A Flexible Approach For Synchronizing Video With Live Music

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Abstract. This paper presents a brief history of systems and philosophies for automatically synchronizing imagery with live music. The paper describes various systems created over the last 300 years that automatically present imagery in response to music. These systems are categorized as using an absolute or flexible approach to sound-image correspondence. After discussing the advantages and disadvantages of these opposing strategies, the paper describes a computerized system that can enact an absolute or flexible approach to sound-image correspondence.

The ideas presented in this text were originally written in 1992 as part of a research project funded by the Canada Council. A small amount of editing was undertaken on the grammar in 2009, though the core ideas and the diagrams of the original document are the same. Portions of this paper were published in: Ritter, Don (1993) "Interactive Video as a Way of Life," *Music Works,* vol. 56, p. 48-54. Toronto.

Synchronization of Imagery and Music

Over the past 300 years, the synchronization of imagery with music has been described as ocular music, visual music, color-music, color organ, light organ, and music for the eyes (Burnham 1968; Castel 1725; Eisenstein 1947; Klein 1927). Louis-Bertrand Castel, a Jesuit priest, mathematician and philosopher is usually credited for creating the first instrument capable of synchronizing imagery with music when he created a color organ in 1734. His instrument was a modified clavichord that contained a series of colored tapes illuminated from behind by candles; the playing of each key invoked the display of a different colored tape.

Although Castel supposedly constructed the first instrument, the notion of corresponding image with sound had been proposed a few years earlier by physicist Isaac Newton who had observed a correspondence between the proportionate width of the seven prismatic rays and the string lengths required to produce the musical scale.

> May not the harmony and discord of colors arise from the proportions of the vibrations propagated through the fibers of the optic nerve into the brain, as the harmony and discord of sounds arise from the proportions of the vibrations of the air? (Newton 1967)

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A detailed description of Castel's instrument is not available, however, Karl von Eckartshausen (1791) presents a vivid explanation of his own device that was influenced by Castel's design.

> I have long tried to determine the harmony of all sense impressions, to make it manifest and perceptible. To this end I improved the ocular music invented by Pere Castel. I constructed this machine in all its perfection, so that whole chords can be produced, just like tonal chords. Here is a description of the instrument. I had cylindrical glasses, about half an inch in diameter, made of equal size, and filled them with diluted chemical colors. I arranged these glasses like the keys of a clavichord, placing the shades of color like the notes. Behind these glasses I placed little lobes of brass, which covered the glasses so that no color could be seen. These lobes were connected by wires with the keyboard of the clavichord, so that the lobe was lifted when a key was struck, rendering the color visible. Just as a note dies away when the finger is removed from a key, so the color disappears, since the metal lobe drops quickly because of its weight, covering the color. The clavichord is illuminated from behind by wax candles. The beauty of the colors is indescribable, surpassing the most splendid of jewels. Nor can one express the visual impression awakened by the various color chords.

While research into the synchronization of imagery and sound is nearly 300 years old, some researchers who are currently pursuing this field with computer graphic and electronic music technology are under the impression that this research began with the introduction of MIDI and real time computer graphics (Pfitzer 1991). In "Color-Music: The Art of Light," a book devoted to the exploration of synchronized sound and image, Adrien Bernard Klein (1927) stated "...it is an odd fact that almost everyone who develops a color-organ is under the misapprehension that he, or she, is the first mortal to attempt to do so."

Although various performers, scientists, artists, and composers from this century have presented works containing synchronized imagery and music, perhaps the most well known composition is Scriabin's *Prometheus, the Poem of Fire,* written in 1910. His work used a "light line," know as "Luce" in the score, which specified color changes to be made during presentation of the music (Galeyev 1988). Although Scriabin had first attempted strict correspondence between music and color, he later rejected this approach and began organizing color into counterpoint relationships with the music. The first performance of "Prometheus" was presented in 1915 at Carnegie Hall in New York City using the "Chromola," an instrument that could present various patterns of color.

Some visual artists who have explored the synchronized presentation of imagery and sound include Wassily Kandinsky. His *Pictures at an Exhibition* was presented at the Bauhaus in 1928, and it contained physical scenery that moved to music (Burnham, 1968). Also at the Bauhaus, Lásló Moholy-Nagy created the sculpture *Light-Space Modulator* (1922-1930), a work that incorporated kinetics, sound and light, and provided inspiration for later artists working with art and technology.

