers all onsets between the edge of the strike range and the midbeat on either side of the beat. Basically, the more drumming activity around the beat, the less the amount of head bobbing. In this way, the drummer will not bob his head so violently during drum rolls, and deeper head swings will occur at points where the beats are marked with rest. The closer the rest space is to the beat, the higher it is weighted because if activity clustered near the midbeat, the drummer would still have time to bob his head.

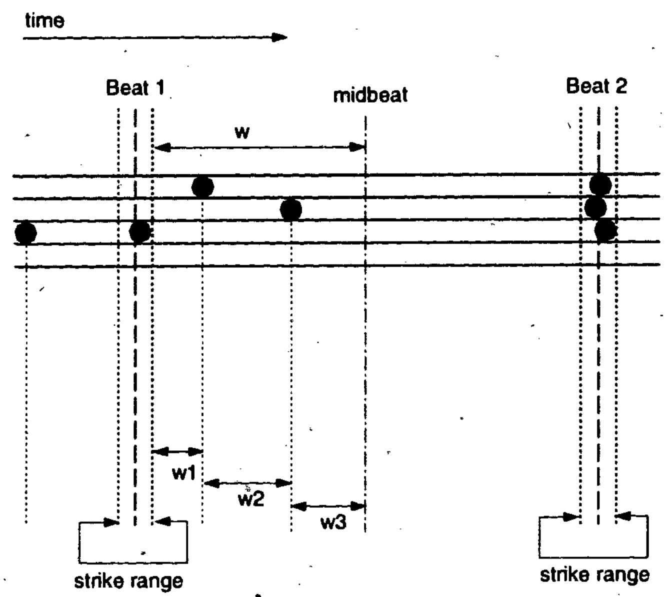


Figure 4.13: Illustration showing section score and onsets. Assume that each onset has the same velocity. The head bob for beat 1 will have a lower amplitude than that for beat 2 for two reasons: (a) beat 1 has only one note in its strike range, whereas beat 2 has three, and (b) the intervals before and after beat one are divided by onsets, whereas beat 2 has an interval before it which will result in the maximum value for a density cofactor. Interval w is divided into three subintervals, $w1$, $w2$, and $w3$, by two onsets.

Consider an interval on one side of the beat of w seconds (Figure 4.13); n onsets divides the interval into $n+1$ subintervals with lengths of w_1 to w_{n+1} seconds. The weight of interval i will be $w_i/(1+ic)$, where $c >= 0$; c is a constant that determines the affect of the proximity of the rests to the beat. A c value of 0 will cause rests to be weighted strictly by their length in time. A "useful" c value will be in the neighbourhood of 0.5 to 3.0. The $n+1$ weights are summed and divided by w to yield a density cofactor between 0 and 1. The interval on each side of the beat is calculated, and the higher factor is taken.

Shoulder Location

Once torso rotations have been determined, the location of the shoulders and the angle required to point the arm at the centre of the drum for each onset are determined. This is done trigonometrically, and is described in Figures 4.14 and 4.15.

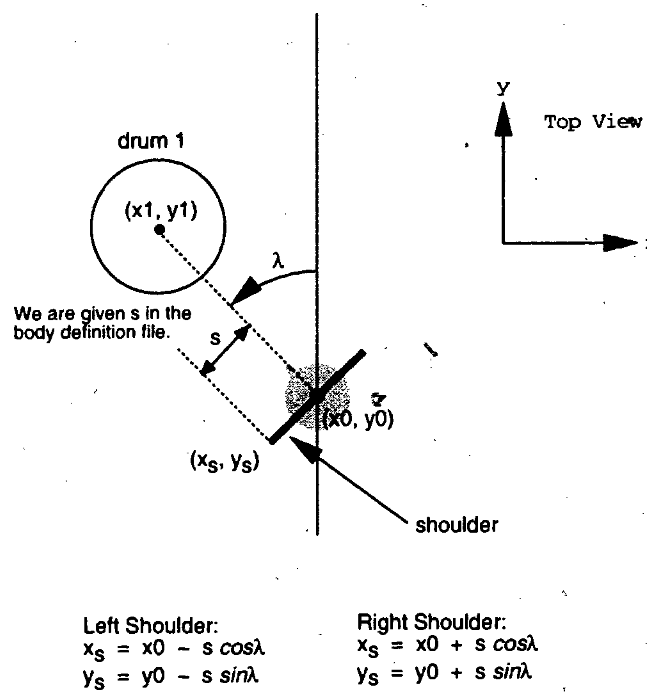


Figure 4.14: Formulae for determining the location of the shoulder in the x, y plane. $(x0, y0)$ represents the coordinates of the base of the neck. λ represents the angle of rotation of the torso, which may or may not be directly facing a drum as shown here.

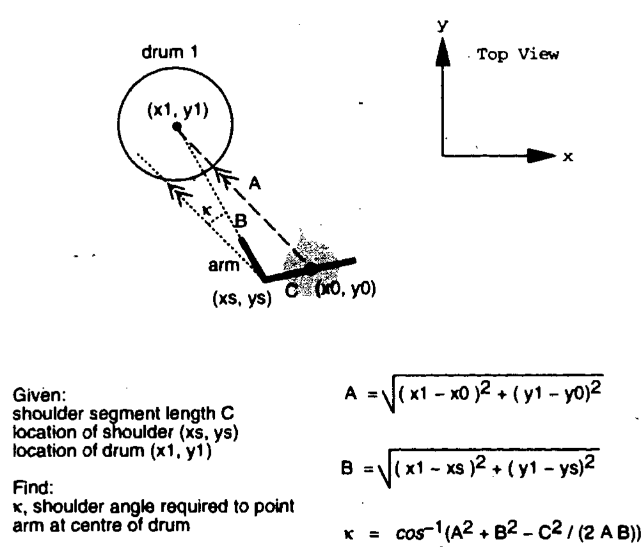
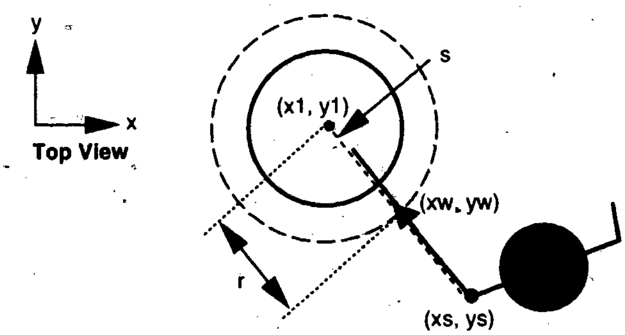


Figure 4.15: Formulae for determining κ, the angle which the shoulder twists about the z axis.

Wrist Location

The location of the wrist for each onset is then determined. The kit script explicitly states the height of the wrist for each drum. The x and y coordinates of the wrist are determined by the intersetion of the line connecting the centre of the drum to the shoulder and the circle of a radius specified in the kit script (called the *wrist radius*). The z coordinate of the wrist is also defined in the kit script (called the *wrist height*). Figures 4.8 and 4.16 provide details.



s is xy distance from the shoulder to the drum:

$$s = \sqrt{(x1 - xs)^2 + (y1 - ys)^2}$$

a shows how close the wrist is to the centre of the drum along s:

$$a = r / s$$

Location of wrist:

$$xw = x1 + a * (xs - x1)$$
$$yw = y1 + a * (ys - y1)$$

zw is given as the wrist height for that drum

Figure 4.16: The distance between the wrist and the centre of the drum projected on the xy plane is given by the wrist radius (r). The line segment connecting the centre of the drum and the shoulder projected onto the xy plane is represented by s. The x and y wrist coordinates are yielded by the point found a distance of r from the centre of the drum along segment s. The z wrist coordinate is given by the wrist height (h) for the associated drum.

Knowing the locations of the wrist and the shoulder, the required elbow and shoulder angles can be deterimined. The wrist angle is computed as the angle required to bring the stick to the plane of the drum surface. By keeping the stick, lower arm, and upper arm coplanar throughout the stroke, the movement is sufficiently constrained to avoid requiring inverse kinematics [24], although some range of motion is compromised. This direct, analytic approach is efficient and real-time animation is readily achieved.

Elbow Angle

Once the locations of the wrist and shoulder are known, the angle of the elbow can be determined. The distance between the elbow and the shoulder is known, as well as the forearm and upper arm segment lengths. The triangle can be solved for the elbow and shoulder angles, as Figure 4.17 shows.

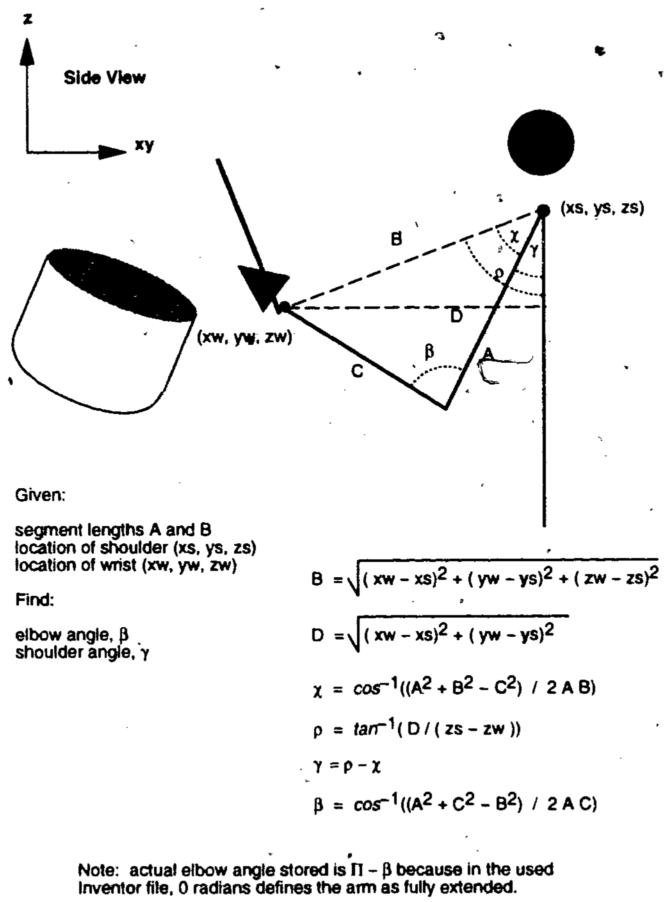


Figure 4.17: Formulae for determining the remaining elbow and shoulder angles.

Wrist Angle

The remaining angle to be determined is that of the wrist in order to place the tip of the stick on top of the drum head (Figure 4.18). The plane of the face of the drum is determined. The coordinates of the tip of the stick are then evaluated as the angle of the wrist changes. When the tip of the stick crosses the plane of the drum head, an approximation of the contact point has been found, and the associated wrist angle is stored.

4.2.2 Hand Assignment

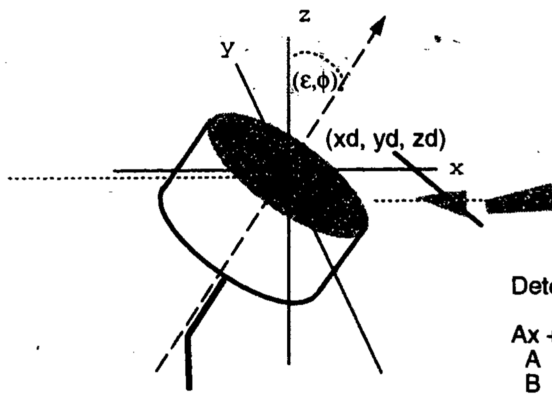
SMED requires a solution to the interesting problem of determining a limb assignment for each onset since MIDI does not encode this information. To achieve a "good" hand assignment, one should keep in mind that "[a musician's] actions can be characterized by ease of execution, accuracy, repeatability, fatigue, and response" [60].

A common technique drummers use to reduce fatigue is to alternate hands while playing. This is commonly observed while sixteenth-note hihats or tom fills are played. However, alternation is not a strict rule. For simple, repeated patterns which typically involve the snare in combination with the hihat or ride cymbal, limbs are "stationed" at specific instruments. One hand (usually the left) will hover near the snare while the other plays the hihat or ride. Developed muscular control allows advanced drummers to quickly and repeatedly play the hihat or ride with one hand, but there is typically some "threshold" at which the left hand will alternate with the right to help play some notes.

When determining an appropriate hand assignment, it is desirable to minimize the distance hands need to move and reduce the number of crossovers (where the left hand is playing to the right of the right hand).

Pattern Matching

One possible approach is the use of pattern matching. If the score could be expressed as a combination of drum patterns within a database, it may be possible to achieve a hand assignment by simply using the assignments stored with the individual patterns in the database. Researchers have used pattern matching in a small corpus to assign fingerings to single-voice keyboard music [41]. Note that this method may produce undesirable results if the body must make awkward movements *between* patterns. Also, the pattern matching method is limited to pieces consisting solely of patterns in the database.



Given:
centre of drum, (xd, yd, zd)
tilt of drum about x axis, ε
tile of drum about y axis, φ
location of wrist, (xw, yw, zw)

Determine plane of drum head:

$Ax + By + Cz + D = 0$, where

$A = \sin\phi \; \cos\varepsilon$

$B = -\sin\varepsilon \; \cos\phi$

$C = \cos\varepsilon \; \cos\phi$

$D = -(A\,x1 + B\,y1 + C\,z1)$

Given:
length of stick from palm centre to tip, S
distance from palm centre to wrist, h
angle of stick in palm about x axis, μ
angle of wrist about x axis, α
angle of elbow about x axis, β
angle of shoulder about x axis, γ
angle of back about x axis, ω
angles of back and shoulder about z axis (twist — not shown), τ

Find:
α, angle of wrist required such that the tip of the stick touches the surface of the drum

$$b = \sqrt{h^2 + s^2 - 2\,h\,s\,\cos(\pi - \mu)}$$

$$xt = xw - b\,\sin(\alpha + \beta + \gamma + \omega + \mu)\,\sin\tau$$
$$yt = yw + b\,\sin(\alpha + \beta + \gamma + \omega + \mu)\,\cos\tau$$
$$zt = zw - b\,\cos(\alpha + \beta + \gamma + \omega + \mu)$$

Wrist angle α is varied until tip of stick crosses plane of drum face (when $Axt + Byt + Czt + D$ changes sign).

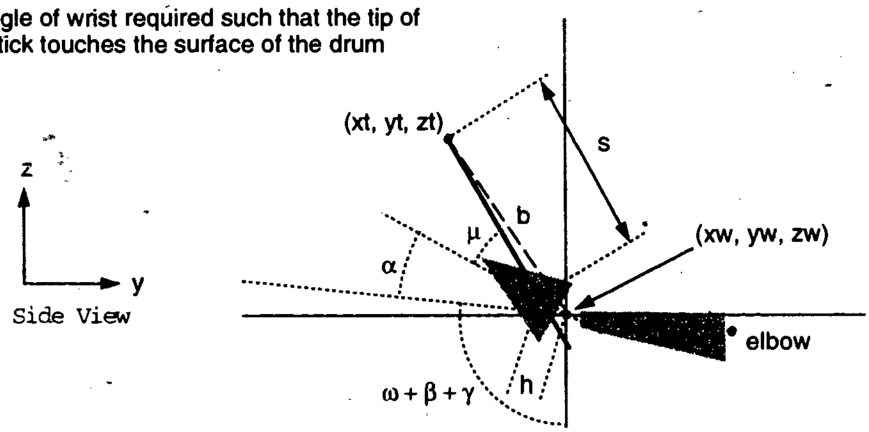


Figure 4.18: Formulae for determining the angle of the wrist.

Production Rules

Production rules could map strings of notes to hand assignments. There is often more than one way to play a given string of notes, but there is usually a preferred way. Each rule could be weighted so that higher-weighted rules are preferred, but lower-weighted rules will be chosen if a combination of higher-weighted rules cannot coexist. Production rules would be appropriate because they could be added, removed, and modified easily once the production rule engine is in place.

One problem with production rules is that the produced solution may have a feasible, but "odd" hand assignment. For example, hi-hats may be played by the left hand for a measure, and then switch to the right hand for another measure.

Determining the weights of each rule is a non-trivial task. Aspects of timing, position, and fatigue contribute to the weight of an assignment and their influence on the weight must also be considered.

Constraint Satisfaction Problem

It may be possible to solve the assignment problem as a constraint satisfaction problem. In terms of the well-studied Scheduling Problem:

- the hands are resources
- the drum strokes are tasks
- the MIDI file contains a clearly specified list of task times (the schedule)
- physical limitations of the body would serve as additional constraints (such as for crossovers)

The difficulty of this approach is having to *specify the constraints* so that where more than one possible assignment is possible, the optimal one will be chosen.

Implemented Approach

A hybrid algorithm was ultimately used to assign limbs to onsets so that programming effort could be directly applied to the given task rather than in implementing, say, a production rule engine. The "knowledge" is embedded in the algorithm directly. Although this is not a general solution to include other instruments such as the piano, it serves well enough to process simple drumming scores so that SMED's features can be tested.

This algorithm (Figure 4.19) runs in $O(n)$ time, where n is the number of onsets in the score. This is in the spirit of the computational "economy" of SMED. The algorithm makes multiple passes on the score. An onset is assigned a limb during one of the passes. During the first pass, hard-coded assignments are considered. For example, pedal hihats and kick drums can be expressly assigned to the left and right feet, respectively. During the second pass, onsets whose difference in time is below a certain threshold are assigned to different limbs. The third pass is a backwards traversal that ensures that onsets are assigned to properly lead in to sequences of quick notes. Now that sections of the score which require alternating hands have been assigned, the fourth pass is free to assign the dominating limb for each of the ride, hihat, and crash cymbals. The fifth pass simply assigns alternating hands to the remaining drums.

Figure 4.20, 4.21, and 4.22 demonstrate how the algorithm works. One of the non-optimal results of the algorithm is also shown in Figure 4.22.

This algorithm incorporates knowledge of drumming styles specific to rock and jazz. Certain assumptions are made to simplify the assignment process. The algorithm is based on a "standard" kit layout, with a snare, hihat, crash cymbal, high tom, mid tom, ride cymbal, and floor tom positioned clockwise in front the drummer. This is typical for drummers playing right-hand ride, but the crash and ride would be switched for a drummer playing left-hand ride. A better algorithm would incorporate the geometry of arbitrary kits, and possibly the geometry of the drummer. Also, double strokes (playing two notes quickly with the same stick) could be considered to help lead fills.

4.3 Design Decisions

4.3.1 Kinematics vs. Dynamics

Dynamic control of movement would be attractive because of the natural motion created. The velocity parameter in the score could be mapped to the force exerted by the body on the drum to vary the motion. The most important aspect of control is having the stick strike the surface of the drum. A constraint-based approach could be used to specify each onset as a temporal and positional constraint. Accurate collision detection could be used to model stick-drum impacts.

Hand Assignment Algorithm

```
Input: Score without limb assignments.
Output: Score with limb assignments.

THRESHOLD = minimum time between two onsets in order to be
            played by the same hand; otherwise, must alternate hands

BEGIN Assignment

First pass: hard-coded assignments

For each note, if note is
 kick drum:   assign to right leg
 pedal hihat: assign to left leg
 ride cymbal: assign to right hand
 other:       mark note as unassigned

Second pass: alternate hands for quick notes on different drums

note1 = first note not assigned to a leg
note2 = next note not assigned to a leg

while note1 is not the last note
 if note2 has not been assigned
  if the time between note1 and note2 is below THRESHOLD
   if note1 has been assigned
    assign note2 to the opposite limb
   else
    if note1 and note2 are not the same drum
     assign the left arm to the note for the drum on the left
     assign the right arm to the note for the drum on the right
    else
     don't assign note1 or note2 yet

 note1 = note2
 note2 = next note not assigned to a leg
end while

Third pass: propogate assignments backward for quick notes on same drum

note1 = last note not assigned to a leg
note2 = previous note not assigned to a leg

while note1 is not the first note
 if note2 has not been assigned
  if the time between note1 and note2 is below THRESHOLD
   if note1 has been assigned
    assign note2 to the opposite limb
   else
    if note1 and note2 are not the same drum
     assign the left arm to the note for the drum on the left
     assign the right arm to the note for the drum on the right
    else
     assign right arm to note closer to 8th/16th/32nd note division
     assign left arm to other note

 note1 = note2
 note2 = previous note not assigned to a leg
end while

Fourth pass: make hard-coded assignments to notes of specific drums

For each unassigned note, if note is:
 hihat:        assign to right arm
 crash cymbal: assign to right arm
 low tom:      assign to right arm

Fifth pass: alternate limbs for remaining notes

For each unassigned note,
 assign the opposite limb of that of the previous note
```

Figure 4.19: Hand assignment algorithm.

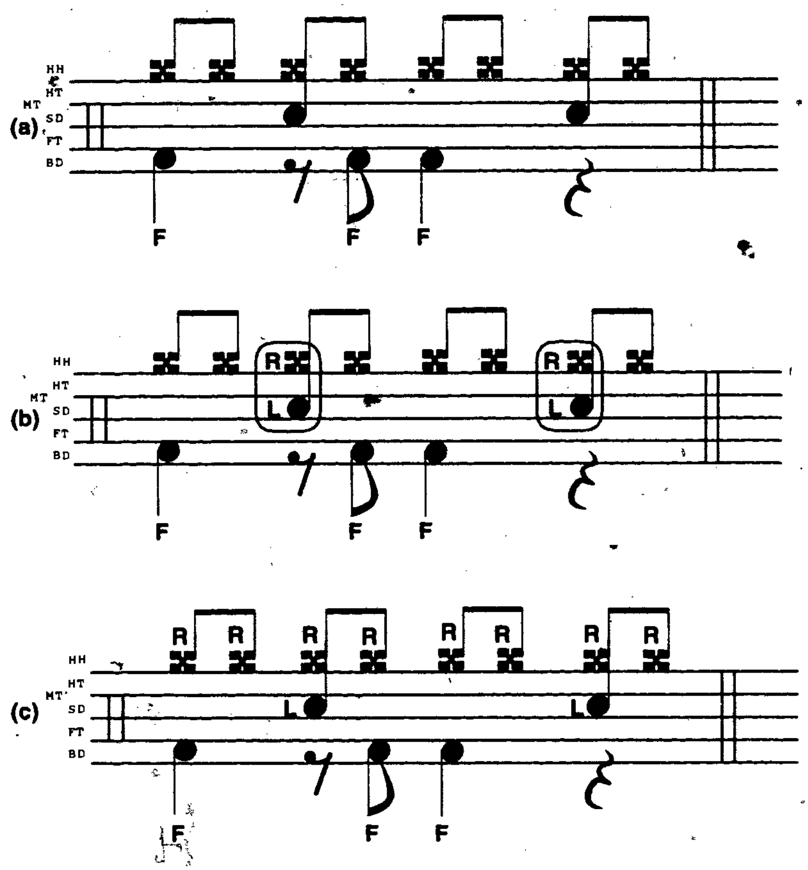


Figure 4.20: A standard drum pattern is processed by the limb-assignment algorithm. In (a), hard-coded assignments, such as the foot pedals, are made in the first pass (shown by marking assigned onsets with an F). In (b), notes within a certain distance in time (circled), are assigned to different limbs if the onsets are on different drums in the second pass (shown by marking assigned onsets with L and R). In (c), remaining notes which can be played by a fixed limb are assigned in the fourth pass.

