

LEONARDO ELECTRONIC ALMANAC

VOL NO

> > >
>
> >
> >

LEA is a publication of Leonardo/ISAST.

Copyright 2013 ISAST

Leonardo Electronic Almanac

Volume 19 Issue 3

July 15, 2013

ISSN 1071-4391

ISBN 978-1-906897-22-2

The ISBN is provided by Goldsmiths, University of London.

LEA PUBLISHING & SUBSCRIPTION INFORMATION

Editor in Chief

Lanfranco Aceti lanfranco.aceti@leoalmanac.org

Co-Editor

Özden ahin ozden.sahin@leoalmanac.org

Managing Editor

John Francescutti john.francescutti@leoalmanac.org

Art Director

Deniz Cem Önduygu deniz.onduygu@leoalmanac.org

Editorial Board

Peter J. Bentley, Ezequiel Di Paolo, Ernest Edmonds, Felice Frankel, Gabriella Giannachi, Gary Hall, Craig Harris, Sibel Irzik, Marina Jirotko, Beau Lotto, Roger Malina, Terrence Masson, Jon McCormack, Mark Nash, Sally Jane Norman, Christiane Paul, Simon Penny, Jane Prophet, Jeremy Shaw, William Uricchio

Cover Image

The Encounter, Elif Ayiter, 2010, Screenshot of Cinematic Play Session in Second Life. © Elif Ayiter. Used with Permission.

Editorial Address

Leonardo Electronic Almanac

Sabancı University, Orhanlı – Tuzla, 34956

Istanbul, Turkey

Email

info@leoalmanac.org

Web

- » www.leoalmanac.org
- » www.twitter.com/LEA_twitts
- » www.ickr.com/photos/lea_gallery
- » www.facebook.com/pages/Leonardo-Electronic-Almanac/209156896252

Copyright © 2013

Leonardo, the International Society for the Arts,
Sciences and Technology

Leonardo Electronic Almanac is published by:

Leonardo/ISAST

211 Sutter Street, suite 501

San Francisco, CA 94108

USA

Leonardo Electronic Almanac (LEA) is a project of Leonardo/ The International Society for the Arts, Sciences and Technology. For more information about Leonardo/ISAST's publications and programs, see <http://www.leonardo.info> or contact isast@leonardo.info.

Leonardo Electronic Almanac is produced by

Passero Productions.

Reposting of this journal is prohibited without permission of Leonardo/ISAST, except for the posting of news and events listings which have been independently received.

The individual articles included in the issue are © 2013 ISAST.

LEONARDO ELECTRONIC ALMANAC, VOLUME 19 ISSUE 3

Live Visuals

VOLUME EDITORS

LANFRANCO ACETI, STEVE GIBSON & STEFAN MÜLLER ARISONA

EDITOR

ÖZDEN ŞAHİN

The Leonardo Electronic Almanac acknowledges the kind support for this issue of

Sabancı
Universitesi



Goldsmiths
UNIVERSITY OF LONDON



NYUSteinhardt
Steinhardt School of Culture, Education, and Human Development

NYUSteinhardt

Steinhardt School of Culture, Education, and Human Development



MUSIC AND PERFORMING ARTS PROFESSIONS

Ron Sadoff, Director

Music Technology

B.M., M.M., Ph.D.

Including a new 3-Summer M.M.

Immersive Audio, Computer Music, Informatics, Cognition, Recording and Production

Music Composition

B.M., M.M., Ph.D.

Concert Music, Jazz, Film Scoring, Electro-Acoustic, Songwriting

- **Study with a premier faculty** who are active in the local and international music field, including Juan Pablo Bello, Morwaread Farbood, Phil E. Galdston, Paul Geluso, Tae Hong Park, Kenneth Peacock, Agnieszka Roginska, Robert Rowe, S. Alex Ruthmann, Ronald Sadoff, David Schroeder, Mark Suozzo, and Julia Wolfe
- Work within a **large and enriching university environment** in the heart of New York City
- Have access to **state-of-the-art facilities** including the James L. Dolan Music Recording Studio, one of the most technologically advanced audio teaching facilities in the United States
- **Collaborate** with an outstanding variety of department performance groups, along with choreographers, visual artists, writers, filmmakers, and scholars in other fields
- Take advantage of **special courses** offered abroad and during the summer

Visit www.steinhardt.nyu.edu/music or call **212 998 5424** to learn more.



NEW YORK UNIVERSITY

NEW YORK UNIVERSITY IS AN AFFIRMATIVE ACTION/EQUAL OPPORTUNITY INSTITUTION.

Leonardo Electronic Almanac
Volume 19 Issue 3

8 EDITORIAL Lanfranco Aceti

12 REVISITING CINEMA: EXPLORING THE EXHIBITIVE MERITS OF CINEMA FROM NICKELODEON THEATRE TO IMMERSIVE ARENAS OF TOMORROW Brian Herczog

22 THE FUTURE OF CINEMA: FINDING NEW MEANING THROUGH LIVE INTERACTION Dominic Smith

30 A FLEXIBLE APPROACH FOR SYNCHRONIZING VIDEO WITH LIVE MUSIC Don Ritter



46 AVATAR ACTORS Elif Ayiter

64 MULTI-PROJECTION FILMS, ALMOST-CINEMAS AND VJ REMIXES: SPATIAL ARRANGEMENTS OF MOVING IMAGE PRESENCE Gabriel Menotti

78 MACHINES OF THE AUDIOVISUAL: THE DEVELOPMENT OF "SYNTHETIC AUDIOVISUAL INTERFACES" IN THE AVANT-GARDE ART SINCE THE 1970S Jihoon Kim

88 NEW PHOTOGRAPHY: A PERVERSE CONFUSION BETWEEN THE LIVE AND THE REAL Kirk Woolford



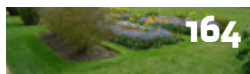
108 TEXT-MODE AND THE LIVE PETSCII ANIMATIONS OF RAQUEL MEYERS: FINDING NEW MEANING THROUGH LIVE INTERACTION Leonard J. Paul

124 OUTSOURCING THE VJ: COLLABORATIVE VISUALS USING THE AUDIENCE'S SMARTPHONES Tyler Freeman

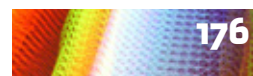


134 AVVX: A VECTOR GRAPHICS TOOL FOR AUDIOVISUAL PERFORMANCES Nuno N. Correia

148 ARCHITECTURAL PROJECTIONS: CHANGING THE PERCEPTION OF ARCHITECTURE WITH LIGHT Lukas Treyer, Stefan Müller Arisona & Gerhard Schmitt



164 IN DARWIN'S GARDEN: TEMPORALITY AND SENSE OF PLACE Vince Dziekan, Chris Meigh-Andrews, Rowan Blaik & Alan Summers



176 BACK TO THE CROSS-MODAL OBJECT: A LOOK BACK AT EARLY AUDIOVISUAL PERFORMANCE THROUGH THE LENS OF OBJECTHOOD Atau Tanaka



190 STRUCTURED SPONTANEITY: RESPONSIVE ART MEETS CLASSICAL MUSIC IN A COLLABORATIVE PERFORMANCE OF ANTONIO VIVALDI'S FOUR SEASONS Yana (Ioanna) Sakellion & Yan Da

