VECTOR SYNTHESIS:

A MEDIA ARCHAEOLOGICAL INVESTIGATION INTO SOUND-MODULATED LIGHT

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Abstract
Vector Synthesis is a computational art project inspired by theories of media archaeology, by the history of computer and video art, and by the use of discarded and obsolete technologies such as the Cathode Ray Tube monitor. This text explores the military and techno-scientific legacies at the birth of modern computing, and charts attempts by artists of the subsequent two decades to decouple these tools from their destructive origins. Using this history as a basis, the author then describes a media archaeological, real time performance system using audio synthesis and vector graphics display techniques to investigate direct, synesthetic relationships between sound and image. Key to this system, realized in the Pure Data programming environment, is a didactic, open source approach which encourages reuse and modification by other artists within the experimental audiovisual arts community.

Keywords media art, media-archaeology, audiovisual performance, open source code, cathode-ray tubes, obsolete technology, synesthesia, vector graphics, audio synthesis, video art

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ABSTRACT

Vector Synthesis is a computational art project inspired by theories of media archaeology, by the history of computer and video art, and by the use of discarded and obsolete technologies such as the Cathode Ray Tube monitor. This text explores the military and techno-scientific legacies at the birth of modern computing, and charts attempts by artists of the subsequent two decades to decouple these tools from their destructive origins. Using this history as a basis, the author then describes a media archaeological, real time performance system using audio synthesis and vector graphics display techniques to investigate direct, synesthetic relationships between sound and image. Key to this system, realized in the Pure Data programming environment, is a didactic, open source approach which encourages reuse and modification by other artists within the experimental audiovisual arts community.

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1.0

INTRODUCTION

The Vector Synthesis project proposes a media-archaeological reenactment of key moments in the history of computer graphics and video art. The purpose of this reenactment is not based solely on nostalgia for past eras or a fetish for retrograde aesthetics, but rather on considering the kinds of societal needs and desires media technology was designed to address, and how those needs and desires persisted in spite of our inventions. This particular case study focuses on one specific graphics technology, which renders images by sending voltage signals representing the horizontal and vertical axes of a vector image to a Cathode Ray Tube monitor. The fact that this particular method of creating electronic images was abandoned as obsolete in the 1980's allows us to consider it as we might consider any fossil or artifact from a past civilization, such as a cave painting in Lascaux, a mosaic tile in Pompeii, or the mummified remains of a king in Cairo.

Following this introduction, chapter two of this paper considers the problem of how tools which we consider working for us are actually working on us due to assumptions about their use which have been engineered into them. For our field of survey, the history of electronic graphics, the assumptions we must pay closest attention to arise from the techno-scientific aims of World War II and Cold War computer science to predict, simulate, and control reality in a military defense context. Section two concludes with analysis of how this military paradigm has filtered into the popular culture of computing today.

Chapter three turns its attention towards the artistic goals set out for the design of a media-archaeological performance system which draws on the history and aesthetics of vintage vector graphics. Using examples from the history of electronic, computer, and video art, I lay out my requirements that such a system involve real time bodily interaction with an ongoing and generative process, that it be based on continuous analog signals working 'below' the level of the rendered movie frame, that it maintains a close synesthetic relationship between image and sound

by using the same electronic signal to manifest both phenomena, and that the system itself is transparent and didactic in the sense that it contains within itself all the keys necessary to decode its own operation and therefore can be used by other artists with similar aims. In this section, I also consider whether the universalizing narratives bound up in the mathematical models of symmetry and beauty found in much mid-Century electronic and computer art are relevant in a world ruled by asymmetry and inequality, and propose the 'glitch' (as elaborated by theorist Rosa Menkman) as a useful artistic tool to crack the 'black boxes' which have enshrined these narrative assumptions.

The technical implementation of a live performance system, coded in the Pure Data programming environment, is covered extensively in the fourth chapter. Here, I introduce the Cathode Ray Tube and the two main methods of drawing images on its screen (vectors and rasters) in more detail before turning to my own first attempts with analog synthesizers to create experimental audiovisual artworks using them. Following this, I survey the work of various colleagues in the field who have developed their own hardware and software based vector performance systems and examine the kinds of issues in combining digital audio synthesis and analog graphics they all have inevitably faced. I then lay out the core of my Vector Synthesis library for Pure Data itself, and the three main areas of audiovisual image synthesis it involves; Lissajous and two-dimensional figures along with the transformations which can be made on them; three-dimensional figures and the simulations of 3D space which are possible within the audio signal domain; and finally scan processed imagery from a live video camera, digital still image, or digital movie file. As the didactic component of my research depends very much on the involvement of others in the creative process, the next few sections of this chapter cover the various residencies, workshops, performances, and conferences which helped shape the project through sharing and interacting with various artists, academics, and institutions along the way. And finally, I conclude chapter four with a look ahead towards the further development of Vector Synthesis for use with ILDA laser displays.

The fifth, closing chapter evaluates my research into the

field of historical electronic imagery in relation to the creative work I have realized based on this research, and speculates on whether an awareness of the agencies built into machines is enough to alter it towards more humanist purposes. I consider whether improvisational, abstract visuals are the most appropriate medium for asking the kinds of societal questions raised in the first chapter, and how the content of the performance benefits from these questions all the same. I also present a breakdown of why I consider the somewhat unorthodox technique of sending vector graphics as audio signals to antique CRT monitors to be a worthwhile area of exploration for other artists. Lastly, I examine the immediate benefits of a transparent, open source process (in opposition to a closed source working method which values secrecy and scarcity) to the technical development and more widespread adoption of the tools used in creating the Vector Synthesis project by other artists.

2.0 THE AGENCY OF MACHINES

The practice of media archaeology, Jussi Parikka tells us, is primarily concerned with digging through the "materialities of technology" in order to determine how the "structures of power" are located in them through a process of techno-cultural "reverse-engineering" (2012: 164). It forms a counterpoint to the dominant narratives in media history, critiquing the idea that technological development automatically equals progress and that our current techno-culture is the "best of all possible worlds" (43), and giving heightened significance to failed, neglected, suppressed, or even imaginary projects (Kluitenberg 2011: 51). Analysis of such 'lost' technologies places the past and present of media in conversation, in order to "illuminate ideological mechanisms behind them" (Huhtamo 2011: 28). In this section, we will consider first an object brought to our attention through the writings of Friedrich Kittler (1999: 200-215). This object is Nietzsche's typewriter, and from it we can trace the lineage of a symbolic order which gave birth to modern computing. By further looking at concepts of technological determinism advanced by Armin

Modesch coupled with an analysis of Cold War era computing, we can start to piece together a view of contemporary techno-culture where the ideological agency of machines is both omnipresent and somehow rarely acknowledged. I propose adopting this view as a first step towards the media-archaeological reenactments described further in this paper, following Siegfried Zielinski's exhortation not to "seek the old in the new," but rather to "find something new in the old" (2006: 3).

2.1 TECHNOLOGICAL DETERMINISM: NIETZSCHE'S TYPEWRITER

In 1881, Friedrich Nietzsche purchased one of the first typewriters available on the market; the Malling-Hansen Writing Ball. This writing machine appears slightly different from the Remington style typewriters we are more familiar with from history, since the Malling-Hansen machine's keyboard described a dome shape directly over the paper to be imprinted upon, making it impossible to read what has just been written. By this time already half-blind, Nietzsche hoped the machine would help liberate his writing from his deteriorated physical conditions. However, the machine lasted only a few short months before itself becoming mechanically unusable. This short moment corresponds with a period during which his style moves from the somewhat ponderous prose of *On the Birth of Tragedy* (1872) to the terse declarations of *Human, All Too Human* (1878) and *Thus Spoke Zarathustra* (1883), and the effects of the machine did not pass unnoticed. During this period, his expression "changed from arguments to aphorisms, from thoughts to puns, from rhetoric to telegram style", and Nietzsche himself observed in a letter to Peter Gast that "[o]ur writing tools are also working on our thoughts." (Kittler 1999)

Within the next decade, another newly-invented inscription machine began to work not only on the inner thoughts of philosophers, but on the social status of the burgeoning urban working class. According to Charlie Gere, Herman Hollerith's census tabulating system of 1890 effected a formalization of

individuals into a system of power relations and signs which "makes them interchangeable and manipulatable as data", and thereby easier to control and discipline. It should therefore not be surprising that, when Alan Turing searched his own thoughts for a metaphor to describe his imaginary universal computing machine in 1936, the idea of a typewriter inscribing symbols on a long paper ribbon came quite quickly to him. Gere writes:

> "[E]mbedded in a network of social and cultural meaning [...] derived from contemporary capitalism [...] the typewriter standardizes and mechanizes the production of language, reducing the elements out of which it is composed to abstracted signs[...] Like the typewriter and, by extension, Turing's device, the operations of capitalism are fundamentally predicated on abstraction, standardization and mechanization, to ensure that it can operate as a universal machine, capable of treating disparate phenomena as equal and interchangeable."

> (2008: 23-24)

Of interest in both of these narratives is the question of technological determinism. In his 2005 thesis for Sussex University, Armin Medosch traces the influence of technological deterministic thinking in media art. He defines technological determinism as the belief that science and technology are "the major, if not the only forces which cause social change." (5) Those who support this view see science and technology as operating independently from human agency, and developing in accordance with their "own internal logic" which is "supported by the belief in the authority of science and by the joined together narratives of modernist progress and capitalist economic growth". (9) Medosch counters that science and technology are actually deeply driven by the particular interests which give birth to them. He asserts that under capitalism, technology cannot be considered as neutral, but rather that it is shaped socially:

> "Technology is never just technical but combines what is possible in terms of engineering techniques of the time and what is desirable in a certain sociohistoric context. Technologies do not just exist as technical artefacts but imply certain forms of social organization which they help to create and maintain and on which they depend."

> (12)

For Medosch, the concept of technological determinism absolves human beings from responsibility for the consequences of their actions, denying their roles as "actors in a historic process which involves decisions of free will" (16) and instead casting them as subjects of forces beyond their control. This kind of ideology is inherently conservative, and "suits the interests of dominant social groups" (13) while leaving the vast majority in a condition which lacks any sort of autonomy or self-determination.

2.2 TECHNO-SCIENCE AND TECHNO-CULTURE

Techno-science is the practice which puts the ideology of technological determinism to work. Medosch defines techno-science as "the fusion of technology and science" within the framework of "the patronage of the state and large corporations". It's social form, techno-capitalism, exercises a "profound influence on the methods, content, research areas" of scientific study, with the most "prominent example [being] the influence which the military won over technoscientific progress, especially during and after WW2." (Medosch 2005: 17-18) He further goes on to discuss the techno-imaginary, a discourse which "uses scientific findings, popular science, visual means (computer graphics and animations) and sensational announcements" to persuade "the world that [the actions of techno-science] are not only justified but necessary." For Medosch, the use of technologies such as virtual reality, artificial life, and artificial intelligence in new media art all align themselves within the power structures of the techno-imaginary for both inspiration and institutionalization.

Paul Crogan explores another contemporary form of new media, computer games, in his 2011 study of "war, simulation and technoculture", describing game play as an "adoption of the military technoscientific legacy forged in the face of total war and the nuclear age inaugurated by the cold war,"

(Crogan 2011: xii). He cites Paul Virilio's concept of "pure war", which undermines "any definitive separation of wartime and peacetime existence", and transfers the entire potential of a nation into its armed forces, such as occurred "in the course of World War II and gained momentum in the cold war era" (xvii). This links explicitly to key developments in digital computing and simulation technologies, namely the "cybernetic approach to modeling complex phenomenon, realtime interactive control through virtualization, and the convergence of simulated and real events." (xxii) Lamenting that contemporary media studies tend to gloss over the implications of the military funding and development of these central ideas in computing, he observes that

> "[t]his may strike one as particularly strange today in the wake of large-scale military involvements of the United States, the United Kingdom, and so many other Western and developing states around the world in the first part of the twenty-first century."
>
> (xiv)

We will return to one especially influential locus of this military techno-scientific legacy, and the SAGE (Semi-Automatic Ground Environment) air defense system of 1958, in the section 2.3 of this text.

Medosch takes up the theme of techno-utopianism in art, particularly during the years of 1900-1939 when the dominant high modernist narrative celebrated the "tabula rasa: a radical break with the past." (Medosch 2005: 42) He differentiates between the "totalitarian techno-utopianism" of Futurism, Suprematism and Constructivism, which "demanded that artists should use science and technology to help create the utopian society populated by the new man" (31), and the "more participatory or democratic form of utopianism" which employs media "purposefully to facilitate social change" (32), as embodied in Bertolt Brecht's suggestion that every radio receiver should also be capable of transmission (Brecht 1932/2005), or in Walter Benjamin's demand that artists should not concern themselves with creating master works, but rather with channeling their energies into empowering others to produce art themselves (Benjamin 1934/1992). However, one easily can surmise that the state of "pure war" which began in 1939 favored the totalitarian over the participatory, and for the

purpose of military superiority rather than egalitarian utopianism. Medosch finds that the techno-imaginary born of the Second World War and the Cold War, and still influential in the techno-culture of today, propagates itself through "threats and promises", where "apocalypse and salvation are the two stabilizing poles". (Medosch 2005: 22)

While an engineer might (perhaps naively) claim that technology such as a typewriter is neutral and has no will of its own, an artist who works with narrative alongside technology would recognize the role that non-human actors play. Richard Barbrook's *Imaginary Futures* comes down fairly hard on some of the Cold War era pioneers of computing, essentially implicating them in strategies of mass murder (2007: 52). Cybernetics guru Norbert Wiener envisioned a use of communications between people and machines as a liberation of their minds from the drudgery of labor towards higher creative purposes—a "human use of human beings" (Wiener 1950) as it were. At the same time however, his Macy Conference colleague John von Neumann was advocating a first nuclear strike on the Soviet Union as the only solution for peace (Barbrook 2007: 49). Barbrook pinpoints the 1964 New York World's Fair as a seminal moment for the American techno-imagination, where an

> "imaginary future [of] artificial intelligence[,] unmetered energy and space tourism [...] prevented visitors [...] from discovering the original motivation for developing IBM's mainframes: killing large numbers of people."
>
> (2007: 53)

This raises some interesting questions. First, could the contemporary interest in early computer techniques and graphics — up to and including the first examples of artificial intelligence, virtual reality, and computer games — without acknowledging their military-industrial origin be akin to the re-use of other sorts of problematic imagery related to doctrines of fascism, sexism, or racism, while remaining willfully ignorant of their political origins? And secondly, is it possible to reconcile the concept of technological determinism as removing human agency in the largest social

sense with an acknowledgment that our tools do in fact work
on our thoughts, channeling and filtering our creative impulses
through a framework invented by a programmer, designer, or
engineer in some other place and time, whose intentions may or
may not correspond to those of our own? My own response to these
issues is articulated in sections 3.1 and 3.5, where I describe a
media archaeological re-use and re-interpretation of discarded and
obsolete technologies combined with a didactic, open source, and
participatory approach towards interactive media.

2.3 COLD WAR COMPUTING

The public of the United States, and presumably the
leadership of the Soviet Union as well, were acquainted with the
capabilities of the largest computer system ever built through
a short film clip released in 1960. Clocking in near the average
length of a radio pop song at two minutes and forty-eight seconds,
it was clearly designed to stimulate the technoimaginary of both
Cold War nations. In this clip, we are informed that every flight
crossing the frontiers of the USA is registered ahead of time
by computer, and any radar anomaly which the computer does not
recognize appears as a "blip" on the screen to be quickly assessed
through an innovative light gun interface device, and potentially
just as quickly destroyed through the push of a single button.
The SAGE (Semi Automated Ground Environment) system (figure I),
a product of joint research by MIT and IBM for the US Air Force,
automates the rest by creating a simulated model of reality,
comparing reality as seen by radar data with that model, providing
a simplified realtime mode of interaction with the model, and
finally enabling a convergence of model and reality in the form
of a computer guided, long range BOMARC surface-to-air missile.
"There is no escape," the deep-voiced narrator informs us
confidently. "Intercept!" Perversely, the corporate tag line for
this particularly dystopian vision of the annihilation of the
unknown echoes Norbert Wiener's peacefully utopian cybernetic
vision. "This is IBM," we hear at the end of the clip. "Freeing
man's mind to shape the future" (IBM 1960).