The medium that is perhaps the most advanced in the presentation of synchronized imagery and music is film. Pioneering this application was Sergei Eisenstein. His innovative pairing of music and imagery is used in his films *Alexander Nevsky* (1938) and *Ivan the Terrible Part I* (1944), and discussed in his books *The Film Sense* (1942) and *The Film Form* (1948). Eisenstein's approach, however, did not support a direct synchronization of visual and musical qualities, but rather consisted of selecting music and film imagery to provide a unified and desired mood. "The search for correspondence must proceed from the intention of matching both picture and music to the general, complex 'imagery' produced by the whole.” (Eisenstein 1947, p.78)

Synchronized imagery and music within a film, however, differ significantly from presentation through an instrument that can provide imagery in response to live music, like Castel's clavichord. The creation of a film that contains both imagery and music typically follows from a series of disconnected procedures: film footage shot at one or more locations, music recorded at another, sound and image combined at third, and viewing of the finished film at thousands of different locations. Although this process is not necessarily faulty, it is quite different from a live performance. This difference is linked to the inherent ability of musical instruments to present a live experience. Most visual media, such as film or video, cannot be used for this purpose. Musical instruments, by design, allow the playing of music and the simultaneous hearing of music by an audience. Film, however, must first be exposed, edited, duplicated, distributed and projected before being viewed by an audience. An audience who attends a film does not view or hear the creation of images or sounds, but instead experiences a series of intricately composed elements created at distant locations and disconnected times. While this disconnected process is similar to the creation of recorded music, the experience of live music is often considered to contain elements that are not present on music recordings. "An essential part of ‘real’ music is the live element, the indefinable but undeniable interaction between players and audience which makes music exciting." (Puckette 1991).

My own involvement with systems and performances of synchronized video and music is motivated by a desire to present living images that are composed before an audience rather than in an editing room. While the moment of creation corresponds with the moment of experience for some visual art forms, such as performance, most visual media have separated these acts, including painting, sculpture, photography, film and video. John Whitney (1990), a twentieth century advocate of synchronized sound and image, considers this medium to be relatively unexplored, but suggests the current availability of inexpensive video, computer and music equipment will make live performances of synchronized music and imagery more common in the future.

The remainder of this paper discusses the different approaches and considerations for synchronizing imagery with music during performances, and provides a detailed description of *Orpheus*, the author's system that permits real time synchronization of video imagery with music.

Approaches for Synchronizing Imagery and Music

The process of corresponding imagery and music for live presentation or recording contains three areas of concern: music, imagery, and correspondence. The creation of a work incorporating music and imagery is usually undertaken with dominance in one of these areas. Although a filmmaker will likely give dominance to imagery, a composer will probably emphasize the music. This situation is exemplified by composers and performers who have criticized the quality of music used in expensive works of computer animation. Many visual artists, however, would consider systems that present flat fields of color in response to music, like Castel's, are lacking in visual complexity. Whether image or sound is given dominance, both approaches require rules or assumptions between specific visual and musical qualities. The Prometei Group in Russia is devoted to investigations of corresponding sound with image and they suggest that correspondence can be based on individual qualities, musical themes, or through contrapuntal approaches (Galeyev, 1988).

One method for synchronizing imagery with music is to present specific images in response to specific qualities of music. Castel used this approach by corresponding pitch with hue using the following rules: C=blue, C-sharp=blue-green, D=green, E-flat=olive green, E=yellow, F= yellow-orange, F-sharp=orange, G=red, A-flat=crimson, A=violet, B-flat=Agate, B=indigo. This closed, or absolute, approach does not permit changing the correspondence between the pitch and hue. Regardless of the performer or composition being played, the visual imagery, colored light, would always appear the same, albeit in different orders.