202 INTERACTIVE ANIMATION TECHNIQUES IN THE GENERATION AND DOCUMENTATION OF SYSTEMS ART Paul Goodfellow



214 SIMULATING SYNESTHESIA IN SPATIALLY-BASED REAL-TIME AUDIO-VISUAL PERFORMANCE Steve Gibson

230 A 'REAL TIME IMAGE CONDUCTOR' OR A KIND OF CINEMA?: TOWARDS LIVE VISUAL EFFECTS Peter Richardson

240 LIVE AUDIO-VISUAL ART + FIRST NATIONS CULTURE Jackson 2bears



256 OF MINIMAL MATERIALITIES AND MAXIMAL AMPLITUDES: A PROVISIONAL MANUAL OF STROBOSCOPIC NOISE PERFORMANCE Jamie Allen

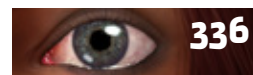
272 VISUALIZATION TECHNOLOGIES FOR MUSIC, DANCE, AND STAGING IN OPERAS Guerino Mazzola, David Walsh, Lauren Butler, Aleksey Polukeyev

284 HOW AN AUDIO-VISUAL INSTRUMENT CAN FOSTER THE SONIC EXPERIENCE Adriana Sa



306 GATHERING AUDIENCE FEEDBACK ON AN AUDIOVISUAL PERFORMANCE Léon McCarthy

322 CHOREOTOPOLOGY: COMPLEX SPACE IN CHOREOGRAPHY WITH REAL-TIME VIDEO Kate Sicchio



336 CINEMATICS AND NARRATIVES: MOVIE AUTHORING & DESIGN FOCUSED INTERACTION Mark Chavez & Yun-Ke Chang

352 IMPROVISING SYNESTHESIA: COMPROVISATION OF GENERATIVE GRAPHICS AND MUSIC Joshua B. Mailman

When Moving Images Become Alive!

“Look! It's moving. It's alive. It's alive... It's alive, it's moving, it's alive, it's alive, it's alive, it's alive, IT'S ALIVE!”

Frankenstein (1931)

Those who still see – and there are many in this camp – visuals as simple ‘decorations’ are living in a late 19th century understanding of media, with no realization that an immense cultural shift has happened in the late 20th century when big data, sensors, algorithms and visuals merged in order to create 21st century constantly mediated social-visual culture.

Although the visuals are not actually alive, one cannot fail to grasp the fascination or evolution that visuals and visual data have embarked upon. It is no longer possible to see the relationship of the visual as limited to the space of the traditional screens in the film theater or at home in the living room with the TV. The mobility of contemporary visuals and contemporary screens has pushed boundaries – so much so that ‘embeddedness’ of visuals onto and into things is a daily practice. The viewers have acquired expectations that it is possible, or that it should be possible, to recall the image of an object and to be able to have that same object appear at home at will. The process of downloading should not be limited to ‘immaterial’ digital data, but should be transferred to 3D physical objects. ¹

Images are projected onto buildings – not as the traditional trompe l'oeil placed to disguise and trick the eye – but as an architectural element of the building itself; so much so that there are arguments, including mine, that we should substitute walls with projected information data, which should also have and be perceived as having material properties (see in this

volume “Architectural Projections” by Lukas Treyer, Stefan Müller Arisona & Gerhard Schmitt).

Images appear over the architecture of the buildings as another structural layer, one made of information data that relays more to the viewer either directly or through screens able to read augmented reality information. But live visuals relay more than images, they are also linked to sound and the analysis of this linkage provides us with the opportunity “to think about the different ways in which linkages between vision and audition can be established, and how audio-visual objects can be composed from the specific attributes of auditory and visual perception” (see “Back to the Cross-modal Object” by Atau Tanaka).

iPads and iPhones – followed by a generation of smarter and smarter devices – have brought a radical change in the way reality is experienced, captured, uploaded and shared. These processes allow reality to be experienced with multiple added layers, allowing viewers to re-capture, re-upload and re-share, creating yet further layers over the previous layers that were already placed upon the ‘original.’ This layering process, this thickening of meanings, adding of interpretations, references and even errors, may be considered as the physical process that leads to the manifestation of the ‘aura’ as a metaphysical concept. The materiality of the virtual, layered upon the ‘real,’ becomes an indication of the compositing of the aura, in Walter Benjamin's terms, as a metaphysical experience of the object/image but nevertheless an

experience that digital and live visuals are rendering increasingly visible.

“Everything I said on the subject [the nature of aura] was directed polemically against the theosophists, whose inexperience and ignorance I find highly repugnant. . . . First, genuine aura appears in all things, not just in certain kinds of things, as people imagine.” ²

The importance of digital media is undeniably evident. Within this media context of multiple screens and surfaces the digitized image, in a culture profoundly visual, has extended its dominion through ‘disruptive forms’ of sharing and ‘illegal’ consumption. The reproducibility of the image (or the live visuals) – pushed to its very limit – has an anarchistic and revolutionary element when considered from the neocapitalistic perspective imbued in corporative and hierarchical forms of the construction of values. On the contrary, the reproducibility of the image when analyzed from a Marxist point of view possesses a community and social component for egalitarian participation within the richness of contemporary and historical cultural forms.

The digital live visuals – with their continuous potential of integration within the blurring boundaries of public and private environments – will continue to be the conflicting territory of divergent interests and cultural assumptions that will shape the future of societal engagements. Reproducibility will increasingly become the territory of control generating conflicts between *original* and *copy*, and between the layering of *copy* and *copies*, in the attempt to contain ideal participatory models of democracy. The elitist interpretation of the aura will continue to be juxtaposed with models of Marxist participation and appropriation. ³

Live visuals projected on public buildings and private areas do not escape this conflict, but present interpretations and forms of engagements that are reactions

of social ideals. The conflict is, therefore, not solely in the elitist or participatory forms of consumption but also in the ideologies that surround the cultural behaviors of visual consumption.

Object in themselves, not just buildings, can and may soon carry live visuals. There is the expectation that one no longer has to read a label – but the object can and should project the label and its textured images to the viewer. People increasingly expect the object to engage with their needs by providing the necessary information that would convince them to look into it, play with it, engage with it, talk to it, like it and ultimately buy it.


Ultimately there will be no need to engage in this process but the environment will have objects that, by reading previous experiences of likes and dislikes, present a personalized visual texture of reality.

Live visuals will provide an environment within which purchasing does not mean to solely acquire an object but rather to ‘buy’ into an idea, a history, an ideology or a socio-political lifestyle. It is a process of increased visualization of large data (Big Data) that defines and re-defines one's experience of the real based on previously expressed likes and dislikes.

In this context of multiple object and environmental experiences it is also possible to forge multiple individualized experiences of the real; as much as there are multiple personalized experiences of the internet and social media through multiple avatar identities (see “Avatar Actors” by Elif Ayter). The ‘real’ will become a visual timeline of what the algorithm has decided should be offered based on individualized settings of likes and dislikes. This approach raises an infinite set of possibilities but of problems as well.

The life of our representation and of our visuals is our 'real' life – disjointed and increasingly distant from what we continue to perceive as the 'real real,' delusively hanging on to outdated but comfortable modes of perception.

The cinematic visions of live visuals from the 19th century have become true and have re-designed society unexpectedly, altering dramatically the social structures and speeding up the pace of our physical existence that constantly tries to catch up and play up to the visual virtual realities that we spend time constructing.

If we still hold to this dualistic and dichotomist approach of real versus virtual (although the virtual has been real for some time and has become one of the multiple facets of the 'real' experience), then the real is increasingly slowing down while the virtual representation of visuals is accelerating the creation of a world of instantaneous connectivity, desires and aspirations. A viscosity of hyper-mediated images that, as pollution, pervades and conditions our vision without giving the option of switching off increasingly 'alive' live visuals. 