While some commentators ascribe the beginning of modern computing to the founding of the Advanced Research Projects Agency (ARPA) by the US in response to the Sputnik launch of 1957 (Boulton 2014), many place SAGE, which was already rendered obsolete upon it's commission in 1958 by the first functional Intercontinental Ballistic Missile tests of 1957 (Ulmann 2014), as the starting point. Regardless of the precedence of peace- or war-time digital activities, the legacy of the way SAGE enacted computing survives to this day. SAGE development pioneered the fields of magnetic core memory, video displays, light guns, graphic display techniques, simulation techniques, and computer networking via telephone connections (Edwards 1996: 99-100), as well as "train[ing] the leading figures of the emerging computer programming profession" (Crogan 2011: 6). But in considering early computer graphics, it remains impossible to separate the display technology from the content being displayed. Chillingly, and recalling how SAGE logic dictates that anything unknown must be shot out of the sky, Patrick Crogan reminds us that the emerging science of modeling and simulating reality comes from the urge to anticipate the future and thereby control reality, which he explicitly links to the postmodern:

> "The virtualization of the real that in other quarters has occupied the attention of theorists of techno-culture, postmodernity, and the information age was first undertaken as a key plank of the technoscientific solution to the problem of defense from nuclear attack."
>
> (Crogan, 2011, 10)

and that the "drive to foreclose the future shuts off the future as such" (xxi). In other words, if all the eventualities of real life can be mapped out ahead of time virtually through simulation, they can be prepared for to such an extent that none of them might actually come to pass.

Despite the fact that "[w]e live in a world anticipated by our computer-based predictive and preemptive systems" (Crogan 2011: 5), the complexities of our world are not so easily reducible, nor are our models free from the subjectivities of their inventors. The impact of the simplification of reality through game theory can been seen decades after SAGE in the

work of T.C. Schelling, for example, whose agent-based computational model attempts to illustrate how individual tendencies regarding neighbors can lead to racial segregation(Schelling, 1971). Jess Bier points out that this highly influential model assumes freedom of choice for all participants, and fails to account for any forms of institutionalized economic or physical coercion (Bier, 2018). This continues to be a topic of interest, as we now discover that the sophisticated Artificial Intelligence algorithms we create can easily embed gender or racial bias within themselves (Olson, 2018).

The SAGE system was also the site of some of the first digital artistic expression. Benj Edwards writes that some of the earliest computer art — a vector representation of a Vargas pinup girl — was created by anonymous IBM engineers as a test-screen for the SAGE display terminals in the late 1950s (Edwards, 2013). Later, in 1966, Leon Harmon and Ken Knowlton produced a giant poster print by scanning a photograph of dancer Deborah Hay and reducing the image of her naked body into a grayscale of tiny electronic symbols, which could only be discerned at a great distance. They hung this in the office of a colleague as a masculine "sophomoric prank", which caused some consternation with Bell Labs management. It was only after the image appeared in the *New York Times* that it moved from "frivolous in-your-face pornography" to the computer art icon that it is considered today (Knowlton, 2005, 10). Notable here is the situation of scientifically-trained engineers acting as visual artists, and—probably due to a complete lack of artistic education—the traditional, conservative format of the female nude they chose to express. One could even speculate further on a techno-cultural desire to model, to simulate, to reduce to interchangeable symbols and to control the bodies of women. But, despite the fact that women were widely employed in computing at the time, until the arrival in the computer art world of Collette Bangert in 1967 and Lillian Schwartz in 1968, there are no recognizable women's names written in the history (Taylor 2013).

The artistic career of the anonymous, military-industrial engineer continued to unfold with the Computer Art Contest started by *Computers and Automation* magazine in February 1963. The first winning image, known by the name "Splatter Pattern", depicted the visual distortions of a camera lens, and the

second winning image in 1964 plotted the ricochet trajectories of a projectile. Both were not the product of a single artist, but rather were credited to the United States Army Ballistic Research Laboratory (BRL) at the Aberdeen Proving Ground, Maryland (Taylor 2012: 20). BRL was home to one of the first functional mainframe computers, ENIAC, which was designed to calculate artillery firing tables during WWII, but ended up being used for calculations of the feasibility of a hydrogen bomb under the direction of von Neumann in 1946 (Goldstine 1993). Grant D. Taylor notes that, even though the culture of engineering is archetypally masculine, hidden within this category of the anonymous engineer there were certainly women working in numerous computational capacities for BRL at the time, although we may never know which of them were involved in these particular images (Taylor 2013).

Taylor goes on to point out that the position of such techno-scientific computer graphics was difficult for traditional art historiography to digest in the 1960's:

> "Art historians commonly analyze artistic lineage, stylistic change, and a variety of economic and social conditions that inform and impact various creative groups and individuals. Computer art's pedigree had no recourse to normative art histories or modes of development. Rather, computer art emerged from various cultures of engineering that — even prior to the invention of the computer — had explored feedback mechanisms, control systems, and communication theory."

(Taylor 2012: 21)

He notes that the reception of computer art by the visual arts establishment was largely marked by antipathy, and that two positions solidified themselves rapidly in the debate through writers like Herbert W. Franke, who claimed that only scientists, technicians, and mathematicians possess the knowledge required to investigate this new art form, and through critics like Robert Mueller, who insisted that technicians lacking any knowledge of artistic tradition and development can only create works which are meaningless and sterile (Taylor 2012: 23-24). Ultimately however, many of the politically leftist inhabitants of the art world of the 1960's found the military-industrial

connotations of computer art utterly unpalatable, leading anti-war
activist and artist Gustav Metzger to quip in 1969, "[t]here is
little doubt that in computer art, the true *avantgarde* is the
military" (Higgins & Kahn 2012:7).

This avant-garde position is easily observed in contemporary
computer technology, where hot topics of the media arts world such
as immersive viewing techniques, computer vision, and artificial
intelligence remain closely connected with the development of
remotely-operated and autonomously-functioning weapons systems,
with an expected backlash against "killer robots" ongoing by
scores of human rights organizations (Campaign to Stop Killer
Robots, 2018). Recently, for example, Google employees protested
against a Pentagon contract by their company to develop video
analysis tools for military drones (Tung 2018), a coalition of
Microsoft workers wrote an open letter to their CEOs against a
$479 million HoloLens augmented reality visor contract with the US
Army (Microsoft Workers 4 Good 2019), and a coalition of over 50
researchers from 30 countries agreed to boycott South Korea's
KAIST university over its plans to open an artificial intelligence
weapons lab (McLean 2018). With such highly publicized events
taking place, it would be incredibly naive for a contemporary
media artist working in such areas as computer vision and image
recognition, machine learning, augmented reality, or artificial
intelligence — naming just a few — to feel safely insulated from
associations with the dystopian aspects of these technologies.
Those artists who become early adopters on the new media hype
cycle often commit themselves, wittingly or unwittingly, to the
often poorly-remunerated research, development, and cultural
promotion of technologies whose commercial purposes are far
from benign or cultural.

Even recreational activities can bear the stamp of this
techno-scientific functionalism. German media historian Claus Pias
describes how the IBM AN/FSQ7 mainframe at the heart of the SAGE
project was connected to many display terminals, and therefore
considered the user "as one device among many others", and was,
in fact, the slowest device in the entire system. The duty of the
SAGE user was to show that he was there, able to respond to the
"ping" of the computer, and able to give correct input regarding
whether one blip on the screen might be an enemy or not by using

his light gun. Failure to do so in a timely manner might result in the loss of a "life", whether symbolically or in reality (Pias 2011: 169). While Army game theory extended in the direction of computers playing simulation games with themselves rather than with humans, scientists such as William Higinbotham wished to engage the public through interaction with computers, and in 1958 programmed *Tennis for Two* on an analog computer at Brookhaven National Laboratories in Long Island NY USA, using an oscilloscope as the display. It combined a two-player interface with physics models of a bouncing ball displayed as vectors in motion, and is arguably the first publicly-playable video game (170-1). *Spacewar*, developed in 1962 at MIT as a demonstration of the capabilities of the PDP-1 computer (Gere 2002: 180), closely followed this model of two players interacting with each other in a simulated, simplified model of Newtonian physical reality. *Spacewar* provided the inspiration for Nolan Bushnell, who went on to form the Atari company and popularize games based on this idea, and who ascribed his success to the fact that he had "come up with a game [...] so simple that any drunk in any bar could play" (quoted in Pias 2011: 171-2), thus setting the threshold for public interaction with technology to a remarkable low.

Popular author Matthew B. Crawford describes how present-day capitalist culture increasingly offers us limited selections from a menu of ready-made, "hyperpalatable" solutions to problems without engaging our critical reflexes in any way (Crawford 2015: 17). At the extreme end, he cites the example of electronic gambling machines, whose only function is to entice the player to continue responding to simple prompts to the point of "extinction" (100-101), and catalogs the behaviors of gambling machine addicts, such as wearing dark clothing so that others don't notice when they have urinated on themselves rather than leave the game play (96). In this section of the paper, I have tried to paint a picture of the similarly dystopian legacy of techno-scientific thinking on our electronic culture through the example of the SAGE system and the kind of relationship with computers it engendered. One could characterize this field of interaction as a highly simplified environment, deliberately freed of ambiguities through a process of anticipation and preemption, populated by a number of

programmatic response options requiring little mental analysis, and over which a user may gain a satisfying sense of mastery by responding to the prompts of the computer in a correct and timely manner. One is reminded of the hundreds of interactive art exhibitions, championed by institutions such a ZKM in Karlsruhe or the European Media Art Festival in Osnabruck since the late 1980's, where the spectator is acknowledged by the machine and offered a reward in the form of a flashing light, a sound, or a moving image, for such common gestures as waving one's hands in the air, riding a stationary bicycle, or pushing a large red button.

Certainly, a human use of human beings should not be similar to that of a lab rat, activating a sensor to receive a portion of food, an electrical charge to our pleasure neurons, or a dose of morphine. Yet that is precisely the paradigm offered to us by interactive systems of the SAGE lineage, and continued in such formats as computer games, many kinds of web sites, and a great deal of end-user-oriented media art. If there is a way out of this totalitarian and dystopian ideal of virtuality, simulation, and ultimately cybernetic control of both virtual and real-world phenomena, it must lie in a deeper level of engagement and participation than simple stimulus/response triggers. In the following section, I will present examples of computation and cybernetics in media and the arts that moved away from well-funded military-industrial institutions, whose problematic ideologies shaped the tools which in turn come back to shape our thoughts.

3.0 DESIGN GOALS AND POINTS OF DEPARTURE

I set out to create the Vector Synthesis project with a number of design goals in mind. The key design goal was to create a live, audiovisual performance which explored a direct, non-symbolic, and synesthetic relationship between sound and image through the use of 'obsolete' media technology. The goals which followed, such as the requirement of a real time, signal-based

method of generating both image and sound, were immediately suggested by the materiality of the medium I had chosen. The additional goal of addressing the ideologies which go into the making of any kind of technological medium became evidently clear while investigating the theoretical and historical contexts reviewed in this paper. A final set of goals became obvious when I considered both how to engage others in the project and how to contribute back to the art and technology communities which inspired and supported my work through the use of didactic, well-documented, and open source code.

3.1 MEDIA ARCHAEOLOGICAL REENACTMENT

The deliberate use of obsolete media technology implies a critical dialog with the historical legacy of "hearing and seeing by technical means" (Zielinksi 2006). One method of doing this is through media archaeological re-enactments of earlier moments in its development. In such scenarios, the artist is invited to consider alternate or hidden histories of technological devices, and speculate 'what if' situations where these devices would have been used for radically different purposes, and their subsequent evolution took radically different turns. The artistic practice of media archaeology can involve engaging with historical themes, such as the history of early computing; considering alternate histories or alternative presents based on them, as often occurs in the steampunk genre of science fiction; creating art from obsolete objects and practices, such as the *Cracked Ray Tube* duo; the formulation of imaginary media which embody techno-utopias of the future, or techno-utopias of the past which have still not been realized; creating works drawn from archive materials, such as the films of Gustav Deutsch (*Film Ist*, 1998), Martin Arnold (*Alone: Life Wastes Andy Hardy*, 1998), or Peter Tscherkassky (*Outer Space*, 1999); or searching for "buried conditions" within contemporary media, such as Rosa Menkman's 2011 work *The Collapse of PAL*, which considered the contemporary

obsolescence of a broadcast video format (Parikka 2012: 138-141; 152-153). A critical, media archaeological approach stands in contrast to the design-oriented approach of "retrovation" (Suominen and Sivula 2016), a portmanteau of the words "retro" and "renovation" describing what I view as the un-critical appropriation of signature aesthetics from a past era, and their use towards creating a false sense of association or nostalgia between that era and a modern day object, location, or situation.

The search for alternative histories of technical objects can take into account unintended or subversive uses of those objects contemporary to their intended uses. For example, there is little technically which separates an oscilloscope (a cathode ray tube device which is used to inspect the waveforms of periodic electronic signals) from the vector monitors employed by analog and early digital computers to output calculations and data (such as the blips to which SAGE operators must rapidly respond with their trusty light guns) as well as by the displays of radar units. During her keynote at the Vector Hack Festival, Stefanie Bräuer related how filmmakers such as Mary Ellen Bute, Norman McLaren, and Hy Hirsh all began repurposing these laboratory devices for imagery in their works in the early 1950's. For Bräuer, "[t]his combination of cinematography and oscillographics marks a shift from the mechanical-kinetic to the analog-electronic paradigm" (Bräuer 2018) in the history of cinema, marking a midway point between the visual music animations of the 1920's and 30's and the CGI-laden Hollywood superhero blockbusters of today. Bute, who marketed her oscilloscope films on the "novelty" of combining science and art (Moritz 1996), worked together with Dr. Ralph Potter of the Bell Telephone Laboratories, who provided her with an oscilloscopic instrument:

> By turning knobs and switches on a control board I can "draw" with a beam of light with as much freedom as with a brush. As the figures and forms are produced by light on the oscilloscope screen, they are photographed on motion picture film. By careful conscious repetition and experiment, I have accumulated a "repertoire" of forms. The creative possibilities are limitless. By changing and controlling the electrical inputs in the 'scope an infinite variety of forms can be made to move in pre-determined time rhythms, and be combined or altered at will.
>
> (Bute 1954)

Even before Bute, Hirsh, and McLaren's animations, Ben Laposky had begun his *Oscillon* series of still photographs, capturing complex Lissajous curves and other patterns based on natural forms and mathematical principles, which he also referred to as "visual music" and "electronic abstractions" as displayed on the CRT oscilloscope, and which were first published in 1952 (Kagan 1980).

Alternate histories can also take shape once the technological object in question has become obsolete or fallen out of its intended use. Garnet Hertz and Jussi Parikka detail the transition cycle of technological goods from cutting edge development, through mainstream acceptance, and finally to abandonment as an avenue for artistic reappropriation, and also as a critique of the ideology of planned obsolescence which is built into every device produced today (Hertz and Parikka 2012) (figure II). While many new media artists prefer to work as early adopters of technology, discussing and exploring its potential long before any sort of maturation of content, hardware, or software, the financial and knowledge-base resources required are highly restrictive. Maintaining this position often requires an intimate relationship with the business, industry, or scientific research power centers at the heart of techno-culture, and each comes with its own compromises of content in order to access their resources. While the dominant ideologies of innovation — which claim to govern everything from hairstyles to home appliances to agricultural developments — criticize the "late majority" and "laggards" who resist change as conservative or stubborn in comparison with innovators and those who adopt and bring their ideas to market (Rogers 2003), Hertz and Parikka see great opportunity in "mainstream obsolescence" as fruitful territory for "surplus/reuse/resampling/bending" activities that benefit from "mature technologies at no cost" (Hertz and Parikka 2012: 428). In fact, those re-users of obsolete market cast-offs seem to wrap the linear model of eternal progress Ouroboros-style from tail back to head.