The specific correspondence rules used by Castel were determined by matching the relative wavelengths of different hues with the relative pitches of notes within an octave. Although this strategy may have mathematical and physical justification, it does not consider the psychophysical differences between the nervous system's perception of sound and visual imagery. Although two lights bulbs produce twice the light of one from a physical perspective, nine bulbs are required before the human eye will perceive a doubling in brightness (Stevens 1957). Because the human nervous systems experiences phenomena in nonlinear manners, with the degree of nonlinearity being different for every sense (Goldstein 1980), an absolute correspondence cannot be justified according to physical properties.

> The question must, nevertheless, be undertaken, for the problem of achieving such absolute correspondence is still disturbing many minds, even those of American film producers. Only a few years ago I came across on an American magazine's quite serious speculations as to the absolute correspondence of the piccolo's tone to--yellow! (Eisenstein 1942, p. 109)

Eisenstein differed from his predecessors who explored sound-image correspondence by suggesting that mood be the determining element rather than a particular quality of music or imagery. His book *The Film Sense* (1942) proposed different methods for corresponding sound and imagery. A "factual" or "natural" approach has sound depicting an image, such as an image of a frog with a croaking sound. Eisenstein, however, did not view this form of synchronization as being "art" and referred to it as "merely recorded." Eisenstein also suggested correspondence according to the meter, phrase, rhythm, or timbre.

> It is important to keep in mind that our conception of synchronization does not presume consonance. In this conception full possibilities exist for the play of both corresponding and non-corresponding "movements," but in either circumstance the relationship must be compositionally controlled. It is apparent that any one of these synchronization approaches may serve as the "leading" determining factor in the structure, dependent on the need. Some scenes would require rhythm as a determining factor, others would be controlled by tone, and so on. (Eisenstein, 1942, p. 85)

In contrast to an absolute approach to sound-image correspondence, a flexible approach does not assume a best or true combination for music and image, but instead advocates a combination according to a desired result. This approach has a practical advantage over an absolute method: it is all encompassing. If a particular color is best presented in response to a particular pitch--as espoused by an absolute approach to sound image correspondence--a flexible system still permits creation of this relationship and many others because of its flexibility. A system using absolute correspondence rules, however, can only be used in one manner, in accordance to the rules that are inherent in the system.

Orpheus Interactive Video System

Based on the conclusion that an absolute or best correspondence does not exist between music and image, since 1987 I have been developing an interactive video system that presents real time video in response to music. The main feature of this system is complete flexibility in the selection of imagery, music type, and correspondence. This system was designed to provide an environment that allows exploration of any form of correspondence between synchronized video and music. Terminology unique to this system and from the fields of animation, film, and video are defined at the end of the article.

This interactive system, known as *Orpheus*, allows precise synchronization of video imagery with any form of improvised or composed music. During operation, *Orpheus* listens to live music and controls moving video imagery according to various musical elements. The listener or *music categorization* portion of the software provides a musical rating based on pitch, loudness, note duration, rest length, tempo, rhythm, intervals, note density, or measure. Each category of music can potentially evoke an associated *video action* consisting of specific video images and a cinematic effect. For example, the system could be programmed to present an image of a face laughing with a particular *music type*, while another music type would present the same face crying. Music could alternate between these two music types, up to 30 times per second, while the face would alternate between laughing and crying in synchronization with the music. The musical categorization can be viewed as an aesthetic judgment created by the system to allow association of music with imagery having similar aesthetic qualities. Because the flexibility of the system permits any type of correspondence, a dissonant relationship can also be created between video and music.

The major criterion in developing the software for this system was to allow complete flexibility when creating a composition. Additional concerns were aesthetic potential, overall cost, responsiveness, and simplicity of operation. The overview of the system provided in Figure 1 indicates the various components of the software.