The lack of 'real' in Jean Baudrillard's understanding is speeding up the disappearance of the 'real' self in favor of multiple personal existential narratives that are embedded in a series of multiple possible worlds. It is not just the map that is disappearing in the procession of simulacra – but the body as well – as the body is conceived in terms of visual representation: as a map. These multiple worlds of representations contribute to create reality as the 'fantasy' we really wish to experience, reshaping in turn the 'real' identity that continuously attempts to live up to its 'virtual and fantastic' expectations. Stephen Gibson presents the reader with a description of one of these worlds with live audio-visual simulations that create a synesthetic

experience (see "Simulating Synesthesia in Spatially-Based Real-time Audio-Visual Performance" by Stephen Gibson).

If this fantasy of the images of society is considered an illusion – or the reality of the simulacrum, which is a textual oxymoron at prima facie – it will be determined through the experience of the *live visuals becoming alive*.

Nevertheless, stating that people have illusory perceptions of themselves in relation to a 'real' self and to the 'real' perception of them that others have only reinforces the idea that Live Visuals will allow people to manifest their multiple perceptions, as simulated and/or real will no longer matter. These multiple perceptions will create multiple ever-changing personae that will be further layered through the engagements with the multiple visual environments and the people/avatars that populate those environments, both real and virtual.

In the end, these fantasies of identities and of worlds, manifested through illusory identities and worlds within virtual contexts, are part of the reality with which people engage. Although fantastic and illusory, these worlds are a reflection of a partial reality of the identity of the creators and users. It is impossible for these worlds and identities to exist outside of the 'real.' This concept of real is made of negotiated and negotiable frameworks of engagement that are in a constant process of evolution and change.

The end of post-modernity and relativism may lead to the virtuality of truism: the representation of ourselves in as many multiple versions – already we have multiple and concurrent digital lives – within the world/s – ideological or corporate – that we will decide or be forced to 'buy into.'

It is this control of the environment around us and us within that environment that will increasingly define the role that live visuals will play in negotiating real and virtual experiences. The conflict will arise from the blurred lines of the definition of self and other; whether the 'other' will be another individual or a corporation.

The potential problems of this state of the live visuals within a real/virtual conflict will be discovered as time moves on. In the end this is a giant behavioral experiment, where media and their influences are not analyzed for their social impact *ex ante facto*; this is something that happens *ex post facto*.

Nevertheless, in this *ex post facto* society there are some scholars that try to understand and eviscerate the problems related to the process of visuals becoming alive. This issue collects the analyses of some of these scholars and embeds them in a larger societal debate, hinting at future developments and problems that society and images will have to face as the live visuals become more and more alive.

The contemporary concerns and practices of live visuals are crystallized in this volume, providing an insight into current developments and practices in the field of live visuals.

This issue features a new logo on its cover, that of New York University, Steinhardt School of Culture, Education, and Human Development.

My thanks to Prof. Robert Rowe, Professor of Music and Music Education; Associate Dean of Research and Doctoral Studies at NYU, for his work in establishing this collaboration with LEA.

My gratitude to Steve Gibson and Stefan Müller Arisona, without them this volume would not have been

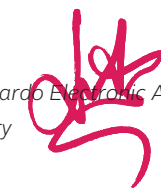
possible. I also have to thank the authors for their patience in complying with the guidelines and editorial demands that made this issue one that I am particularly proud of, both for its visuals and for its content.

My special thanks go to Deniz Cem Öndüğü who has shown commitment to the LEA project beyond what could be expected.

Özden Şahin has, as always, continued to provide valuable editorial support to ensure that LEA could achieve another landmark.

Lanfranco Aceti

Editor in Chief, *Leonardo Electronic Almanac*
Director, *Kasa Gallery*



1. 3D printing the new phenomenon will soon collide with a new extreme perception of consumer culture where the object seen can be bought and automatically printed at home or in the office. Matt Ratto and Robert Ree, "Materializing Information: 3D Printing and Social Change," *First Monday* 17, no. 7 (July 2, 2012), <http://rstmonday.org/ojs/index.php/fm/article/view/3968/3273> (accessed October 20, 2013).
2. Walter Benjamin, "Protocols of Drug Experiments," in *On Hashish*, ed. Howard Eiland (Cambridge, MA: Harvard University Press, 2006), 58.
3. "The point here is not to issue a verdict in the debate between Adorno and Benjamin, but rather to understand the debate between them as representing two sides of an ongoing dialectical contradiction." Ryan Moore, "Digital Reproducibility and the Culture Industry: Popular Music and the Adorno-Benjamin Debate," *Fast Capitalism* 9, no. 1 (2012), http://www.uta.edu/huma/agger/fastcapitalism/9_1/moore9_1.html (accessed October 30, 2013).
4. Paul Virilio, *Open Sky*, trans. Julie Rose (London: Verso, 1997), 97.

A Flexible Approach for Synchronizing Video with Live Music

by

Don Ritter

School of Creative Media
City University of Hong Kong
aesthetic-machinery.com

INTRODUCTION

Performances of synchronous video and music have become increasingly popular over the past 15 years, supported by a proliferation of appropriate software.¹ Live music events, nightclubs, operas, and world fairs are now popular venues for a performance format that has existed for nearly 300 years under various monikers, including ocular music, visual music, color-music, music for the eyes, interactive music-video and, now, VJing.^{2 3 4 5} Louis-Bertrand Castel (1688–1757), a Jesuit priest, mathematician and philosopher, is acknowledged for creating the first device that synchronized imagery with music in 1734.⁶ Castel's instrument, known as an "ocular clavichord," exposed small pieces of colored glass when its keys were pressed, each key being associated with a different color.⁷ Karl von Eckartshausen (1752–1803) created an instrument similar to Castel's in 1791, which he describes in his book *Disclosures of Magic from Tested Experiences of Occult Philosophic Sciences and Veiled Secrets of Nature*:

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 in-

ABSTRACT

Performances of synchronous imagery and music have existed for almost 300 years, but they have become popular only in the past 15 years. Synchronous imagery and music refers to their simultaneous presentation, but synchronization refers to an interactive correlation between the imagery and music. The article will discuss pioneering works that use synchronization by examining their strategies for correspondence. An absolute approach to synchronization uses fixed correlations between musical and visual characteristics, but a flexible approach permits the selection of music, imagery, and forms of correspondence. The paper discusses the characteristics of a computer-based system that uses a flexible approach for synchronizing video with live music. This flexible system imposes no specific rules for synchronizing video with music, and it provides a programming environment that enables the creation of a composition using various forms of correspondence. The paper is based on the author's work since 1988 on the creation of software and performances of video synchronized with live music.

vented 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.⁸

I consider synchronous imagery and music to be the simultaneous presentation of these two media, such as a piano accompanying a silent film or a VJ performing with recorded music. The synchronization of imagery and music also involves the concurrent presentation of these two media, but the imagery and music are intricately correlated. Using this distinction, performances of synchronous imagery and music can be differentiated according to the presence or absence of synchronization. The ocular clavichord created by

Castel enabled synchronized performances because pressing its keys produced a musical pitch and a specific color of light corresponding with the pitch.

The synchronization of imagery and music can be created by having music correlate with imagery, imagery correlate with music, or through an independent action that directs the correspondence in unison. An important discriminator for this synchronization is whether an *absolute* or a *flexible* approach is used for the correspondence. The instruments created by Castel and von Eckartshausen used absolute approaches because their devices would always provide the same color of light in response to a particular note being pressed, regardless of the lingering style of the performer or the desires of the composer. In contrast, a *flexible* approach imposes no specific rules for synchronizing imagery with music, and it provides versatility by permitting a composer to change the imagery, the music, or the rules of correspondence between imagery and music.