Consider the work of Desmond Paul Henry, who during the 1960's built a series of three automated drawing machines using components from mechanical WWII bombsights he found in an army

surplus market in 1952. According to researcher Elaine O'Hanrahan,

> Bombsights were analogue computers originally used in bombers to calculate the accurate release of bombs onto their target. The bombardier entered information on height, air speed, wind direction and bomb weight into the computer that then made the necessary calculations for when best to release the bomb load.
>
> (O'Hanrahan 2018: 158)

While these bombsights were cutting edge technology and very much a product of the wartime power centers of techno-science at the time they were made, they were vastly obsolete by the time Henry stumbled on them and later utilized them for his incredibly intricate graphical works of mathematics and chance. A self-taught artist, Henry was largely unaware of the Computer Art movement in the 1950's and 60's. He relied on his personal wartime experience with automatic fire-control technology to make sense of the bombsights, and on his lifelong love of mechanics to inspire him in their use (O'Hanrahan 2018: 158). His second drawing machine traveled with the highly influential *Cybernetic Serendipity* exhibition during the late 1960's (Reichardt 1968), where Henry became an icon in an international art scene of which he previously had little knowledge.

The parallels of Henry's work with the more well-known history of filmmakers John Whitney and — in particular — his brother James Whitney are striking. John Whitney's lifelong project was to achieve a complementary relationship between music and visual art (Whitney 1980). In 1950's, he began buying "mechanical junk excreted from army depots around the country […] such as brand new, thirty-thousand dollar antiaircraft specialized analog ballistic problem solver computers dating back to World War II" (Whitney 1980: 184). Zabet Patterson writes:

> The machine he purchased was an M5 antiaircraft gun director […] weighing in at approximately 850 pounds and comprising approximately 11,000 moving parts. [T]hey performed the delicate task of calculating the lead necessary to fire at and hit a moving target from a particular distance. The machine took in elevation, angle, and range […] in order to ensure the antiaircraft missile would arrive and explode precisely on time.
>
> (Patterson 2012: 339)

The predictive control of such weapons was in fact one of the genesis points of post-war cybernetics, and this area of research was Norbert Wiener's specialty during the war years at Bell Labs (Gere 2002: 54). The reason the M5 was so effective was that the target airplanes needed to fly straight and level so that their own bombing computers — like the ones used by Desmond Paul Henry for his drawings — could calculate their ground targets correctly (Patterson 2012: 339). Patterson notes how the gun computer works on the thoughts of its user:

> [It] trains its users to look at the world in highly specific ways […] One sees an object quickly; then focus, lock, fire. To look at a particular object is to target it. The machine translates the object into data […] for the singular purpose of burning that object out of the world. *To see is to model is to comprehend is to destroy.* This would become, in subsequent years, the model for a new kind of visual experience.
>
> (339-340. Emphasis mine.)

James Whitney made one film using the M5, *Lapis* (1966), which involves innumerable small dots coalescing into mandala-like forms before disintegrating and forming a different pattern again, over and over. Patterson notes how the film works on the mind of the viewer as well, comparing the viewer with the antiaircraft gunner, who must un-focus their eyes, "take in the whole field at once", wait for motion, and find a new target (343), demonstrating that tools and their original design goals are not so easily decoupled. The experience of making *Lapis* was traumatic for James, who eventually had the machine removed from his studio and turned to ceramics instead, and it was only through the influence of fellow filmmaker Jordan Belson that Whitney pieced the animation together into the form we can see today (350).

The model presented by Henry, the Whitney brothers, Bute, and others of reclaiming a particular technology and repurposing it towards new creative situations remains a powerful inspiration, particularly for the 'circuit bending' scene of artists, makers, and hackers. Two such contemporary artist-hackers are James Connolly and Kyle Evans. Their work with cathode ray tubes recognizes that media is never

immaterial, but remains dependent on physical hardware which refuses to die once it's market-determined lifespan has ended, becoming instead "undead" e-waste (Hertz and Parikka 2012) with a longevity which could be considered geological. Their *Cracked Ray Tube* performance explores the CRT as "an icon of the growing toxic e-waste crisis we face after decades of planned obsolescence" which can be reanimated through the application of digital audiovisual tools "to generate genuinely new aesthetic experiences of latent musicality" (Connolly and Evans 2014: 53-54).

The initial concept of my Vector Synthesis project places it in dialog with previous media-archaeological works of mine which similarly explored light and sound, namely the performance *Tonewheels* (2007-14). *Tonewheels* used the century-old technology of the optical film soundtrack, and created sound from modulated light, inspired by some of the pioneering 20th Century electronic music inventions such as the Light-Tone Organ (Edwin Emil Welte 1936), the ANS Synthesizer (Evgeny Murzin 1937-57), and the Oramics system (Daphne Oram 1957). In any normal movie film projector, areas of transparency and shadow on the film encode sound as a modulation of light which falls on a phototransistor, which converts the instantaneous amount of light it sees into an electrical current which can be used to move the membrane of a loudspeaker. In the *Tonewheels* sound-synthesis system, the linear filmstrip has been replaced with a number of rotating disks, whose speed and design create waveforms of different frequencies and timbres (figure III). My aim for Vector Synthesis was to reverse the *Tonewheels* process, and create light images from modulated sound using another type of obsolete technology, the CRT display.

The use of antiquated, oscilloscope-type hardware to visualize of the signal was deliberate, both for its unique aesthetic characteristics as well as its media-archaeological resonance as an object with a vast amount of cultural significance and an immediate visual association with television, video games, and Cold War military technology. But in appropriating this historical resonance, my aim was not simply to create nostalgia, but rather to present an alternate history where tools designed for simulation, control, and destruction were not used to create

media which emulate those purposes (as most CGI films and video games do), but rather to create non-symbolic, synesthetic audiovisual works which highlight the completion of the artistic experience in the perceptual systems of the listener/viewer themselves.

3.2 REAL TIME PERFORMANCE SYSTEM

The ability to improvise, expand or reduce sections, respond to spontaneous inspiration, jump from situation to situation, and access performance materials in an arbitrary or random manner are all contained within the idea of a live performance which is not predetermined or bound to a linear timeline. The works of John Cage – exemplified in the 1958 piece *Fontana Mix*, which uses a series of graphical transparencies to generate a unique score each time it is performed (figure IV) (johncage.org 2018) – signify a shift in consideration of the musical score as a list of deterministic actions to be reproduced as accurately as possible (a job more suited to a machine, in cybernetic terms), to a description of a system through which performers might arrive at indeterministic results through their own interpretations – a "human use of human beings" (Wiener, 1950). Likewise, the 'scores' of David Tudor for his *Rainforest* works (1968-73) (figure V) contain elaborate schematics detailing the means of distributing sounds throughout a number of objects placed in a space, and absolutely no information at all about what kinds of objects these would be or what sorts of sounds would be run through this system, nor for how long or at what volume, etc. These all-important issues were left to the experimentations of the individual performers (Rogalsky 2006: 202-206). "David never led the group," remarks *Rainforest* ensemble member Ralph Jones, "unless it was to a particularly good restaurant" (182). In fact, a great deal of the systematic automation inherent in electronic music could be seen in this cybernetic light of freeing the composer's mind from the mundane aspects of repetitive performance to consider the higher levels of the work.

If we are to think of the composition of a performance as creating a system to achieve results rather than a list of prescribed events, then the concept of 'real time' becomes incredibly important. Real time should be considered in the sense used by the computer game demo scene, which refers to code which is executed and rendered at the moment it is experienced, rather than being stored in memory or fixed media (Tasajärvi et al. 2004), but also in the sense used by pioneering video artists Woody and Steina Vasulka as a system where "signals propagate from input to output" in a continuously modifiable sequence which can be played like a musical instrument (Haller 2008: 493). An improvisational, real time approach also indicates an experimental output, meaning that the results may not be known in advance. Woody Vasulka refers to this principle as the "fire in a cave", which he discovered while exploring video feedback in the late 1960's, remarking on the medium's ability to "self-generate and self-organize" to the extent that you can "control it like you can control fire, but you cannot predict all its phases" (Vasulka et al. 2008: 415).

Contrast this with the experience of early digital computer-based animation systems. According to Manfred Mohr, creating his pioneering film of geometric permutations *Cubic Limit* (1973-1974) was "a very painful experience at the time because an adequate technology for making films with a computer was not yet developed" (Mohr 1974). John Whitney's computer animations of the 1960's and 70's were likewise calculated, displayed as vectors on a CRT, and photographed at a rate far slower than real time, meaning 30 minutes of computer time could be required to generate a 20-second sequence (Youngblood 1970: 198-199). The processing of the film itself would then take several hours more, before the artist would actually be able to view the results of their work as they were meant to be seen. This rendered approach absolutely precludes any sort of intuitive intervention in the pre-coded script, direct gestural or musical interaction with the running process, or generative feedback propagation from output back to input. In a documentary interview, Whitney referred to the duration and unidirectional linearity of this process as "agonizing" (Whitney 1992). Even later, when animator Larry Cuba designed what is probably the most widely seen piece of vector computer animation — the Death Star trench simulation from

Star Wars (1977) – on a Vector General 3D terminal connected to a PDP-11/45 computer, the 40 second sequence still required four months of programming time and 12 hours to render and shoot frame-by-frame onto film stock (Sweet 1981: 29-30).

The situation changed dramatically in 1968 when the Sony Portapak – the first camera and recorder set which was relatively inexpensive compared with commercial television studio equipment – entered the market (Burris 1996) and arguably brought video art as a form distinct from film and television into being. The real-time aspects of video allowed artists for the first time to manipulate moving visual forms in the same way that electronic musicians were already manipulating sound (Gagnon 2014: 315). 'Relatively inexpensive' did not necessarily mean that the new video tools were within the budget of a single person however, and artists who in the 1960's had already become accustomed to working collectively to reach their creative goals began forming co-operative groups to share the costs of entry into this new art form (High, Hocking, & Jimenez, 2014, xviii). They also began to create their own tools. One of these co-ops, the Experimental Television Center (ETC), was founded in New York in 1971. Hank Rudolf explains that the aims of ETC, and the technology they use in pursuit of those aims, differ from the dominant paradigms of film editing and television production in a number of ways. He places an emphasis on the following qualities as being integral to the ETC workshop environment:

- a "real time" aspect to the creative process;
- an "open-ended architecture" to the tools;
- "indeterminacy" in respect to the outcomes;
- "interactivity" with the tools and with the resulting works;
- "sound-image synchronization" which strives for a synesthetic link between the two phenomena;
- and "electronically-generated, or camera-less images" which place focus on the possibilities of the medium itself.

> o the last of the three qualities — interactivity, synchronization, and camera-less imagery — "merge with the placement of our body in a real-time environment"
>
> (Rudolf 2014: 477-482)

Also in 1971, Dan Sandin set out to create a visual equivalent of the Moog audio synthesizer, which eventually became known as the Image Processor, or IP, which was completed in 1974 (Vasulka et al. 1992: 132). The IP is a "general purpose, patch programmable analog computer, optimized for processing video information" (Sandin 1973). At the Design/Electronic Arts Conference in Buffalo in 1977, Sandin presented the design principles he imagined for the device. For him, the ideal tool should be interactive in real time ("Analog systems are so dumb they can't store information, so the stuff's got to come out as fast as it goes in"); capable of rich feedback; general purpose, patch programmable, and modular rather than full of pre-programmed, deterministic, specialized functions; easy to learn (which Sandin admits is sometimes is at odds with being general purpose); possessed of a high amount of physical tactility; portable; low cost; and safe in the sense the neither the user nor the device present a threat to each other through misuse (Minkowsky 2014: 399-400).

Steina Vasulka's *Violin Power* video performances of 1970-78 "demonstrate how the sound of a violin being performed live governs the display of the video signal" (Spielmann 2014: 512), with the image of Steina on the screen being directly manipulated through various video keying devices and the Rutt/Etra Scan Processor by the sound of the violin we simultaneously see her playing. Her approach includes "the presence of her own body in modulating audio and video signals" and directly transforms in real time "the dialogue with the machine into an intermedial connection of body and machine" (Spielmann 2008: 208). Real time involvement in the signal process is essential for Steina, providing her with the means to "continuously modify the sequence which, in a process, resembles [the] playing of a musical instrument, giving you a great amount of variations and immense capacity to discard unnecessary themes" (Haller 2008: 493). Ultimately, she assures us "I would sacrifice any kind of image resolution, any kind of perfect image, rather than sacrifice real time" (Turim and Nygren 1996: 53). The

interchangeability of audio and video signals, as utilized to maximum effect in the last sections of *Violin Power*, also plays a decisive role in the work of both Steina and Woody Vasulka, and this will be discussed in more depth in the following sections on signal-based images and synesthesia.

While Larry Cuba was happy to have worked on the Death Star scene, a highly stylized simulation of war and destruction in outer space which certainly reflects the shaping ideologies of the technology he used to animate it, he is much more proud of his own experimental films (Borelli 2017). He explained to Gene Youngblood that what makes a film experimental is that it is not "previsualized", but rather it is "the result of experiments and dialog with the medium", unlike traditional film which is first scripted and storyboarded, and then executed. In contrast, Cuba does not start out with an idea of the scenes or the final film. "I only have basic structural ideas that come from algebra, or from the nature of the [computer] drawing process", he tells Youngblood. Two other vector animated films he produced involved very different animation processes which affected their outcome sharply. His 1978 film *3/78 (Objects and Transformations)* used a real-time system where Cuba could immediately see the results of his work. This gave him the advantage of being able to create "a more varied rhythmic structure", and the disadvantage in terms of complexity since "there's a limit to what can be calculated and drawn in real time". Another film, *Two Space* (1979), was composed on a system which took several seconds to render each frame, and must be shot on film and processed before it could be viewed. According to Cuba, this allowed more complexity but left the rhythmic structure "rather limited" (Youngblood 1986), and demonstrates the deterministic affect that technology can have on artistic output.

For Woody Vasulka, the indeterminacy of the "fire in the cave" is the main attraction of the real time environment. His stated goal is "to achieve the transformations and reinforce their appearance through the physical structure of the system, rather than to enter the system as a cerebral organizer" (Vasulka and Hagen 2008: 435). And one must be such an organizer if they wish to create computer art using the linear compositional

methods of Whitney and Mohr, or if one wishes to produce sequences on demand for others' films, as Cuba did. Such indeterminacy is in fact the outcome of what are referred to as chaotic systems, which are characterized by "a high sensitivity to initial conditions" and require the presence of a "nonlinear feedback path", such as those existing within networks of "crosscoupled, frequency-modulated" analog synthesizer modules (Slater 1998: 12), or even by simply within the "strange loop" (Hofstadter 1999) of pointing a video camera at a monitor displaying its own output and rotating the camera (Crutchfield 1984). Steina concurs with Woody that there "is a danger of being infatuated with an 'idea' and then trying to impose it on the material" when in fact the materiality of a medium such as audio/video feedback defies such a topdown approach and only becomes rewarding when "you can drop all preconceptions" and "end up with something completely different from what you intended to do" (Vasulka, Foresta, and Carlut 2008: 500).

This emphasis on creating the accessible, open-ended, indeterminate devices mentioned by Sandin and Rudolf, which actualize the body in real time, clearly echoes the concerns of Walter Benjamin mentioned in the section on techno-culture, that artists should strive towards creating tools for others' expression rather than definitive works of their own (Benjamin 1934/1992). For me, a system which is non-linear and unpredictable, played in a live situation, resists being subsumed into techno-cultural narratives of simulation and control since clearly the most interesting results are the ones which cannot be predicted, cannot be completely controlled, and cannot be simulated by any other means, leaving them completely localized in the material conditions which created them in the first place and essentially non-referential to any world external to their own process (this will be discussed further in section 3.4 on synesthesia). Nor can such means accurately simulate other audiovisual objects, phenomena, and situations, as doing so would be dependent on reliable, predictable, and pseudo-realistic modeling of an idealized, previously existing form. Rather, such essentially chaotic and generative systems may even start with recognizable geometric or photorealistic forms as the initial condition, only to output them beautifully transformed into something completely unrecognizable. Therefore, such real time, generative behaviors which are resistant to prediction, pre-emption, or micro-management,

but which can still be guided and interacted with bodily, became a major design objective when considering the Vector Synthesis system.