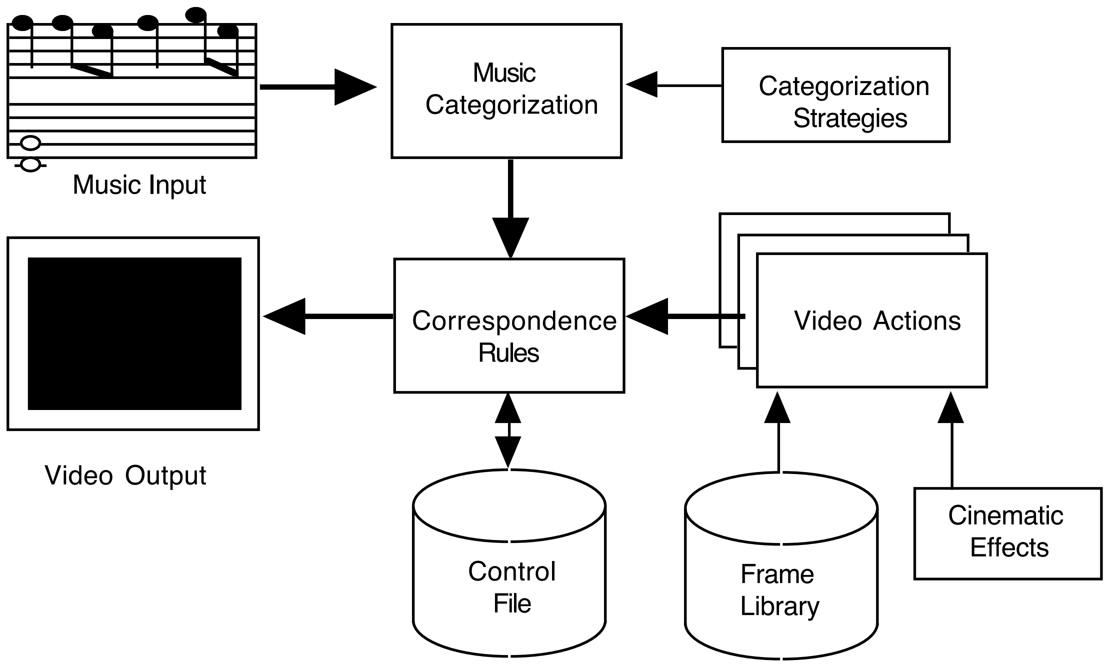

Figure 1. Overview of Orpheus Interactive Video System

The system interprets music in the form of MIDI data and can be used with any instrument that provides this form of output. For synchronization with acoustic instruments, translation of an instrument's sound into MIDI data is achieved through a pitch follower.

The remainder of this section describes in detail the system's incorporation of video imagery, music categorization, and their correspondence.

Video Imagery

The first form of flexibility available in the system is an ability to incorporate various forms of moving or static imagery. While operating, the system requires that all video imagery to be stored as digital frames within the computer's RAM. As in film, video, or animation, the smallest compositional element is the frame, a single static image that is combined with other frames in the creation of shots or sequences of moving imagery. Digital frames can be created using various 2 dimensional or 3 dimensional rendering software, or by digitizing existing images from videotape, videodisk, or video camera. An alternative approach for controlling imagery is available by using the system to manipulate and process a *video signal* directly from tape, videodisk, or camera. Although this latter approach provides more frames of imagery, less control is available relative to storage of frames in a digital format.

Digital storage permits the presentation of frames using methods that are not possible with film, videotape or videodisk, these advantages being speed, order of presentation, and potential for image manipulation. Because frames are not stored in a linear fashion--as with film, video, or videodisk--they can be displayed in any order without limitation by physical characteristics of a playback device. Although random presentation of frames is obtainable with videodisk, retrieval speed is relatively slow compared to storage in a RAM. This speed advantage also permits the playing of frames in any order and at different rates, enabling a particular sequence of frames to be played slowly, quickly, forwards, backwards, or randomly. The third advantage is an ability to manipulate frames using image-processing techniques, such as color changes and rearrangement of areas within the individual frames.

Because the digital storage of frames within *Orpheus* enables the presentation of the same video frames in numerous manners, the term *video action* was created to indicate a specific combination of frames in combination with a cinematic effect, and control variables. The system currently provides 70 different cinematic effects that can be used in presentation of any video frames, each effect containing a number of control variables, such as speed. An example of a cinematic effect is the *position-screen-random-reverse* effect. Frames presented through this effect are displayed in reverse order with each frame at a random position on the screen; the amount of randomness is adjustable through the variable settings.