This aim of this paper is to discuss the differences between an absolute and flexible approach for synchronizing video with live music during a performance. These ideas were developed between 1988 and 1992 when I developed a software that provided interactive control of video through live music. This software was born near the end of my graduate studies at MIT, and I continued developing it for four more years. The software, later christened *Orpheus*, enabled interactive control of full-screen, digital video through any musical instrument. Orpheus could be controlled by electronic music instruments that provided MIDI output⁹ or by acoustic instruments in conjunction with a hardware device that converted audio into MIDI.

I collaborated with various musicians during those years, and we presented performances of interactive video controlled by trombone, synthesizer, saxophone, trumpet, vocals, electronic drums, electric guitar, and sampling keyboard. These events were performed at numerous venues, including the MIT Media Lab, New Music America in New York and Montreal, The Art Institute of Chicago, STEIM in Amsterdam, and the Verona Jazz Festival. Most of these performances were collaborations with trombonist and interactive music pioneer George Lewis. Our performances

featured electronic music and large video projections that were both controlled by Lewis's improvisation on trombone. Orpheus provided the interactive video for these events, while Lewis's interactive music software – called *Voyager* – produced the electronic music.¹⁰

In addition to creating Orpheus and presenting many performances, the other outcome from that work was the development of a general strategy for synchronizing video with live music. The primary problem I had during the creation of Orpheus was not the writing of the software, it was deciding how music and video should correspond. What eventually evolved was a strategy that I called a *Flexible approach for synchronizing video with live music*. The goal of this method is to provide flexibility when synchronizing video with music by enabling the use of any type of video imagery or musical instrument, and by providing a high level of versatility when composing the correspondence between music and imagery.

The following pages present a detailed description of this method as it was finalized in 1992. I will occasionally discuss how this approach was used within Orpheus, but the core ideas are independent of specific computer hardware, software, musical styles, musical instruments, or media formats. Many of the references cited in this paper were obtained between 1988 and 1992, but I believe they are still relevant today, including Adrien Bernard Klein's observation from his 1927 book, *Color-Music: The Art of Light*: "...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."¹¹

SYNCHRONOUS IMAGERY AND MUSIC

Prometheus: The Poem of Fire is the symphonic composition written by Alexander Scriabin in 1910 that included synchronous imagery.¹² The part of the score labeled as "Luce" contained directions for playing a keyboard that controlled 12 colored lights. This keyboard was played as accompaniment to the live music, though it produced no music. Scriabin had initially used an absolute correspondence between the music and the lights – assigning a different colored light to each of the 12 pitches in the chromatic scale – but he later rejected that approach and began organizing color into counterpoint relationships¹³ with the music. The first performance of *Prometheus* was presented in 1915 at Carnegie Hall in New York City, and it was presented more recently at Yale University in 2010 using modern lighting and MIDI technologies.¹⁴

Film director and theorist Sergei Eisenstein (1898–1948) was a pioneer of synchronous music within film, which he discusses in his books *The Film Sense* (1942)¹⁵ and *The Film Form* (1949).¹⁶ Eisenstein proposed that sound and music should be combined with imagery to create a specific mood, rather than attempting to create a realistic correspondence between imagery and sound. He writes, "The search for correspondence must proceed from the intention of matching both picture and music to the general, complex 'imagery' produced by the whole."¹⁷ Experiencing synchronous imagery and music within a film is obviously different from attending a performance of imagery synchronized with live music. An audience that attends a film does not experience the creation of imagery and sound, they experience a recording of disconnected elements that were created at various production locations, a process that is similar to the creation of recorded music. Miller Puckette, a pioneer of interactive music software, wrote in 1991 that "An essential part of 'real' music is the live element, the undeniable but undeniable interaction between players and audience which makes music exciting. It is hard to

prove this interaction is there...but any musician will swear to its reality, and to its importance to the music-making process."¹⁸

SYNCHRONIZED IMAGERY AND MUSIC

The instruments that Castel and von Eckartshausen created in the eighteenth century for synchronizing imagery with music would be categorized today as being interactive media devices. The definition of interactive media that I will adopt in this article is the following: a media environment that enables a user to direct significant perceptual changes in media content.

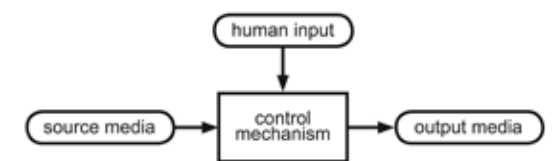


Fig 1. Primary components of an interactive media system. © Don Ritter, 2013. Used with permission.

Figure 1 diagrams the primary components of an interactive media system based on this definition. The *human input* component refers to the actions required by a user for directing the interactive media, such as a finger gesture, body motion, or voice. The *source media* component refers to media content that can potentially be output by the system, such as a specific collection of text, graphics, moving imagery, or sound. The *control mechanism* activates the correspondence rules that specify which source media will be output in accordance with the human input.

The *degree of interactivity* within an interactive media system is dependent on the number of opportunities provided to a user for directing the media output. For example, an interactive system has a low degree of interactivity if it provides a user with 2 options every

30 minutes, but it has a high degree of interactivity if 100 options are available every 2 seconds. The degree of interactivity within an interactive system can be enhanced by increasing the number of human gestures that are recognized by the human input component or by increasing the amount of media available to the control mechanism, but only if these increases are incorporated into the control mechanism.

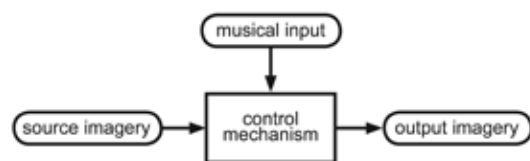


Fig 2. Primary components of a system for synchronizing imagery with music. © Don Ritter, 2013. Used with permission.

Figure 2 diagrams the primary components within an interactive media system that provide synchronization of imagery with live music. In this system, the control mechanism directs the correspondence between the music being performed and the imagery being output by the system. The quantity of source imagery and the number of musical input characteristics that are incorporated into the control mechanism determine the system's degree of interactivity. The control mechanism has the following functions: to recognize the format and quantity of source imagery; to recognize characteristics of the musical input; to maintain a collection of correspondence rules between the musical input, source imagery, and output imagery; and to direct the output imagery according to activation of these rules. An example of a correspondence rule is the pairing of a specific image with a particular musical pitch. Castel used this approach in his ocular clavichord, which used the following 12 correspondence rules for pairing color with musical pitch.¹⁹

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

Scriabin had initially used a similar method of correspondence in his *Prometheus* symphony; though his approach had paired different colors with the pitches.²⁰

C : intense red
C-sharp : violet or purple
D : yellow
D-sharp : flesh color
E : sky blue
F : deep red
F-sharp : bright blue or violet
G : orange
G-sharp: violet or lilac
A : green
A-sharp : rose or steel
B : blue or pearly blue

Three areas of composition are involved in the creation of synchronized imagery and music: the imagery, the music, and the correspondence between them. The instruments created by Castel and Scriabin used 'absolute approaches' for synchronization; their control mechanisms, source imagery, and the musical characteristics associated with the correspondence are fixed: a certain color is displayed when a specific key is pressed, regardless of the composition being played.