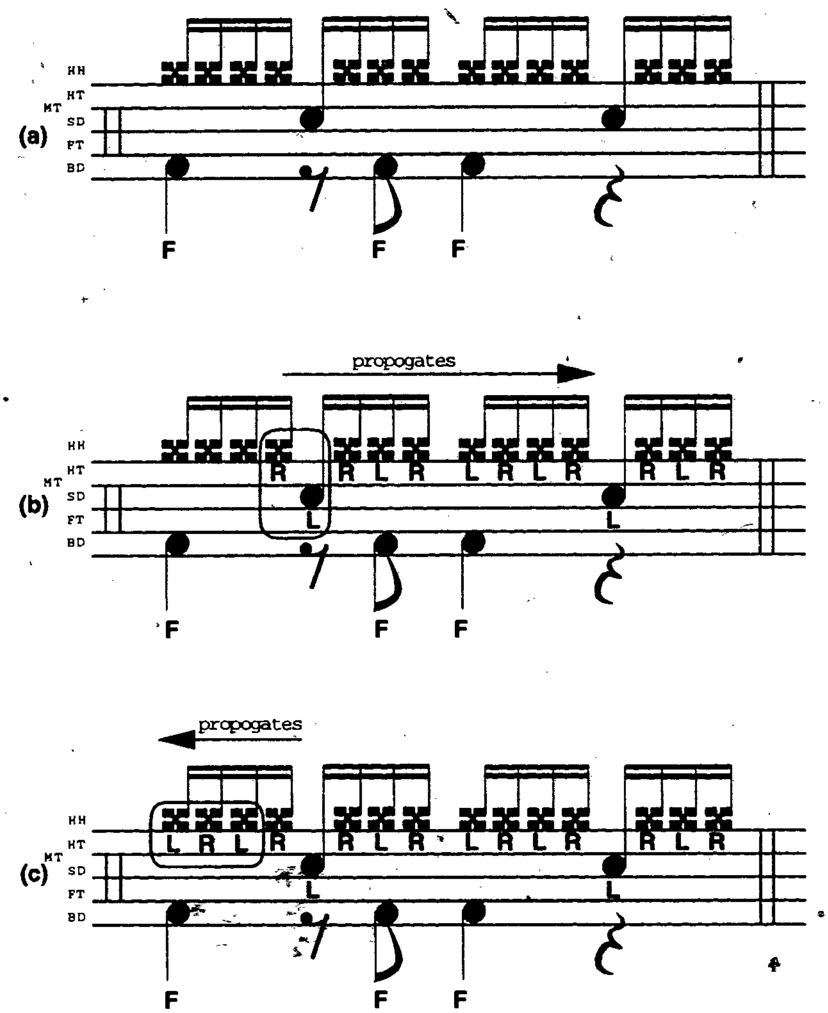


Figure 4.21: Another standard drum pattern is processed by the limb-assignment algorithm. In (a), hard-coded assignments, such as the foot pedals, are made in the first pass. In the second pass (b), notes within a certain distance in time (circled), are assigned to different limbs if the onsets are on different drums. The sixteenth notes at the beginning of the measure are skipped because they are the same drum, and a local onset has not been assigned to provide context. The sixteenth notes after the first snare hit are assigned since the first snare onset provides a starting point for alternating hands. In the third pass (c), notes within a certain distance in time (circled) are assigned, propagating changes backwards through the score.

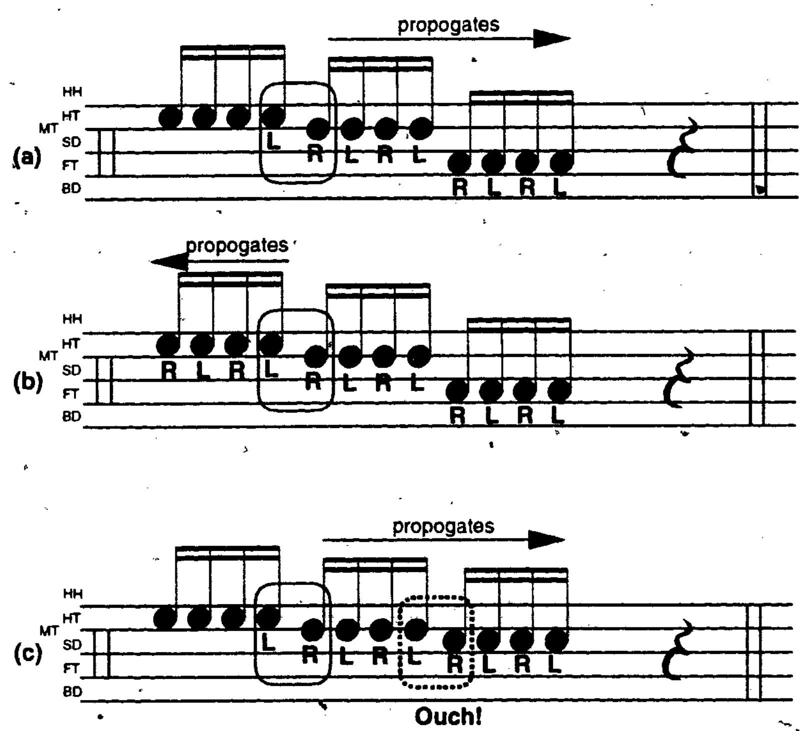


Figure 4.22: A drum fill is processed by the limb-assignment algorithm. In the (a) second and (b) third passes, an optimal hand assignment is produced. The fill consists of sixteenth notes from the high tom, to the mid tom, to the floor tom, which are typically situated in the drum kit from left to right. However, a non-optimal assignment may be produced, as in the example illustrated in (c), where the floor tom onsets are replaced by snare onsets. The forward propagation of the hand assignment causes the left hand playing the high tom to be crossed-over by the right hand playing the snare drum. Such crossovers are visually interesting. However, they would not be suitable in an educational setting.

However, dynamic methods are computationally expensive, and particularly so in an interactive environment such as SMED. As users change the expression, the underlying equations which define the motion will also change. It is unlikely that stable solutions could be reached at interactive speeds.

Consequently, SMED uses a keyframe system whose frames are determined using forward kinematics. A kinematic system is relatively simpler to implement since movements can be designed and implemented independently. For example, adding a foot movement to play a closed hihat will affect the distribution of forces on the body in a dynamic system. In a keyframe system, this movement is isolated to the channels of the foot and hihat.

Forward kinematics in particular offers unique, stable solutions which are faster to compute than dynamics or inverse kinematics. Smooth, life-like motion can be approximated with non-linear interpolation. Yet the movement is not constrained to physical laws as it would be in a dynamic system.

A dynamic approach may be suitable for a final rendering of the drumming movement (providing that physical laws are obeyed), but only kinematics offer the interactivity essential for exploring the space of expressive movements.

4.3.2 MIDI vs. SMDL and others

Since MIDI has substantial advantages over other encoding methods, it was a clear choice to represent the drumming scores. MIDI has been tested and used professionally in studios and live performance for over ten years. Its reliability, availability, and cost effectiveness has led to thousands of home studios. Many amateur and professional musicians have posted their scores on the Internet, leading to archives of thousands of songs. Because of MIDI's standard drum instrument assignments, many of these songs are usable as test data for SMED. Specific data sets can be generated in almost any MIDI sequencing environment.

Drum scores can be recorded live in a MIDI format by using a MIDI drum kit. Bob Peele is a drummer and music teacher in Australia. It was possible to collaborate and visualize his performances in SMED by using the MIDI standard drum assignments.

Finally, MIDI programming and hardware resources are available on the Silicon Graphics platform. This platform was the choice for modelling the movement because of its rendering power. The existence of an SGI MIDI library, as well as source code for processing MIDI files, facilitated incorporating MIDI into SMED.

SMDL has the advantage of storing gestural performance information. In this way, SMDL may be an appropriate representation for including the kinematic output of a SMED-generated performance with the score. However, SMED was created so that expressive performance could be designed, not simply played back from a recorded performance.

4.3.3 Interpolation

CTB spline interpolation was chosen to calculate inbetween frames. Smooth movements between frames of adjacent strokes are produced at default continuity, tension, and bias settings. To get similar movement with Bezier or Hermite curves, consideration must be given to the tangent vectors between segments. B-splines are smooth, C2 continuous curves by default, but they do not go through control points as is the case with CTB splines. This is a problem while generating the movement to strike the drum because the limbs will only be shown come *near* the drum and not strike the surface. Also, B-spline curves are constrained to be C2 continuous, which is not desirable for modelling the discontinuous motion during a stick-drum impact. CTB splines can easily model the impact by setting one continuity value at a single control point.

4.3.4 Drumming Technique

Initial decisions on the drumming technique to be used were made to simplify the modelling process. The matched grip was chosen because it allowed the rotations of the wrist, elbow, and shoulder to be constrained within the same plane. This simplified the calculations required to determine the position of the arm when striking the drum.

The pedals of the kick drum and hihat are played heels down. While a heels up style would provide for additional interest, it may be distracting from the kinematics of the arms. Heels down is more appropriate for educational situations since beginner drummers are taught foot control by playing heels down.

4.4 Treatment of Expression

One may wish to algorithmically generate expressive movements based on the score. However, the expressive power of MIDI limits what a score can encode.

4.4.1 Levels of Interpretation

MIDI does encode the velocity of each onset. From this, one has some measurement of how hard the instrument was played, from which the movement required to play that note may be inferred.

The louder the note, the higher the rotational velocity of the stick at impact. This is supported by the statement "the faster the louder, the slower the softer" [53]. While this phrase typically refers to how tempo and volume (dynamics) relate, it also applies well to the kinematic (physical performance) domain.

MIDI velocity is a very low-level facet of musical expression. SMED also generates expressive movement at a slightly higher level: *measures*. Clark [17] showed that changing the location of the bar lines (which delimit measures) caused musicians to sight-read a passage with different acoustic expressions. Thus the additional knowledge of the beginning of the measure provides musical context for the ensuing notes.

A previous implementation of SMED attempted to model the performance with only timestamps of onsets (without measure information). The current version is more expressive because head and back movements synchronized with each beat of a measure could be added, given information about the beat length and number of beats per bar. These secondary movements provide a visual tempo cue (like a metronome) and enforce the audible beat of the score.

For higher levels of interpretation, it would be better to offer the user local control of the kinematics so that different performance styles could be used at different locations in the piece.

4.4.2 Repetition

Many of the built-in features of SMED help to avoid the problem of robotic and "canned" movements. Drum scores created from MIDI drum kits will have variations in the velocity of each note; causing perturbations in the amplitude of the arms. MIDI velocity will also affect the amplitude of cymbal vibrations, hihat and hihat pedal movements, and kick pedal and hammer movements. Movements of the torso provide interest not only by the movement of the upper body, but also by changing the positioning of a limb when it strikes a drum. Variations in head bobbing also provide visual interest, but are also reflective of the score since they are driven by the velocity and density of the surrounding notes.

Local control would allow for user-controllable variation, but it is encouraging to see effective results from the procedurally generated motion.

4.4.3 Animator Control

Without additional performance information in the encoded score, it would probably be unwise to assign expressive movements to the primitive elements encoded in MIDI. This is why it has been resolved to give the user (animator) a few high-level tools to create an animation which is a personal expression of the score.

4.5 Applications

SMED should be readily applicable in music education. Abeles et al. [1] describe five fundamental methods in which computers can be used in music instruction: *tutorial, drill and practice, computer games, simulation,* and *tools.* As a simulation, SMED provides a moving example of how a piece should be played and shows limb placement at any given moment. SMED has an advantage over video instruction because the student has complete control of the viewpoint and greater control of the playback speed. Also, the frequency and amplitude controls can be used to tailor the demonstration to serve the needs of the score, or to suit the drumming style the student has learned.

By adding a looping feature, SMED could be used to repeatedly demonstrate patterns for drills and exercises. In combination with a MIDI drum kit, the student's timing and accuracy could be evaluated, and the difficulty of the drills could automatically change as required.

Abeles et al. [1] praise games as being motivational and thus a valuable instructional tool. A system with a MIDI drum kit could be used to create a musical game, such as "battling drummers" in which the student would compete against the drummer by repeating certain scores at a target level of accuracy by "out-improvising" the computer drummer.

"Tutorials typically present both information to the learner and then test the learner's acquisition of the knowledge" [1]. With an appropriate curriculum, SMED could aid tutorials by demonstrating particular drumming techniques or rudiments such as three-stroke rolls and paradiddles. In a video instruction scenario, the video cameras, lighting, microphones, sound recording equipment, and drum kit must be set up, which is a time-consuming and expensive process. This makes it difficult for creating new tutorials. Changing tutorial demonstrations with SMED can simply be done by changing MIDI files.

Tool programs are those which are used by working professionals. Such programs can sometimes be used in educational environments. The tool programs to which music students are exposed are music composition programs. Since SMED is not (yet) used by working professionals, it cannot serve in such a manner. However, with a feature to export animation sequences, SMED may be a useful tool program for introducing animators to forms of higher-level animation.

Musicians creating their own drum scores can use SMED to see their written work in action. SMED could help expose portions of the music which are too difficult to play. The score could then be edited appropriately in the artist's MIDI song writing environment.

The methods used in SMED could be used to model other forms of figure animation by replacing the modelling algorithms with those for the desired movement. The user would continue to use the high-level tools to create a variety of expressive movements rather than use motion-capture or traditional keyframe animation systems to create individual movements from scratch.

The technique of manipulating keyframe placement and value would be valuable in interactive environments. Applying this technique to only a few joints has provided for a wide array of expressive movements in SMED. Both subtle and dramatic variations are important to maintain users' interest in an interactive environment, whether it be a game or some form of virtual reality.

4.6 Summary

In summary, SMED is a program which visualizes performances of drum scores. Any MIDI drum score, with standard assignments for an 8-piece modern drum kit, is accepted and the corresponding 3D animated performance is produced using forward kinematics. The animation of the basic drumming stroke is automated, as are other movements such as cymbal vibration and pedal movement. The user is allowed to affect the kinematics of the animation using frequency and amplitude controls (see Figure 4.23 for a summary of motion control). Additionally, SMED uses dynamics and note timing information to affect the amplitude of the neck. The automation of movement has been done judiciously so that the space of possible drumming styles is not over-constrained while controlling the animation

Summary of Kinematic Control

	User–controlled	Automated
Primary Movements	frequency and amplitude of wrist, elbow, and shoulder joint rotations.	point of impact for arm swing. MIDI velocity effect on amplitude of: wrist, elbow, and shoulder joints, hihat and hick hammers, vertical hihat movement. torso twist to face drums.
Secondary Movements	frequency and amplitude of back. frequency of neck. general amplitude of neck.	beat of head bobbing and back sway. amplitude vairations of head bobbing. vibrations of hihat, ride, and crash cymbals. colouring of drum face.

Figure 4.23: This chart shows which kinematic aspects are controlled by the user, and which are automated by SMED.

can be done at a high-level.

Chapter 5

User Evaluation

A user study was conducted to evaluate the extent to which the goal of creating a tool to specify kinematic expression in the animation of musical scores has been met. The aim is to show that SMED can be used in an intuitive manner to create a wide range of expressive movements.

SMED was evaluated (1) in terms of its usability and (2) in terms of its success in allowing *meaningful* visualizations of musical scores. The usability of SMED was tested by asking each subject to use the interface to create appropriate animations for each of five scores of contrasting musical styles. The quality of the visualization was tested by determining whether the subjects' interpretations of the scores changed when the kinematics of the performance changed.

When subjects are asked to create appropriate performances for pieces with different musical styles, it is not important that there is a general consensus among the subjects as to what a "jazz style" should look like. The user's interpretation of the expression will be influenced by his/her personal experience. What *is* important is that *given a set of contrasting musical pieces, the subject expresses the piece with contrasting performance styles (kinematics).* In this way, it can be shown that:

- different musical styles elicit different kinematic expressions of the piece, and
- SMED is able to allow the user to specify those expressions.

Likewise, when subjects are asked to interpret the kinematic style of a piece, it is not important that there is a common interpretation among users. What *is* important is that *given a single score and a set of contrasting kinematic styles, the subject interprets the piece with contrasting descriptions.* In this way, it can be shown that:

- SMED is capable of generating different kinematic styles which elicit different interpretations of the performance.

A record was kept of each subject's UI settings and comments for each created animation to determine a sample breadth of the possible expressions that SMED can generate.

Other questions were used to prompt the subject's ratings and comments on

1. how intuitive SMED is to use, and
2. SMED's scope for expressive movement.

Appendices A and B contain the questionnaire and raw survey data.

5.1 Subject Profile

SMED was designed to be controllable by the most novice computer user, regardless of experience in music or animation. However, questions concerning the subjects' backgrounds in music, animation, and computing were asked in order to expose biases and variations of experience within the group.

Subjects were asked what instruments they play, and how long they have played. Whether the subjects play a percussive instrument or some other instrument, or whether the subjects are musicians or non-musicians will likely influence their understanding and interpretation of kinematics in musical performance.

Subjects were asked which styles of music they listen to, and how long they listen to music each week. A subject's musical tastes may influence how they interpret rhythmic aspects of music and movement. Particular interest in certain styles may allow a subject to distinguish more subtle differences in their musical performances. Subjects may rely on cursory experience or stereotypes to interpret performances of music they are not accustomed to.

Subjects were asked how much time they spend watching music videos and the number of live musical acts they see yearly to get a feel for the subjects' regular exposure to watching musical performance. Subjects were also asked whether or not they take an active interest in watching drummers perform to see how their interests aligned with modelling drumming movements.

Finally, subjects were asked to rate their experience with dancing, creating animation, and computing. This background information will provide a coarse representation of the subjects' understanding of related fields, and may affect how they perceive, interpret, describe, and create drumming animations.

5.1.1 Creation of Evaluation Group

The user evaluation group consisted of eleven subjects. Each subject was either a computing science graduate student or a member of the Graphics and Multimedia Research Lab. Selecting subjects from a common source, whether it be from a class of computing science students or from an entire university, will introduce certain demographic biases. However, whether these biases significantly affect the results depends on the experiment. The subject profile attempts to expose such biases since obtaining a truly "random" sample is difficult.

This research is exploratory in nature, and the experiments are not intended to be used to establish strong correlations or be processed by advanced statistical techniques. Thus, the size and background of the evaluation group is sufficient to test SMED, provide a coarse measure of success, and suggest future refinements and directions of research.

5.1.2 Analysis

The subjects' backgrounds in musical performance were varied (see Figure 5.1). Eight of the eleven subjects studied a musical instrument, such as the guitar, piano, cello, trumpet, marimba, and saxophone. Years of experience greatly varied from 0.5 to 19 years, with a median experience of 4.5 years among musicians and 3 years among the entire sample.

Note that there is no documented experience in drumming among subjects. Instruments such as the guitar and piano are more commonly studied, so the lack of a drummer in a small sample should be no surprise. This does not miss the intent of the experiments because this research is concerned with the more general appeal and communication of kinematic expression. Drummers may be more sensitive to errors in limb assignment or imperfections in movement. This vacuum of expertise can hopefully be offset by separate commentaries by professional drummers.

Subjects' weekly music listening ranged from 2 to 22 hours, with a median of 11 hours.

Subject Profile Overview

subject	1	2	3	4	5	6	7	8	9	10	11
Musician?	✔	✔		✔	✔	✔	✔		✔	✔	
Instrument	guitar	piano/guit		french horn	guitar/piano	guitar/trmpt.	piano		cello	sax./guitar	
# Yrs. Study	0.5	10		3	16	3	6		19	2	
# Hrs. Music Listening Weekly	22	11	20	2	8.5	3	3	20	15	20	10
Listened Styles											
heavy metal				✓	✓		✓			✓	
rock			✓	✓	✓	✓	✓	✓		✓	✓
alternative	✓		✓	✓	✓	✓	✓	✓		✓	✓
jazz	✓	✓	✓	✓						✓	✓
classical	✓	✓		✓			✓	✓	✓	✓	✓
blues		✓									
funk		✓	✓								
dance/disco			✓							✓	✓
polka											
latin		✓	✓				✓				
world	✓	✓	✓								✓
other		folk							techno rave		
#Hrs. Watching Music Videos Weekly	0	0	0	0	0.5	0	0	0	0	0	0
# Musical Acts Seen Yearly	2	5	5	0	15	0	1	1	2	3	8
Watch drummers?			✓		✓				✓	✓	✓
Experience with dancing	low	high	med	low	none	low	low	low	low	low	med
Experience with animation	none	high	none	none	med	none	none	none	none	med	low
Experience with computing	high	high	low	high	high	high	high	high	high	high	high

Figure 5.1: Profile of subjects participating in Experiments 1 and 2.

The subjects' backgrounds in music listening taste are also quite varied. Subjects listened to a median of 5 different musical styles, and the distribution of listening varied as well: heavy metal was listened to by 4 subjects; rock, 8; alternative, 8; jazz, 6; classical, 8; blues, 1; funk, 2; dance/disco, 3; polka, 0; latin, 3; world, 4. These are suitable variations because SMED will be tested with scores from different musical genres.

Eighty-two percent of subjects see musical acts at least once yearly, with a median of 2 acts and a mean of 3.8 acts. Forty-five percent of subjects take an active interest in watching drummers. This is a suitable mix of interest to test whether SMED is useful independent of a subject's exposure to visual musical performance.