Frames are stored on hard disks when the system is not operating. A file--the *frame list*-- selected immediately after starting the software, indicates which collection of frames is to be loaded. This file is created in a text editor or through a support program, known as *Frame Builder,* that represents all the frames on a hard disk as representational full color icons. The maximum number of frames that can be loaded is limited by the memory on the computer. Works have usually been presented on a computer with 7 Mbytes of memory, which allows loading 90 frames having a *resolution* of 240x352 and 4096 colors. When frames with 2 colors are used, however, this amount of memory can accommodate 700 frames. Although 90 frames of video represent only 3 seconds of video tape or video disk imagery, the use of video actions allows a limited number of frames to be presented in hundreds of different manners using various combinations of frames, cinematic effects, and variable settings. This approach is analogous to using a few seconds of sampled sound to create a 10 minute music composition. Although the maximum number of video actions is technically limited by memory, the space occupied by a single video action is very small, permitting the creation of thousands of actions with a limited amount of memory.

Because this system does not provide visual images directly, and permits combining any video frame with a cinematic effect, a wide variety of imagery can be incorporated, ranging from complex sequences to a minimalist approach as used by Castel.

Listener Component

The *listener* component in *Orpheus* is similar to those used in other interactive music softwares, enabling the generation of output that is related to musical input (Rowe 1993). The listener within *Orpheus*, however, differs from those used for interactive music systems because the characteristics of music that are appropriate for controlling interactive music are not necessarily appropriate for controlling interactive imagery. This conclusion was reached after testing listeners having different characteristics and observing that most forms of music contained more information than necessary for synchronization with imagery. When the system was configured to respond to every nuance of music, the resulting imagery was chaotic and appeared to have no synchronization with the music. When a more limited listener was used, however, an impression of increased correspondence and synchronization was observed. Thus, the listener component within *Orpheus* does not listen to music in intricate detail, but rather provides a stream of information appropriate for correspondence with imagery.

Rather than implementing a listener having limited potential, a method was incorporated that permits intricate adjustment of a listener's characteristics. This approach permits video imagery to be controlled by numerous musical qualities, or just a few. Besides allowing synchronization with different qualities of music, this approach also permits the use of a strategy that is most appropriate for the instrument and style of music being used. This flexible approach was implemented after collaborating with various performers who played different instruments, and by observing the musical qualities that were important with one instrument were less important with others. Although the duration of a note was found to be important when imagery was controlled by trombone, it was less important with percussion.

The listener within *Orpheus* provides an ongoing indication of musical activity in the form of constantly changing variables that control the selection and presentation rate of video imagery. The first stage of the listener component involves the identification of each event with a sequentially increasing event number, and placing the MIDI note number, velocity and onset time of each event into associated array elements. Additional descriptions are provided by the software that calculates each event's interval size and direction relative to the previous event. The software also calculates the duration of each continuing event. The obtained and calculated data are used to provide an ongoing indication of overall musical activity as indicated through the number of notes playing simultaneously (vertical density), number of notes played over a specific unit of time (horizontal density), and selection of an *active event*. An active event refers to the selection of a single event among simultaneously occurring events that will have priority for the next level of analysis. The criterion for selecting an active event among simultaneously occurring events is pitch: high pitches have more priority than low, or temporal occurrence: a more recently occurring event has more priority than an earlier one.

The flexibility for analyzing music is available by permitting categorization of music according to any combination of pitch, loudness, duration, interval, duration, vertical density, or horizontal density. A specific categorization that consists of ranges or specific combinations of variables is referred to as a *music type*. Currently 127 different music types can be defined. The system provides various strategies for categorization of music types and also permits modification or addition of strategies. Independent of a strategy being used, all variables involved in describing the music are updated every 1/30 second. This rate is determined by the refresh rate of the video signal used in presentation of the video imagery.

Figure 2 provides an example of music categorization. The vertical axis of the categorization graph represents different music types, while the horizontal axis represents the change in categorization over time.