SIGNAL-BASED IMAGERY
3.3

What follows from the previous goals — of using a very specific type of hardware in a real time situation with a high degree of interactivity and feedback to display oscilloscopic visuals — is a signal-based approach to image generating that assures a fluidity between the audio and video domains. A CRT uses analog electrical voltages to control the horizontal and vertical positions of a single beam of light, as well as the brightness of that beam. This beam can only be in one place at a time, therefore the concept of a unified video frame is in fact a complete illusion created by our own biological perceptual systems. Turim and Nygren remind us that modern cognitive science has rejected the idea that we receive images as whole pictures projected onto our passive retinas and brains, but rather that "sensory and brain processes are intertwined" and that "no perception occurs prior to cognition". In video, the frame itself is never actually fully present as it is being drawn line by line by a single, flickering point in a CRT, and is only "assembled in the viewer's mind" at a much slower rate. Therefore, signal-based image generation "undermines and illuminates the threshold of our perception of discrete units" and calls to attention the "role of mental processes in perceiving stimuli as 'images'" (Turim and Nygren 1996: 54-5). This indicates that the viewer is an active participant in the creation of the artwork, and that the primary area of artistic interest of signal-based imagery is not in the transition/ montage from one frame to another to create meaning, as in film theory (Youngblood 2008: 443), but in the activity that takes place below the time domain level of the frame and which constructs the frame itself in the viewer's mind. "The cinema language ends with the word 'frame'," according to Woody Vasulka. However, at that point the "[c]omputer image begins with quite extended terminology" (Youngblood 2008: 445).

   Op Art is one relevant point of departure when considering
the active role of the viewer in completing a work. To many
critics in the 1960's, Op Art appeared overly scientific and
soulless, and held no deep or serious artistic meaning (Houston
2007: 19-22). Additionally, it was considered populist in the
sense that it did not require any special artistic education
to appreciate, or even that it "encouraged a non-intellectual
engagement with art" (Dziewanska et al. 2017: 15) due to
its reliance on visual effect alone. Op Art is in fact based
on science, in particular the studies of perception and Gestalt
psychology which reached popular audiences through books such
as Rudolf Arnheim's *Art and Visual Perception* in 1954 (2009) and
E.H Gombrich's *Art and Illusion* in 1959 (2000). Its disruptive
visual patterns affect the movement of the eye across the image
surface, offering contradictory information which interferes with
the brain's ability to make out one distinctive image, and instead
forces it to consider a number of possibilities at once (Lancaster
1973: 30). This action demands "viewer participation" (Barrett
1970: 104) through either fixing the attention on one of the
several possibilities offered by the image, such as in the work
of Bridget Riley, Julian Stanczak, and Reginald Neal (Houston
2007), or by physically changing one's relationship to the work
in order to see it from a different angle and be presented with
other facets, as in the work of Jesús Rafael Soto, Carlos
Cruz-Diez, and Mira Schendel (Dziewanska et al. 2017).

   The cinematic illusion of motion takes advantage of our
cognitive threshold for perceiving individual visual events,
itself a combination of the phi phenomenon, beta movement, and
the flicker fusion effect (Anderson and Anderson 1993), which has
been formalized into standard frame rates of either 25 or 29.97
frames per second. These rates are roughly analogous to the
sensation of continuous tone versus that of discrete sonic events,
which begins at a frequency of approximately 20 cycles per second.
Therefore, if one wants to work below the level of the frame and
manipulate the components which make up its illusionary unity,
then continuous signals operating in the range from 25-30 Hz up
to the bandwidth of video itself at 6.5 MHz (see figure VI),
rather than the still pictures locked in celluloid frames,
or the buffered blocks of imagery output at a constant rate by
the graphics processor unit (GPU) of a modern computer, are an

excellent place to begin. One could consider signal-based images in parallel to Curtis Roads' concept of "microsound", where sonic particles near the threshold of auditory perception in the time domain combine to create complex sound objects organized within the "meso" and "macro" structures of a composition (Roads 2004: 3) (figure VII). And while full scale, signal-based raster video synthesis requires a collection of high-bandwidth oscillators and other specialized electronic hardware (Larsen 2010), a great deal can be done with vectorbased graphics in combination with signals within the audio range, and this is the territory I sought to explore with the Vector Synthesis library.

There are a great many ways of drawing images with sound, namely through Lissajous figures as well as through mathematically constructing signals to render two- and three-dimensional figures on the vector monitor, which will be covered in the chapter on Vector Synthesis implementation. However, one of the most sophisticated methods of affecting a video image with an audio signal comes from the technique of scan processing. The Rutt/Etra Scan Processor (sometimes referred to as the Rutt/Etra Video Synthesizer), is one of the more well-known tools to emerge from the early period of electronic video experimentation. Inspired by the Raster Manipulation Unit (otherwise known as the "Wobbulator"), a standard, consumer Sony television hacked with additional electromagnets for image manipulation by video artist Nam June Paik (Hocking 2014: 458), in 1972 Steve Rutt and Bill Etra designed their device to radically alter the video frame itself through "reorganiz[ing] imagery by electromagnetic deflection of the electron beam" (Vasulka and Nygren 2008: 402). Ad copy from the time of its release displays an awareness of military technological history, and perhaps sums up the moment when the engineers of electronic imagery stopped playing war games and started dropping acid:

> Emerging from the early principles of video image manipulation used for radar in the 40's, expanded in video flight simulators of the 50's and in experimental video art of the 60's, the RUTT/ETRA VIDEO SYNTHESIZER represents engineering and cost-saving breakthroughs bringing this incredible facility within the financial grasp of many video and film producers.
>
> (Pictured in: Vasulka & Nygren 2008: 402)

While the Rutt/Etra's original purpose was to provide a portable, cheaper, and more accessible alternative to the massive Scanimate systems used by major television studios to manipulate TV and film images (Hocking 2014: 456), its adoption by video artists took its development in a new direction. The device was used so extensively by Woody and Steina Vasulka, for example, that one of its signature transformations — involving the addition of the signal representing the brightness of the video input to the vertical deflection, which causes "the brighter parts of the video to 'pull' the video raster lines upward" — was labelled the "Vasulka effect" (Vasulka et al. 1992: 139).

The transformational effects of the Rutt/Etra are achieved by summing the ramping signals which control the horizontal and vertical scanning movements of the electron beam inside the CRT with other signals from internal function generators or external audio sources (such as Steina's violin). Through careful application of these other signals, the otherwise flat and rectangular visual plane of the video raster can appear to be warped in three dimensions (see figure VIII). This manipulation of the raster is referred to as "scan processing", and such operations by their very nature require signals moving at rates related to the scanning frequencies of the video ramps (50 or 59.94 Hz for the vertical field rate, and 15.625 or 15.734 kHz for the horizontal line rate, depending on whether the video signal is PAL or NTSC). All of these frequencies are faster than that of the video frame itself (25 or 29.97 Hz for PAL or NTSC, respectively), and thus the Rutt/Etra can be said to work below the level of the frame.

The Rutt/Etra allowed for camera-less imagery to be created as well, leading Woody Vasulka to label its product not as a video frame, but as a "time/energy object" consisting of a "programmable building element — the waveform" (Vasulka and Nygren 2008: 403). "Waveforms are normally an acoustic product," he remarks, "but when you create them as frames, you can see them as image objects" (Spielmann 2008: 204). He sees this time/energy (i.e. signal) based method as a means of producing electronic images without recourse to "light/space image models" and "visual-perceptual references", allowing the "eventual construction of new realities without the necessity of external referents as a means of control"

(Vasulka and Nygren 2008: 403). In other words, the capabilities of the Rutt/Etra allowed Vasulka to escape the realm of simulation and the reproduction of real world visual forms. These time/energy objects represent such a "violated state of standard television signal" (Spielmann 2008: 206), that in order to store, replay, edit, process, or broadcast them, the display monitor of the Rutt/Etra itself must be filmed with a video camera. This process of capturing the deviant signal and forcing it back into normal, rasterized frames is referred to as a "rescan" (Hocking 2014: 455), or 'rescanning'.

The Rutt/Etra model, with its capacity to both generate camera-less abstract imagery and process camera-created live video, became highly influential on the design process of Vector Synthesis, as did the necessity of rescanning the vector monitor in order to capture and project the images I create with it. When viewing the direct output of the Vector Synthesis system directly on the monitor, the strengths of the signal-based approach are highly apparent. Because activity on the screen occurs at a number of rates instead of as a series of frozen frames, the image has a depth, clarity, and complexity which I consider unsurpassed. However, a great deal of this detail can be lost in the rescanning process of converting it to frames through a camera (see section 4.6). Here the question arises, why not simply do the entire process digitally, inside the computer, and project my laptop display instead? There are a number of existing softwares that produce or display oscilloscope-type graphics digitally, and even a number of Rutt/Etra-inspired video processing tools — most notably a collaboration between programmer Anton Marini (aka Vade) and Bill Etra himself. Video synthesizer designer Dave Jones notes that many video tools from the past have been simulated in the computer based on a programmer's idea of how the original looked and functioned; however, this interpretation is not always correct, and even then the digital simulation can be "a little too perfect", or lack either the interface tactility or the characteristic distortions of the original device (Jimenez 2014: 587-588). Likewise, Vade writes of his attempt to "capture some of the beauty of the original [Rutt/Etra] hardware", while acknowledging that "modern graphics and

computer systems make fundamentally different assumptions from analog video systems" (Etra and Marini 2008).

The question of simulation is also eternally bound to the qualification of how well the model is being simulated, and often that is simply a question of how many resources in terms of time and money one can throw at the task. One can find a topical parallel to this in the rise of cryptocurrency 'mining', which at one point created a massive shortage in soon-to-be-discarded, high-end graphics cards which could be harnessed to do the necessary calculations (Warren 2018), in addition to it's larger issues of rampant energy consumption, CO2 emissions, and other ecological damage (Atkin 2017) all done in the name of progress and profit. Larry Cuba's position on computer art suggests that upgrade culture and ideals of technological 'progress' are a distraction from the actual art itself, and have little relevance:

> My work is not part of that big race for the flashiest, zoomiest, most chrome, most glass, most super-rendered image. My interest is experimental animation as the design of form in motion, independent of any particular technology used to create it. The underlying problems of design in motion are universal to everyone working in this tradition whether they use the computer or not. So in that sense what I do is not 'computer art.'
>
> (Youngblood 1986)

Rather than allow the computer to lead him in pursuit of the ever-moving target of 'perfect' simulation — essentially a problem of engineering rather than artistic expression — Cuba seems to consciously limit himself to the set of tools which most closely coincide with the issues of motion design he wishes to explore. For me, the idea of using a computer simulation of a vector monitor to critique the techno-culture of computer simulations seemed far too contradictory, and also struck me as trying to make a digital word processing application simulate the behavior and tactility of Nietzsche's typewriter. Thus, rather than force a modern, raster-based system capable of accelerated motion graphics to behave like a mid-century, analog oscilloscope, or become forever caught up in improving the verisimilitude of that simulation through software and hardware upgrades, I made a clear decision to use the computer only to

generate the signals which the various analog monitors I experiment with would then display, each with their own characteristic distortions and idiosyncrasies.

3.4 SYNESTHETIC RELATIONSHIP BETWEEN IMAGE AND SOUND

Fluidity between the audio and video domains, and the interchangeability of signals between the two, necessitates a discussion of synesthesia as a primary sensory effect of such systems. A cultural history of synesthesia might include items such as: the 17th Century writings of Sir Isaac Newton; the pyrophones and color organs invented in the 19th Century, the mystical compositions of Scriabin such as *Prometheus*, *Poem of Fire*; the jazz-influenced musical paintings of Mondriaan; Kandinsky's writings on art and music which inspired der Blaue Reiter group towards experiments in *Gesamtkunstwerke*; and the visual music films of the early 20th Century by Hans Richter, Oskar Fischinger, Viking Eggeling, Walter Ruttmann, and others. However, in every case the correspondence between sound and image was arbitrary and often deeply personal. For example, Scriabin's system assigned colors to keys rather than notes as others had done, and the composer even kept a private system which reflected his own experiences alongside a 'universal' one used in public compositions (Campen 2010: 45-62).

At its root, one could consider the synesthetic urge as seeking to locate synchronicity and direct rather than coincidental correspondence between the visual and the auditory. While historically this has often been done through pitch/color associations as detailed above, the terrain is in fact much broader, and involves many different methods to create an ambiguity of the senses which — as with Op Art — is completed in the perceptual systems of those who experience these works. In the 1960's, the New Tendencies movement offered an even more radical proposal to their audience than Op Art. Founded by art critic and researcher Matko Mestrovii and painter Almir

Mavignier in 1961, New Tendencies gathered artists interested in what they referred to as continuous visual research from across Europe in several exhibitions in France, Italy, West Germany, and Yugoslavia. Their methods drew extensively from cybernetics, perceptual psychology, mathematics, industrial design, and computer science, and their agenda was egalitarian to the utmost (Rosen et al. 2011, Medosch 2016). One section of Karl Gerstner's 1964 catalog text *What Is the Nouvelle Tendance?* does a very succinct job of summing up the group's aspirations:

> *What Is the New Tendency After?*
>
> Our goal is to make you a partner.
>
> Our art is based on reciprocity.
>
> It does not strive after perfection.
>
> It is not definitive; it leaves the space between the work and you permanently open.
>
> More precisely, our art requires your active participation.
>
> What we seek is that the joy you feel at a work of art should not be that of an admirer but of a partner.
>
> Besides, art does not interest us as such. For us it is a means of procuring visual sensations, a material that displays your talents.
>
> Since everyone is talented, everyone can become a partner.
>
> And it will be perfect if the work makes you forget the painting, 'the work of art.'
>
> (Quoted in Rosen et al. 2011: 163)

In discussing the Cold War construction of techno-culture, I laid out the grounds that to simplify, symbolically represent, and simulate some aspect of reality through technical means is an attempt to control reality through that simulation, and to eradicate those aspects which do not fit within or substantiate the simulation. At their essence, Op Art and the various kinetic and cybernetic works of the New Tendencies members run directly

contrary to this ideology by requiring the viewer themselves to complete a work which lacks a definitive perspective and which embodies ambiguity and individual interpretation. Likewise, Yvonne Spielmann uses Rosalind E. Krauss's concept of "logically incompatible situations" (Krauss 1994: 220-221) to describe the "paradoxical events" created by the Vasulkas on the Rutt/Etra machine (Spielmann 2004), while Armin Medosch reminds us, "perception is not a passive and mechanical process", meaning that "we often see what we want to see" and "based on our intentionality we focus on aspects of reality and suppress others" (Medosch 2016: 128) to deal with these situations which present themselves as visually or logically incompatible. An active perceptual process makes these branches of art participatory by nature; however, this participation is quite different from the interactive model presented by much digital art. Rather than expect a machine to model reality for us, and reward us for successfully playing by the rules of that model, the optical, kinetic, and video works of the 1960's and 70's take the bold step of expecting us to experiment with and ultimately accept simultaneous and often conflicting points of view which our senses simply cannot reconcile into a unified 'frame'.

In signal-based image works, a key ambiguity of the senses derives from the interchangeability of the signals used to manifest the image and the sound. This interchangeability forms the basis of the synesthetic effect, and can be arrived at in a number of ways electronically. Hank Rudolf describes four main methods of syncronizing sound and image available through modern analog and digital media technology:

- Sound and image are derived from the same electronic signal
- Sound is used to modulate image
- Image is used to modulate sound
- Sound and image are modulated simultaneously by a third source

  (Rudolf 2014: 482)

Yvonne Spielmann's assessment of works by the Vasulkas mirrors
three of Rudolf's four methods:

> The information in the video signal can be transmitted
> both auditively and visually. Video is an audiovisual
> medium, meaning that audio signals, such as those
> generated by an audio synthesizer or oscillator, can
> be used to affect video. Vice versa, video signals can
> have either audio or visual outputs. More importantly,
> video-audio and video can be transformed into one
> another, and the electronic information can at the
> same time be heard and seen.
>
> (Spielmann 2014: 505)

Through reviewing examples of these four distinct methods of
establishing a connection between two distinct senses, I was able
to establish which were most appropriate for the Vector Synthesis
project. It should be noted that most of the 'visual music' films
with animated, computerized, or electronic imagery from the 1960's
and even into the 1970's by artists like Mohr and Whitney, and
Cuba still utilize the same scored orchestral or ensemble music
soundtrack approach as those from the 1920's and 1930's by Richter,
Fischinger, Eggeling, Ruttmann and other pioneering abstract
animators. While John Whitney dreamed for most of his career
of a solution that would allow the simultaneous composition of
image and sound together, which he eventually found in the desktop
multimedia computer and the MIDI keyboard (Whitney 1992), the
new accessibility of real-time video techniques after 1969 opened
the door to this possibility and the Vasulkas were among the first
to explore and exploit it.