Castel's approach was based on Isaac Newton's proposal that the relative wavelengths of different hues could be paired with the relative pitches of notes, which he justified mathematically.²¹ Two centuries later, Sergei Eisenstein criticized an absolute approach to image and sound correspondence, "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 in an American magazine quite serious speculations as to the absolute correspondence of the piccolo's tone to yellow!"²²

Eisenstein's approach differed from Castel's by proposing that a 'desired mood' could be the determining element for the correspondence between music and imagery, rather than a fixed relationship based on the physical properties of light and sound. He describes several methods for combining sound and imagery within the *Film Sense*, including correspondence according to the meter, phrase, rhythm, or timbre of music:

*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.*²³

A FLEXIBLE SYSTEM FOR SYNCHRONIZING VIDEO WITH LIVE MUSIC

Eisenstein's writings were very influential in the creation of a flexible system for synchronizing video with live music because his ideas emphasized the creation of multi-sensory composition rather than a synchronization mechanism. An instrument that uses an absolute approach for synchronizing imagery with music provides a composer with unchangeable rules of correspondence, thereby limiting the potential of a composition. The alternative to an absolute approach for synchronizing imagery with music is a 'flexible' method that permits a composer to decide the correspondence between music and imagery. A flexible approach has a practical advantage over absolute methods because it is encompassing. If a composer wants a particular color to be presented consistently in response to a particular pitch, a flexible system permits this relationship, along with many other types of correspondence. A system that uses absolute correspondence can only be used in accordance with the rules inherent in itself.

My knowledge of music theory and composition was quite limited when I started to create *Orpheus* 24 years ago. Consequently, I adopted certain terminology and a perspective of musical structure that rejected the mechanical operation of this software. The purpose of the terminology was to create a conceptual model that assisted in the development of a system that used a flexible approach for synchronization. Figure 3 depicts this model, followed by explanations of its components and terminology.

The *music-listener* component of this system provides a continuous stream of features and categorizations that continually describe changes in the structure of the incoming live music. This analysis is used for activating video actions in conjunction with correspondence rules that are contained within the 'control mechanism.' A *video action* is comprised of single or multiple video sources – such as video clips, live video,

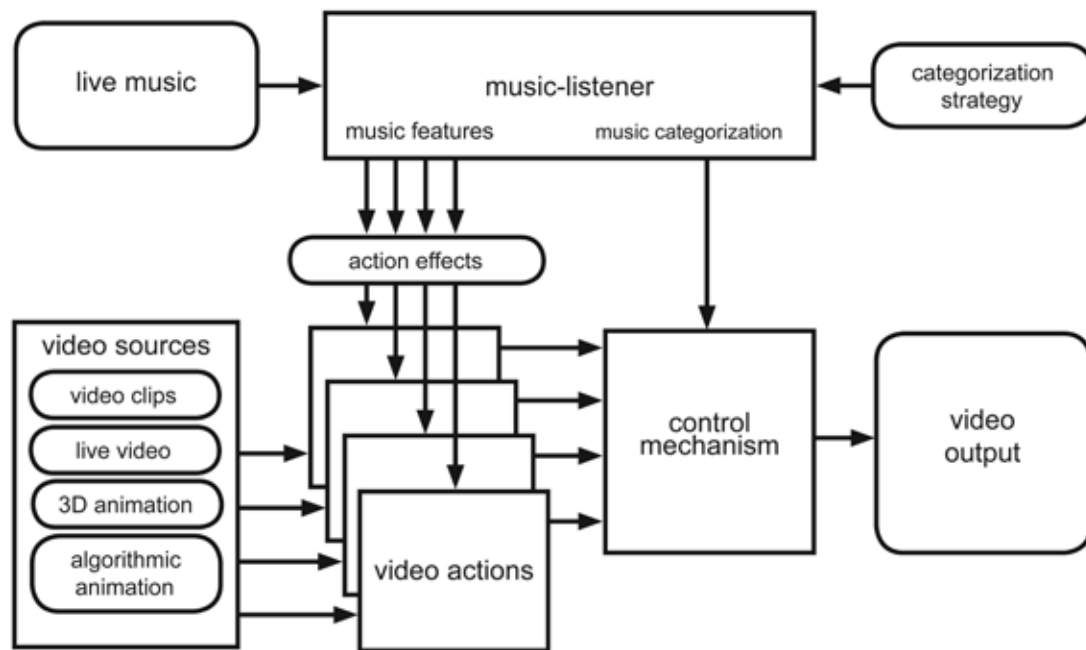


Fig 3. A flexible system for synchronizing video with live music. The music-listener extracts features from live music for directing video output using the correspondence rules contained in the control mechanism. © Don Ritter, 2013. Used with permission.

3-D animation or algorithmic animation – in combination with a method for playback, called an *action effect*.

The specific musical characteristics that control the video actions are determined by a strategy for categorizing the music. This configuration provides three forms of flexibility for composing a performance of video synchronized with live music: the construction of video actions, selection of a strategy for analyzing music, and selection of correspondence rules between video and music. The remainder of this article describes the components of this system in more detail.

VIDEO ACTIONS

An initial limitation of Orpheus was the duration of video it could control. The software used full-screen, digital video clips that were activated to loop forward

or backward from a computer's memory. The maximum amount of memory that the computer could accommodate – which was 18 MB in 1988 – determined the total number and duration of clips that could be used within a performance. That year, the average price of memory was \$333 per MB, or 8000 times more than today's price.²⁴ The limitation imposed by my financial empire was overcome by 1991, and the computer's limitation was solved through the notion of a video action.

Within Orpheus, a video action is comprised of a specific collection of video frames, an action effect, and various control parameters. An example of an action effect is *skip-to-note-oscillate*. If this action effect is used within a video action, the relative pitch of the incoming music determines the playback speed of the video; lower pitches produce slower moving imagery and higher pitches produce faster imagery. An adjustable parameter for this action effect is the reference pitch for determining the playback speed. When a

video action uses the *skip-to-note-oscillate* effect, the frame order oscillates forward and backward, while the speed of the clip is determined by the pitch difference between the incoming music and the reference pitch. The *skip-to-note-oscillate* effect can be adjusted to play for certain duration of time, or it can play continuously until stopped by a specific musical event.

The use of video actions was created to overcome the memory limitation imposed by the computer, but this notion is independent of the format of the source video. A video action can be comprised of a digital video clip, live video from a camera, pre-rendered animation, algorithmic animation generated in real time, or 3D animation generated in real time. Orpheus has 70 different action effects that can be used to create video actions, each adjustable through various parameters. By using a specific collection of frames within different video actions, 15 minutes of video footage can be created from 15 seconds of source video stored in the computer's memory. At the early stage of the software's development, different video actions were activated sequentially and according to the number of musical notes received by the software. For example, video action 1 would respond to the first 10 music notes, video action 2 would respond to the next 15 notes, video action 3 would respond to the next 12 notes, and so on. Eventually the software could analyze music to a greater extent, and various musical characteristics became associated with video actions in a non-sequential manner.

The next level of flexibility to be incorporated was the arrangement of video actions into lists, with each list associated with a particular category of music analysis. By that stage of development, a specific video action was not associated with a particular musical feature; it became part of a list that was activated according to combinations of music features and categorizations. Stated simply, the software became more interactive

by recognizing additional features within the music and using these numbers to control the video more intricately.

MUSIC-LISTENER

In order for an interactive system to synchronize video precisely with musical input, it must recognize the continuously changing characteristics of the music. Using music as an input to a human interface is significantly different from using finger gestures. Most interactive media use a human interface that is activated through fingers on a touch screen, computer keyboard, or mouse. With these devices, the number of options available to a user at a decision point is typically determined by a two dimensional arrangement of buttons. This spatial approach, however, cannot be used effectively with music because sound is a temporal phenomenon.