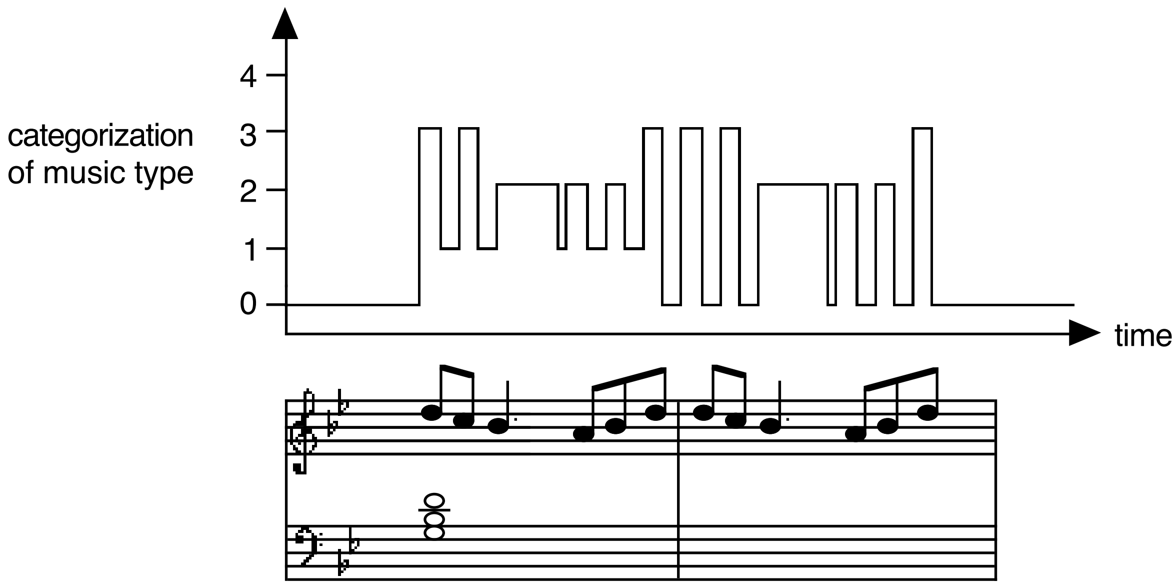

Figure 2. Example of Music Categorization

In this example, a strategy was selected that categorizes music according to specific chord types and pitch ranges. Specifically, the chord in the first measure will be rated as music type 1, the two highest pitched eighth-notes as type 3, and the remaining notes as type 2. Prior to the playing of these measures, the music type is 0, indicating that no notes are playing. Upon receiving the first notes, the software categorizes the music as type 3 because the first eighth-note is within that pitch range. Although the system is aware of the chord at this point, the categorization strategy gives priority to the highest pitch if notes from two different categories begin at the same time. Music type 3 remains active only for the duration of the eighth-note, followed by music type 1 because the chord--being a whole note--is still being played. The rating becomes music type 3 as the second eighth-note begins because the most recent note always has priority. The categorization resorts back to type 1 after this note is completed because the chord is still playing. For the remainder of the first measure the rating alternates between category 2 for the durations of the shorter notes and category 1 for the whole note.

Although the higher notes are repeated in the second measure, it differs musically from the first measure because it lacks the chord. This difference is noted in the music categorization during the times between the notes. In the first measure the categorization resorted to type 1, indicating the playing of the chord, while in the second measure the categorization becomes type 0, indicating that no other notes are playing at that moment.

The system also allows recognition and categorization of complex musical structures or phrases. As discussed by Wessel (1991), however, the major problem with this approach is that a complex structure is recognized only after the phrase has begun, and this is particularly problematic with improvised music. To properly synchronize, one would have to reach back in time.

Selecting Correspondence Between Video and Music

This system allows flexibility when creating correspondence between video and music by supplying no specific rules of association; instead, it provides an environment for creating any associations between a music type and a video action. This flexibility permits selection of correspondence rules that could be based on various elements, including time, tempo, change over time, or similarity of structure between music and image: a type of isomorphism.

Prior to using the system in a live situation, correspondence rules are defined in the *control file editor*. This iconic and menu based environment allows selection of a strategy for categorizing music, designing of video actions, designation of correspondence between music types and video actions, and specification of global variables. Within the editor, available frames are depicted as 4096 color, 3/4" by 1" representational icons that can be quickly arranged into desired shots and sequences. Menus or the keyboard are used for entering textual and numeric information for selection of cinematic effects, control of video actions, modifying strategies, and global parameters. A collection of video actions, correspondence rules, strategy for categorizing music, and global variables is collectively referred to as a *control file* that is saved and retrieved as a single data file. The typical edit functions of cut, paste, delete, and insert functions are available for modifying the control file.