   Important discoveries in the Vasulka's early analog video
works included "the modulation of sound from image" (i.e. using
video signals to control the EMS Putney audio synthesizer),
"locating a frame through a time zone" (i.e. the drift of a
video image in and out of the frame through adjustments to its
horizontal or vertical sync, which Woody characterized as the
"broken cable" effect and for all intents and purposes replicates
under the artist's control a widely recognized television 'glitch'
or malfunction), and "the derivation of images from sounds"
by connecting the audio signals from the Putney directly to
the television monitor (Vasulka 2008: 415). In each case, the
results deviate strongly from what would normally be considered

a 'properly composed' musical or cinematic result. Rather, the results are strikingly noisy in both the sonic and visual sense.

For Yvonne Spielmann, this noise becomes an important factor in the new audiovisual medium. She invokes the new conception of sounds pioneered by John Cage in the 1950's. "For Cage," she writes, "the composition 'of' sounds would be of higher relevance than the composition 'with' sounds". The subsequent history of electronic music delved deeply into "sounds and clustering of tones rather than on music with a traditional sense of composition", and this led directly to the use of noise as a "raw material" for audiovisual work, where "video is just another kind of noisy sound, and experimentation in electronic music can be seen as a precursor to video experimentation" (Spielmann 2014: 514). In works by Woody Vasulka such as *No. 25* (1975), when an "empty image" derived from rewinding a video tape is "curved, stretched and compressed" by the scan processor, we are able at the same time to both see and hear "video noise" (504-505). Steina Vasulka, despite or perhaps because of her background as a classical violinist, is quite adamant that what she uses is "sound" and "not music" (New Mexico PBS 2013). In *Violin Power*, "[n]ot only are the audio and video interacting" but also the electronic signal structure of the live video medium itself is "forced into visible and audible appearance and expression" (Spielmann 2014: 512) through sharp, dissonant sounds adjusted by the Harold Bode Frequency Shifter not for their musical value, but for their compatibility with signals producing the visual effects within the Rutt/Etra Scan Processor and the George Brown Multi-Level Keyer (2008: 201). Thus, image-created-sound and sound-created-image are well represented in key works by this artistic duo, with Woody remarking that Steina's "leitmotif" is "that the sound synthesizer can drive [the] image", while his own approach is the opposite; "I take sound out of the image, because these two things become to us both, the building material" (New Mexico PBS 2013).

Chief among the paradigms of sound and image relationship that I wished to avoid was the idea of controlling the audiovisual output symbolically, with information derived from

a third, external source not directly related to either phenomena. While I am aware that the fields of data visualization and particularly data sonification (de Campo, 2009; Hermann et al. 2011) are both important and expanding, I have personally often found the aesthetics of visualization and sonification algorithms to speak much more about the creative aspirations of the artists involved, or towards some techno-scientific narrative or didactic purpose, than about the information which they attempt to present. Prime contemporary examples of this would be composer Johannes Kreidler's *Charts Music*, which mapped out the rise of and fall of various companies' stock market values as musical melodies (Kreidler 2009), or the recent proliferation of 'brainwave music' performances driven by the availability of cheap, digital, wireless electroencephalogram (EEG) sensors such as the NeuroSky, Muse, or Thync headsets which, due precisely to their arbitrary numeric and symbolic relationship between a visually-imperceptible input process and its sonic output, add little or nothing of note to Alvin Lucier's now classic work of direct simplicity *Music for Solo Performer* (1965) in the half-century since its premiere.

In a sense, contemporary digital artists exploring the relationship between data, sound, and moving image have merely rediscovered what signal-based artists of the 1970's like the Vasulkas, Dan Sandin, and Nam June Paik knew already — that the difference between an audio signal and a video signal can sometimes be arbitrary, and simply a function of whether the output is connected to a monitor or a loudspeaker. What is new is old again. Therefore I am quite careful to emphasize that the images I create are not an interpretation of the sound, nor vice versa. Rather, both experienced sensations are a manifestation of the same electronic signal by two different types of electromagnetic energy transducers, one being the coils of the loudspeakers which convert these signals into air movements, and the other being the coils which use these signals to guide the electron beam inside the CRT. The works of Lucier, in particular *I Am Sitting in a Room* (1969), *Music On A Long Thin Wire* (1977), or the aforementioned *Music for Solo Performer*, with their clear, direct, and expressive relationships between physical phenomena alongside his equally clear, direct, and self-descriptive written scores for these works (Lucier et al. 1995), stand as marvelous examples of this type of approach.

In the words of Lucier, "I regard this activity not so much as a demonstration of a physical fact" (312) that — in this case — a sound can be an image, or the other way around. I would rather see it as an opportunity to show how a synesthetic approach is rich in the potential to both bypass and disrupt the narrative structures which techno-culture depends upon to deliver its "threats and promises" of "apocalypse and salvation" (Medosch 2005: 22). In 1970, just at the moment when experimental film was tipping headlong into video, Gene Youngblood published his formative text *Expanded Cinema*. In it, Youngblood describes at length his vision of a "synesthetic cinema" which "abandons traditional narrative because events in reality do not move in a linear fashion" (Youngblood 1970: 97), and which instead combines multiple audiovisual elements together through a process of "syncretism" to activate the "inarticulate conscious" of the viewer (Youngblood 1970: 84-85). He provides an encapsulated definition as follows:

> [S]ynaesthetic cinema is an alloy achieved through multiple superimpositions that produce syncretism. Syncretism is a total field of harmonic opposites in continual metamorphosis; this metamorphosis produces a kind of kinaesthesia that evokes in the inarticulate conscious of the viewer recognition of an overall pattern-event that is in the film itself as well as the 'subject' of the experience. Recognition of this pattern-event results in a state of oceanic consciousness.

This he contrasts with traditional cinema, which through its inheritance of tropes from classical drama, only seeks to be a "catalyst" for "predetermined emotions" (Youngblood 1970: 111) and their programmatic responses.

Where 19th and early 20th Century experiments in synesthesia sought to unify sound and image into a single, harmonious flow, and synesthetic cinema of the 1960's sought to evoke a psychedelic state of "oceanic consciousness" in the viewer, Woody Vasulka's "broken cable effect" and the use of noise (i.e. the absence of information) as raw material both invoke the very contemporary concept of the "glitch". In contemporary audiovisual works since the Vasulka's first

experiments, the glitch has become a powerfully disruptive tool to expose the techno-cultural narratives lurking within the machines that sustain them. Glitch theorist Rosa Menkman cites Raymond Williams' 1974 groundbreaking study of television (Williams 2003), which argues that this media format is both "flow-centric", and "ideologically 'transparent'". This flow appears to be quite natural, "but is in fact strictly guided by larger corporations and powers". Menkman asserts that the "machinic functions" of television only become apparent when the format breaks down through some sort of "glitch", a "not yet defined break from a procedural flow". She describes the "critical potential" of the glitch as an "accident, chaos or laceration [that] gives a glimpse into normally obfuscated machine language". "Rather than creating the illusion of a transparent, well-working interface to information," Menkman concludes, "the glitch captures the machine revealing itself" (Menkman 2011: 27-30). A machine which opens itself to scrutiny by accident could be considered a 'cracked' black box. However, a machine that reveals itself intentionally is another matter entirely. In the following section, I will discuss the nature of open systems in terms of their didactic, creative, and community building values.

3.5 DIDACTIC AND OPEN SYSTEMS

If we are to consider the act of composition as the construction of a system to produce results, rather than an itemized list of what those results should be or a record of one momentary use of that system, then we should also consider how one might creatively interact with such a system. In 1969, the cybernetic sculptor Robert Mallary predicted six stages in which the computer might participate in the creative act. In the first stage, the computer simply "performs calculating chores" which an artist may not have time or ability to do themselves. In the second stage, the computer becomes "an indispensable component" in creating art which would otherwise be impossible without it. In the third stage, the computer is capable of making autonomous

decisions "governing the whole system […] within guidelines sharply defined by the program". By the fourth stage, the computer has developed a heuristic system which allows it to take creative steps based on the "crucial form decisions and preferences" of the artist, but which have not been anticipated in the original program. At this level of artificial intelligence, Mallary writes, "the man and the machine together, in achieving a level of performance and productivity beyond that of either alone, will have fully realized the synergistic potential". Stage five is alternately utopian and dystopian, and involves the capabilities of the machine being so advanced that the artist "like a child, can only get in the way". However, here the artist still has the option to "pull the plug", which is lacking in the most far-flung, sixth stage, where the computer has become embedded or immaterial enough to be considered "pure, disembodied energy" (Mallary, 1969). Presumably, the involvement of a human programmer would also cease at the fifth stage, as any machine with the power of autonomous, independent creativity would be capable of creating new and different versions of itself as well.

For the Vasulkas, the most creative act was their collaborative work with various engineers and programmers (Steve Rutt, Bill Etra, George Brown, Jeffrey Schier, and many others) in the design of a system itself. What followed for them was simply the "ability to turn the right knobs" (Yalkut 1973) and document what the system could do, corresponding to Mallary's second stage of art which is impossible without the use of the machine. The high level of automation in electronic sound tools of today, both on the level of performance (drum machines, sequencers, auto-tuning plugins) and composition (pattern and melody generators, auto-accompaniment, time signature quantization), lives up to many of the Vasulka's observations regarding how technological artwork is created by "shar[ing] the creative process with the machine", which "is responsible for too many elements" (Spielmann 2014: 208) for the work to be considered a product of the artist alone, and appears far closer to Mallary's third stage in many ways. At this stage, the computer user could hardly be considered as an independent artist any longer, as

they rely heavily on creative decisions made by algorithms of others' design. What I hope my earlier discussion of techno-culture has highlighted is the awareness that the development of computational tools is not ideologically neutral, and that the tools themselves are not free of deterministic components based on those ideologies. So if we are to allow machines to take up more and more of our creative processes, we should be exceptionally aware what sort of biases they are bringing into the bargain. Mallary's fourth stage is currently being played out by neural network-based learning algorithms such as Google's Deep Dream project (Mordvintsev et al. 2015), or the artificial intelligence system Flow Machines, programmed by engineers at Sony to write songs in the style of the Beatles (Papadopoulos et al. 2016), but it remains to be seen how long it takes before the human artist simply begins to 'get in the way'.

Stepping back a bit from such heady predictions, one can still easily observe that the highest creative power in the human-machine art collaboration does not come from 'turning the right knobs' of an interactive composition engineered by someone else, whose creative goals may or may not align with your own, but from designing a system to reach the kind of results you envision for yourself. Siegfried Zielinski recalls the burgeoning computer culture of the 1990's, when graphical interfaces began to be oriented towards making the boundary between the user and the device as seamless as possible. He writes that "[t]he vision was to use a computer and be unaware that it is a machine based on algorithms for calculating and simulating", designed much like "a camera obscura; one works with them, enjoys the effects they produce, and has no access to their mode of function" (Zielinski 2006:259), while Parikka points out that, in the culture of applications, we no longer program the computer as active creators, but are in fact programmed by the computer to be passive consumers of media (Parikka 2012: 81). Adrian Ward's software art project *Auto-Illustrator* (2000-2002) addresses this issue by providing a "canvas and paintbrush" user interface highly reminiscent of a "well established vector graphics application by Adobe", but then progressively taking more and more control over the drawing away from the user through "partially generative and overtly semi-autonomous" software algorithms. (Foote 2010).

One escape from this situation for Zielinski would involve establishing "unusual connections between existing means of expression and/or material" (Zielinski 2006: 257) in ways highly familiar to the remix culture of electronic dance music, DJing and VJing, and user-generated video content for platforms like YouTube. More radical action than recontextualizing existing material, however, requires a deeper understanding of the tools than simply turning other people's knobs or clicking other people's buttons:

> The only effective form of intervention in this world is to learn its laws of operation and try to undermine or overrun them. One has to give up being a player at the fairground sideshow and become an operator within the technical world where one can work on developing alternatives. For artistic praxis with computers, this means learning the codes they function with.
>
> (260)

This does not mean however that one must 'go it alone' and engineer something entirely new, since, as Rick Prelinger puts it, "the ideology of originality is arrogant and wasteful" (Prelinger 2013). It is arrogant in the hubris of assuming one's ideas exist outside of any sort of historical context, and wasteful in the sheer capitalist squandering of material resource by competitors hoping to profit from similar innovations before any others. The animation and drawing machines of the Whitney brothers and Desmond Paul Henry clearly demonstrate the creative potential of re-engineering 'obsolete' computational machineries designed for radically different purposes, and thereby liberating them from their past, destructive potentialities.

But how does one encourage this process of re-engineering? When working initially with film, Woody Vasulka noted how the technology of cinema was strongly linked to ideologies of the "economic structure of existing productions-studios, laboratories [and] equipment". When he started working with electronics, he noticed how the relevant technology "filtered down from this commercial or industrial world to the point where they were within [his] reach" through a system which was "based on individuals, in much the same way as art is

based on individuals". "These people," he continues, "the electronic tool designers, have maintained their independence within the system. And they have continuously provided tools for people who wanted to use them, or they have themselves become artists and have used the electronic tools which they created" (Vasulka and Hagen 2008: 430). His own feelings about sharing knowledge are in fact quite strong:

> I felt this primitive need to disclose the secrets. Maybe it's a jealousy against the sciences, which are operating in this unbelievable poetic area of code transformation. Imaging itself is a total mystery to me, how technology produced so powerful an element. That was the reason: I wanted to be the person who takes the fire from the gods and brings it down to the common level.
>
> (Vasulka and Hagen 2008: 436)

Vasulka's feelings are backed up by the didactic quality of the videos such as *Transformations* and *Objects* which he and Steina produced for the WNED television station in Buffalo, New York in 1978. Supplementary to these videos are the extensive taxonomical documentation Woody produced in 1975 for the scan processing techniques of the Rutt/Etra Video Synthesizer under the title "Didactic Video: Organizational Models of the Electronic Image" (Vasulka and Nygren 2008) (figure IX), the technical manual for the Digital Image Processor (Vasulka; Schier; and Moxon 1977), and a further article entitled "A Syntax of Binary Images", which methodically illustrates the various bitwise logical operations which could be produced by running two images through the Arithmetic Logic Unit at the heart of the Digital Image Processor (Vasulka and Hagen 2008). Turim and Nygren note:

> The Vasulkas' video was conceived in the context of a late 1960s rhetoric that celebrated involvement and exploration. Individual videotapes were not valued intrinsically as commodities or objects, but emerged as the by-product of a largely intangible generative process. Recordings were imagined as supplemental, analogous to the notes of physicists or anthropologists exploring an unknown domain.
>
> (Turim and Nygren 1996: 49-50)

In every case, the content of these publications is not 'artistic'

in the sense of expressing a narrative or meaning external
to the phenomena of sound and image, nor do the videos employ
anything but the most banal subject matter (Woody's hand,
a view of the street from the studio window, a cantaloupe)
to achieve a rather Constructivist result wherein the
visual materials seek to document their own construction.
An interesting observation is that these videos can be
simultaneously didactic in format, and completely abstract
or visually 'illogical' in their content. This approach
deliberately fosters curiosity about the formal technique
of the videos, and both supports and encourages others'
exploration into the technology which created them.

Dan Sandin is forthright about his motivations of
curiosity, as well as his technical 'qualifications', in
undertaking such an involved project as the Image Processor:

> I'd been a radio amateur when I'd been a kid but I
> certainly didn't know how to design circuits. I could
> certainly copy things out of Popular Electronics.
> I was comfortable with it but I didn't know enough.
> So [in nine months] I taught myself electronic design
> by getting photo boards and building circuits.

(Vasulka et al. 1992: 133)

My own suspicion is that this autodidactic process — which
exactly mirrors David Tudor's immersion into Popular Mechanics
magazines to create the *Rainforest* transducer system only a
few years previously (Rogalsky 2006: 72-73) — combined with the
counterculture of teach-ins which Sandin had participated
in during the Cambodian crisis of 1969 (Vasulka et al. 1992:
132), impressed upon Sandin an urgent need to share the
results of his investigations. The videos Sandin produced,
such as *Five-minute Romp through the IP* (1973) and *How TV
Works* (1977), sought to explain what differentiated video
from any other media form. His 'video letter' to the Vasulkas,
*Triangle in Front of Square in Front of Circle in Front of
Triangle* (1973), depicts one of the "physically impossible
relations arising between objects in analog video" (Spielmann
2014: 207) native to the medium. By employing basic video
shapes to point out that "using common language concepts and
normal spatial relationships to talk about things that are

happening on the video screen […] is very dangerous" (Sandin 1973), Sandin emphasizes that, in video, one "cannot refer to image planes as in front of or behind, etc., that is just an illusory human perception [and t]he Cathode Ray Tube knows nothing of this" (Vasulka et al 1992: 132).