Research on the automated analysis of music – also known as *machine listening* – is a complicated endeavor that is undertaken for various reasons, including comprehension of music, automatic transcription of music into scores, music therapy, teaching of music, identifying music, identifying instruments, and within interactive performance systems.^{25 26 27 28} The characteristics of live music that can currently be identified through computerized techniques include the pitch, duration and timbre of individual notes, and the key, rhythm and melody of a series of notes.²⁹ This discussion will provide a brief overview of the process of computerized music analysis and its use within a performance system for synchronizing video with live music. Specifically, I will discuss the use of machine listening within the Orpheus software and its use of a flexible music-listener.

From a practical perspective, automated music analysis can evaluate the actual sound produced by musical instruments, or it can analyze the MIDI data corresponding with the music. The use of MIDI within music analysis is convenient because the pitch and loudness of musical notes are conveyed as discrete units of digital data, though MIDI messages cannot convey the actual timbre or volume envelope of a note. The MIDI note number 60, for example, indicates that the pitch of a note is C4, but there is no information specifying its actual harmonics. More advanced techniques of music analysis use fast Fourier transform analysis (FFT), a computerized algorithm that can identify the harmonics that make up a note's timbre.³⁰ Machine listening using any computerized technique is not yet a perfected technology; Robert Rowe states in his book *Machine Musicianship*, "We must labor mightily to make a computer program perform the analysis required of a freshman music student."³¹

A detailed discussion on the current state of automated music analysis is beyond the scope of this article and my ability, therefore I will primarily describe how I have used machine listening when synchronizing video with live music. The music analysis used within my interactive performances and installations until 1998 was accomplished solely through MIDI. When working with musical instruments that did not provide MIDI output – such as a trombone or saxophone – an instrument's sound was converted into MIDI messages using a hardware pitch follower.³² Since 1998 I have also used the analysis of audio signals within various projects that employed machine listening. My primary interest in machine listening is to develop practical methods for identifying changes in musical structures that are perceivable and relevant for controlling video.

The music-listener diagrammed in figure 3 is the component within the system that executes a specific strategy for analyzing music. It provides an ongoing

stream of features pertaining to the incoming music that are used by the control mechanism for directing the video output. The music-listener provides two categories of features, instantaneous and temporal. *Instantaneous features* are characteristics of the music at a specific moment in time, while *temporal features* are those that span a longer duration of time or calculated from combinations of features and parameters. Creating a music-listener that can recognize a large variety of musical features is an important strategy for enhancing the system's degree of interactivity.

The smallest musical event recognized by the music-listener is the *note*. The features within a note include its pitch, loudness, and duration. The pitch of a note is an example of an instantaneous feature, such as an A note in the fourth octave (A4). The term *pitch* in the music-listener refers to the fundamental frequency of the sound produced by the note, such as A4 being 440Hz. A temporal feature of a note is its *pitch interval*, the difference in pitch between this note and the one previously played. The calculation of a pitch interval within the music-listener is determined according to the chromatic scale that is comprised of 12 pitches per octave: C, C#, D, D#, E, F, F#, G, G#, A, A#, and B. The pitch interval between adjacent notes on this scale is 1, also known as a semitone. For example, if the notes played sequentially were C4, C4, C#4, D#4, E4 and C4, the series of pitch intervals would be as in the following example.

C4 to C4 pitch interval = 0
 C4 to C#4 pitch interval = 1
 C#4 to D#4 pitch interval = 2
 D#4 to E4 pitch interval = 1
 E4 to C4 pitch interval = -4

The pitch of a specific note can be determined independently of other notes or time, but a pitch interval can only be determined from the occurrence of two

sequential notes. This type of pitch interval is also called a horizontal or melodic interval.³³ In contrast, a vertical pitch interval is the pitch difference between two or more notes playing simultaneously – known as a chord. A vertical pitch interval is classified as an *instantaneous polyphonic feature* because it describes the relationship between two or more notes playing at a particular instant. An *instantaneous monophonic feature* refers to the characteristic of single note playing at particular moment. Eventually Orpheus was able to recognize these four categories of music features: instantaneous monophonic features, temporal monophonic features, instantaneous polyphonic features, and temporal polyphonic features. Listed below are some of the features that were recognized by the music-listener used by Orpheus beginning in 1990. All of these features were extracted from music that was represented as MIDI messages.

Instantaneous monophonic features used for a series of single notes:

- » Active note pitch: note currently playing
- » Active note loudness: loudness of note currently playing
- » Active note octave: octave of note currently playing
- » Active rest: no note playing

Temporal monophonic features used for a series of single notes:

- » Designation of active note for use in higher level analysis
- » Active note start time relative to beginning of music
- » Active note interval, relative to pitch of previous active note
- » Active note loudness interval, relative to previous active note
- » Active note duration relative to its start time
- » End time of previously active note relative to beginning of music

- » Number of occurrences of individual pitches
- » Tempo: rate of occurrence of active notes
- » Rest start time, relative to beginning of music
- » Rest duration, relative to its start time

Instantaneous polyphonic features used for chords:

- » Total number of notes playing at one time
- » Pitch of each note currently playing
- » Loudness of each note currently playing
- » Octave of each note currently playing

Temporal Polyphonic Features used for chords:

- » Start times for all notes playing relative to beginning of music
- » Durations of all notes currently playing
- » End times of notes previously played relative to beginning of music
- » Designation of active note: most recently played note or with lowest pitch
- » Tempo: rate of occurrence of active notes
- » Pitch interval of active note relative to previous active note
- » Loudness interval of active note relative to previous active note
- » Designation of active note to be used in higher level analysis
- » Number of occurrences of all pitches played

Figure 4 provides an example of the music-listener within Orpheus using a reduced collection of features. The top section of the example indicates a sequence of notes represented as black rectangles, with pitch indicated vertically, duration horizontally, and a note's loudness as the white number within a rectangle. MIDI note numbers are indicated to the right of the note names on the music keyboard. A list of instantaneous and temporal features is listed beneath the notes, corresponding with time units 1 to 19. Each time unit represents 0.425 second, but in actuality the sampling time used by Orpheus was 0.0333 second. The center