At any point during the editing of a control file within the editor, the system can be placed into play mode and within 2 seconds be available for interactive operation. In the play mode, the system categorizes incoming music, and presents the video action that is associated with the current music type. A specific music type, however, is not necessarily associated with only one video action. Each music type corresponds with a list of video actions with the activity of a specific video action being determined by the total number of events having the associated music type. Thus, a single music type can potentially invoke thousands of different video actions. Upon leaving the play mode, a summary is provided of the music. This feedback is helpful for selecting and adjusting the music categorization strategy.

A more recent enhancement to the software is an ability to change correspondence between music type and video actions while the system is in play mode. Although a particular music type is by default associated with a particular list of video actions, an association can be changed through the keyboard while the system is categorizing music and presenting live imagery.

Composing a Piece for Synchronized Video and Music

Since I typically work with a composer-performer, the initial stage for composing a work of synchronized video and music begins with a desire for collaboration and an agreement to work with a particular piece of music, with a particular group of images, or to develop a concept requiring creation of new music and imagery. The next step involves decisions on appropriate groupings of video images, cinematic effects, musical voices and other musical elements. After the frames, music, and voices have been created, a method for categorizing music is determined. Because I typically work with improvisational music, a program was created to assist the selection of a strategy for categorizing music. This software provides a summary of music through a series of graphs and numeric figures to indicate frequency of occurrence, distribution, maximum, minimum, and average values for pitch, loudness, intervals, number of notes playing, and note density. A strategy is typically incorporated that has more sensitivity in the regions having higher activity.

The strategy for categorizing music along with the correspondence between music and imagery is then implemented in the control file editor portion of the software. While alternating between editing of the control file and playing, modifications, additions and deletions are made to the music, video imagery, and correspondence rules until a desired composition is attained.

Performances

Since first using this system during a performance at the MIT Media Lab in 1988, I have presented over 30 performances in North America and Europe of video controlled by live music. Most of these performances were presented in collaboration with George Lewis who controlled the video imagery through improvised trombone. Other performances have been presented with video controlled by trumpet, saxophone, electric guitar, electric bass, acoustic bass, percussion and keyboards. Video imagery during these events--ranging from 15 feet to 35 feet in size--was presented through a video projector that received a video signal created by two systems running the software. Each system contained different video frames, and each was programmed with different collections of video actions. Music for all of these events was primarily improvised, although the degree of improvisation varied among the performers. Imagery and cinematic effects for the different events alternated between minimalist fields of color and texture, and surreal imagery of distorted body parts.

Audience's reactions to these events have been varied, ranging from extremely supportive to rejection. Some viewers commented that they were unable to see any synchronization between music and imagery, while others stated the correspondence was too strict. Some audience members also praised the performers for having played along in perfect harmony with the videotape they thought was being played.

Research funding for the work described in this document was provided by the Computer Integrated Media Arts Division of the Canada Council during 1988-1990.

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Terminology

cinematic effect: a type of visual transition from one frame to the next, such as dissolve, fade in, or fade out

control file: editable data file that describes how music will affect video imagery

control file editor: the editing environment in Orpheus software allowing creation and editing of correspondence between music and video imagery

digitizing: converting an analogue video frame into a digital format using a video digitizer

frame: a single static image from a collection of video, film, or computer animated imagery

frame list: text file indicating the complete path names of frames to be loaded into the Orpheus software

music type: a term created by the author referring to a specific categorization of music according to selectable combinations of pitches, loudness, durations, chords, note density, number of notes playing, etc.

rendering software: computer graphic software that creates colored objects--typically in 3 dimensional space-- according to user defined wire frame objects, surface qualities, light sources, and viewing location

resolution: the quality of a computer graphic image according to the number of discrete horizontal and vertical pixels--dots--within an image video action: a term created by the author referring to a specific combination of digital frames, cinematic effect, and control variables

video digitizing: the process of translating an analog video signal into a digital format for use in a computer system

video genlock: a computer peripheral that combines the image on a graphics computer with an external video signal and outputs a standard video signal that can be recorded or displayed on a video monitor

video signal: an analog electrical signal produced by a video source--such as a camera, video tape, or video disc--that defines the colors and intensities of frames making up video imagery