Sandin was among the first technologists to formalize the didactic process into a doctrine governing the sharing of the knowledge. A decade before Richard Stallman's 1985 manifesto launched the GNU Project (Stallman 2015), and two decades before Eric S. Raymond described the foundations of open source culture (Raymond 2001), Sandin and Phil Morton wrote up what they call a *Distribution Religion*. This proto-license allows for non-commercial copying of the Image Processor hardware, with Sandin elaborating his position as follows:

> **I view my responsibility to the evolution of new consciousness higher than my responsibility to make a profit. I think culture has to learn to use high-tek machines for personal aesthetic, religious, intuitive, comprehensive, exploratory growth. The development of machines like the Image Processor is part of this evolution.**
>
> **(Sandin and Morton 1978)**

Jeffery Schier notes that the IP's success in the educational world was very dependent on this "free dissemination of information", remarking that '[m]ore IP's were built in its time than any other commercial 'video-art' synthesizer" (Vasulka et al. 1992: 135). Sandin's position sets him close to a historical precedent in terms of technological art, where a work's artistic-communicative value does not rely on obscuring the secrets of its operation, nor does its socio-economic value rely on creating scarcity. Working in opposition to both of these market-oriented tendencies, Sandin ensured that the products of his labor would spread like waves through the emerging video art world.

4.0 VECTOR SYNTHESIS IMPLEMENTATION

The primary outcome of the Vector Synthesis project is a library of code for the Pure Data audiovisual environment which allows for a number of different 2D and 3D vector shapes, as well as simplified digital images and video, to be rendered as continuous audio signals sent to analog displays such as oscilloscopes, vector monitors, or ILDA laser projectors. The library has been employed both didactically in tutorials and workshops for students and artists, and in live performances by myself (and presumably by others of the ever-growing community who use this library). This section will describe the technical background and evolution of this library, its implementation in both hardware and software aspects, and detail each of the major sections of its features: two-dimensional objects and Lissajous figures; three-dimensional objects placed in a perspective projection; and scanprocessed or raster-manipulated imagery derived from digital video and image files as well as from live camera input.

While discussing the socially constructed nature of both scientific facts and technical artifacts, Bruno Latour invokes the cybernetic metaphor of the "black box", which "is used whenever a piece of machinery or a set of commands is too complex" and about which nothing more need be known than its inputs and outputs. He goes on to apply this metaphor to aspects of science whose period of "[u]ncertainty, people at work, decisions, competition, [and] controversies" have ended, and which are assumed to be "certain, cold, unproblematic […] ready made science" — black boxes which "cannot and should not be reopened". (Latour uses the example of the double-helix structure of the DNA molecule as an uncontested scientific black box.) Instead, such ready-made science forms a stable platform for the debates and developments of further "science in the making" (Latour 1987: 2-4). Arguably however, a great deal of media archaeological practice — such as Menkman's *The Glitch Moment/um* (2011) or Connolly and Evans' *Cracked Ray Tube* (2014) — concerns itself precisely with reopening,

reverse-engineering, hacking, bending, or breaking such black boxes in order to investigate the kinds of technical and social processes involved in their making.

In this spirit, and in order to understand the development and functions of the Vector Synthesis library, we must peer inside three black boxes to see what makes them tick. Firstly, we must understand how a Cathode Ray Tube monitor functions. Following this, we should make clear the difference between a raster display and a vector display. Ultimately, we will discuss how a Lissajous figure is created on a CRT monitor and the various parameters of frequency and phase which make up its characteristic appearance. Once these basic elements of the technical platform have been covered, we can then move on to detail their implementation in the Vector Synthesis project.

A great deal of effort is spent in this paper describing how one might obtain stable, mathematically 'correct' graphical figures on an analog vector display. However, a perfectly harmonic and stable figure may always not be the goal from the artistic point of view. In the following sections, I will detail how I explored a signal-based, synesthetic approach to audiovisual vector synthesis which embraces unplanned 'imperfections', first through analog synthesizer hardware experimentation, and finally through meticulous software design to arrive at the Vector Synthesis library for Pure Data.

4.1 THE CATHODE RAY TUBE

The first black box we must crack open is the dark vacuum of the Cathode Ray Tube, which formed the basis of most electronic image-viewing devices from the 1930's up until their eventual demise in favor of Liquid Crystal Display monitors in the 2000's. Inside this hollow, glassy chamber, a heated cathode at the rear of the tube emits a stream of negatively charged electrons. These electrons are attracted to a positively charged anode which accelerates them and forms them into a beam aimed at the inside of the viewing screen at the far end of the tube. On the inside of

the glass of the screen lies a thin layer of phosphor, which glows in response to the charge of the electrons. Left to its own devices, this stream of electrons hits the very center of the screen. However, its path can be modified by pairs of electromagnetic (in the case of a television set) or electrostatic (in the case of an oscilloscope) deflectors. These deflectors respond to the polarity and amplitude of an input voltage signal by changing their charge proportionately, which then either attracts or repels the electron beam and bends its trajectory towards different areas of the screen. One set of deflectors, with its corresponding input signal, moves the beam up and down, and a second moves it side to side. Finally, the quantity of electrons streaming off the cathode can be controlled with a third electronic signal, which results in a modulation of the brightness of the beam as seen on the screen. Altogether, these inputs provide us with three axes of control over the beam output: X (horizontal movement); Y (vertical movement); and Z (beam intensity).

Now that we have ascertained the contents of this black box and established its inputs and outputs, let's look at what has been built upon its foundations. Because the CRT can only display a single point at a time, it relies on fast, repetitive motions to fool our perceptual system — and by this I refer to the eye in combination with the cognitive systems discussed by Turim and Nygren (see section 3.3 of this paper) — into seeing images drawn on the screen. How we proceed from here depends on which kind of display system we have chosen: an oscilloscope, a vector monitor, or a raster display.

4.2 LISSAJOUS FIGURES ON THE OSCILLOSCOPE

The simplest CRT display systems are oscilloscopes. Generally, these are technical devices meant to analyze a continuous electronic signal from a device under test, or to visualize the output of an analog computational device. As such, the position of the electron beam in their CRT responds

quite linearly to any voltages sent to their inputs. While often
the horizontal movement of an oscilloscope is normally controlled
by an internal ramp waveform generator whose frequency can be
adjusted to the time-base necessary to view the changes in
amplitude of a signal sent to the vertical input, in a hardware
setting referred to as 'XY mode' both horizontal and vertical
movements of the beam are completely controllable by separate
input signals. In this mode, we can view phenomena known as
Lissajous figures on the screen. These are produced using pairs
of electronic oscillators tuned to specific ratios, with a
different oscillator connected to each of the X and Y inputs.

Lissajous figures are visual representations of harmonic
motion on two axes, whose origins predate the electronics we
use to visualize them now. The first experiments in the 19th
Century utilized the motion of pendulums suspended by two
points (Bowditch 1815) and beams of light reflected by mirrors
on vibrating tuning forks (Lissajous 1857) whose vibrations were
initiated and sustained through the use of either a violin bow or
an electromagnet (Mann 1878). Interest in the aesthetic qualities
of Lissajous figures led to the development of the Harmonograph
drawing machine, which utilized two or more weighted pendulums
moving a pen or brush in relation to a drawing surface to inscribe
Lissajous images on paper (Goold et al 1884). In the post-WWII era,
Ben Laposky's *Oscillon* oscilloscope artworks were Lissajous
figures, as were the drawings produced by Desmond Paul Henry's
hacked bomb-computer device.

Besides their pleasing visual appearance, Lissajous figures
(figure X) can also show us important aspects of the relationship
between two periodic signals; the difference in frequency or
harmonic, and the difference in phase. Before the use of frequency
counters became common, engineers often used Lissajous figures
to tune the frequencies of precise electronic equipment, and
later continued to use them to test for phase problems in the
stereo image of audio signals for broadcasting and vinyl mastering
purposes. Any basic demonstration with the oscilloscope will show
that a 1:1 ratio (i.e. unison) between two oscillating signals
can produce a line, circle, rectangle, or square depending on the
waveforms and phase relationship of the signals being used. A 1:2
ratio (one octave difference) produces a figure with two lobes,

a 1:3 ratio (two octaves difference) produces a figure with three lobes, and so on. If we connect the same signals driving the inputs of the oscilloscope to a pair of loudspeakers, we will be able to both hear these octaves as well as see them. And just as with sound, where frequencies below approximately 25 Hz are perceived as discrete events rather than as a sensation of continuous tone, our perceptual system registers movements of the oscilloscope beam at rates under approximately 20-25 Hz as a traveling dot rather than as a continuous line.

While normally Lissajous patterns are formed from basic waveshapes at common harmonic relationships (fifths at 3:2, fourths at 4:3, thirds at 5:4, etc etc), the basic techniques of electronic sound synthesis become extremely useful in making the figures more complex. For example, shapes with more lobes, curves, or angles can be created through additive synthesis by summing together additional harmonically-related waveforms on each of the two axes. If we follow Fourier's theorem that any periodic waveform can be synthesized through a combination of sinusoidal waveforms, then in principle any sort of shape could be drawn once we have determined the correct harmonic series of sine waves and their relative amplitudes — even ones which do not display the reflectional or rotational symmetry around a central line or point commonly found in Lissajous figures. For example, Jerobeam Fenderson creates the complex and constantly changing Lissajous figures in his *Nuclear Black Noise* video (2013) with an additive synthesis approach involving up to 128 harmonics (Fenderson 2017b).

Additionally, one can produce highly detailed images through methods of amplitude or frequency modulation synthesis well-known from the audio world, using other signals as modulators to the two carrier waveforms creating the figure. For example, amplitude modulation of both the X and Y signals by the same modulator at slower speeds modulates the size of the entire figure, and at faster rates impresses the waveform of the modulator on the perimeter of the carrier waveforms. Frequency modulation of only one of the axes sweeps the Lissajous figure through its range of harmonic relationships, while frequency modulation of both axes by the same modulator has no visible effect whatsoever since the harmonic relationship

between the two axes is preserved no matter how it is transposed up or down in frequency.

The phase relationship between the two signals is equally as important as the harmonic relationship. Changing this phase relationship can expand the image from a flat diagonal line at 0 degrees phase difference to become a full shape at 90 degrees difference (referring again to figure X). Interestingly, our perceptual systems register a continuous modulation of the phase relationship from 0 to 360 degrees as a complete 'rotation' of the figure on its central axis in visual space. However, without any depth cues such as a diminishment in the brightness or size of the simulated rear side of the object, the direction which it appears to be rotating in remains as ambiguous to our brain as the apparent motion in one of Bridget Riley's Op Art paintings. Additionally, an inharmonic signal which is also not coherent in phase — in other words, not *phase-locked* — with the signal at the other axis will cause visible beating (similar in appearance to the phase shift 'rotation') in the Lissajous figure at the same rate in Hz as the beating frequency (f_b) created by the interference between two audio waveforms (f_1 and f_2), if they are sufficiently close to each other:

$$f_b = |f_1 - f_2|$$

There is a caveat that, just as in music when intervals (such as the octaves, fifths, fourths, and thirds previously mentioned) reinforce each other to create a stable sensation of tone, this visual beating becomes invisible at whole number ratios between the two frequencies regardless of their phase relationship. And finally, we should also recognize that an inharmonic signal which is phase-locked with the opposite axis will simply produce a visual deformation of the stable figure without any beating motion. These principles also hold true for any frequencies used in amplitude or frequency modulation as well, i.e. whole number frequency ratios between the modulator and the carrier will produce fixed figures, as will modulators which are phase-locked with the carrier.

Knowing all these facts, which easily can be observed through simple experiments, we can now state that stable Lissajous patterns are formed by pairs of harmonic and/or phase-locked signals, and that simple animation in the time domain can be introduced to the figure by two different methods. Either one can modulate the phase of one of the signals, which will create motion at the rate of the phase modulation; or one can introduce a signal with no clear harmonic or phase relationship between it and the opposite axis, which will create motion at a rate which is the absolute difference in Hz between the two signals. This information goes a long way towards explaining why most recorded music, when sent to the X and Y inputs of the oscilloscope, fails to resolve into any kind of stable image whatsoever! It simply contains far too many different, and constantly changing, harmonic and phase relationships. In practice, stable Lissajous images on the oscilloscope are created by waveform pairs specifically synthesized for this purpose, and these pairs are often phase-locked when one desires the most control over the figure's appearance.

4.3 VECTOR MONITORS AND RASTER DISPLAYS

Many of the first technical and scientific CRT displays — such as those of the SAGE defense system we met in the beginning of this paper and other early digital computers, as well as early flight simulators and video games consoles like the Vectrex — use a so-called 'random scan' vector graphics system (figure XIa). In such a vector-based system, movement of the beam is free and arbitrary within a Cartesian coordinate system. Like an oscilloscope, the beam's movements are directly controlled by voltages sent to its X and Y inputs, and drawing a fixed image involves directing the beam in a straight line at a given speed between two points on the screen. A series of such lines, each defined by their starting and ending

points on the Cartesian grid, make up a complete image (Vector General Inc. 1972: 1.6).

In contrast to Lissajous figures drawn on the oscilloscope by two independent signals whose continuous motion creates the illusion of image, computer vector graphics tend to be calculated and executed as discrete units. As we know from motion picture film, the same discrete image viewed at least 24 times per second can result in the visual sensation of a clear, flicker-free image. Each repetition can be referred to as a frame, and the number of frames per second is called the frame rate. In a vector graphics system, the computer sends continuous analog voltage signals, which make up the vertical and horizontal movements necessary to draw all the lines representing the image in the frame (figure XIb), to the X and Y inputs of the CRT. These signals are repeated as long as necessary at the given frame rate until the image in the frame changes and a new set of signals is calculated. Portions of an image can be made to appear further away from the screen by decreasing the brightness of the beam exponentially in proportion to the simulated distance (Vector General Inc. 1972: 1.14) through control of the CRT's Z (intensity) axis. And finally, for portions of the lines which are not meant to be seen at all — for example a path the beam follows between two independent shapes in an image, or when the beam reaches the last point of an image and 'flies back' to its first point — the beam intensity is shut off, or blanked.

Compared with the relative freedom of movement found in a vector graphics monitor, a raster display is rigidly locked in its format. In other words, the frequency of the horizontal and vertical movements of the electron beam are defined by the video standard used to display images, and the content of the electronic signal (in the case of composite video, broadcast television, etc) or signals (in the case of VGA or other multi-signal formats) simply contains the level of intensity of the monochromatic beam, or RGB levels of a color monitor or television, at any given point in the frame along with information necessary to sync the internal ramp generators of the CRT with the video signal. The PAL video standard used in Europe and much of Asia describes a vertical rate of 50 Hz (or 25 alternating frames per second) and a

horizontal rate of 15.625 kHz (or 625 lines per frame), while the NTSC format used in North America and Canada calls for a vertical rate of 59.94 Hz (or 29.97 alternating frames per second) and a horizontal rate of 15.734 kHz (or 525 lines per frame). Understanding these frequencies and the harmonics of them are essential to the processes of both analog video synthesis and raster manipulation or scan processing, each of which proposed to 'unglue' television in a unique way during the era of Cathode Ray Tube imagery.

4.4 ANALOG HARDWARE EXPERIMENTS

My own, early oscillographic explorations simply involved plugging analog synthesizer signals into various types of CRT oscilloscopes to get an idea of what might happen. Eventually, I obtained two different vector monitors for my experiments. One was a Panasonic VP 3830 designed for displaying technical measurements in a laboratory, and the other a Vectrex video game console from approximately 1983, which I modified by disconnecting the internal game computer and adding jack inputs connected to the CRT driver board to accept external audio signals (Duff 2014). Each has three main control inputs to control its light beam: the horizontal axis, the vertical axis and the z-axis (an adjustment of the brightness of the beam). A self-made DC (direct current) voltage mixer allowed me to combine up to four analogue signals to each of the monitor's inputs, control the individual and overall levels of those signals, and add an offset voltage if necessary to move the entire image up and down, or left and right.