Most subjects were found to have little or no experience in dance or creating animation. This is not a significant problem because the medium of animation has a wide appeal and, like music and other arts, does not require a technical background for interpretation to occur. However, more experience in dance or animation among subjects might have provided more appreciation of a high-level animation tool and a more technical vocabulary for critiquing the movement and articulating their interpretations.

Clearly, one of the most significant biases of the group is the high level of computing experience. Such a group would be more experienced than a random sample with using both simple and complex user interfaces. Although the subjects would likely find the GUI of SMED simple, such background could be beneficial because subjects have experience with other user interfaces with which the UI of SMED could be compared. Such a group would also have a greater understanding of the kinds of tasks which can readily be achieved in computing, and could suggest logical, feasible extensions to the system.

To summarize, the subjects have a varied background in musical performance and listening tastes, which provides a spectrum of viewpoints from which to interpret musical performance; a generally minimal background in dance and animation, which may not provide subjects with a technical vocabulary to describe the movement; and a solid background in computing, which should provide a foundation for logical suggestions to improve the system.

5.2 Experiment 1: Interpretation

5.2.1 Purpose

This experiment was designed to test SMED's ability to model expressive movements which can be interpreted and *differentiated* among different kinematic and musical styles.

Each subject watched five scores played with five kinematic settings, for a total of 25 performances. The subject was asked to describe the performance in "free words," and in terms of a musical style, if possible. Each subject described which performance styles were most suited to particular drumming scores. The subject's opinion of the kinematics of performance in different musical genres (independent from the animations) was also recorded.

5.2.2 Environment

Testing was done in the SFU Graphics and Multimedia Research Lab since that was the location of the computer (a 200 MHz SGI Indigo[2] High Impact) which could run SMED. Thus, subjects were not in a particularly isolated environment.

A single audio kit was used for all performances. Some audio processing techniques and drum timbres lend themselves to certain musical styles. For example, richly reverberated sounds are commonly heard in rock and heavy metal, while gated sounds are often found in dance music. The samples used were simple, dry (unprocessed) samples for maximum usability across musical styles.

It may be argued with some validity that playing the audio track will influence a subject's interpretation of the performance. However, the goal of SMED is to create expressive movement for a given musical score. To disembody the movement from the music would be to remove the animation from the context in which it was created. Interpretation of live musical performance invariably includes the music produced, and so it makes sense to test a simulation of musical performance in the same manner.

The subjects were not allowed to see the frequency and amplitude controls of the interface so that they would not be aware of how the movement was modelled. Also, score filenames were generic so that no textual clues were given about the genre of the music. For example "style1.score" was used to name a file instead of "blues.score." The subjects were allowed to control of the point of view in the 3D scene.

Users were provided with a word list to help stimulate thought and induce descriptions about the score. The word list was: laid back, forced, fluid, stiff, groovy, chunky, uncontrolled, finessed, demonstrative, excited, disinterested, sporadic, melancholic, peppy, and angry.

The frequency of the neck and back movements were not varied in this experiment and automated variations to head bobbing were not used since these features had not been implemented at the time of experiment.

5.2.3 Test Data Set

Five contrasting scores from different genres were used. (Note that rhythms contained in the named genre are not necessarily exclusive to that genre.) Table 5.1 shows the classification of the scores.

Score	Genre
1	Blues
2	Funk
3	Rock
4	Jazz/Swing
5	Jazz/Latin

Table 5.1: Styles of tested scores for Experiment 1.

Each score was played with kinematic settings which are shown in Figure 5.2 and described in Table 5.2.

5.2.4 Process

The subject's interpretations of 25 SMED-generated musical performances were recorded as follows:

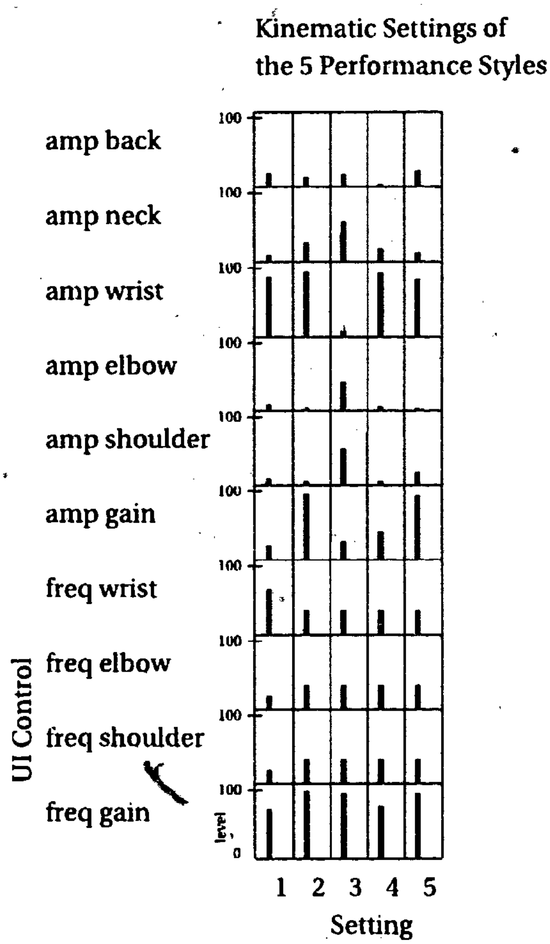


Figure 5.2: Kinematic control settings used for Experiment 1.

Setting	Quality of Movement
1	The low amplitude gain creates a subdued motion across all three arm joints. The wrist receives a realistic proportion of the amplitude gain. Low neck amplitude contributes to passive motion.
2	The high wrist amplitude combined with high amplitude gain across all arm joints creates a notably wrist-biased movement. The high frequency gain adds a crisp "snapping" motion in arm joints. Moderate head bobbing and back movements are created by the corresponding neck and back amplitudes.
3	This setting creates a dramatic movement with high elbow and shoulder amplitudes, in addition to heavy head-bobbing by the high neck and back amplitudes (relative to neck and back levels in other settings). The high frequency gain provides a strong "snap" to all arm joints.
4	This setting combines moderate head bobbing, very little back movements, and a smooth, wrist-biased arm movement.
5	Although the shoulder amplitude is relatively low, its combination with a high amplitude gain across all arm joints creates a dramatic shoulder and wrist biased movement. Relatively high back amplitude and low neck amplitude causes the figure to sweep the entire upper body and head to the beat.

Table 5.2: Descriptions of kinematic settings for Experiment 1.

```
For each score
  Play animated score with each of the 5 different kinematic settings.
  For each score/setting combination
    Ask subject:  What style of drumming does this movement look like?
                  (Describe in other words if you cannot pin it down to
                   a particular genre.)
                  Why?

  After playing a score with the different kinematic settings:
    Ask subject:  What style best fits the given score?  Why?
```

The subject's personal opinion of the kinematics of performance in different musical genres is recorded as follows:

```
For each style (blues, funk, hard rock, jazz, latin)
  Ask subject:  What types of movement characterize this style?
```

5.2.5 Analysis

Interpretation with Free Words

Figures B.3 and B.4 show the subjects' comments for the five performances of each of the five scores. With so few scores and kinematic settings, it is difficult to draw statistically significant conclusions. But a qualitative analysis of the descriptions clearly shows that the kinematic settings affected each subjects' interpretation of the performance of the same score. For example, consider the cell containing the comments for Subject 10, Score 1. As the kinematic settings changed, the perceived style changed from blues to jazz to alternative to classical to rock, with corresponding changes in the continued descriptions of the movements.

Subjects were allowed to describe the movement in their own words if they could not describe a performance according to a particular musical style. Fifty-six percent of subjects used four or more different "style words" to differentiate among the performances. This leaves 44 percent who used three or fewer style words, but by no means were these subjects incapable of such differentiation. Their interpretations (and differences in interpretations) can be noted by their free word descriptions. For example, Subject 7 used no style words, but differentiated among the five performances using words such as "unenthusiastic," "laid back," "natural," "jerky," "stiff," and "energetic."

Sometimes performances seemed similar to one another and subjects were heard to make comments that it was difficult to articulate a description of the movement. Nonetheless, most performances were successful in conveying a distinct kinematic style.

Interpretation with Musical Genres

It is not necessary to find a consensus in the subjects' interpretations, but trends may provide some evidence that SMED is effective as a tool to communicate through movement.

The 5 by 5 setting/score chart (Figures B.1 and B.2) reorganizes the the subjects' descriptions of each performance, grouping all subjects' comments of a given performance (setting/score combination) in a given cell. The 5 by 5 setting/score chart (Figure 5.3) shows how often particular musical styles were referenced in the subjects' descriptions of each performance. If a style is mentioned in a positive association (e.g. "very JAZZY") or in combination with another style (e.g. "ROCK/FUNK mix"), one is added to the count of each mentioned style. (Style words which had a positive association to the score were changed to upper case (e.g. "very JAZZY") and negative associations were left in lower case (e.g. "not very jazzy") to help automate the analysis of the data.)

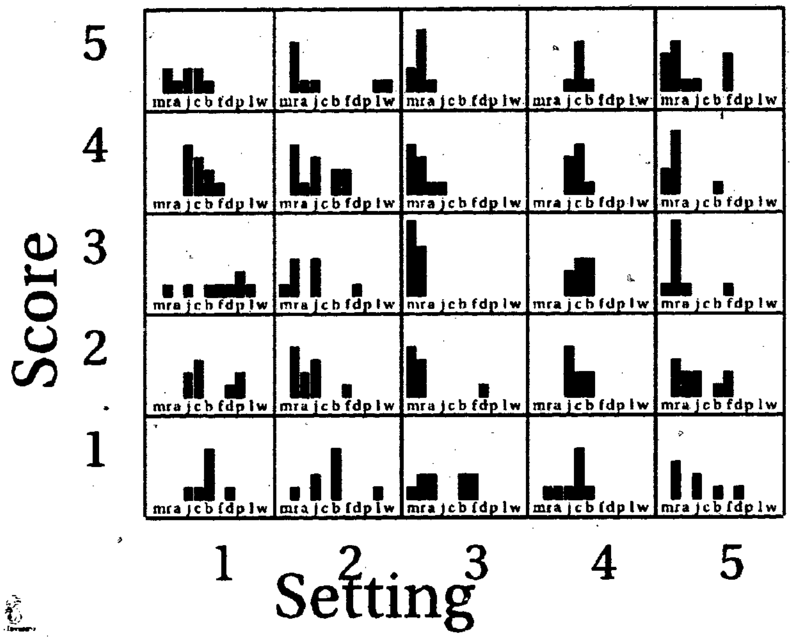


Figure 5.3: Cumulative result of musical style words used in subjects' descriptions of performances. Legend: m = metal; r = rock; a = alternative; j = jazz; c = classical; b = blues; f = funk; d = disco; p = polka; l = latin; w = world.

Inspection of the bar chart reveals that different kinematic settings of the same score were successful in producing different interpretations among performances. There were also trends in the interpretation of some performances. For the purposes of simplifying analysis, heavy metal, rock, and alternative will be grouped together (herein called *Group A*), while jazz, classical, and blues will be grouped together (herein called *Group B*).

Note that such a grouping is not entirely arbitrary. One only needs to look at the organization of a record store, or the format of a radio station or the demographics of its target audience to understand that there is an association among these musical styles. Also, where subjects mentioned a style from Group A to describe a performance, such as "demonstrative," "pronounced," and "dramatic" prevailed. Where subjects mentioned a style from Group B, the description was often accompanied by words such as "stiff," "disinterested," and "laid back."

Inspection of Figure 5.3 reveals that *kinematic Settings 3 and 5 caused a clear majority of performances being interpreted as a style from Group A, and kinematic Settings 1 and 4 elicited more interpretations referencing styles from Group B* for most scores. It can be seen from Figure 5.2 that Settings 3 and 5 included higher amplitudes of the neck, elbow and shoulders than those of Settings 1 and 4. These higher amplitudes create head bobbing and demonstrative motions associated with styles in Group A, and the lower amplitudes create more subtle motions associated with styles in Group B. These associations are supported by the subjects' independent comments about their perception of the performance styles of particular musical genres (see Figure B.7 showing user/style descriptions). Rock, from Group A, was described as "explosive," "uncontrolled," and having "wild head and arm movements." Blues and jazz, from Group B, were each described as "laid back" and "fluid."

Kinematic Setting 2 did not seem to create a consensus to a particular style across all scores. Score 1, predominately blues based, was interpreted mostly as a blues score with Setting 2. The interpretations of the other scores varied among the remaining styles, with rock and jazz receiving the most votes.

Voting for Best Performance

Subjects were asked to choose which of the five performances best reflected each score. Figure 5.4 graphically shows the cumulation of votes. Figure B.5 in the Appendix contains the raw voting results. Setting 2 received more votes as the most appropriate kinematic setting than any other setting for every score.

One may question why Setting 2 was consistently perceived to be the best performance style when other settings achieved more consensus as to the kinematic style of a given performance. This may be explained as follows: Setting 2 represents a "middle-of-the-road" kinematic setting. Subjects may prefer to "fence-sit" when *evaluating* the score. The other kinematic settings may be caricatures of the performances of their associated musical styles and thus be successful in achieving consensus in *interpretation* through a stereotype.

There were few votes for styles such as dance/disco, funk, polka, latin, and world. This could be accounted for by the comparatively lower interest in these music styles among subjects (see Figure 5.1) and to the inherent rhythms in the drum scores.

Summary

Having categorized the data into two main style groups (A and B), one should be careful not to reduce SMED's expressive range down to a passive/aggressive dichotomy. The purpose of this categorization was to simplify the analysis and to expose trends in a relatively

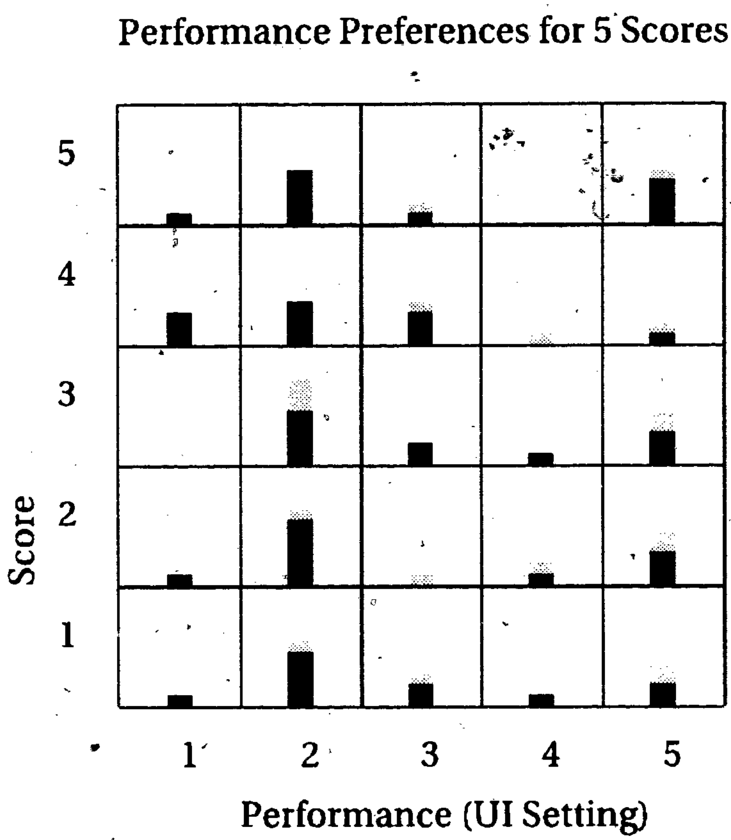


Figure 5.4: Each cell contains a black bar representing the number of votes attributed to the kinematic setting as being the most appropriate for the score. The grey extension of the bar represents the number of times the kinematic setting was voted second best.

small sample. One may argue that one cannot avoid the dichotomy since each kinematic parameter is a scalar within a one-dimensional high/low scale. However, a given setting and the rhythmic and dynamic information from the score create a gestalt which cannot be so easily linearized. One only needs to refer to the descriptions of the performances (Figures B.1 and B.2) to see how the interpretations vary, with phrases such as "subdued," "habitual," "getting into it," "tired," "showing off," "deliberate," "efficient," and "looks like he should have a tie and suit."

5.3 Experiment 2: Expression

5.3.1 Purpose

This experiment tested the usability and effectiveness of SMED as a high-level animation tool and determined both efficiencies and shortcomings of the interface. Each subject was asked to use SMED to create performance animations which best "expressed" the musical content for five contrasting scores.

5.3.2 Environment

The same environment was used for Experiments 1 and 2, except that the subjects were shown how to use the frequency and amplitude controls for Experiment 2.

5.3.3 Test Data Set

Five contrasting scores from different genres were used. (Note that patterns contained in the named genre are not necessarily exclusive to that genre. Also note that these are different scores from those used in Experiment 1). Table 5.3 shows a possible classification of the scores.

Score	Genre
1	Jazz
2	Blues
3	Latin
4	Funk
5	Rock (Twist)

Table 5.3: Styles of tested scores for Experiment 2.

5.3.4 Process

```
For each score
  Ask subject:  Use the UI of SMED to create a performance that best
                  reflects the score.
  Time subject.
  Ask subject:  What types of movement characterize that style?
                Why did you choose the settings you used?

Ask subject:
  Was the interface (i.e. the manipulation of freq/amp of joint angles)
    an intuitive method for the creation of expression?
  Was the interface sufficient for the creation of expression?
  Any additional suggestions/comments?
```

5.3.5 Analysis

Timing

We will call a subject's use of the UI to create an animation for a given score a *task*. The task number is not necessarily the same as the score number denoted above. The subjects' timing information is shown in Table 5.4 and visualized as a bar chart in Figure 5.5.

The mean time to complete each task decreased for each successive task from Tasks 1 through 4. This is what one would expect as subjects would become more familiar with the interface and understand the effects of the individual controls.

However, the average time to complete Task 5 was over 15 seconds than that of Task

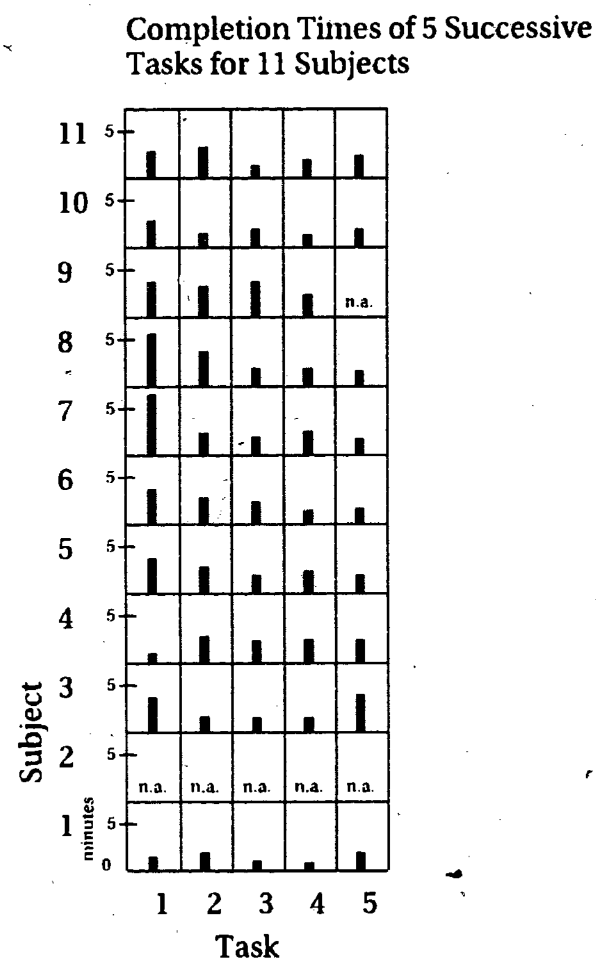


Figure 5.5: The height of each bar represents the amount of time for the subject to complete the task.

Subject	Task				
	1	2	3	4	5
1	1.5	2.0	1.0	0.8	2.0
2	n.a.	n.a.	n.a.	n.a.	n.a.
3	4.0	1.7	1.6	1.6	4.3
4	1.0	3.0	2.5	2.6	2.6
5	4.0	3.0	2.0	2.5	2.0
6	4.0	3.0	2.5	1.5	1.7
7	7.0	2.5	2.0	2.7	1.8
8	6.0	4.0	2.0	2.0	1.7
9	4.0	3.5	4.0	2.5	n.a.
10	3.0	1.5	2.0	1.3	2.0
11	3.0	3.5	1.3	2.0	2.5
Mean	3.75	2.77	2.09	1.95	2.29

Table 5.4: Task completion times in minutes for Experiment 2.

4. Most of the subjects were given Score 1, the jazz score, as their fifth task. Other scores were pattern-based and more regular, whereas Score 1 was fairly "open" and unrepetitive in its style. This may have provided some difficulty for subjects to anticipate the rhythm and thus find an appropriate setting. Subject 5, a fairly experienced musician and active music listener, commented that he/she "...didn't get a clear mood off the music so it was difficult to capture the mood [using the kinematic controls]." Therefore, in order to help subjects learn to manipulate the UI, this relatively difficult score was given as the last task to all other subjects.

To consider how the score influenced completion times, note Table 5.5 which organizes completion times according to score. The order in which scores were assigned to tasks is shown in Table 5.6.

One can see from the task/score chart that scores tended to be worked on in the following order: 2, 3, 4, 5, 1. From the Song Completion Times chart, it can be seen that the mean time to complete these scores decreases: 3.35, 2.82, 2.29, and 1.90 minutes for Scores 2 through 5. The mean time to complete Score 1 is 2.51 minutes. This may be a lower mean than others since subjects would be more familiar with the controls, but may be higher than other means due to the musical complexity of this score.

Once a user has become familiar with the controls, the complexity of the score would be

Subject	Score				
	1	2	3	4	5
1	2.0	1.5	2.0	1.0	0.8
2	n.a.	n.a.	n.a.	n.a.	n.a.
3	4.3	4.0	1.7	1.6	1.6
4	2.6	2.5	1.0	3.0	2.6
5	4.0	3.0	2.0	2.5	2.0
6	1.7	4.0	3.0	2.5	1.5
7	1.8	7.0	2.5	2.0	2.7
8	1.7	2.0	6.0	4.0	2.0
9	n.a.	4.0	4.0	3.5	2.5
10	2.0	2.0	3.0	1.5	1.3
11	2.5	3.5	3.0	1.3	2.0
Mean	2.51	3.35	2.82	2.29	1.90

Table 5.5: Song completion times in minutes for Experiment 2.

more of a factor in how difficult it will be to create an appropriate animation.