MIDI note analysis

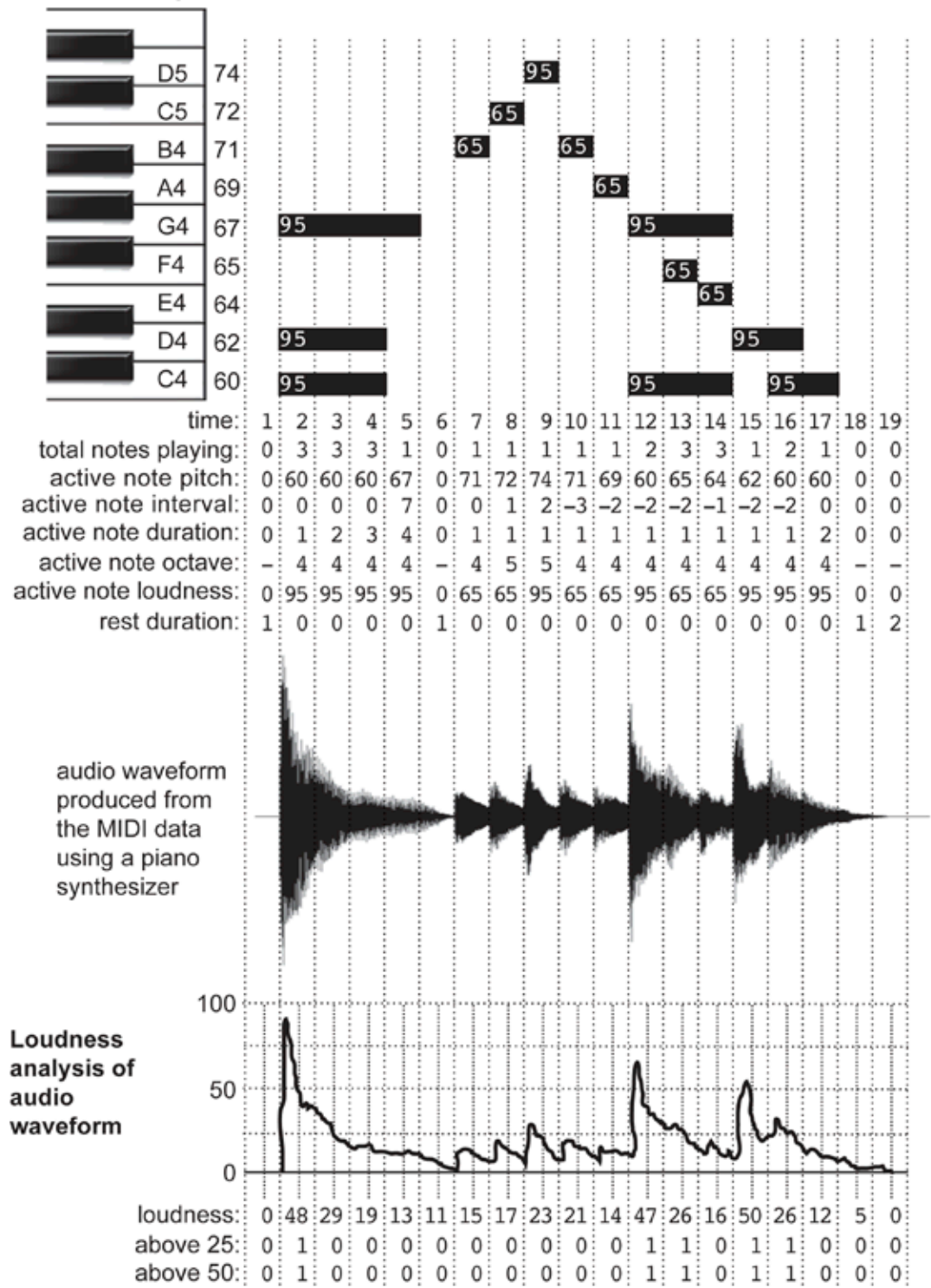


Fig 4. Music-listener analysis using MIDI and audio wave. An example of analyzing the MIDI data output by a piano synthesizer that provides a continuous stream of instantaneous and temporal features. An analysis of the instrument's audio wave provides additional details of the loudness envelope. © Don Ritter, 2013. Used with permission.

of the diagram is a representation of an audio wave that was created by sending the MIDI messages into a piano synthesizer. The lower section of the example depicts an analysis of the loudness envelope associated with this audio wave.

At time 1 within the example, no music is playing and the music-listener indicates a musical rest of duration 1. At time 2, the active note is MIDI note 60 (C4). When multiple notes are played simultaneously, the note with the lowest pitch is designated as the active note. If a new note begins while a previous note is still playing, the new note is designated as the active note. For example, two notes are playing at time 12, but MIDI note 60 (C4) is the active note because it has the lowest pitch. At time 13, MIDI note 65 (F4) is the active note because it occurred more recently than MIDI note 60 (C4). The note designated as being active is used within the next level of analysis, when the music is categorized into different music-types.

The bottom of the example depicts a simple audio analysis of the loudness envelope that was created by sending the MIDI messages into a piano synthesizer. The result of the loudness analysis is a stream of numbers – ranging from 0 to 50 – that correspond with the loudness of the music at the 19 sample times. Orpheus never used this method because the software's only form of input was MIDI, but I have used this form of analysis since 1998 within installations and performances that did not use Orpheus.

RELATIONSHIPS BETWEEN MUSIC FEATURES, MUSIC CATEGORIZATION, AND VIDEO ACTIONS

The music-listener contains 3 levels of analysis:

1. acquisition of instantaneous features, such as the pitch of the active note
2. calculation of temporal features, such as the duration of the active note
3. categorization of the music into a music-type

The categorization of music into a music-type is made according to different groupings of instantaneous and temporal features. For example, incoming music could be categorized according to pitch ranges, loudness ranges, or a combination of pitch and loudness ranges. Below are two simple examples of categorization strategies that can be used within the music-listener. In these examples, pitches are designated using MIDI note numbers. In actual practice, categorization strategies were more complex than what is listed below, and up to 999 different categorization rules could be created within a strategy.

Example of a music categorization rule according to loudness:

- » the loudness of an active note corresponds with the music-type; for example, the music-type is 96 when the loudness of the active note is 96.

Example of music categorization rules according to pitch ranges:

- » active note below 36 is music-type 1,
- » active note between 37 and 42 is music-type 2,
- » active note between 43 and 46 is music-type 3,
- » active note between 47 and 52 is music-type 4,
- » active note between 59 and 127 is music-type 5.

Example of music categorization rules according to note duration:

- » active note duration under .25 second is music-type 1,
- » active note duration between .25 and .5 second is music-type 2,
- » active note duration between .5 and 1.0 second is music-type 3,
- » active note duration between above 1.0 second is the music-type 4.

When music is analyzed by the music-listener, it provides a continuous stream of instantaneous features, temporal features, and music-types. The specific manner for categorizing music into music-types is completely adjustable: any combination of instantaneous features and temporal features can be used within a strategy.

Figure 5 provides an example that depicts the relationships between music features, music categorization, and video actions. In this example, a music-listener strategy has been selected for categorizing music into three types: music-type 0 when no music is playing; music-type 1 when the pitch of the incoming note is less than MIDI note 60 (C4); and music-type 2 when the incoming note is greater than MIDI note 60. I am using an overly simple strategy for categorizing the music to make the flexible structure of the system more apparent. Thousands of different strategies for categorizing music can potentially be created using various combinations of musical features, and a single strategy can create a large number of music-types. Because a video action is not video media – it is only a manner for playing video media – the amount of memory occupied by a video action is small and thousands of different video actions can be used without reducing the system's performance.

Returning to the example in figure 5, the total number of music categories created by this music-listener is 3. The number of video action lists that can be controlled by a music-listener corresponds with the number of music categories it can identify. Therefore, this listener can control 3 different action lists. Each of these lists contains 3 video actions, though a video action list can potentially hold thousands of video

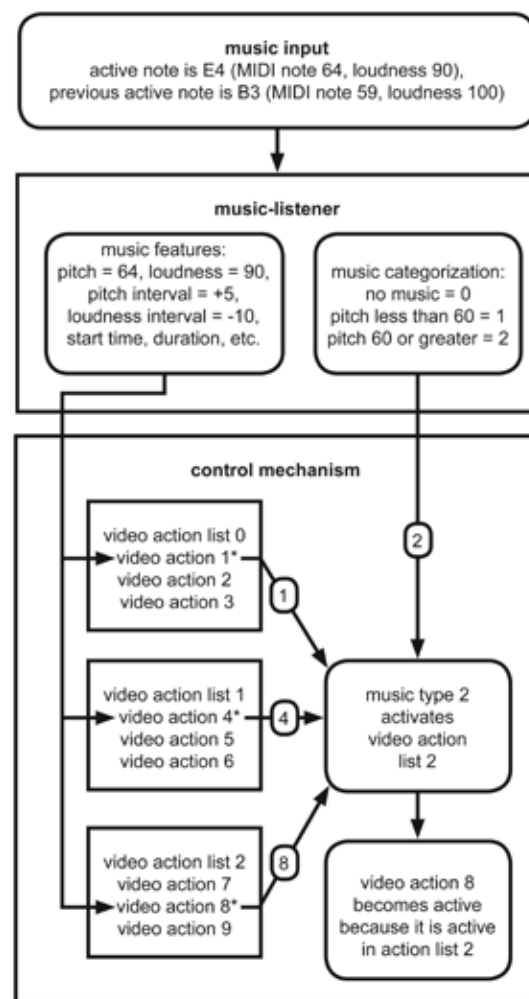


Fig 5. Example of a video action activated by a music-type.