The X and Y inputs of the Vectrex respond to a bipolar voltage of approximately 5V peak-to-peak (+2.5V to -2.5V), where greater voltages are not necessarily harmful but can send the image off the bounds of the screen, while the Z input responds to a unipolar voltage range of approximately 0 to +2.5V, depending on the bias added by the manual brightness

control knob on the back of the monitor. When working with Vectrex game consoles, one must take into account the limitations of the driver circuits and electromagnetic coils used to move the beam. While the bandwidth of most vintage CRT oscilloscopes was factored in increments of 1, 10, or 100 MHz, modern digital oscilloscopes are designed for high speed signals which often go into the GHz range. In contrast, a simple circle rendered on the screen of a Vectrex at a frequency of a few kHz already shows signs of distortion, gradually flattening the edges as the frequency increases to end up as a somewhat round-corned diamond shape.

The illusion of shape — a circle, for example — in a vector-based monitor depends on the light beam moving in both the X and Y axis at a rate faster than our perceptual systems of eye and brain can make out individual events. This is aided by the luminescence of the phosphorescent coating inside the CRT, which continues to emit light for a short time even after the light beam has moved from that exact location on the screen. This image persistence can also be adjusted manually on many oscilloscopes and other vector monitors by increasing or decreasing the beam strength. Depending on the beam strength and residual luminescence of the CRT, frequencies as low as 15-20 Hz can produce a continuous, nearly flicker-free image. However, when dealing with low drawing frequencies one must always keep in mind the so-called 'spot killer' built into the Vectrex's brightness control circuitry. This is a safety mechanism which prevents the light beam from resting too long on one location in the phosphorescent lining inside the screen the CRT and thus burning a hole in it and destroying its luminescence in that particular spot. It is implemented by transistor number Q503, as designated in the Vectrex service manual (General Consumer Electronics 1982: 29) (figure XIII). The detection circuitry located just before this transistor follows the overall amplitude of the vertical deflection of the beam. If this amplitude falls below a certain threshold for a specific amount of time, the detection circuit instructs Q503 to open the connection between its collector and emitter pins. The simplest solution to this issue is simply to short Q503's emitter and collector pins together (Konopaska and Kopp 2018) as illustrated in figure XIV, however a switch rated for at least 110V in this position would be more beneficial and could both allow game play on the device (the Vectrex game programmers appear to

have relied extensively on the 'spot killer' for blanking purposes) and help prevent unintentional screen burns.

The main source of the signals I used was an analog synthesizer known as the Benjolin (figure XII), a standalone device designed by artist and instrument builder Rob Hordijk from the Netherlands. It contains two voltage-controlled oscillators, a voltage-controlled filter, and a chaotic, stepped-voltage generator called a Rungler, which allows cross-modulation possibilities between the different parts of the instrument. Hordijk refers to the Benjolin as a circuit which has been "bent by design" (Hordijk 2009a). I have been working with this instrument for several years now, both performing with it regularly as well as building expanded and customized versions of it for myself and other artists. Using three such Benjolin circuits in combination with the DC mixer, I was able to create on the monitors basic Lissajous shapes made from different waveforms, modulate the frequencies and amplitudes of those wave shapes, and in a fairly haphazard way derive more complicated shapes from a combination of waveforms sent to each axis and to the brightness control. I performed live several times during the first half-year of the project using this setup, and each performance was a constant struggle to re-discover the settings on the synthesizer necessary to produce shapes which I had seen earlier in my studio, or even during the soundcheck the same day.

4.5 OVERVIEW OF EXISTING SOLUTIONS

During the development of this project, I quickly realized that in order to obtain more precise, controllable, and reproducible results, I would need to investigate more sophisticated means of generating the figures. A survey of the field, conducted largely among the members of the Video Circuits, LZX Video Synth, and Vector Synthesis communities on Facebook, revealed a continuum of approaches towards

audiovisual oscilloscope vector graphics (Holzer 2018). Naturally, there exists a substantial overlap between all of the groups described, as well as a number of different, hybrid analog/digital synthesis approaches, as well as methods which rescan vector graphics from the CRT and process them further through an analog or digital video signal path. The overall bias of the first two groups is towards analog video synthesis, which explains a preference for hardware which might not be found in more software-oriented communities.

The largest majority of those surveyed are using hardware EuroRack audio synthesizer modules, varying in levels of complexity from simple voltage controlled oscillators (such as the ones in my Benjolin circuits) to more specialized collections of modules with phase, amplitude, and waveform control parameters, for example. Both Andrew Duff and Benton C. Bainbridge are stand-out examples in this category. Duff has become quite renown in the video synthesis community for both his complex, hardware-only, audiovisual Vectrex performances (Duff 2017) and his widely-shared tutorial on how to modify the Vectrex game console for external signal inputs (2014). Bainbridge also enjoys a reputation for pushing the medium of the Vectrex to new limits using analog hardware for gallery installations with his *Lisa Joy* project (Bainbridge 2016), and recently for performing audioreactive vector graphics in combination with throat-singing and musical saw played by improvisational musician Gryphon Rue as the duo Rue Bainbridge (2019).

The second largest group uses EuroRack or similar hardware modules designed for the higher bandwidth and specific signal processing needs of video synthesis, such as those manufactured by the LZX company, or of their own construction. The Rutt/Etra Video Synthesizer holds a special place of admiration within this scene, and many artists here have made attempts to replicate the hardware functionality of this rare device by reinterpreting its circuitry. Notably, the Rutt-Cadetra project by Ethan Hoerr (aka Ernav K) aims to reproduce the basic building blocks of the Rutt/Etra (see figure VIII) using the inexpensive Cadet series of DIY modules by LZX (Hoerr 2017, 2018). Video artists and instrument builders Philip Baljeu and Jonas Bers have both embarked on their own Rutt/Etra-influenced scan processing systems in recent

years as well, using them to produce remarkable and almost sculptural transformations of architectural photography (Baljeu 2017) and stunning, scan-processed tributes to Bill Etra himself (Bers 2017). Software versions of the Rutt/Etra also exist, such as Felix Turner's browser-based Rutt/Etra-Izer (Turner 2011) coded in JavaScript, or the v002 Rutt/Etra 2.0.1 Quartz Composer plugin by Bill Etra and Anton Marini (aka Vade) (Etra & Marini 2008). However, as both of these aim to emulate (and expand into color) the visual effects of the original hardware device using pixels on a computer screen rather than analog vector signals sent to CRT monitors, they did not factor strongly into my own research.

A third grouping uses the digital audio synthesis tools available in softwares such as Max/MSP, Pure Data, VCV Rack, Propellerhead Reason, Native Instruments Reaktor, Ableton Live, Max For Live, Touch Designer, and other free or commercial packages for their own video recordings and performances. While there is a wealth of oscilloscope-type digital imagery to be found online, again I focused only on those projects which created analog XY signal output sent to an analog visualization device. Two of the most influential artists for me in this area are Robin Fox and Robert Henke. Fox's *Backscatter* DVD (2004) catalogs ten phenomenal approaches to oscillographic audiovisual composition, employing the wealth of digital synthesis techniques found in the MaxMSP platform. Fox went on to apply the same Lissajous-type techniques to a monochromatic green laser projector in 2007, and starting in 2013 he expanded to include two other lasers in red and blue before developing the *Single Origin* performance in 2018. "At times", Fox writes, "sound is converted directly into light geometry and at others the image itself is sonified so you hear the mechanics of the light drawing." In every instance, "[s]ound and light are synchronous" (Fox 2014).

Likewise, Henke has moved from his early involvement in the development of the Ableton Live software, and in the production of minimal electronic dance music as half of Monolake, to becoming one of the most innovative, large scale laser performers and installation artists working today. Henke's first *Lumière* laser performances in 2013 grew out of an earlier

generative audiovisual laser installation titled *Fragile Territories*, developed in 2011. His signature approach relies on avoiding commercial laser show softwares with their built-in scenes and transitions, and instead synthesizing his laser figures directly using Ableton and other audio applications. Over the evolution of *Lumière*, Henke gradually abandoned the principle of a unified analog signal for both image and sound, opting instead for a counterpoint sonic layer "running in parallel with the lasers" (Henke 2017).

Finally, the most fertile territory was found among the programmers who are coding and publishing oscillographic libraries for such platforms as Pure Data, Max/MSP, or Processing; are using environments such as Open Frameworks to develop end-user applications; or are writing oscillographic firmware for embedded DSP platforms such as the Axoloti or Bela boards. An overview of these libraries and applications can be found in figure XV. The interest in and openness towards communicating and collaborating among this group pushed my own programming in exciting new directions, and I remain grateful to all of them for this inspiration and assistance. Perhaps the artist who has strived hardest to popularize what he calls "oscilloscope music" in recent years works in Austria under the pseudonym Jerobeam Fenderson. Fenderson began coding his audiovisual oscilloscope works in Pure Data, releasing his *Nuclear Black Noise* video in 2013 and a quirky tutorial on *How To Draw Mushrooms On An Oscilloscope With Sound* in 2014, both of which attracted considerable attention on the internet. Fenderson's compositions employ a 'what you hear is what you see' approach, using only the left and right stereo audio channels to create demo-scene and retro-gaming influenced images on the CRT screen.

While Fenderson released a series of Pure Data and Max For Live patches corresponding to effects used on his *Oscilloscope Music* audiovisual album (2016), the most elaborate application for this type of medium is OsciStudio, written by Fenderson's close collaborator Hansi Raber. Based on OpenFrameworks, and released in 2016, OsciStudio provides a rather traditional media-software user interface of channels for individual shapes followed by plugins for basic transformations (frequency, scaling, translation, rotation, etc) and a parameter automation timeline. This simple

skin conceals far more powerful features however, such as
the ability to import 2D SVG and 3D OBJ files (discussed
further in section 4.8), a realtime link with the Blender 3D
modeling software, and a versatile livecoding environment which
was newly implemented in late 2018. Raber is also responsible
for the only digital display software I have taken seriously
in this survey. His Oscilloscope application, also written
in OpenFrameworks, was first released in 2015 as a means of
playing back Jerobeam's Oscilloscope Music tracks without a
hardware oscilloscope, as well as accepting audio inputs from
other applications via the OSX utility SoundFlower. It provides
the best-looking and most fluid emulation of a hardware CRT
that I have found so far, and has become a vital part of my
Vector Synthesis workshops by allowing participants to preview
their work before connecting to an analog display.

The video synthesis community's love affair with the Rutt/
Etra Video Synthesizer took another turn with the release of
Ivan Marušić Klif's REWereHere in early 2017. Unlike previous
Rutt/Etra emulators, which displayed digital simulations of what
might occur within a CRT display, Klif's software "takes video
from any connected live video source or movie and displays
low resolution Rutt/Etra style video on an analog oscilloscope
using almost any external soundcard" (Klif 2017). It's signal-
based, modular workflow remains true to the spirit of the
original hardware device, as in both processes the video
frames are quickly broken down into a trio of component signals
(horizontal ramp, vertical ramp, and brightness) which can
then be manipulated through a number of basic summing and
multiplying signal operators in combination with external
modulation sources such as waveform oscillators. In addition,
since the horizontal and vertical ramps no longer need to
be derived from an analog video signal, arbitrary waveforms
and framerates can be used to access the pixel brightness
information in any manner desired. This feature is essential
for working with the limited bandwidth of audio interfaces
and of some CRT displays such as the Vectrex console. Klif's
approach differs from mine in the sense that he presents a
finished application with a fixed interface full of MIDI-enabled
knobs to turn, but because the level of the patch is available
below the user interface, my study of how this process was

realized using Jitter led directly to my first attempts at reproducing Klif's research in Pure Data through its own graphical external library, Gem (discussed in section 4.9).

Ted Davis takes an entirely different approach to converting digital graphics into analog signals with his XYScope library for Processing (2017). XYScope is able to convert primitive shapes such as points, lines, rectangles, and ellipses into wavetables and play them as audio signals through the soundcard utilizing the Minim library written by Damien Di Fede and Anderson Mills (2013). The power of Davis' approach is that any sort of native function or external library of the Processing language can be used to generate these shapes, opening the way for such computer vision techniques such as outline recognition, blob tracking, or Kinect data — or for generative geometric, mesh, and typographical shapes — to be visualized as signals on the CRT or laser display, without need for the user coding these features themselves. Davis has showcased the flexibility of XYScope through presentations by his students at the Basel School of Design's Institute of Visual Communication, where they combine digital projection graphics with ILDA laser imagery during his Laser Letters workshops (Davis 2018b).

For me, one of the most exciting developments of recent years is the ability to compile Pure Data patches into firmware for embedded DSP platforms like the Bela board (https://bela.io), and I foresee future Vector Synthesis projects taking advantage of these new hardware opportunities. At the beginning of my explorations, I came across the work of another artist named Roland Lioni (aka akirasrebirth), who was creating audiovisual Vectrex art on a different DSP board from Belgium called the Axoloti (http://www.axoloti.com/). Lioni's work often involves three- and four-dimensional vector forms rotated and projected into two-dimensional space (Lioni 2018), and it was through him that I became aware of the possibilities to work with Wavefront OBJ files converted to wavetables by OsciStudio, but outside the confines of that particular software. He also shared with me the block diagram upon which I based my first 3D rotation matrix, and which paved the way for a whole series of experiments detailed in section 4.8 of this paper.

In giving these specific examples, my intention is not to exhaustively catalog every artist or approach within each category (an impossible task, where the map would grow to the size of the territory!), but to pinpoint those people whose work helped give my own efforts shape and direction, and of whom many became collaborators with me over the duration of the project. The fact that many of the software approaches in this section (OsciStudio, REWereHere, XYScope, and the Axoloti patches) were being developed or updated concurrently with my own Vector Synthesis Pure Data library provided many opportunities for discussion and cross-pollination which benefited everyone working in the community.

DIGITAL HARDWARE ISSUES

4.6

There is a small number of digital audio concepts which also must be 'unpacked' from their black boxes in respect to oscilloscope graphics for our consideration, and these are DC coupling, sampling rate, and digital aliasing. DC coupling refers to the ability of an audio interface to pass analog signals below the audible threshold of 20 Hz all the way down to unchanging voltage offset levels at zero Herz. Normally, DC offset in an audio signal is not beneficial, since it can reduce the overall dynamic range of the signal and lead to clipping. However, DC offset is necessary for oscilloscope graphics for three important reasons. The first is that, when trying to draw a vector shape through a normal audio interface, the AC coupling causes the image to "wander around on the screen" (Fenderson 2017a) since the capacitors in the signal path will always try to center the signal symmetrically around the 0dB line, and as a result the drawn figure will always seek to be symmetrical around the center of the CRT screen (i.e. 0dB on both the horizontal and vertical axis). The second is that, if we wish to translate our vector shape away from the center of the screen, we must sum a DC voltage with the AC drawing signal on the desired axis to get the offset necessary to move the shape across the screen. The third reason

is that normally the signal sent to the Z axis of the oscilloscope or Vectrex, which controls the brightness of the beam, remains at an unchanging DC level unless the beam is being blanked due to a transition from one location on the screen to another. Two exceptions to this would be in scan processing, where the level of the brightness is constantly being changed by information acquired from the source image, and in simulating the depth cues of three-dimensional figures, where the 'deeper' portions of the shape are displayed at proportionately less intensity according to their distance from the viewer.

Sampling rate is of course a more familiar parameter of digital audio, however its relevance to analog vector graphics may be far less so. Simply put, where the sampling rate limits the highest sinusoidal frequency which can be reproduced by a digital audio system, the number of samples used to construct a vector shape can limit its visual resolution as well. Essentially, as Fenderson explains in one of his video tutorials, "the more points there are, the higher the resolution and the clearer the quality". Lower sampling rates, such as the standard 44.1 kHz found in most sound cards, can limit both the frequency at which a figure can be drawn on the screen, and the complexity of that form. Square waves and sharp changes in the waveform are particularly problematic to reproduce without obvious digital aliasing artifacts in the form of overshoots and ripples at the corners. These artifacts are caused by the ambiguity of trying to reproduce a frequency above the Nyquist limit of half the sampling rate, and can be avoided by using the highest sampling rate available (Fenderson 2017a). A final frequency-related limitation is of the display hardware itself, however. While any analog oscilloscope has bandwidth in the MHz range, which is tens or hundreds of times higher than what is necessary to reproduce signals from a computer sound card, vector monitors designed to analyze audio signals and vector game computers such as the Vectrex do not enjoy such headroom in their bandwidths, and high frequency signals sent through the driver circuits and deflection coils of these CRTs result in a visual image which is distorted or 'folded over' in appearance. The frequency limitations of ILDA laser displays will be discussed further in section 4.13.