Foreword to User Interface Discussion

The following sections discuss the subjects' manipulation of the user interface. Figure 5.6 illustrates where the interface values are obtained in order to clarify interpretation of the graphs. A *UI setting* simply refers to a value on one of the sliders of the interface. An *effective UI setting* refers to the net effect of all of the UI settings on a particular joint. For example, if the amplitude gain is 75 and the wrist amplitude is 60, the *effective* wrist amplitude is $0.75*60 = 45$. (UI settings are percentages.) Effective UI settings are discussed in order to compare the kinematic result from manipulating the UI. Raw UI settings are discussed to determine how subjects interacted with the interface.

For each score, the subject sets each UI control to some level in the range from 0 to 100. Means and standard deviations will be discussed, but these values are meaningless if no kinematic association about a value can be made. A number of screen shots have been blended to provide an example of the "visual significance" of changing an amplitude by a relatively small amount. Figure 5.7 shows a difference in amplitude for the back; Figure 5.8, the neck; Figure 5.9, the shoulder; Figure 5.10, the elbow; Figure 5.11, the wrist.

It is difficult to be effective in graphically representing the changes in the frequency

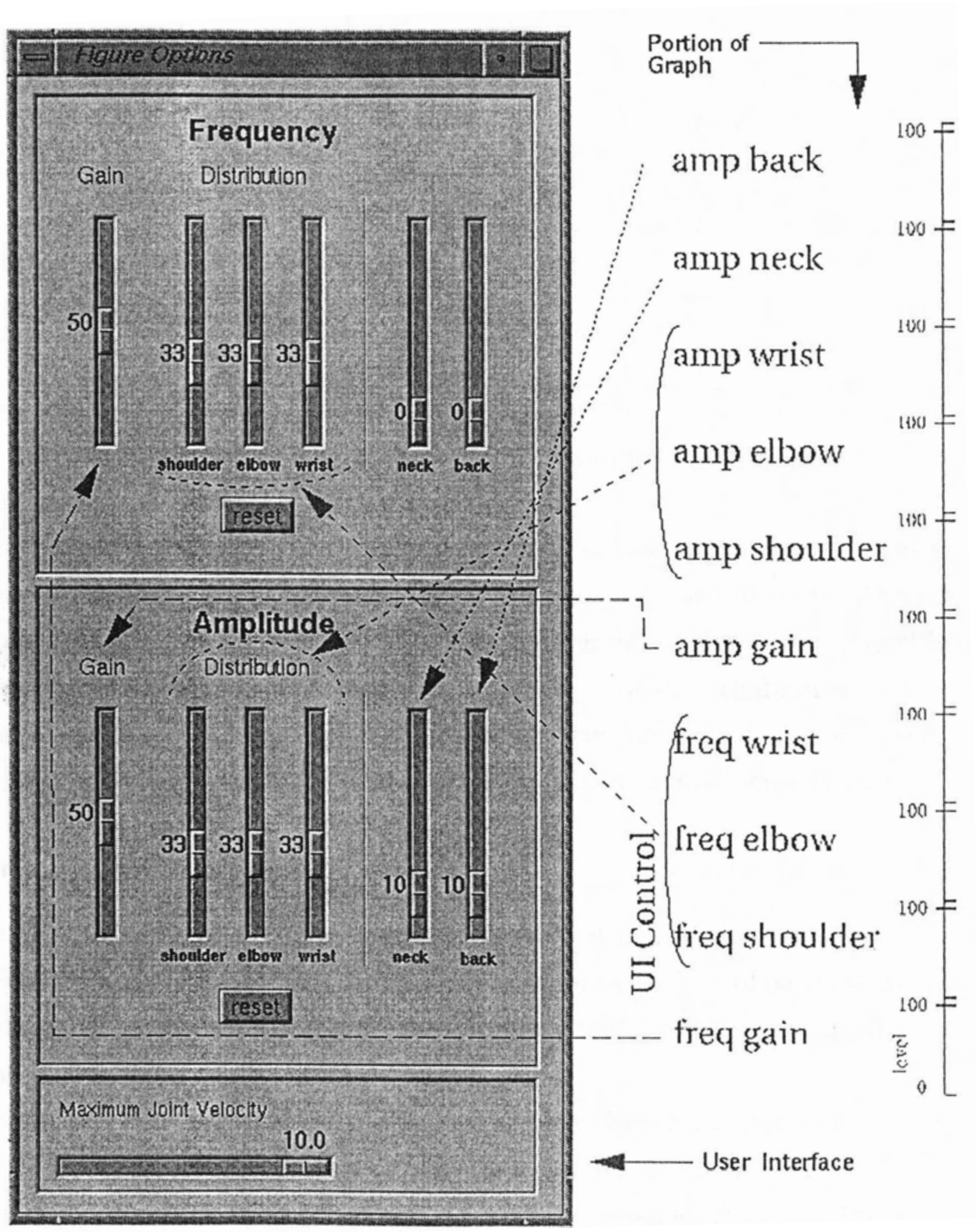


Figure 5.6: Relationship between graphs and UI.

Subject	Score				
	1	2	3	4	5
1	2	3	4	5	1
2	n.a.	n.a.	n.a.	n.a.	n.a.
3	2	3	4	5	1
4	3	4	2	5	1
5	1	2	3	4	5
6	2	3	4	5	1
7	2	3	4	5	1
8	3	4	5	2	1
9	3	4	2	5	n.a.
10	3	4	2	5	1
11	3	2	4	5	1

Table 5.6: Association of tasks to scores for Experiment 2.

controls because the effect of such controls is temporal. Joint angle plots could be shown, but it may not be enough to illustrate a significant change in the frequency. Also note that a difference of 5 and 10 in the wrist amplitude may be more (or less) visually significant than the difference between 55 and 60. Again, it is difficult to show such differences as effectively on paper as could be done with an animated demonstration. The discussed figures attempt to provide some visual context for the ensuing discussion and volumes of data.

Consensus of UI Settings for Scores

The settings for each of the five edited scores were stored for each subject. Figure 5.12 groups the settings by score. The means and standard deviations of each cell are illustrated in Figures 5.13 and 5.14 respectively, in order to visually expose general preferences and consenses.

Some of the data suggests that the score influenced each subject in a similar manner. Score 1, a light jazz score, received the lowest mean amplitude in each of the back, neck, wrist, and shoulder joints, and had the second lowest mean elbow amplitude. This is a notable indication that users responded to the light style by expressing the score with subtle movements. Score 4, a funk score, received the highest neck, back, elbow, and shoulder amplitudes. Here, the busy, high-energy score elicited more demonstrative performances from subjects.

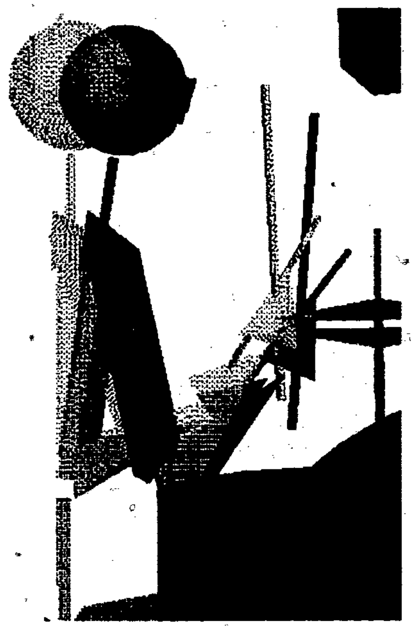


Figure 5.7: Illustration of a difference of back amplitude of 8. The black figure is at the forward limit of a sway for a back amplitude of 10; the grey figure, 2.

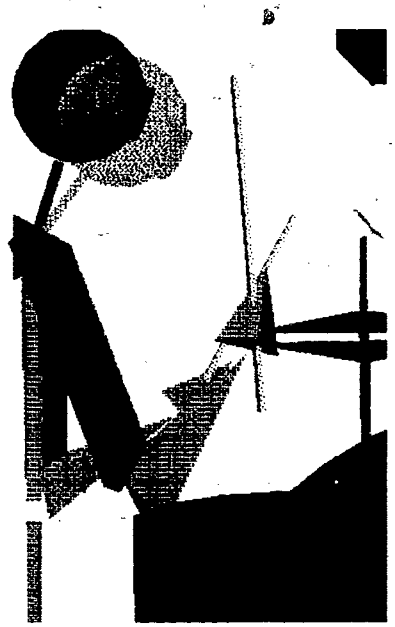


Figure 5.8: Illustration of a difference of neck amplitude of 15. The black figure is at the bottom limit of a head bob for a neck amplitude of 20; the grey figure, 35.

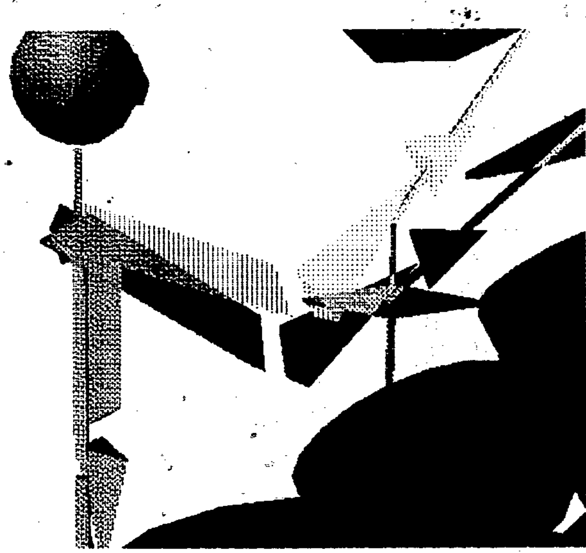


Figure 5.9: Illustration of a difference of shoulder amplitude of 5. The dark arm is at the height of preparation of a swing for a shoulder amplitude of 5; the light arm, 10.

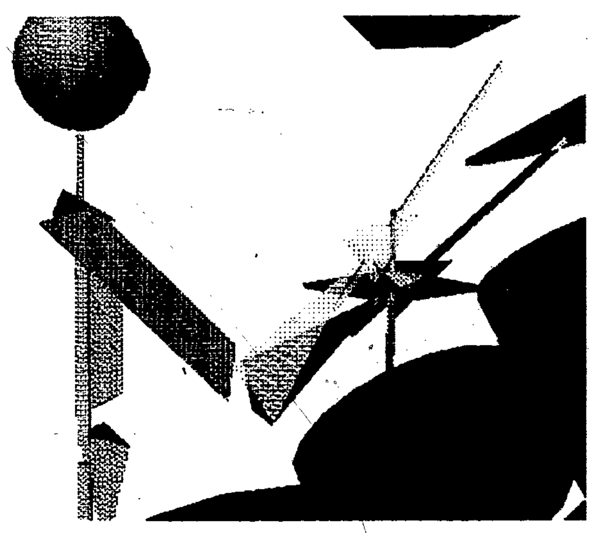


Figure 5.10: Illustration of a difference of elbow amplitude of 5. The dark forearm is at the height of preparation of a swing for an elbow amplitude of 5; the light forearm, 10.

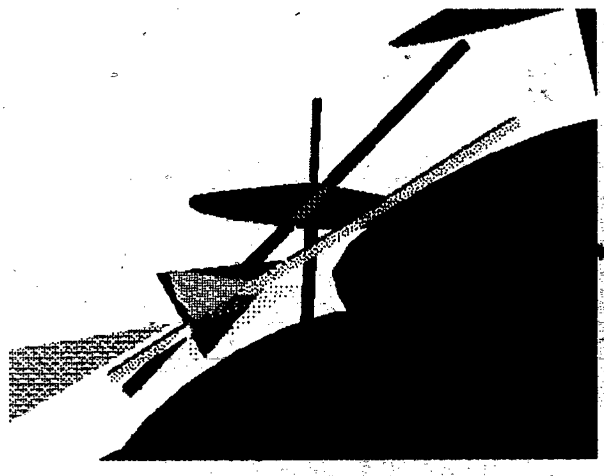


Figure 5.11: Illustration of a difference of wrist amplitude of 10. The dark hand is at the height of preparation of a swing for a wrist amplitude of 15; the light hand, 5.

Score 2, a slow blues score, received a similarly low shoulder amplitude as the jazz score. However, the neck amplitude is very high (at 26.1) relative to other scores such as that of rock (at 18.5). This curious result may be explained by the fact that the tempo of the score affects the rate of oscillation of the neck. The slow tempo of the blues score would allow the neck to sink deeper and still move slowly, while the same amplitude on the rock score would result in an exaggerated head-banging motion.

Even though such general trends exist, the standard deviations (Figure 5.14) show that subjects were not in complete agreement as to how each score should be kinematically expressed. All but 3 of the 40 standard deviations are greater than 5, meaning that each setting in a group of settings lies within approximately 5 units above or below the mean for that group. Such differences are visually significant, as shown in Figures 5.7 through 5.11.

Effect of Score on Subject

Figure 5.15 groups the effective UI settings by subject and illustrates how individual subjects manipulated the interface. The mean for each subject's effective settings is shown in Figure 5.16 and the corresponding standard deviation in Figure 5.17.

Comparing the means of effective UI settings among subjects only reflects personal preferences or biases within a subject, and does not state anything about the effectiveness of SMED. However, it can be clearly seen from Figure 5.16 that wrist amplitudes are relatively

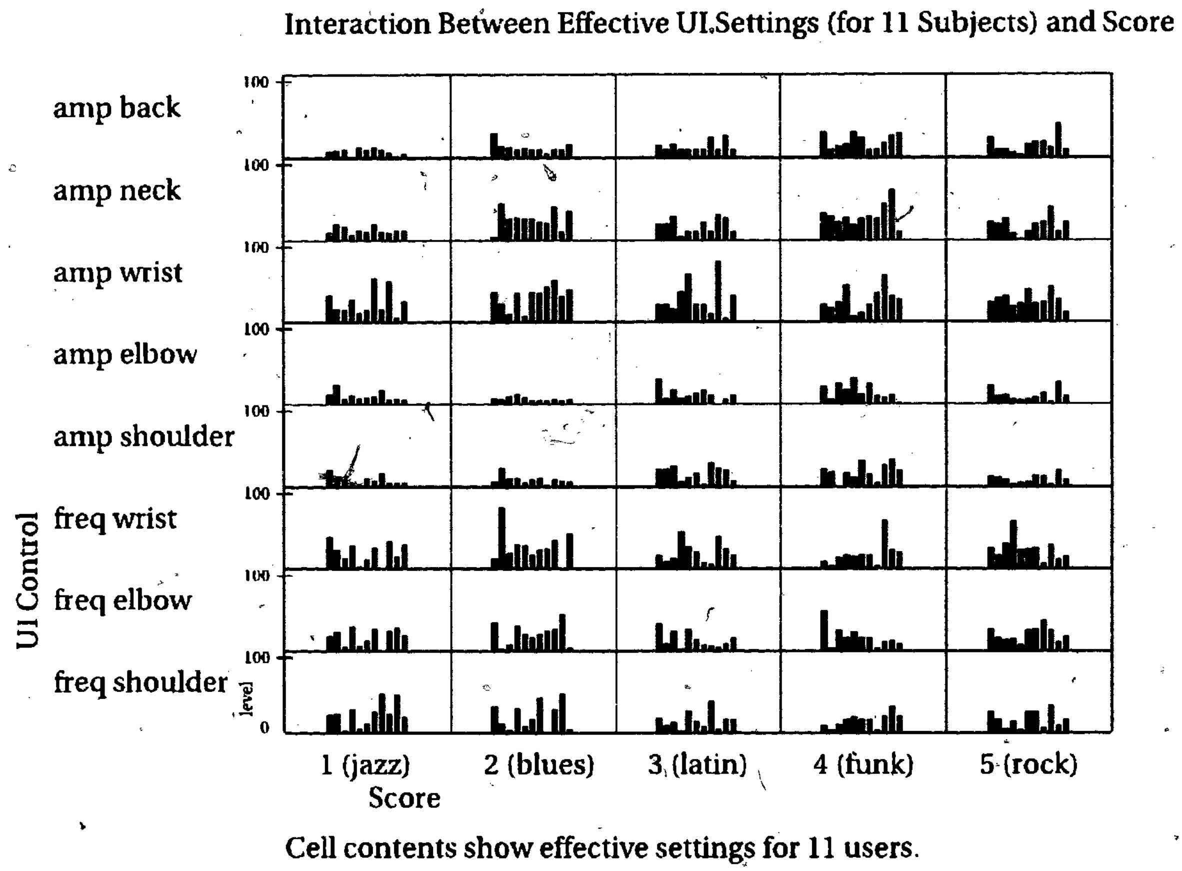


Figure 5.12: Interaction between effective UI settings and score.

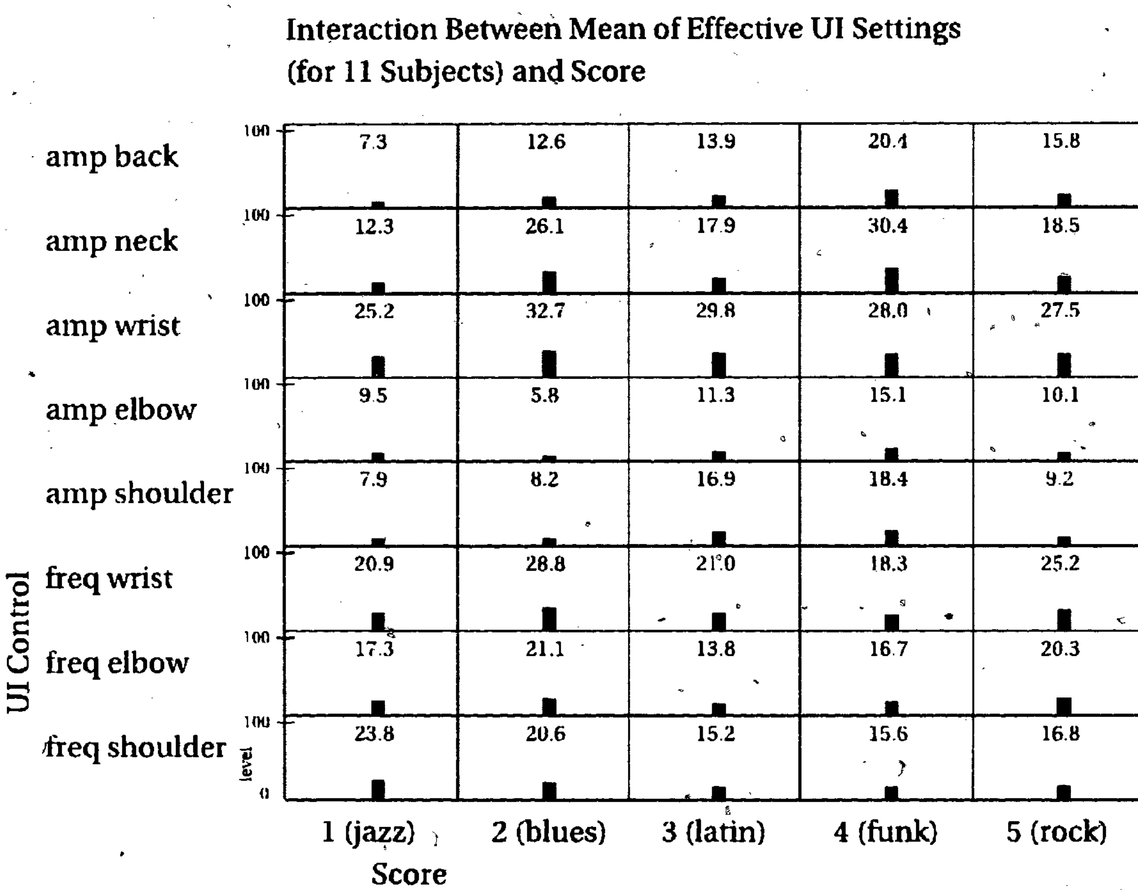


Figure 5.13: Interaction between mean of effective UI settings and score.

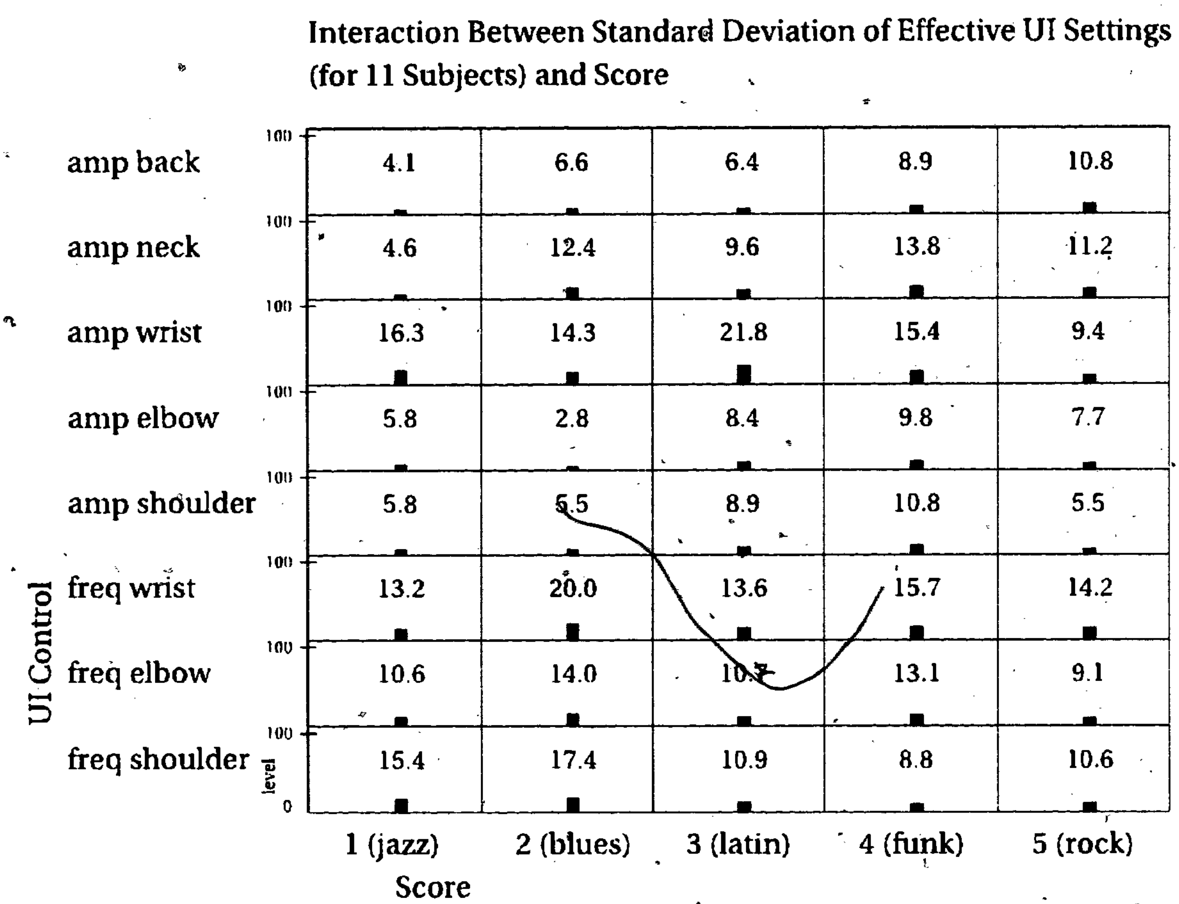


Figure 5.14: Interaction between standard deviations of effective UI settings and score. Standard deviations in amplitude as low as 5 can have visually significance.