A specific video action is activated according to musical features and music categorization. Don Ritter, 2013. Used with permission.

actions. A video action list becomes active when the active music-type corresponds with that list, such as video action list 2 being activated when the incoming music is categorized as type 2. A specific video action within a list is available for activation according to the number of times the list has been activated. The video actions marked with an asterisk are available for activation. In the example, video action 8 is designated as being active within action list 2, so the video output of the system is video action 8 when the music-type is 2. The categorization of music into different music-types is simply a method of using a single number to represent the overall musical activity at a certain moment in time, similar to a stock market index representing the overall activity of a stock market at a certain instant in time. The more intricate synchronization of the system is provided through the various instantaneous and temporal features that control the various parameters within the video actions.

CONCLUSION

The interactive system described in this document evolved over thousands of hours of software development, testing, and live performances. I typically collaborate with an improvising musician for the creation of a performance of synchronized video and music, and I am fortunate to have worked with some outstanding musicians. The process of composing a performance typically begins by giving priority to either the music or the imagery, or by jointly developing a unified concept with the musician. If the video imagery is given priority, the musician selects a specific musical instrument, compositional structure, or a collection of sounds that relate to the predetermined video material. If the music is given priority, I create new video material that relates to the predetermined music. Creating a work that uses new video material and new music according to a mutually selected concept is usually the most

fulfilling approach, but very laborious. The next step is to create numerous correlations between the specific musical and visual elements and then incorporate them into the system's control mechanism.

The primary advantage of a flexible system for synchronizing video with live music is the compositional freedom it provides. After working with various musicians, I found that different types of correspondence were more effective according to the instrument and musical style employed by a musician. For example, synchronization according to subtle changes in loudness and pitch were most effective with saxophone, but this approach was less interesting when used with percussive instruments. A flexible approach for synchronizing video with live music enables the creation of a composition that uses counterpoint relationships between imagery and music rather than a strict trigger and response approach.

ACKNOWLEDGEMENTS

I would like to thank the musical collaborators who were involved in performances using Orpheus since 1988, including George Lewis, Thomas Dimuzio, Trevor Tureski, Amy Denio, Nick Didkovsky, Ben Neill, Geneviève Letarte and Tom Walsh, and also Robert Rowe who has answered my questions on machine listening for many years. Portions of the work described in this paper received support from the Canada Council during 1989-1991.

REFERENCES AND NOTES

1. David Eagen, "VJ Software Listings," Audio Visualizers, <http://www.audiovisualizers.com/toolshak/vjprgpix/soft-main.htm> (accessed July 18, 2012).
2. A. B. Klein, *Color-Music: The Art of Light* (London: Crosby Lockwood and Son, 1927).
3. Jack Burnham, *Beyond Modern Sculpture* (New York: George Braziller, 1968), 286–288.
4. Kenneth Peacock, "Instruments to Perform Color-Music: Two Centuries of Technological Experimentation," in *Leonardo* 21, no. 4 (1988): 397–406.
5. D-Fuse, *VJ: Audio-Visual Art and VJ Culture* (London: Laurence King Publishing, 2006).
6. Kenneth Peacock, 398–400.
7. Louis-Bertrand Castel, *L'Optique des couleurs* (Paris, 1740). Online version of this illustration at http://en.wikipedia.org/wiki/Louis_Bertrand_Castel (accessed November 25, 2012)
8. Karl von Eckartshausen, "Disclosures of Magic from Tested Experiences of Occult Philosophic Sciences and Veiled Secrets of Nature," (1791) quoted in Sergei Eisenstein, *The Film Sense*, ed. and trans. Jay Leyda (New York: Harcourt, Brace & World, 1942), 88.
9. MIDI is an acronym for Music Instrument Digital Interface, a digital language for describing music in real time. MIDI messages specify musical characteristics – including the pitch, loudness and timing of musical notes – but contain no actual audio.
10. George Lewis, "Too Many Notes: Computers, Complexity and Culture in Voyager," in *Leonardo Music Journal* 10 (2000): 33–39.
11. A. B. Klein, *Color-Music: The Art of Light* (London: Crosby Lockwood and Son, 1926), 21.
12. B. M. Galejev, "The Fire of Prometheus Music-Kinetic Art Experiments in the USSR," in *Leonardo* 21, no. 4 (1988): 383–396.
13. Counterpoint in music composition refers to independent rhythms being combined to create a unified structure.
14. Youtube, "Scriabin's Prometheus: Poem of Fire," Yale University, February, 2010, <http://www.youtube.com/watch?v=V3B7uQ5K0IU> (accessed October 15, 2012).
15. Sergei Eisenstein, *The Film Sense*, ed. and trans. Jay Leyda (New York: Harcourt, Brace & World, 1942)
16. Sergei Eisenstein, *The Film Form*, ed. and trans. Jay Leyda (New York: Harcourt, Brace & World, 1949).
17. Ibid., 78.
18. Milller Puckette, "Something Digital," in *Computer Music Journal* 15, no. 4 (1991): 65.
19. Kenneth Peacock, 400.
20. B. M. Galejev and I. L. Vanechkina, "Was Scriabin a Synesthete?," in *Leonardo* 34, no. 4 (2001): 357–362.
21. Kenneth Peacock, 398–400.
22. Sergei Eisenstein, *The Film Sense*, 109.
23. Sergei Eisenstein, *The Film Sense*, 85.
24. Memory Prices (1957–2012), <http://www.jcmit.com/memoryprice.htm> (accessed October 15, 2012).
25. Robert Rowe, Skype interview by author, October 19, 2012.
26. Robert Rowe, *Interactive Music Systems: Machine Listening and Composing* (Cambridge, MA: The MIT Press, 1993).
27. Nick Collins, "Towards Autonomous Agents for Live Computer Music: Realtime Machine Listening and Interactive Music Systems," (PhD thesis, University of Cambridge, 2006).
28. Brian Whitman, Gary Flake, and Steve Lawrence, "Artist Detection in Music with Minnowmatch," *Proceedings of the 2001 IEEE Workshop on Neural Networks for Signal Processing*, Falmouth, Massachusetts, (September 2001): 559-568.
29. David Gerhard, "Computer Music Analysis," (Technical Report CMPT TR 9713, Simon Fraser University, 2002).
30. Wikipedia, "Fast Fourier transform," http://en.wikipedia.org/wiki/Fast_Fourier_transform (accessed October 22, 2012).
31. Robert Rowe, *Machine Musicianship* (Cambridge, MA: The MIT Press, 2001), 8.
32. Synthony Music, "IVL," Synth and Midi Museum, <http://www.synthony.com/vintage/pitchrider.html> (accessed November 20, 2012).
33. Wikipedia, "Interval (music)," http://en.wikipedia.org/wiki/Interval_music (accessed October 28, 2012).



la Biennale di Venezia

**Arte
Architettura
Cinema
Danza
Musica
Teatro
Archivio Storico**



MOCCK **The MOCCK Pavillion**
Museo di Arte Contemporanea