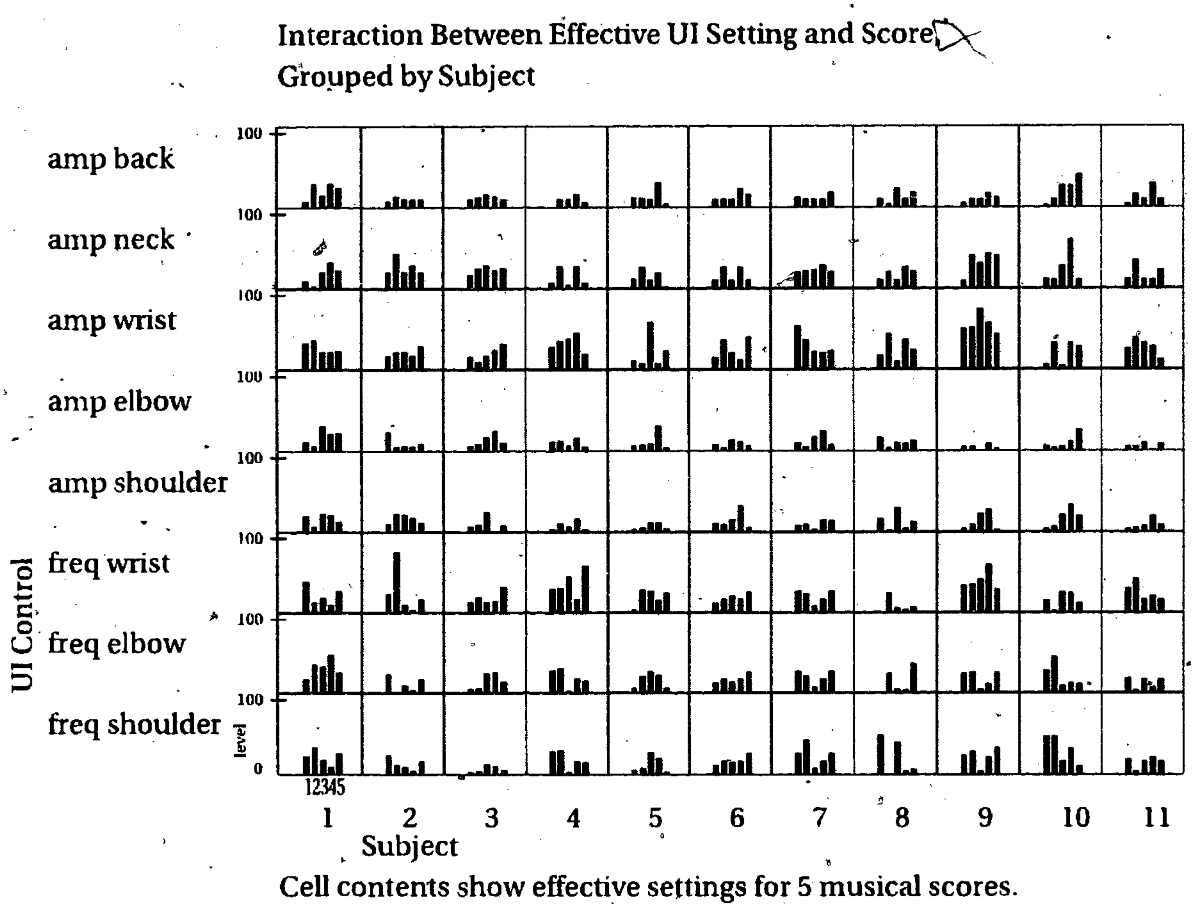


Figure 5.15: Effective UI settings grouped by control and subject.

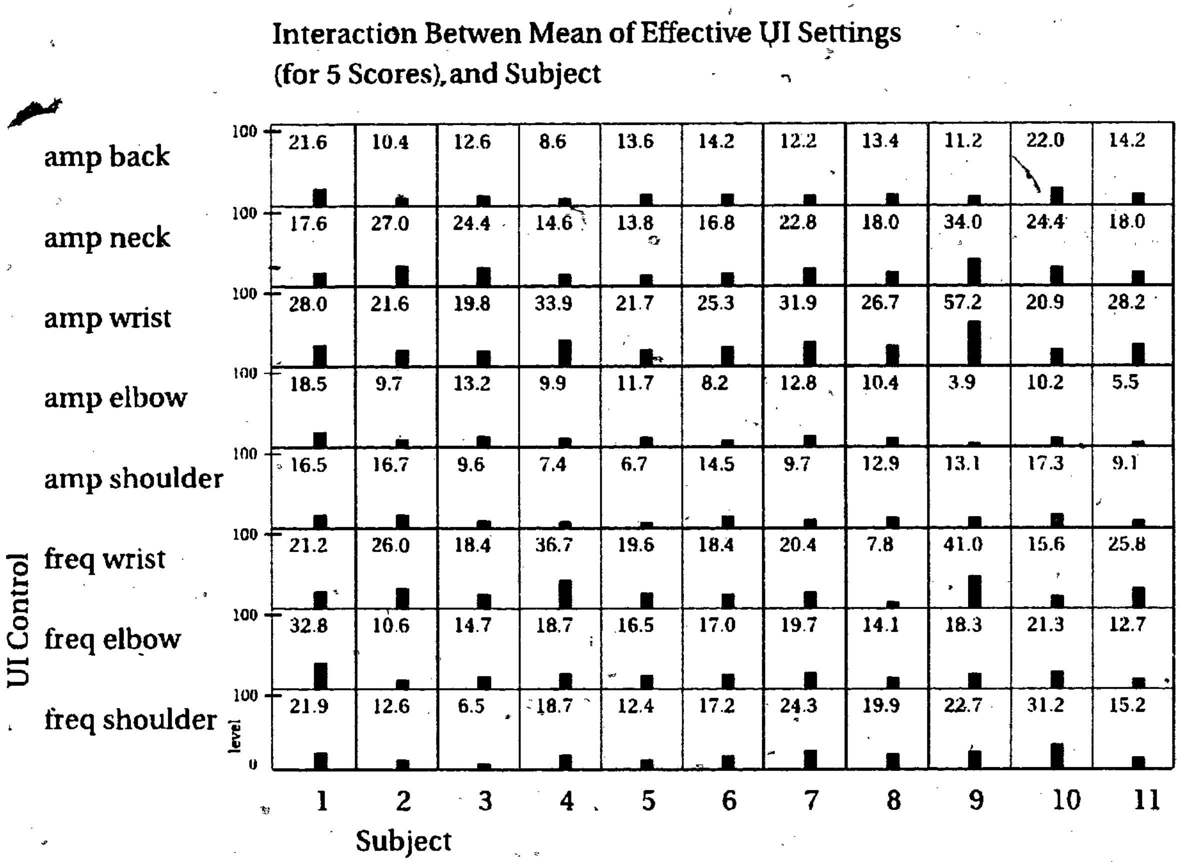


Figure 5.16: Interaction between mean of effective UI settings and subject.

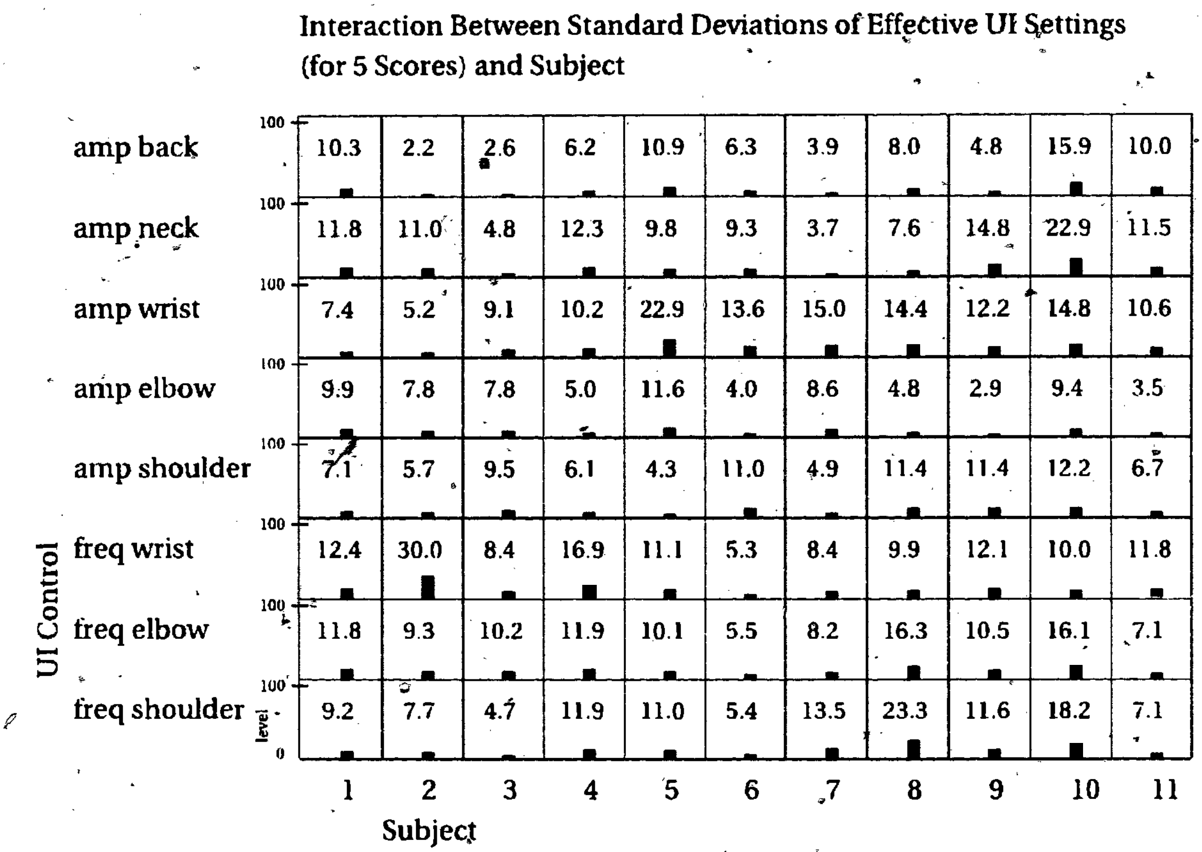


Figure 5.17: Interaction between standard deviations of effective UI settings and subject.

higher than elbow and shoulder amplitudes. This variation in amplitude shows that subjects perceived typical drumming movements as having a proportionally greater amount of movement in the wrists than in the elbows and shoulders. This observation is supported by descriptions of proper drumming technique [8].

The standard deviations of the UI settings shown in Figure 5.17 provide an indication of the amount of variation of effective setting levels. Eight of the eleven back amplitudes had a standard deviation of at least 4.8 units about the mean. Consider the range from 4.8 units below the mean to 4.8 units above the mean. This is a difference of 9.6 units, more than the difference depicted in Figure 5.7, showing that those eight subjects made visually significant changes to the kinematic result of the back when the score changed.

Likewise, all but two of the neck amplitude settings had a standard deviation from 7.6 to 22.9. Even a standard deviation of 7.6 would have differences of 15.2 in the neck amplitude, approximately the difference depicted in Figure 5.8.

Similarly, the standard deviations of the effective shoulder, elbow, and wrist amplitudes represent noticeable changes, as supported by Figures 5.9, 5.10, and 5.11.

It is difficult to discuss changes in the frequency settings without some visual context. However, it should be noted that the frequency settings have less effect for scores with quick sequences of notes than for those with longer notes and rests. This is because the frequencies of the wrist, elbow, and shoulder are automatically increased if it is necessary to keep up with the score. Thus, changing a frequency setting may sometimes have no noticeable effect and may not be an intuitive kinematic control.

Manipulation of the UI

The raw UI settings and changes from the default settings are illustrated in Figure 5.18. This chart shows that the frequency gain was increased more than twice as many times as it was decreased. This means that subjects desired a faster stroke in most styles. The amplitudes used for the neck and back were found in a fairly narrow range. These results suggest that the controls should be recalibrated so that unusable ranges are removed, the remaining range is appropriately scaled, and the default settings are changed to be closer to values typically used.

The standard deviations of the raw UI settings are shown in Figure 5.19. This chart may be misleading in showing the amount of kinematic variation among the performances. For example, the standard deviation for the raw elbow amplitude is greater for Subject 2

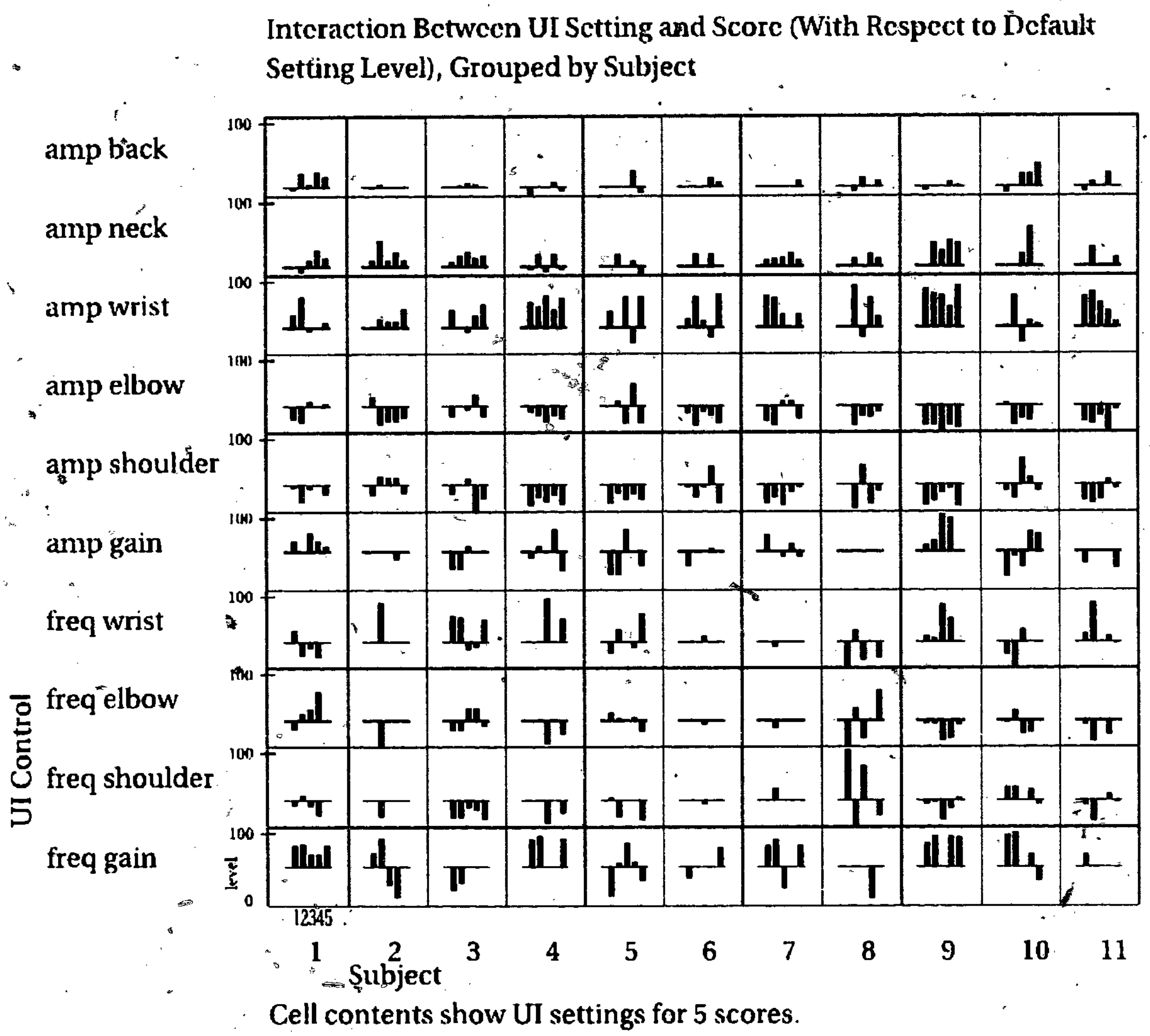


Figure 5.18: Kinematic settings grouped by control and score, illustrating deviation from default setting.

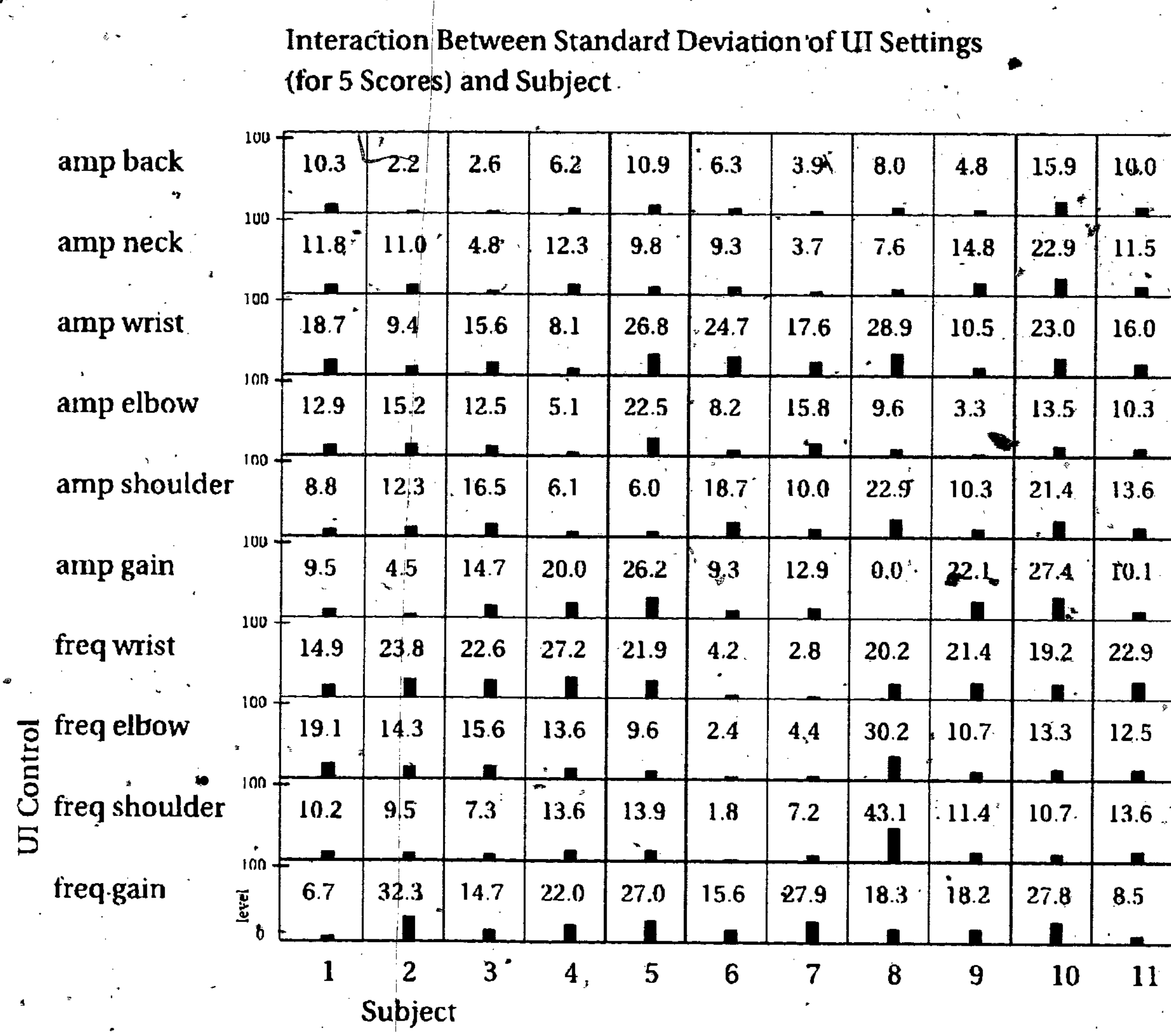


Figure 5.19: Standard deviations of subjects' raw UI settings.

than for Subject 1, but the standard deviation for the *effective* elbow amplitude is greater for Subject 1, as shown in Figure 5.17. This discrepancy is due to the variation of the amplitude gain, which is a factor in determining the effective elbow amplitude, not the raw elbow amplitude.

Evaluation of the User Interface

Subjects were asked to rate the intuitiveness of the SMED UI on a scale from 1 to 5, where a rating of 1 meant "very difficult to use;" 2, "not very intuitive;" 3, "sometimes intuitive, sometimes awkward;" 4, "intuitive, with some more practice;" 5, "very intuitive, with little practice" (for raw data, see Appendix B). Eight subjects found the UI intuitive or very intuitive, and the other three found it sometimes intuitive, sometimes awkward. This relatively positive rating may be biased by the subjects' relatively high level of experience in computing, and thus being able to easily grasp interfaces which are not particularly intuitive. However, the subjects' exposure to other interfaces would provide a solid foundation on which to make such an evaluation.

Subjects were asked to rate the range of expressions producible with SMED on a scale of 1 to 5 where a rating of 1 meant "couldn't do anything expressive at all;" 2, "very limited in its range of expression" 3, "can only make a couple of expressions;" 4, "can make a useful array of expressions;" 5, "can make any expressive movement."

Eight of the subjects found that it was possible to make a useful array of expressive performances, while the remaining three found that only a few were possible. The latter three represented all but one of the subjects who had some experience in animation. Perhaps this experience lent a more critical eye in judging the scope of SMED.

Suggested Improvements

Subjects were asked open-ended questions to allow them to freely suggest improvements to the UI. Some improvements were independently suggested by more than one subject. Three subjects wrote that the wrist, elbow, and shoulder amplitude and frequency controls should not be constrained.

Some subjects felt that more kinematic variation was needed within a given performance. Two subjects suggested that the UI sliders should be animated so that kinematic settings automatically change during playback of the score. This way, different phrases or larger sections of the score could be performed with different kinematic styles. One subject suggested that individual drums have different amplitudes so that a hit on a snare would have a different amplitude than that on a hihat, for instance. This feature would be helpful if the volumes of the samples were not appropriately scaled to the MIDI velocity information, if the MIDI velocity information were not properly calibrated among the different drums, or if different instruments of a drum kit were played with different amounts of force.

Other subjects suggested additional degrees of freedom for motion control. The most popular suggestion was the addition of more neck movements (by four subjects). One can easily see from drummers such as Kenny Aronoff [5] that neck movements can be complex. Other movement suggestions included controls for torso rotation speed, the standing/seated posturing of the drummer, and "wing" motion in the arms. A few subjects suggested movements such as spinning drums sticks or tossing them in the air. These embellishments would add to the character of the animation and provide visual interest.

Suggestions for other aspects of the UI included a loop function to help view specific portions of the score while manipulating the controls, recalibration of the controls, and a graph correlating the score and the plot of the joint angles.

Adding new degrees of freedom may affect the computational complexity of the drumming, and may require a review of the currently assumed geometric constraints. Also, it is important that added features do not significantly affect the frame rate nor the interactivity of the program.

5.4 An Informal Study

A video of SMED was shown at Tom Lee Music, Vancouver, after a drum clinic in order to get feedback from drummers. Because the UI of the system could not be interactively demonstrated, this informal study was used to get feedback about the realism of the motion, the expressiveness of the movement, and the viability of SMED as a tool in music education (Figure 5.20).

The results (Figure 5.21) showed that respondents thought that the movement was somewhat realistic or realistic, somewhat expressive or very expressive, and that SMED would be somewhat useful or very useful as a music education tool. Although only a small number of responses were obtained, the results are encouraging, especially considering that all of the respondents were either professional or student drummers.

Questionnaire

SMED provides an example of how musical performances can be modelled by a computer. Although not all drumming movements have been modelled, an effort has been made to make the movements expressive and realistic.

1. How would you rate the realism of the movement?

__ realistic
__ somewhat realistic
__ unrealistic

2. How would you rate the expressive quality of the movement?

__ very expressive
__ somewhat expressive
__ not expressive at all

3. Combined with an appropriately designed curriculum, how useful would a program like SMED be in a music instruction setting?

__ very useful
__ somewhat useful
__ not useful at all

4. Comments? Suggestions? How would you use SMED?

For more information, contact:
Adam Wood–Gaines
Simon Fraser University, Graphics & Multimedia Research Lab
woodgain@cs.sfu.ca
(604) 298–9781

Please leave questionnaire in box. Thank you!

Figure 5.20: Questionnaire presented to student and professional drummers at Tom Lee Music, Vancouver.

participant	realistic	somewhat realistic	unrealistic	very expressive	somewhat expressive	not expressive at all	very useful	somewhat useful	not useful at all	comments
1	x				x			x		good for reinforcing proper technique to new students
2		x		x			x			
3		x			x			x		real life instruction should be full time, SMED, part time; I prefer to learn from a person
4	x				x		x			needs better definition on ghost notes, double stroke, etc.
5		x			x			x		
6	x			x				x		

Figure 5.21: Results of questionnaire. Six student and professional drummers responded.

5.5 Future Studies

A number of improvements could be made for a more formal study of the effectiveness of a system such as SMED. Experiment 1 could be made easier for subjects by providing a series of adjectives and scales of one through seven on which to evaluate a performance. Experiment 1 was particularly time-consuming as subjects searched for the "right words" to describe each of the 25 performances. Also, more subjects should be tested. This would help to bring about results with more statistical significance. Ideally, there would be three subgroups: animators, drummers, and people with no experience in animation or drumming. Differences due to such experience could then be examined. One group may wish to have more detailed editing of the movement, whereas another group may wish to have yet higher-level control. Even within groups, subgroups may want different controls, such as drumming students versus drumming teachers. These results would then shape how SMED would continue to be developed, since a different application may require a different approach to the control of the movement.

5.6 Summary

To summarize, Experiment 1 found that the kinematic settings were successful in influencing the subjects' perception of the kinematic expression. Certain kinematic settings notably influenced the subjects' perception towards two distinct groups of musical styles. The kinematic setting which did not have strong influence was chosen as the best setting across all scores. Its kinematic proportions were not extreme, resulting in realistic motion which had a broad appeal across musical styles.

Experiment 2 showed that subjects found the user interface intuitive, and that a limited-to-usable range of expressive kinematic styles were producible. The amount of practice and complexity of the score seemed to affect the times to complete tasks. Most importantly, it was shown that subjects were active in changing both primary and secondary movements to kinematically express contrasting drum scores.

These results show that the goals of this thesis have been met because:

- SMED was successful in eliciting different interpretations from subjects with *different* kinematic settings of the *same* score, and
- SMED provides a usable framework to specify kinematic expression in musical scores.

However, there are some alterations that could improve SMED. New degrees of freedom for the neck and arms would allow for a greater expressive kinematic range. Local control of the animation would allow kinematic changes to mark phrases and reflect *changing* expression in the score. Unconstraining the wrist, elbow, and shoulder controls would provide more direct control of the movement. Phase control would allow the strike keyframes to exist at different times for the wrist, elbow, and shoulder joints and add a sinuous motion to the basic stroke. Finally, controls should be recalibrated and have individual default values to provide a better "starting place" and range of control for users.

Chapter 6

Conclusions

With a solid foundation for modelling drummers, the question quickly arises as to how to model other musicians. The research from SMED raises a number of points which should be considered when modelling the performance for any instrument:

- The *encoding* of the score is a fundamental aspect regarding what can be modelled. While MIDI is the most common digital protocol for the storage of musical notation, it may not be suitable for storing performance data for certain musical instruments. Kinematic elements which are to be modelled automatically by the system should be encodable, implicitly or explicitly, in the chosen format. Also, the encoding should be carefully considered if the modelling system may be extended to interact with other systems.

- The *primary movements* to play the instrument should be carefully analysed and represented. For SMED, the basic stroke was represented with three keyframes. Other drumming movements, such as taps and brush movements could also be represented in a similar fashion.

- *Secondary movements* that characterize the instrument should also be identified. Drummers tend to bob their heads. Clarinetists tend to sway. Pianists may rest a single wrist if it is not playing, and reed players may move the instrument away from their mouth when not playing for eight measures.

- Consideration should be given to *how the movements change* with volume, pitch, timbre, duration, or other encoded aspects of the score. In SMED, keyframe values were changed to change the size of the swing for onsets of different volumes. Changing the pitch (or in the case of SMED, the instrument) caused the body to face a different direction. For a piano, fingers will move differently for different pitches. Changing pitch can affect the location of the wrist, and hence the orientation of the hand and the kinematics of the fingers.

- Consideration should also be given to *how the user affects the movements.* How will the movement be parameterized? What controls will be given to the user?
- It is also important to determine the *motion between onsets.* The drummer's stroke lengths tend to shorten for a series of quick onsets (drum rolls). A pianist's wrist may lift high to mark a phrase.
- If the encoding does not include necessary *limb or finger assignments*, an algorithm must created to generated one, or such an assignment must be done manually.

SMED has shown that by thoughtfully addressing these points, simple modelling methods can be used to achieve realistic looking animation.

6.1 Future Work

Currently, the scores which SMED uses are generated in a separate environment, typically a MIDI sequencer. Integrating a score-design environment would allow scores to be interactively created and tested. Such an environment would be simpler and more appropriate than a fully-featured sequencer since it could be tailored for drum score editing.

SPAM, score visualization for piano using animation and MIDI [62], uses linear interpolation, has no effective finger assignment algorithm, and does not model movements above the pianist's wrist. The experience gained from modelling drumming could be applied to SPAM to create a better system for modelling piano playing.

One point of interest would be to create a fully-rendered animation strictly for artistic value. A more complex body model, drum kit, and environment could be designed in a commercial animation system. SMED could readily be modified to export joint angle information, and the performance could be complemented by other movements created under artistic direction.

Facial animation has proven to be an important area of research for modelling human expression. Combining the kinematic expression of SMED with facial animation would provide for a higher level of expression in musical performance. Mapping musical elements to facial movements could prove to be challenging, but promises to have interesting results.

The head bobbing algorithm is effective for providing variation and visual interest. Other kinds of movement such as spinning the sticks and standing up could also be generated implicitly from timing information in the score. However, caution must be exercised when adding such movement. If such movement is not judiciously automated, the kinematics of the performance will be more of an "expression" of the programmer than of the animator.

6.2 Enfin

This thesis has addressed the problem of modelling expressive movement in human figure animation. In particular, the movements in musical performance have been considered, namely because of their inherently expressive nature. As previously stated, the goals of this thesis are to model the expressive movements of performing musicians, and to create high-level tools to specify the kinematic animation of musical scores. The system SMED was implemented and proposed as a high-level tool to model the expressive movements of drummers.

SMED can process arbitrary MIDI-encoded drum scores and create an animation of a performance of that score. The user can affect the kinematic expression of the performance by manipulating the frequencies and amplitudes of the wrist, elbow, shoulder, neck, and back joints. Techniques such as inverse kinematics and dynamic simulation are avoided in order to save processing time and reduce the complexity of the simulation. Instead, a hybrid keyframing system is used, where some frames are calculated in advance, and others on the fly. The combination of forward kinematics, preprocessing of static keyframes, and CTB spline interpolation allows expressive, *realistic motion* and *real-time interaction* to be readily achieved.

Two experiments were employed in order to determine whether the goals were met. The first experiment determined that subjects were capable of differentiating among the kinematic expressions of the animation of SMED when the UI settings were changed and the score was held constant. The second experiment determined that subjects were able to use SMED to create an animation which reflected the musical content score.

Certainly, the goals of this thesis have been met. SMED models the underlying kinematics of drummers for arbitrary modern drum scores, and it is a high-level tool that allows the kinematic expression of a drum score to be specified. SMED facilitates the control of kinematic expression by modelling both primary and secondary movements, and by providing user control of these movements in both time (frequency) and space (amplitude). Although not all aspects of drumming kinematics were addressed, the study showed that most subjects thought that a useful array of expressions could be modelled. Because the underlying system of SMED is kinematically based, it is readily extendible to accommodate new movements and additional degrees of freedom.

Appendix A

Survey Profile and Questionnaire

The subject profile and questionnaires for Experiments 1 and 2 were distributed as shown in the following sections.

A.1 Subject Profile

```
Profile
=======
Please complete each question by circling your answer or providing
a short answer where appropriate:

1. Are you a musician?    Yes /  No
   If so, which instrument? __________________________________
   How many years have you played? ____________

2. How many hours/minutes of music do you listen to each week? ___:__

   What styles do you listen to? (circle all that apply)
   (a)  heavy metal
   (b)  rock
   (c)  alternative
   (d)  jazz
   (e)  classical
   (f)  blues
   (g)  funk
   (h)  dance/disco
   (i)  polka
   (j)  latin
   (k)  world
   (l)  other: ________________________________________

3. How many hours/minutes of music videos do you watch each week? _________

4. How many live musical acts do you see in a year? ____

5. Do you watch drummers live or on videos?   Yes   /   No

6. What experience do you have with dancing?
   (a) none  (b) bars   (c) have taken lessons  (d) major area of study/work
```

7. What experience do you have with creating animation?
   (a) none (b) hobby (c) have taken courses (d) major area of study/work
8. What experience do you have with computing?
   (a) none (b) hobby (c) have taken courses (d) major area of study/work

A.2 Experiment 1

```
Questionnaire:  Experiment #1
=============================

Please answer all questions on paper provided.  If more room is
required, please use back of page.

1. Five different drum scores will be played; for each, 5 different
  drumming performances will be shown (for a total of 25 performances).

For each performance, answer:
  (a) What style of drumming does the movement convey?
  (b) Why?

Score 1
     Performance 1:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 2:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 3:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 4:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 5:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
Score 2
     Performance 1:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 2:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 3:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 4:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 5:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
Score 3
     Performance 1:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 2:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 3:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 4:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
     Performance 5:  (a) style? ------------------------------------------
     (b) why? -----------------------------------------------------------
```

```
Score 4
     Performance 1:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------
     Performance 2:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------
     Performance 3:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------
     Performance 4:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------
     Performance 5:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------
Score 5
     Performance 1:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------
     Performance 2:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------
     Performance 3:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------
     Performance 4:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------
     Performance 5:  (a) style? ------------------------------------------
     (b) why? ------------------------------------------------------------

2.  For each score, which performance style best fits that score?

Score 1 (a) best style: ------------------------------------------------
(b) why? ---------------------------------------------------------------
Score 2 (a) best style: ------------------------------------------------
(b) why? ---------------------------------------------------------------
Score 3 (a) best style: ------------------------------------------------
(b) why? ---------------------------------------------------------------
Score 4 (a) best style: ------------------------------------------------
(b) why? ---------------------------------------------------------------
Score 5 (a) best style: ------------------------------------------------
(b) why? ---------------------------------------------------------------

3.  For each style, what types of movement characterize that style?

Style 1: [blues]-------------------------------------------------------
-----------------------------------------------------------------------
Style 2: [funk]--------------------------------------------------------
-----------------------------------------------------------------------
Style 3: [hard rock]---------------------------------------------------
-----------------------------------------------------------------------
Style 4: [jazz]--------------------------------------------------------
-----------------------------------------------------------------------
Style 5: [latin]-------------------------------------------------------
-----------------------------------------------------------------------

End of Experiment #1
```

A.3 Experiment 2

```
Questionnaire:  Experiment #2
=============================

1. Use the Figure Options controls in SMED to create a performance that
```

best expresses the score (in your opinion).

IMPORTANT: For each performance, be sure to store your Figure Options controls settings in the Figure Flags window.

JUST AS IMPORTANT: Once all songs have been finished, save your stored settings (Alt-"O", "S"), using the filename convention:
[loginid].drumstyle e.g. woodgain.drumstyle

[note: files were later renamed to hide identity of subject. AWG]

2. For each score, what types of movement characterize that style?
Why did you choose the settings you used?

Score 1: ____
____

Score 2: ____
____

Score 3: ____
____

Score 4: ____
____

Score 5: ____
____

3. Was the interface (i.e. the manipulation of frequency and amplitude of joint angles) an intuitive method for the creation of expression?

(1) very difficult to use
(2) not very intuitive
(3) sometimes intuitive, sometimes awkward
(4) intuitive, with some more practice
(5) very intuitive, with little practice

3b. What would make the interface easier to use? ____________________________
____
____
____

4. Was the interface sufficient for the creation of expression?

(1) couldn't do anything expressive at all
(2) very limited in its range of expression
(3) can only make a couple of expressions
(4) can make a useful array of expressions
(5) can make any expressive movement

4b. What kinds of movement did you want to create, but were not able to? (please indicate which score too).
____
____
____

4c. What kinds of movement should be added or removed for to make the movement more expressive, or to increase the "range" of expressions?
____
____
____

5. Any additional suggestions/comments? ____________________________
____
____

End of Experiment #2

Appendix B

Raw Data

This appendix contains the raw data from Experiments 1 and 2. The complete subject profile data is represented in Figure 5.1. The data has been grouped according to question to facilitate analysis.

B.1 Experiment 1

For Question 1, each subject was asked to describe the animation of five musical scores, each played with five different kinematic settings for a total of 25 performances. The 275 responses have been organized into Figures B.1 and B.2. Words which contain a positive association to a particular music genre are displayed in upper case.

The comments have been reorganized and grouped by subject in Figures B.3 and B.4 in order to facilitate the analysis of all comments of an arbitrary subject.

For Question 2, each subject was asked to indicate which kinematic setting (performance) was the most appropriate for each score and to explain why they chose a particular performance. Subjects were also asked to indicate a "close second best" if they felt one existed. The results of the best choice are shown in Figure B.5 and the reasons are shown in Figure B.6.

For Question 3, each subject was given the names of five musical genres as was asked to express his/her opinion about the kinds of movements found in such genres. The explanations are shown in Figure B.7.

Perception of Performances Described in Free Words (page 1 of 2)

Score	Setting 1	Setting 2	Setting 3
5	slow ROCK; it's ROCKy but slow from waist - moderate range - moderate arm amplitude JAZZy; grooving fluid CLASSICAL; low energy, low amplitude moderate ROCK; average motion throughout BLUES/CLASSICAL; controlled unenthusiastic, unnatural; too stiff in head and shoulders, as opposed to torso stiff; stiff back and arms look stiff and wrong JAZZ; the body beat is JAZZy ALTERNATIVE;	WORLD (African); variety of arm mvmt more arm and head amplitude than #1 mellow ROCK; kinda groovy but not completely expressive JAZZ; don't know ALTERNATIVE; motion of head and neck LATIN; probably b/c it fits w/ score; torso rotating laid-back, natural; mvmts are proportionate ROCK; full body motion in a fluid fashion, motion in head looks good w/that in torso looks right - good effort; effort matches music, so does head bobbing ROCK; the body motion seems like ROCK ROCK; head mvmts and shoulders	ROCK; long/short arm mvmt lots of head amplitude and upper arm - hands are close to face aggressive ROCK; really long arm strokes ROCK; enthusiastic thrash-METAL; dramatic head bobbing ROCK; torso rotation seems higher jerky; mvmts are too big hard ROCK/spaedic; strong, pronounced head mvmt disjointed - weird; arms look arthritic, head bobbing looks okay ALTERNATIVE; the head dips down so low it looks like ALTERNATIVE heavy METAL; crazy mvmts, too excited
4	FUNKy CLASSICAL, kinda mix n c JAZZy; small mvmts CLASSICAL; stiff, low energy bebop-swing, the swinging of his back when alternating b/wn drums JAZZ/BLUES; no head mvmt, but fluid body mvmt n c JAZZ; full rigid upper torso mvmt (no separate head mvmt) a bit stiff - looks more 'right' when the music speeds up; not enough mvmt at first, later looks efficient JAZZ; head mvmt CLASSICAL or BLUES; a little stiff and too precise	ROCK; again arm mvmt JAZZ-FUNK; rhythm w/ Ride cymbal (very JAZZ) - solo uses lots of cymbal - syncopation [] BLUESy, fluid and finessed BLUES; don't know FUNK; he's kicking [butt]. reminds me of "FUNKy drummer" James Brown ROCK; head mvmt, demonstrative, fluid laid-back; natural mvmt a bit more JAZZy than 1; again upper torso mvmt but slight head mvmt makes it seem like he is "w/it" more natural at first - frantic when music speeds up; JAZZy and cool when it's slow [] light ROCK, mvmt not [as violent as] ROCK ROCK or ALTERNATIVE; the way he is turning and moving his back	heavy METAL; the dude is moving crazy lots more head/arm amplitude hard ROCK; big head and arm mvmts heavy METAL; the head motion overriding everything, and goes with the arm swinging heavy METAL, recklessness of arm motion seems to be wasting lots of energy heavy METAL; exaggerated motion (probably 'cause score s! w) forced, too neck-extensive hard ROCK/spasdic; too much head mvmt too energetic for slow bit, looks great for fast part, ALTERNATIVE; dipping head is alterntve JAZZ or ROCK, looks like solo w/high energy
3	FUNK; sounds funky!! ROCK; rhythm is even, strokes are simultaneous, basic BLUES, doesn't move a lot but more than #4 POLKA, stiff, low energy chicken playing music, neck moves like pendulum w/back DISCO, light hits quickly, rigid very rigid, subject is suffering from neck pain .) beginner style, or something; drummer looks nervous or very stiff extremely [stiff]; not moving all that much JAZZ; the straight back mvmt gives a "JAZZy" impression LATIN or POLKA; low energy	JAZZ; seems somewhat like JAZZ more amplitude in head, forearms JAZZ; looks like he's jiving to beat JAZZ; stacatto attacking precise big band; seems very concerned about the band ROCK; fluid mvmt, head mvmt regular; too up and down exactly w/ beat ROCK; rhythmic motion, to the beat (kind of like what you'd see at the bars downtown) very mechanical and bored - looks like he doesn't really feel like a playing; ROCK, head banging but not hvy METAL kind dance/DISCO; excited	ROCK; guy was moving like it lots of head; hands held close to face inb/wn beats, looks [concentrated] heavy METAL; head banging heavy METAL; head-banging METAL; dramatic head motion, makes it look like METAL heavy METAL, seems to be hitting very hard! more mvmt head bangy, ROCKish; extensive bending at the neck ROCK/hard ROCK (mostly); looks like a head banger, should have long hair (much head mvmt) deliberate - weird - forced; the head bobbing w/the cymbal looks quite silly. heavy METAL; the extra head mvmt ROCK or heavy METAL; exaggerated mvmt
2	POLKA, mvmt fwd/backwd rocking of emphasis to left combined w/side/side rocking CLASSICAL, stiff POLKA, stiff reminds me of Charlie Watts (Rolling Stones); he's almost dead motions seem crisp and precise JAZZ, seems relaxed more groovy than 4 and 5, JAZZy?; b/c shoulders move from side to side dance/DISCO; fluid motions, especially in shoulders calm, a bit [stiff]; barely any arm mvmt [] fast CLASSICAL; kind of slow mvmt but faster then [] CLASSICAL CLASSICAL, not very enthusiatic musician	ROCK but slow tempo; it fits the rocking ? more amplitude in head and hands rocking to left FUNKy JAZZ; got the shoulders, head and arms going JAZZ; snappy, attacking the drums medium pace ROCK; moderately paced ROCK; more expressive/demonstrative more laid back than 4, 5,1; greater range of mvmt ROCK/ALTERNATIVE; strong fwd -back motion of head and upper torso more natural than #s 1,4,and 5; not as [stiff] as 1, less spastic than 5 JAZZ; body mvmt seems to remind me of a JAZZ player ALTERNATIVE, i feel it	ROCK, the beat/tempo [rock-blues-funk]; syncopation, "backbeat" (based only on rhythm HEARD) heavy METAL; looks uncontrolled and head banging heavy METAL, head-banger, enthusiastic hard ROCK; dramatic motion in head heavy METAL; even more mvmt - seems to be hitting hard forced, the neck is bending a bit too far hard ROCK, similar to performance 2, but head motions much more pronounced banger style; looks like he's really getting into it - lots of arm mvmt but more natural dance[DISCO]; head mvmt rhythm and the height of the drum sticks heavy METAL; the musician is into it and moves a lot (head is moving)
1	BLUES, just the slow rhythm moving from waist-accents to R side DISCO; stiff and disinterested CLASSICAL, disinterested, stiff very subdued BLUES; the rhythm track sounds bluesy however, motion is similar to a ballad or folk BLUES/JAZZ; mvmts constrained habitual, like it does this often, comfortable; not sure disinterested, mostly upper torso, little arm mvmt very unnatural - no effort, effort for high hat right, but snare seems all wrong BLUES, guy looks depressed doesn't look right; the hand mvmt is too stiff and forced	JAZZ, just because I say so waist/head mvmt combined; accents R side BLUESy, grooving w/small head and arm mvmts BLUES, fluid beat w/motion like "black velvet". southern BLUES, affected by rhythm track ROCK, fluid mvmt more peppy than 1, BLUES; more arm mvmt than in 1, w/ head mvmt important feature much more natural than 1, adding wrist makes effort on high hat & snare more natural JAZZ, extra arm mvmt than in 1 gives JAZZy impression LATIN, i don't know	FUNK; sound like BLUES (heard this one first); slow beat phrase - head keeps the beat ROCK; large head and arm mvmts ALTERNATIVE, enthusiastic drug induced haze; mvmt (head) very dramatic for slower paced song BLUES; mvmts controlled, deliberate and slow absorbed, more head mvmt ROCK/hard ROCK; heavy head and upper torso mvmt stiff; arms look seized up - the head bobbing works well w/ the music though - groovy ALTERNATIVE; FUNKy head dipping heavy METAL; b/c of the head mvmt the head follows the arms and hands

Figure B.1: Subjects' descriptions of performances, grouped by score and control setting (Settings 1 to 3).

Perception of Performances Described in Free Words (page 2 of 2)

Score	Setting 4	Setting 5
5	JAZZ (kind of); sounds like.. limited head only, slide side to side CLASSICAL; stiff CLASSICAL; low energy, bored countrylike; moderate/slow but he hits so many drums it isn't a tight match CLASSICAL, too rigid for beat of music stiff; no rotation on neck not quite disinterested; no body mvmt, but very slight head mvmt calm and efficient; not much motion -works well b/c the piece is quite complex maybe a tiny bit more mvmt would be better BLUES; slow head mvmt but the arm mvmt is faster than classical CLASSICAL; too stiff. He's like a robot	FUNK; arm mvmt tends to/goes towards so called FUNK ALTERNATIVE/heavy METAL; frantic FUNKy JAZZ; brings the sticks right back to shoulder FUNK; wild, maniacal hard-fast ROCK; arm motion and head mvmt heavy METAL/ROCK; demonstrative energetic, joyful; grooves w/the beat ROCK; full body motion, but w/the head stiff efficient - a bit better than 4 ; arm mvmt matches the speed of piece - could have a but a bit too much shoulders heavy METAL; head banging and lots of arm mvmt ROCK; fast mvmts
4	JAZZ; crash interval limited amplitude - appropriate for slow passage but the sound is too 'big' for the limited mvmt during fast sequence CLASSICAL; fluid but kinda stiff CLASSICAL; choked, stiff swing or JAZZ; motion more subdued but quick and crisp when necessary CLASSICAL, uptight, controlled most natural so far (1,2,3); shoulder mvmt but needs more rotation at neck not very relaxed; a bit stiff, minimal in all mvmts doesn't look right - no effort, boring; CLASSICAL; slow mvmt of body/arms JAZZ or BLUES; the musician looks like he should have a tie and suit. He doesn't move much despite the high energy of the beat	ROCK; duration of some beats more upper body/arm amplitude ROCK; large arm mvmts ROCK; wild, loud METAL; dramatic arm motion..wrist motion in this one though seems unnatural BLUES; upright, more expressive/demonstrative than classical energetic; wide mvmts hard ROCK/spasdic; wild arm mvmts, very emphatic and strong looks like he's moving in fast motion...; arms are unnaturally fast ROCK, the overall mvmt (head doesn't dip enough for alternative) heavy METAL; aggressive on the drum
3	CLASSICAL; guy was kinda cool JAZZ-pop (Kenny G); limited range of mvmt- laid back BLUES; head going to the beat but in a mellow sort of way CLASSICAL; stiff, demonstrative new age; he looked bored .not much mvmt <Yanni lover BLUES; controlled, precise, short swings bored, tired, he needs a Mars bar, mvmt is limited laid back, JAZZy, no upper body mvmt aside fr/ head, though still fluid looks like he's on downers, or has a hangover; no effort at all..looks like he's trying to keep it quiet CLASSICAL; a very 'stuck up' minimal mvmt figure BLUES, the musician looks drugged	ROCK; just the mvmt more like ROCK; more amplitude in upper body - less in head, more in 'gut' -ROCK; into it FUNK, high-energy ROCK; arm motion doesn't seem very natural mvmt as drum seems to be struck w/fixed angle at elbow heavy METAL\ROCK, long strokes seem to imply high volume· not as high as 3 laid-back, looks natural, goes w/beat looks forced; much more mvmt in arms (w/stiff elb.s) than rest of body bit forced, but a bit more natural than the rest; forced: head bobbing still looks odd, but natural b/c the force on the drum looks right for the sound ALTERNATIVE; the way the sticks are held when not hitting drum ROCK; L. hand too stiff & goes too high
2	JAZZ; i don't know pop-JAZZ; 'mellow' attitude - torso remains vertical BLUES; fluid but not totally expressive CLASSICAL; very stiff - little head motion more swing-like , although track is not like that, more subdued motions CLASSICAL, little upper body mvmt - rigid a bit rigid, the back does not bend JAZZ-like?, body rather rigid a bit stiff and square - unnatural. stiff, left arm hooked at the beginning - unnatural - way too much shoulder mvmt BLUES; the head rhythm and shoulder mvmt indicates BLUES JAZZ (4 and 1 very similar); however the head motion is better	ALTERNATIVE; frantic arm unable to judge style; I notice this is the same score - he rocks more fwds and bckwds ROCK; strong arm mvmts FUNK; showing off, big wind-up, scary more JAZZ like; motion generated dramatically from arms BLUES/ROCK; holding one stick up for the beat - implies strong beat artistic, repetitive, still a bit stiff, too much head banging, no bend at neck ROCK, full body motion, like JAZZ, but a bit jerkier energetic, spasmic; a lot of arm mvmt - looks unnatural and tiring ALTERNATIVE; angry arm mvmt and body mvmt FUNKy; he looks like a teacher showing to pupil how to use the drum
1	chemical; mvmt of arm BLUES played by JAZZ dude, limited mvmt ALTERNATIVE, stiff CLASSICAL; didactic, stiff CLASSICAL; tame, almost no mvmt other than wrist CLASSICAL; upright mvmt - indicates low volume, precise hits rigid; very little mvmt except for wrists laid-back, slight head mvmt, little arm mvmt same as 1, CLASSICAL, minimal head mvmt - kind of stuck up looking maybe slow ROCK; the shoulders don't seem to move correctly	pop-ROCK, cheesy!!! moving from waist, no head this time JAZZ; big arm and head mvmts but not as big as 3 ROCK, energetic BLUES; steady pace .steady mvmts. regimented JAZZ; mvmts repetitive natural; even mvmts rather nondescript, actually; like performance 1, but w/some arm mvmt slow and deliberate - forced; slow and swaying of back forced lots of effort on the high hat (too much) ROCK/heavy ROCK, exaggerated arm mvmts and head mvmts dance/DISCO, excited

Figure B.2: Subjects' descriptions of performances, grouped by score and control setting (Settings 4 and 5).

Perception of Performances Described in Free Words

Subject	Score 1	Score 2	Score 3
11	doesn't look right; the hand mvmt is too stiff and forced LATIN; i don't know heavy METAL; b/c of the head mvmt. the head follows the arms and hands maybe slow ROCK; the shoulders don't seem to move correctly dance/DISCO; excited	CLASSICAL; not very enthusiatic musician ALTERNATIVE; i feel it heavy METAL; the musician is into it and moves a lot (head is moving) JAZZ (4 and 1 very similar); however the head motion is better FUNKy; he looks like a teacher showing to pupil how to use the drum	LATIN or POLKA; low energy dance/DISCO; excited ROCK or heavy METAL; exaggerated mvmt BLUES; the musician looks drugged ROCK; L. hand too stiff & goes too high
10	BLUES; guy looks depressed JAZZ; extra arm mvmt than in 1 gives JAZZy impression ALTERNATIVE; FUNKy head dipping CLASSICAL; minimal head mvmt - kind of stuck up looking ROCK/heavy ROCK; exaggerated arm mvmts and head mvmts	fast CLASSICAL; kind of slow mvmt but faster than [] CLASSICAL JAZZ; body mvmt seems to remind me of a JAZZ player dance[DISCO]; head mvmt rhythm and the height of the drum sticks BLUES; the head rhythm and shoulder mvmt indicates BLUES ALTERNATIVE; angry arm mvmt and body mvmt	JAZZ; the straight back mvmt gives a 'JAZZy' impression ROCK; head banging but not hvy METAL kind heavy METAL; the extra head mvmt CLASSICAL; a very 'stuck up' minimal mvmt figure ALTERNATIVE; the way the sticks are held when not hitting drum
9	very unnatural - no effort; effort for high hat right, but snare seems all wrong much more natural than 1; adding wrist makes effort on high hat & snare more natural stiff; arms look seized up - the head bobbing works well w/ the music though - groovy same as 1; slow and deliberate - forced; slow and swaying of back forced: lots of effort on the high hat (too much)	calm, a bit [stiff]; barely any arm mvmt [] more natural than #s 1,4,and 5; not as [stiff] as 1, less spastic than 5 banger style; looks like he's really getting into it - lots of arm mvmt but more natural a bit stiff and square - unnatural; stiff, left arm hooked at the beginning - unnatural - way too much shoulder mvmt energetic, spasmic; a lot of arm mvmt - looks unnatural and tiring	extremely [stiff]; not moving all that much very mechanical and bored - looks like he doesn't really feel like a playing; deliberate - weird - forced; the head bobbing w/the cymbal looks quite silly... looks like he's on downers, or has a hangover; no effort at all..looks like he's trying to keep it quiet bit forced, but a bit more natural than the rest; forced: head bobbing still looks odd, but natural b/c the force on the drum looks right for the sound
8	disinterested; mostly upper torso, little arm mvmt BLUES; more arm mvmt than in 1, w/ head mvmt important feature ROCK/hard ROCK; heavy head and upper torso mvmt laid-back; slight head mvmt, little arm mvmt rather nondescript, actually; like performance 1, but w/some arm mvmt	dance/DISCO; fluid motions, especially in shoulders ROCK/ALTERNATIVE; strong fwd -back motion of head and upper torso hard ROCK; similar to performance 2, but head motions much more pronounced JAZZ-like?; body rather rigid ROCK; full body motion, like JAZZ, but a bit jerkier	beginner style, or something; drummer looks nervous or very stiff ROCK; rhythmic motion, to the beat (kind of like what you'd see at the bars downtown) ROCK/hard ROCK (mostly); looks like a head banger, should have long hair (much head mvmt) laid back, JAZZy; no upper body mvmt aside fr/ head, though still fluid looks forced; much more mvmt in arms (w/stiff elb.s) than rest of body
7	habitual, like it does this often, comfortable; not sure more peppy than 1; absorbed; more head mvmt rigid; very little mvmt except for wrists natural: even mvmts	more groovy than 4 and 5, JAZZy?; b/c shoulders move from side to side more laid back than 4, 5,1; greater range of mvmt forced; the neck is bending a bit too far a bit rigid; the back does not bend artistic, repetitive, still a bit stiff; too much head banging, no bend at neck	very rigid; subject is suffering from neck pain :) regular; too up and down exactly w/ beat head bangy, ROCKish; extensive bending at the neck bored, tired; he needs a Mars bar, mvmt is limited laid-back; looks natural, goes w/beat
6	BLUES/JAZZ; mvmts constrained ROCK; fluid mvmt BLUES; mvmts controlled, deliberate and slow CLASSICAL; upright mvmt - indicates low volume, precise hits JAZZ, mvmts repetitive	JAZZ; seems relaxed ROCK; more expressive/demonstrative heavy METAL; even more mvmt - seems to be hitting hard CLASSICAL; little upper body mvmt - rigid BLUES/ROCK; holding one stick up for the beat - implies strong beat	DISCO; light hits quickly, rigid ROCK; fluid mvmt, head mvmt heavy METAL; seems to be hitting very hard! more mvmt BLUES; controlled, precise, short swings heavy METAL\ROCK; long strokes seem to imply high volume: not as high as 3
5	very subdued BLUES; the rhythm track sounds bluesy..however, motion is similar to a ballad or folk like "black velvet", southern BLUES; affected by rhythm track drug induced haze; mvmt (head) very dramatic for slower paced song CLASSICAL; tame, almost no mvmt other than wrist BLUES; steady pace..steady mvmts..regimented	reminds me of Charlie Watts (Rolling Stones); he's almost dead, motions seem crisp and precise medium pace ROCK; moderately paced hard ROCK; dramatic motion in head more swing-like , although track is not like that; more subdued motions more JAZZ like; motion generated dramatically from arms	chicken playing music; neck moves like pendulum w/back big band; seems very concerned about the band METAL; dramatic head motion, makes it look like METAL new age; he looked bored..not much mvmt..<Yanni lover ROCK; arm motion doesn't seem very natural mvmt as drum seems to be struck w/fixed angle at elbow
4	CLASSICAL; disinterested, stiff BLUES, fluid beat w/motion ALTERNATIVE; enthusiastic CLASSICAL; didactic, stiff ROCK, energetic	POLKA; stiff JAZZ; snappy,attacking the drums heavy METAL; head-banger, enthusiastic CLASSICAL; very stiff - little head motion FUNK; showing off, big wind-up, scary	POLKA; stiff, low energy JAZZ; stacatto attacking; precise heavy METAL; head-banging CLASSICAL; stiff, demonstrative FUNK; high-energy
3	DISCO; stiff and disinterested BLUESy; grooving w/small head and arm mvmts ROCK; large head and arm mvmts ALTERNATIVE; stiff JAZZ; big arm and head mvmts but not as big as 3	CLASSICAL; stiff FUNKy JAZZ; got the shoulders, head and arms going heavy METAL; looks uncontolled and head banging BLUES; fluid but not totally expressive ROCK; strong arm mvmts	BLUES; doesn't move a lot but more than #4 JAZZ; looks like he's jiving to beat heavy METAL; head banging BLUES; head going to the beat bot in a mellow sort of way ROCK; into it
2	moving from waist-accents to R.side waist/head mvmt combined; accents R.side BLUES (heard this one first); slow beat phrase - head keeps the beat BLUES played by JAZZ dude; limited mvmt moving from waist, no head this time	fwd/backwd rocking of emphasis to left combined w/side/side rocking more amplitude in head and hands rocking to left [rock-blues-funk]; syncopation, 'backbeat' (based only on rhythm HEARD) pop-JAZZ; 'mellow' attitude - torso remains vertical unable to judge style; I notice this is the same score - he rocks more fwds and bckwds	ROCK; rhythm is even, strokes are simultaneous, basic more amplitude in head, forearms lots of head; hands held close to face inb/wn beats; looks [concentrated] JAZZ-pop (Kenny G); limited range of mvmt-laid back more like ROCK; more amplitude in upper body - less in head, more in 'gut'
1	BLUES; just the slow rhythm JAZZ; just because I say so FUNK; sound like chemical; mvmt of arm pop-ROCK, cheesy!!!	POLKA; mvmt ROCK but slow tempo; it fits the rocking ? ROCK; the beat/tempo JAZZ; i don't know ALTERNATIVE; frantic arm	FUNK; sounds funky!! JAZZ; seems somewhat like JAZZ ROCK; guy was moving like it CLASSICAL; guy was kinda cool ROCK; just the mvmt

Figure B.3: Subjects' descriptions of performances, grouped by subject and score (Scores 1 to 3).

Perception of Performances Described in Free Words
page 2 of 2)

Subject	Score 4	Score 5
11	CLASSICAL or BLUES; a little stiff and too precise ROCK or ALTERNATIVE; the way he is turning and moving his back JAZZ or ROCK; looks like solo w/high energy JAZZ or BLUES; the musician looks like he should have a tie and suit. He doesn't move much despite the high energy of the beat heavy METAL; aggressive on the drum	ALTERNATIVE; ROCK; head mvmts and shoulders heavy METAL; crazy mvmts, too excited CLASSICAL; too stiff. He's like a robot. ROCK; fast mvmts
10	JAZZ; head mvmt light ROCK; mvmt not (as violent as) ROCK ALTERNATIVE; dipping head is alterntve CLASSICAL; slow mvmt of body/arms ROCK; the overall mvmt (head doesn't dip enough for alternative)	JAZZ; the body beat is JAZZy ROCK; the body motion seems like ROCK ALTERNATIVE; the head dips down so low it looks like ALTERNATIVE BLUES; slow head mvmt but the arm mvmt is faster than classical heavy METAL; head banging and lots of arm mvmt
9	a bit stiff - looks more 'right' when the music speeds up; not enough mvmt at first, later looks efficient more natural at first - frantic when music speeds up; JAZZy and cool when it's slow [] too energetic for slow bit, looks great for fast part; doesn't look right -- no effort, boring; looks like he's moving in fast motion...; arms are unnaturally fast	stiff, stiff back and arms look stiff and wrong looks right - good effort; effort matches music, so does head bobbing disjointed - weird; arms look arthritic, head bobbing looks okay.. calm and efficient; not much motion -works well b/c the piece is quite complex maybe a tiny bit more mvmt would be better efficient - a bit better than 4 ; arm mvmt matches the speed of piece - could have a but a bit too much shoulders
8	JAZZ; full rigid upper torso mvmt (no separate head mvmt) a bit more JAZZy than 1; again upper torso mvmt but slight head mvmt makes it seem like he is "w/it" hard ROCK/spasdic; too much head mvmt not very relaxed; a bit stiff, minimal in all mvmts hard ROCK/spasdic; wild arm mvmts, very emphatic and strong	unnatural; too stiff in head and shoulders, as opposed to torso ROCK; full body motion in a fluid fashion, motion in head looks good w/that in torso hard ROCK/spasdic; strong, pronounced head mvmt not quite disinterested; no body mvmt, but very slight head mvmt ROCK; full body motion, but w/the head stiff
7	n.c. laid-back; natural mvmt forced; too neck-extensive most natural so far (1,2,3); shoulder mvmt but needs more rotation at neck energetic; wide mvmts	unenthusiastic; laid-back, natural; mvmts are proportionate jerky; mvmts are too big stiff; no rotation in neck energetic, joyful; grooves w/the beat
6	JAZZ/BLUES; no head mvmt, but fluid body mvmt ROCK; head mvmt, demonstrative, fluid heavy METAL; exaggerated motion (probably 'cause score slow) CLASSICAL; uptight, controlled BLUES; upright, more expressive/demonstrative than classical	BLUES/CLASSICAL; controlled LATIN; probably b/c it fits w/ score; torso rotating ROCK; torso rotation seems higher CLASSICAL; too rigid for beat of music heavy METAL/ROCK; demonstrative
5	bebop-swing; the swinging of his back when alternating b/wn drums FUNK; he's kicking (butt)..reminds me of "FUNKy drummer" James Brown heavy METAL; recklessness of arm motion..seems to be wasting lots of energy swing or JAZZ; motion more subdued but quick and crisp when necessary METAL; dramatic arm motion..wrist motion in this one though seems unnatural	moderate ROCK; average motion throughout ALTERNATIVE; motion of head and neck thrash-METAL; dramatic head bobbing countrylike; moderate/slow but he hits so many drums it isn't a tight match hard-fast ROCK; arm motion and head mvmt
4	CLASSICAL; stiff, low energy BLUES; don't know heavy METAL; the head motion overriding everything, and goes with the arm swinging CLASSICAL; choked, stiff ROCK; wild, loud	CLASSICAL; low energy, low amplitude JAZZ, don't know ROCK; enthusiastic CLASSICAL; low energy, bored FUNK; wild, maniacal
3	JAZZy; small mvmts BLUESy; fluid and finessed hard ROCK; big head and arm mvmts CLASSICAL; fluid but kinda stiff ROCK; large arm mvmts	JAZZy; grooving fluid mellow ROCK; kinda groovy but not completely expressive aggressive ROCK; really long arm strokes CLASSICAL; stiff FUNKy JAZZ; brings the sticks right back to shoulder
2	n.c JAZZ-FUNK; rhythm w/ Ride cymbal (very JAZZ) - solo uses lots of cymbal - syncopation [] lots more head/arm amplitude limited amplitude - appropriate for slow passage but the sound is too 'big' for the limited mvmt during fast sequence more upper body/arm amplitude	from waist - moderate range - moderate arm amplitude more arm and head amplitude than #1 lots of head amplitude and upper arm - hands are close to face limited head only, slide side to side ALTERNATIVE/heavy METAL; frantic
1	FUNKy CLASSICAL; kinda mix ROCK; again arm mvmt heavy METAL; the dude is moving crazy JAZZ; crash interval ROCK; duration of some beats	slow ROCK; it's ROCKy but slow WORLD (African); variety of arm mvmt ROCK; long/short arm mvmt JAZZ (kind of); sounds like. FUNK; arm mvmt tends to goes towards so called FUNK

Figure B.4: Subjects' descriptions of performances, grouped by subject and score (Scores 4 and 5).

Subject's Favourite Performances

Score \ Subject	1	2	3	4	5	6	7	8	9	10	11
5	2	2	1	5	5, 3	2	5	5	2, 5	3	2
4	1	3	1	2	2, 4	3, 5	5	2	2, 3	3	1
3	5, 2	4	2, 5	2	2	5	5, 2	3, 2	2, 5	3	2
2	5	4	2	2, 5	2, 4	2	5, 2	1, 5	2, 3	5	2
1	1	3	5	2	2, 5	2, 5	2	4, 2	2, 3	3	5

Figure B.5: Each cell contains the number of the kinematic setting that the subject felt was most appropriate for the score. If a second value is present, that represents the subjects "close" second best vote.

B.2 Experiment 2

For Question 1, each subject was asked to set the frequency and amplitude controls to create a kinematic style that best reflected the score in their opinion. The raw UI setting data is shown in Figure B.8. The timing data for animating each score has previously been presented in Table 5.5. The subjects' reasons for choosing such settings are given in Figure B.9.

The remainder of the questions pertained to the subjects' evaluations of SMED. Figure B.10 contains the subjects' answers to the two multiple choice questions. Figure B.11 shows the subjects' comments on what would make the interface easier to use. Figure B.12 shows comments on what kinds of movement subjects wanted to create, but were not able to. Figure B.13 contains comments on what kinds of movement should be added or removed for to make the movement more expressive, or to increase the "range" of expressions. Figure B.14 contain any additional comments.

Subjects' Explanations for Choosing Best Performance

Subject	Score	Best Performance, Second Best (0 means no second best chosen)	Reson for choice of best performance.
1	1	1,0	fits the score best, what can I say??
	2	5,0	because the motion fits the score
	3	5,2	fits well with the movement
	4	1,0	I like the mix
	5	2,0	I like the rhythm
2	1	3,0	first one I saw -- identified the style clearly
	2	4,0	on that one I identified pop-jazz and it had stuck; most limited -- a mellow cool dude
	3	4,0	same reason as #2
	4	3,0	favourite one -- not "best"; the head is exaggerated and it's funny!
	5	2,0	amplitude seems appropriate to rhythm
3	1	5,0	head mvmts & arm mvmts seemed to match
	2	2,0	funky groove w/ upper body, arms & shoulders
	3	2,5	look like they're moving to the beat well
	4	1,0	smaller mvmts seemed to fit the slower music
	5	1,0	seemed to mesh well with the music; kinda fluid
4	1	2,0	good stress on the beat
	2	2,5	high energy -- suits the music
	3	2,0	don't know
	4	2,0	suits the music
	5	5,0	suits the music
5	1	2,5	n.c.
	2	2,4	2 and 4 have consistent motion
	3	2,0	n.c.
	4	2,4	2 has more "groove" than 4
	5	5,3	5 seems to have most consistent "drive" to hard rocking song
6	1	2,5	score is very deliberate; doesn't seem to require movement
	2	2,0	seems to be appropriate level of movement for volume level; 4 & 1 are too rigid; 3 is too wild
	3	5,0	music peppy and groovy
	4	3,5	fluid, demonstrative
	5	2,0	fluid and relaxed, but not as relaxed as 5
7	1	2,0	it just looks right
	2	5,2	movement seems to fit the beat
	3	5,2	woman's intuition :) -- I don't know, just looks good
	4	5,0	good showmanship
	5	5,0	it seems to be enjoying it more
8	1	4,2	it seemed like a slow, easy-going piece
	2	1,5	don't know why; score was a bit dancy, I suppose
	3	3,2	score seems a bit too harsh for any of the others
	4	2,0	as stated previously, movements made it seem drummer was "into" music
	5	5,0	as with score 4, movememnts looked natural & drummer seemed "into" the music
9	1	2,3	2 looks more natural, but I like the head bobbing on 3
	2	2,3	calm & groovy, matches the style; music isn't heavy enough for 3 and the others look too unnatural
	3	2,5	2 matches the style, 5 looks a bit more natural (for how hard he's hitting the drums)
	4	2,3	2: slow jazzy, groovy; 3: a bit fast, but effort looks good
	5	2,5	looks most natural... 5 looks good in parts as well
10	1	3,0	like the exaggerated movements
	2	5,0	I like the "emotion" in the arm movements
	3	3,0	lots of interesting movement
	4	3,0	love that dipping head movement
	5	3,0	like the head movement
11	1	5,0	the movements match the beat
	2	2,0	the movements match the beat
	-3	2,0	he seems to be the right musician; the others are faking it
	4	1,0	n.c.
	5	2,0	n.c.

Figure B.6: Subjects' reasons for choosing best performance.

Subjects' Descriptions of Five Musical Genres

BLUES

1: laid back but fluid
2: slow beat; head emphasis/torso
3: fluid, small arm & head mvmts; melancholic
4: laid-back, groovy
5: laid back; consistent mvmt in quarter not hits; no dramatic motions
6: deliberate, slow and fluid
7: not sure
8: body mvmts (head & arms) slight; implying laid back
9: calm, not too much effort (though I'd imaging there to be some head mvmt)
10: slow, depressive head mvmts; minimal arm mvmt
11: finessed

FUNK

1: upbeat, kinda makes one move the legs & shoulders involuntarily
2: n.c.
3: groovy, laid back with med. head & arm mvmts; shoulders move as well
4: excited
5: quick mvmts; not much head motion; lots of torso to get from drum to drum
6: sharp, fast, expressive
7: rotation of shoulders
8: no idea
9: groovy, loose limbs; head bobbing
10: more upbeat mvmt; head moves faster than the base beat
11: excited, forced

ROCK

1: uncontrolled & angry, yet...
2: fast, even rhythm; moderate amplitude
3: large head & arm mvmts
4: energetic
5: lots of mvmt, particularly bobbing of head and back; high energy
6: explosive, broad (i.e. long) motions, demonstrative
7: wide mvmts, hard hits, head banging
8: wild head & arm mvmts
9: intense, lots of hard hitting arm mvmt, head thrashing
10: exaggerated mvmts; angry arm moves and ''head banging'' of the head
11: uncontrolled, excited, angry

JAZZ

1: finessed, classy, smooth
2: limited range
3: groovy, fluid, med. arms, head & shoulder mvmts
4: staccato, precise
5: ltd head motion; motions generally more conservative; crisp attck on wrists
6: fluid, demonstrative, laid back
7: small head mvmts
8: full, rigid upper torso mvmt, with slight head mvmt
9: cool, efficient, not much mvmt
10: smooth body and head mvmt; more arm mvmt than blues
11: controlled, fast, neat, clean

LATIN

1: uplifting, excited
2: n.c.
3: peppy & groovy
4: peppy
5: not sever head or arm or body motion; more in wrist
6: expressive, quick, explosive, short motions
7: note sure
8: little head mvmt as opposed to arm mvmt
9: energetic, fast, dancy
10: head mvmt faster than base beat; arm mvmt a little exaggerated
11: controlled

Figure B.7: Subjects' descriptions of the kinematics of five musical genres, given the name of the genre. Comments are numbered by subject.

Subjects' User Interface Levels For 5 Scores

Subject	UI Control	Level for Song				
		1	2	3	4	5
1	amp back	7	30	15	31	25
	amp neck	9	3	20	33	23
	amp wrist	52	76	29	33	40
	amp elbow	17	12	41	33	38
	amp shoulder	30	12	29	33	21
	amp gain	65	50	76	65	59
	freq wrist	50	15	25	13	33
	freq elbow	22	43	49	73	33
	freq shoulder	27	41	25	13	33
	freq gain	80	82	69	68	80
2	amp back	8	14	10	10	10
	amp neck	20	45	20	30	20
	amp wrist	33	45	43	43	59
	amp elbow	46	9	13	13	17
	amp shoulder	20	45	43	43	23
	amp gain	50	50	50	40	50
	freq wrist	33	86	33	33	33
	freq elbow	33	1	33	33	33
	freq shoulder	33	12	33	33	33
	freq gain	70	90	26	10	50
3	amp back	10	13	16	14	10
	amp neck	17	26	30	23	26
	amp wrist	57	33	28	50	65
	amp elbow	20	33	28	50	19
	amp shoulder	22	33	43	0	15
	amp gain	27	27	59	50	50
	freq wrist	69	68	25	28	65
	freq elbow	20	20	50	51	26
	freq shoulder	10	11	25	20	8
	freq gain	19	29	50	50	50
4	amp back	0	10	10	17	6
	amp neck	6	28	4	28	7
	amp wrist	68	62	77	58	74
	amp elbow	25	21	11	21	17
	amp shoulder	6	16	11	21	8
	amp gain	42	58	50	80	26
	freq wrist	33	33	93	33	67
	freq elbow	33	33	3	33	16
	freq shoulder	33	33	3	33	16
	freq gain	88	92	50	50	90
5	amp back	12	11	10	32	3
	amp neck	12	27	10	19	1
	amp wrist	56	35	75	13	75
	amp elbow	34	41	11	64	10
	amp shoulder	9	23	13	22	14
	amp gain	19	19	81	50	31
	freq wrist	18	51	33	26	73
	freq elbow	44	36	33	39	18
	freq shoulder	37	12	33	34	8
	freq gain	12	56	83	58	33
6	amp back	10	10	10	24	17
	amp neck	10	27	10	27	10
	amp wrist	45	76	42	20	79
	amp elbow	23	7	26	20	10
	amp shoulder	31	16	31	59	10
	amp gain	32	50	50	56	52
	freq wrist	33	33	42	33	33
	freq elbow	33	33	28	33	33
	freq shoulder	33	33	29	33	33
	freq gain	35	50	50	50	78
7	amp back	12	10	10	10	19
	amp neck	20	22	23	29	20
	amp wrist	76	74	52	34	52
	amp elbow	13	8	40	41	16
	amp shoulder	10	17	7	24	31
	amp gain	73	50	43	62	44
	freq wrist	33	27	33	33	33
	freq elbow	33	23	33	33	33
	freq shoulder	33	49	33	33	33
	freq gain	81	88	22	50	81
8	amp back	10	4	24	10	19
	amp neck	10	21	10	27	22
	amp wrist	33	90	20	74	49
	amp elbow	33	7	20	17	25
	amp shoulder	33	2	60	8	25
	amp gain	50	50	50	50	50
	freq wrist	0	50	10	33	12
	freq elbow	0	50	10	33	74
	freq shoulder	100	0	80	33	13
	freq gain	50	50	50	9	50
9	amp back	5	10	10	18	13
	amp neck	9	42	32	45	42
	amp wrist	85	80	77	62	90
	amp elbow	7	7	0	8	5
	amp shoulder	7	12	23	29	4
	amp gain	60	66	100	95	50
	freq wrist	42	39	84	65	33
	freq elbow	29	29	8	11	28
	freq shoulder	29	31	8	23	38
	freq gain	84	92	50	93	91
10	amp back	2	10	28	28	42
	amp neck	11	10	28	63	10
	amp wrist	37	77	12	42	38
	amp elbow	37	7	17	13	35
	amp shoulder	25	15	70	44	26
	amp gain	16	43	30	78	75
	freq wrist	17	1	51	35	35
	freq elbow	31	48	16	17	35
	freq shoulder	51	50	32	47	29
	freq gain	94	96	50	69	32
11	amp back	4	17	10	30	10
	amp neck	11	36	10	10	23
	amp wrist	75	81	66	56	41
	amp elbow	12	9	19	2	29
	amp shoulder	12	9	14	41	29
	amp gain	35	50	50	50	29
	freq wrist	45	88	33	42	32
	freq elbow	27	6	33	15	35
	freq shoulder	27	6	33	42	32
	freq gain	69	50	50	50	50

Figure B.8: UI settings for 5 scores for each of 11 subjects.

Responses for Experiment 2, Question 2

Subject	(Question: For each score, what types of movement characterize that style? Why did you choose the settings you used?) Reasons for choosing UI settings for each score (1 through 5)
1	1: slow JAZZ; slow back of neck, increased wrist "appropriate" 2: don't know; but seemd like more wrist is good in this style 3: repeating strokes; Back & elbow movement corresponded with the strokes!! 4: kinda ROCK; sounded like ROCK beat; the movement (more back & neck) looked more realistic 5: kinda FUNKY!!; increased slaps, head & wrist movement looked appropriate
2	1: BLUES; added more head & waist; attempted to slow attack/decay because beat is slow 2: JAZZ/LATIN?; added small amount of head, slowed down frequency — larger elbow amplitude 3: [intermediate] score — added more head; smooth out elbows 4: added some neck amplitude, less shoulder 5: interesting; more subtl; made different choices
3	1: light mvmts; [] smaller mvmts & freq. but his head is going because it's a FUNKY beat 2: the arm mvmts - shoulder, elbow & wrist are med. speed & gain, neck & back motion small because it is a FUNKY JAZZY beat 3: fairly large arm mvmts & head mvmts; he's grooving with the beat -- has to get to a wide range 4: sharp small mvmts because doesn't have a large range to play to; moving his head a lot because groovy beat 5: small mvmts; fluid & groovy
4	1: low head movement 2: focused on frequency of left arm because of realism; score had more energy than the drummer 3: fucused on wrist; staccatto rhythms 4: high-energy, with high amplitude, more head-movement given 5: head and shoulders were the focus
5	1: pretty mellow; didn't get a clear mood off the music so it was difficult to capteru the modd 2: beat is very important here; created solid, slow head movement to emphasize on beats, avoided large gain on amplitude, avoided larger shoulder motion to give crisper and less aggressive motion 3: lots of motion except on neck and back 4: n to emphasize the snares; bobbing head to emphasize high energy of piece 5: jamaican; not much neck, mostly wrist for crisp snare look
6	1: pissed me off; couldn't get handle on irregular beat; tried to set it to relaxed slow movements but I couldn't fit the movements to the score 2: head movement because of emphasis on steady beat; he needed to be more demonstrative than original settings; wrist 'cause volume not too high 3: broad movements except for head/back; settings ok as is generally 4: lots of movement in back and head because beat strong and quick; also shoulder increase 'cause beat strong 5: quick beat; lots of wrist movement, but not that strong so no shoulder, elbow; gained in overall frequency because beat is fast; no head/back 'cause not strong
7	1: felt like he needed to touch drums lightly, like stacatto piano; wanted some neck 2: increased wrist; medium energy score; playing same note w/ same hand required more wrist motion 3: more rhythmic; wrist needed to be more involved; needed neck movement (not as much to be rockish) 4: looked like score required harder movements; high-energy score 5: easier to do repetitive; .8 energy; .4 strength of beat
8	1: only changed frequency of shoulders; made it rather jerky & happy; liked the stuffiness of the default back movements; very short and abrupt, like the notes 2: most of the movement in wrists & head; low freuency in shoudlers; created an easy, fluid, laid-back look 3: hard, quick movements with the arms (shoulders); a very basic beat; simple, rhythmic movements 4: kept most of the movement in wrists & slight neck; low freq.; this kept motion fluid, which seemed to fit the piece 5: increased neck & back movement; increase frequency in elbows; created an overall "jerky" movement which "snapped" with the beat
9	1: very hard to make this one look right without being too stiff: beat was too fast for head & neck movement: I tried to minimize movement for a cool, collected jazzy style. oh yeah... 2: had a difficult time getting this right; needed more power on the snare and less on the hihat: tried to have a groovy kind of style, but I was a bit hung up on the power differences to get it perfect 3: sounded like a drummer practising — playing/having fun on his own, so I tried to make the drummer look like he wasn't working too hard, or thrashing (as lhe would in a concert)_ 4: more of a drum solo; tried to make the drummer a little more intense (than #3) 5: tried to get a nice hard-hitting beat (which is why I put the frequency so high); funky, groovy, makes me wanna dance
10	1: went for slow, short movement because of the slow beat; used faster movement because of the shorter strokes to make it look like drums were being hit harder 2: used little body and head movement because of the slow beat; short but fast movements seemed best 3: drum sounded louder and a little slower to allow for longer, more stacatto strokes; the body motion looked good as it follows the music; kept head in line with body for this 4: the beat seemed like the head should move to the rhythm more; fast drumming to suit the beat with short strokes 5: kept head and neck in line and moved together; put the arms up high as it seemed more like a rock type of beat and high arms to look cooler
11	1: slow beat; wrist high; shoulder & elbow low; neck higher than back so he looks less stiff 2: medium amplitude for neck to follow the beat; high frequency and amplitude for wrist because the beat is fast and the use of hihat 3: slow movements and low amplitude for neck and back: high amplitude for wrist but low amplitude for shoulder and elbow because the beat is fast 4: the beat is strong; shoulder high, elbow low, back high to help in the whole movement 5: it's fast beat; average amplitude for wrist, shoulder, and elbow as well as average frequency except wrist slightly faster for final hit

Figure B.9: Subjects' reasons for using UI settings for each animated score.

Ratings of User Interface

Experiment 2

Question 3: Was the interface (i.e. the manipulation of frequency and amplitude of joint angles) an intuitive method for the creation of expression?

Question 4: Was the interface sufficient for the creation of expression?

Subject	Question 3: very difficult to use	Question 3: not very intuitive	Question 3: sometimes intuitive, sometimes awkward	Question 3: intuitive, with some more practice	Question 3: very intuitive, with little practice	Question 4: couldn't do anything expressive at all	Question 4: very limited in its range of expression	Question 4: can only make a couple of expressions	Question 4: can make a useful array of expressions	Question 4: can make any expressive movement
1				x					x	
2				x				x		
3				x					x	
4			x						x	
5				x					x	
6					x				x	
7				x					x	
8					x				x	
9			x						x	
10				x				x		
11			x					x		

Figure B.10: Responses for Experiment 2, Questions 3 and 4.

Responses for SMED Evalution: Experiment 2, Question 3b

Subject	What would make the interface easier to use?
1	more practice
2	no constraints, more parameters
3	I found I didn't play w/ the gain as much because there are so many controls to play with
4	maybe a shoulder/elbow/wrist space? not sure
5	in theory, the interface makes lots of sense; however, changes in some paramters didn't seem to give a linear effect in performance; I didn't use frequency much; amplitude captured more feel
6	it is excellent; the dialog boxes are not as intuitive; i.e. how many scores set (why doesn't it go to current) and gain (explain overall); otherwise, excellent!
7	pictures
8	can't think of anything; learning curve was very easy; few controls make it simple
9	instead of relative distribution for wrist/shoulder/elbow, it would be better to have absolute levels; maybe have a way to adjust individual drum amplitudes (at least hihat) as well
10	have an arm that you can set the max/min movement on; need some way to show graphically the reason why the shoulder/wrist/elbow values are related
11	it is not easy to understand how gain affects the distribution; I think (shoulder, elbow, wrist) should be independently changed like neck and back

Figure B.11: Responses for Experiment 2, Question 3b.

Responses for SMED Evalution: Experiment 2, Question 4b

Subject	What kinds of movement did you want to create, but were not able to?
1	I don't think I was unable to create what seemed appropriate given my knowledge (poor!!) of drumming and music styles
2	side-to-side [head movements], limited by constraints
3	sideways body movements (score 1 & 5)
4	can't think of any
5	control lateral torso movement; in terms of speed, perhaps could control (in non-linear terms) speed and keyframe; NOTE - just suggestions; may not be useful if implemented
6	score 1 — couldn't make it match (however, hated score)
7	rotation of neck, more expressive neck movement in general
8	was quite pleased with all of my final products
9	score 1 — wanted to slow down head movement (1/2 beat); most of my other "wants" are stated in question 2 [Experiment 2]
10	I think I was able to express enough movement; would have to study real drummers more to make sure
11	the amplitude should be able to change during the score; example in the beginning the wrist high & shoulder low, then wrist low and shoulder high; all movement described down in 4c and 5

Figure B.12: Responses for Experiment 2, Question 4b.

Responses for SMED Evalution: Experiment 2, Question 4c

Subject	What kinds of movement should be added or removed for to make the movement more expressive, or to increase the "range" of expressions?
1	maybe putting both hands in air for a while & scream!!!
2	side–side constraints! local control of phrases: better vis. representation (could help); see sound & movement represented together
3	sideways head movements & body movements should be added
4	minimum or maximum limits?
5	none apparent at this time; perhaps use head lateral movement
6	none -- I don't think yhou can without violating constraints of human movement
7	see above; none should be removed
8	maybe funky hand movements in the air or something (showy stuff)
9	would be better if some of the controls were more sensitive; I generally had the wrist amplitude up high, others low; also, sometimes the shoulders swing back & forth to much; maybe an amplitude control for that would be good
10	A "shrugging" movement to the head would be a nice addition; tossing the drum stick option? twirling the drumstick?
11	wing movement of arms and shoulders; rotate head; tilt head back before restart; spinning the sticks between fingers :)

Figure B.13: Responses for Experiment 2, Question 4c.

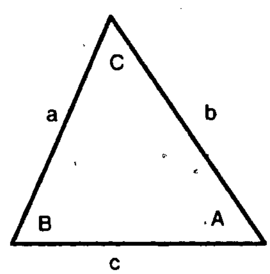
Responses for SMED Evalution: Experiment 2, Question 5

Subject	Any additional suggestions/comments?
1	program looks good; interface is also easy to use; but obviously it requires previous knowledge of music styles. May be some kind of help for users like me to explain w/ some examples
2	n.c.
3	have to movem the slider a lot before a noticeable lchange happens especially in the freq.
4	very impressive
5	main comments: veryh clearly successful in controlling range of motion, depending on emotion and song; energy controlled a great deal by increasing amplitude; examples should be in repeated loop to allow luser to control; amplitude much more powerful than frequency; discrepancies can be very obvious in most joints except the wrist
6	[] looks funky
7	I like the overall gain sliders; the wrist movement was a little finicky but I think I understand why
8	cool program :)
9	great program Adam! Yay!
10	very interesting program; I like the way you can move around to get different views
11	the musician should stand up sometimes for rock or heavy metal; he should turn towards the drum before hitting to aniticipate; loop function to repeat the score while adjusting amplitude and frequency

Figure B.14: Responses for Experiment 2, Question 5.

Appendix C

Mathematical Appendix



Cos Law: $a^2 = b^2 + c^2 - 2\,b\,c\,\cos A$

Sin Law: $a / \sin A = b / \sin B = c / \sin C$

Tan Law: $(a - b) / (a + b) = \tan((A - B) / 2) / \tan((A + B) / 2)$

Figure C.1: The used trigonometric laws (for reference).

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