I quickly settled on the MOTU Ultralight Mk 3 audio interface

for my setup. Featuring ten DC coupled output channels, and capable of running at a 192 kHz sampling rate, the MOTU's balanced outputs are also immediately compatible with the differential inputs of any ILDA laser display. My latest live performances and studio setups have involved two Benjolin circuits, a MacBook pro laptop running Pure Data, the MOTU interface set to a 192 kHz sampling rate, several MIDI controllers, and the Vectrex vector monitor. Once I have created the core vector shape with patches from the Vector Synthesis library, I then go on to modulate it with the more intuitive and immediate interface of the synthesizers with the aim of destabilizing and 'glitching' the controlled digital figures with rough analog signals. The combined signals of the Pure Data vectors and the Benjolins are sent to the Vectrex, and are also heard through the loudspeakers. In this way, a very direct relationship between image and sound is preserved.

Another form of artifact occurs when trying to capture the display of audiovisual vector graphics from a CRT. Digital recording and projection has so far been the most frustrating element. At no point do the analog signals being sent to the display resemble anything like a valid video signal, and the process of capturing the effects of these signals on the monitor, rasterizing them, and turning that into a valid video signal has historically been called 'rescanning'. In my own experience, it has been impossible to perfectly reproduce the depth, movement, and details I see on the screen with any camera available to me. Very precise control of the focus and exposure are essential towards capturing the phenomena on the CRT and avoiding the most obvious artifacts of digital video, such as rolling bars across the screen or large areas of the image being lost.

While in the studio, I sometimes employ a DSLR camera with a large aperture lens for rescanning the vector images; but for live performances and when traveling I follow the adage that the best camera for the job is the one you have with you, and connect my iPhone camera directly to the venue's projector via a Lightning port to HDMI adapter. The FiLMiC Pro app gives me all necessary control over the iPhone camera, which the

built in Apple camera software lacks. However, as the iPhone camera has a fixed aperture lens, only the ISO can be used to adjust the exposure. Shooting the Vectrex monitor with FiLMiC Pro set at 25 fps, with a fixed focus and an ISO of between 50-100, allows the fluidity of the beam with its subtle variations in intensity to show through, rather then having the overexposed and 'burnt out' looking, high contrast line which one obtains with a higher exposure setting. The bottleneck of rescanning with the camera, and the unknown factors of different types of projectors in every venue I play, pushed me towards the exploration of ILDA laser displays for live performance covered later in section 4.13.

4.7 2D OBJECTS AND TRANSFORMATIONS

The initial challenge in developing a system of precise oscillographic tools is finding a method of establishing and controlling the phase relationship between the signals on the X and the Y axis. Luckily, this issue is handled gracefully by the [wrap~] object (by convention, Pd programmers enclose the names of objects in square brackets when writing about them). The [wrap~] object accepts a unipolar audio signal with a value between 0 and 1 at it's input, and outputs a modulo operation (i.e. the remainder of a division by one) result of that signal if it's value exceeds 1. The output of the sawtooth generator [phasor~] object presents just such a unipolar waveform, and through multiplying it by a whole number using the [*~] object and sending the result through [wrap~], one can obtain a phase-locked sawtooth wave at a harmonic of the original corresponding to the value of the multiplication factor (i.e. one octave above for a multiplication of two, two octaves above for a multiplication of three, etc). Also, adding an offset to the sawtooth wave before sending it to the [wrap~] results in a phase shift, for example the shift of 90 degrees necessary to draw a circle using sine and cosine waves. The phase-locked, phase-shifted, and harmonically multiplied sawtooth waves can now be used to read the wavetable of any other shape required for drawing two- or threedimensional oscilloscope graphics, such as the cosine wave of the [cos~]

object or an arbitrary waveform stored in a data array using the [tabread~] object (figure XVI). The first steps of the Vector Synthesis library were then to create a series of abstractions for drawing circles, triangles, squares, and Lissajous figures of varying harmonic and phase relationship. A great deal of this work was undertaken during a residency at Cirkulacija2 in Ljubljana, Slovenia during the summer of 2017.

At the two-dimensional level, many basic transformations became possible with just a few simple Pd objects. Scaling in one or both dimensions can be accomplished with multiplication objects; translation along either the X or Y axis requires only a summing object; simulated translation along the Z axis is realized simply by scaling both the X and Y at the same ratio; and continuous, symmetrical rotation along a central line can be done through applying a ramp waveform to the phase modulation section of any figure. Of note is the fact that scaling a figure larger does not result in any loss of resolution or jagged lines, as one would find in a rasterized video for example, due to the mathematical vectors which make up the image. An n-sided polygon can be synthesized from a circle made of sine and cosine waves by sampling and holding a number of points around its circumference at an exact harmonic rate of the drawing speed (where a harmonic ratio of 1:1 makes a single point, 1:2 makes a line, 1:3 a triangle, 1:4 a square, etc.), with a corresponding increase in harmonics heard with each added point [https://vimeo.com/270966625].

Combining multiple vector shapes has a number of methods and outcomes. One figure can be translated along a path on the screen determined by another figure (a circle, line, triangle, square, etc.) by summing the X and Y signals of the higher frequency first figure with the X and Y signals of the slowly- drawn second figure, where scaling the second figure to determine the distance the first figure travels and the frequency of the second figure determines the speed at which the first moves. Summing two higher frequency shapes yields complex figures with periodic changes in shape equal to the difference in Hz between the nearest whole harmonic relationship. On the other hand, multiplying one vector shape

by another, or by an external audio signal such as a voice or instrument, impresses the harmonics of one on the size of the other and results in a sonic effect much like ring modulation. Since combining the X and Y signals of two different shapes results in the sum of both shapes (in the same way that summing two audio signals provides a mixed waveform of the two), a more complex series of patches is required to multiplex two or more independent figures on the screen. The [vs-multiplex] series of patches assigns different channels to each figure to be rendered, switches their rendering on and off sequentially, and blanks the oscilloscope beam's transitions between the figures if required.

   With these digital foundations in place, my next step was to test them by programming an oscillographic instrument whose structure was already well documented: the Syntheshape by Mitchell Waite (figure XVII). The Syntheshape is a simple analog circuit involving four variable-waveform, phase-synchronized function generators (FG 1-4), three rudimentary phase shifters (PS 1-3), two four-quadrant multipliers (MULT 1-2), and two summing amplifiers (ADD 1-2), designed to produce two-dimensional graphic art on the oscilloscope. According to the original author, various settings of these basic synthesizer building blocks can be used to control aspects of the motion, scale, rotation, "tilt", "flatness", and "angular velocity" of the image; the degree of linearity, curvature, or "sectionality" of the lines; the "convolution" and "component" of its surfaces; and the "skewness", "squareness", "ballooning", and number of its lobes (Waite 1974: 12). During my Toolmaker Residency at Signal Culture in Owego, New York during October 2015, I tried unsuccessfully to hand-build one of these circuits. Now, the rapid prototyping possibilities of Pure Data made the virtual construction of the same circuit much easier. Later on in the project's development, I added other functionality including a depth axis to be used with the 3D rotators discussed in section 4.8, the ability to inject external audio signals into the shapes [https://vimeo.com/296575643], and phase-triggered blanking so that only a portion of the entire shape is visible at once [https://vimeo.com/295220480].

4.8   3D OBJECTS AND TRANSFORMATIONS

Once I had established a system for dealing with two-dimensional objects, my focus then turned to three- (or more-) dimensional figures. While there are certainly mathematical ways of synthesizing the waveforms required to display 3D figures such as cubes, spheres, hourglasses, parabolic cylinders, etc, as well as hyper-dimensional images such as the hypercube or tesseract (Optical Electronics Inc 1975: 6-9) on the oscilloscope, the ability to work with any sort of three-dimensional figure generated by common modeling software seemed much more versatile. Roland Lioni had explained to me that Hansi Raber's OsciStudio is capable of importing Wavefront OBJ files, and that it accomplishes this task through a simplified version of the route inspection problem, which seeks to find the shortest possible, most complete, and least redundant closed-loop path (Roberts and Tesman 2009: 640-642) through the polygons making up the 3D form. The lines and vertices making up this path are saved by OsciStudio within the XML of the project file, and can be easily extracted using either a spreadsheet or simple Python script (included in the Vector Synthesis repository on GitHub) to separate the points necessary to draw the figure into three individual TXT files (one for each axis), suitable for loading into data arrays in Pure Data, the Axoloti environment, or any other digital audio platform. Raber greatly simplified this process with a recent update in October 2018, which allowed OsciStudio users to export a three channel audio WAV file representing the current vector shape, along with any transformations currently active, directly from the application.

Armed with this information, I added a number of 3D shapes to the library, including all the Platonic solids (tetrahedron, cube, octahedron, dodecahedron, and icosahedron) and a polygonal sphere, with the most complex model being a hand made up of 18,748 individual points, which serves as a speed test for any audio interface or analog display to render [https://vimeo.com/270419481]. Rotation on three axes

is accomplished with three simple and standard 2D rotator abstractions, where *x'* and *y'* are the new X and Y coordinates, and *f* is the angle of rotation:

$$x' = x\cos f - y\sin f$$

$$y' = x\sin f + y\cos f$$

(Optical Electronics Inc 1975: 11)

whose chained arrangement in the [vs-rotate] abstraction allows rotation first on the Z, then the Y, and finally the X axis as shown in (figure XVIII). A DC offset added to any of the axis signals before entering the rotation matrix translates the center of rotation away from the center of the object, allowing wide orbits around a point in space.

   A simple isometric projection of the rotated 3D figure can be obtained by discarding one of the three audio channels representing each axis, and sending the remaining two channels to the X and Y inputs of the CRT respectively. More sophisticated results can be obtained by employing that most media-archaeological of all visual technologies, Renaissance-era perspective projection. My [vs-projector] abstraction provides a 3D perspective transformation according to the following equation, where *A* is the viewing distance, *Sx* is the viewing angle on the X axis, and *Sy* is the viewing angle on the Y axis:

$$Xout = (\frac{X - Sx}{Z/A}) + Sx$$

$$Yout = (\frac{Y - Sy}{Z/A}) + Sy$$

(Tilton 1987: 59-61)

An example using this abstraction to place the 3D hand model in perspective with lighting can be seen here [https://vimeo.com/270786056]. The X axis viewing angle parameter (or horizontal parallax) suggests interesting stereoscopic viewing possibilities involving the multiplexing of two instances of the same figure at slightly different viewing angles, combined with the RGB color possibilities of ILDA laser projectors.

The final gesture towards realism comes in the form of brightness attenuation for the simulated depth cues of 3D figures which become less luminous the further they are from the viewer. Here, *i* stands for light intensity, *D* stands for the distance from the viewing point, and *Dmax* represents the maximum distance to be calculated, which can be used to set the point at which shadows start to appear in the figure:

$$i(D) = \frac{Dmax - D}{Dmax}$$

(Dunn and Parberry 2002: 367)

All of these perspective and distance transformations are exceptionally primitive in comparison with those required for the photorealistic simulations found in Hollywood CGI movies or advanced Virtual Reality worlds, and extreme numbers thrown at their different parameters result in gross distortions of the concept of verisimilitude. I should remind the reader that each of these linear transformations is taking place at the DSP level, meaning that every sample of every waveform making up each of the X, Y, and Z axes is being run through each of these calculations at the given sample rate (192 kHz in my usual setup), making it an extremely precise method of calculating graphics for an analog vector display. Thus, while these mathematical processes have an obvious visual result, the effects of the transformations can also be perceived in the audio domain. Three-dimensional rotation in particular has a very distinct sonic character, much like stereophonic

panning between the left and right channel as vector information crosses between X and Y signal axes.

SCAN PROCESSING

4.9

I introduced scan processing — otherwise referred to as raster manipulation when discussing machines such as the Rutt/Etra, Wobbulator, or Scanimate video processing systems (Hocking 2014: 455-460) — in section 3.3 as the epitome of signal based imagery. What most of these machines have in common is the ability to break a composite video signal down into three constituent elements: a vertical ramp waveform whose frequency is set by the frame rate (25 or 29.97 fps); a horizontal ramp waveform synchronized to the vertical ramp, and operating at a harmonic of the vertical ramp corresponding to the number of lines in each frame (525 or 625 typically); and a third signal which represents the luminosity of the beam at any given point in the video raster (see figure VIII). These signals are sent to an oscilloscope or vector monitor, which results in a resynthesis of the original video signal on the CRT. Because the raster no longer needs to conform to the video signal standard, other signals can be summed with the horizontal and vertical ramps to deform the shape of the raster. One defining technique known as vertical deflection (seen in every emulation of the Rutt/Etra to date, and referred to in section 3.3 as the "Vasulka effect") is to apply the luminosity signal not only to the brightness of the beam, but also to the vertical waveform. This causes a perceptual illusion of the brighter parts of the image being raised in three-dimensional space, and imparts a 3D depth effect on twodimensional video images similar in appearance to contemporary Kinect video (figure XIX). Summing in other harmonic or beating frequency signals with the horizontal or vertical ramps can result in beautiful rippling and twisting deformations of the video image [https://vimeo.com/268395033].

The approach Ivan Marušić Klif took, and whose lead I followed, was not to try and simulate the look of these manipulated raster lines and the CRT display digitally on the computer screen,

but rather to take a signal based approach in recreating the waveforms necessary to display this effect once again on an actual CRT. While the original Rutt/Etra derived the horizontal and vertical ramps from the timing of the analog video signal itself, no such constraint exists when analyzing video in the digital domain. This means that a raster of an arbitrary framerate and number of scan lines, a grid of alternating horizontal and vertical scan lines, or even a non-raster figure such as a spiral, can be used to address information within a digital framebuffer (a piece of computer memory dedicated to the storage of the pixel information which makes up an image). These paired audio signals representing a horizontal and vertical location can then retrieve the luminosity information of whatever pixel lies at the given XY coordinate requested. Where Klif uses a collection Max/MSP/Jitter objects for the frame buffer and pixel-scanning, I implemented the same process using the [pix_data] object from the Gem external library. This object retrieves luminance and RGB values of individual pixels by addressing their X/Y coordinates. An additional modification to the original concept is the summing of the luminance signal with the actual depth Z axis of the figure, instead of simply the vertical Y axis (figure XX). In combination with the [vs-rotate] and [vs-projector] abstractions described in section 4.8, this transforms a 2D video or still image into a 3D visual wave terrain which can be navigated using audio signals and DC offsets [https://vimeo.com/276126676]. Of course, the most exciting use of this system is with a live camera input, as this brings the elements of interaction and feedback into the situation, and realizes Hank Rudolf's notion of "the placement of our body in a real-time environment" as discussed in section 3.4 in relation to synesthesia, and calls to mind the succession of Rutt/Etra 'selfies' created by the Vasulkas over their years of working with the device.

The implications of this framebuffer approach are not only that alternative rasters and shapes or 3D perspective can be used, but also that the information required to display video no longer requires 6.75 MHz of bandwidth – which is approximately 70 times higherthan that of a 192 kHz sampling rate audio interface, and over 300 times that of a standard

44.1 kHz interface. By reducing the complexity of the video signal, it can be displayed in a limited resolution (i.e. fewer frames per second and lines per frame) using devices of much more limited bandwidth, such as computer sound cards; vintage solid state and vacuum tube 1-5 MHz analog oscilloscopes; Vectrex game consoles; and even ILDA laser displays. Another historical antecedent for this bandwidth-reduction concept would be Gebhard Sengmuller's Vinyl Video project, a "relic of fake media archeology" designed to present low resolution video material on a television set through the interface of a vinyl record played on a normal audio turntable (Sengmuller 2000), which is itself a sort of reenactment of the Phonovision system, a 4 fps/30 lines per frame system of phonographic video recording invented by John Logie Baird in 1927 (McLean 2000). One idea for the future would be to create a hardware-based, addressable framebuffer solution which could work in combination with, for example, EuroRack format LZX video synthesizer modules.

4.10 PUBLIC ACTIVITIES

Over the past two years, intensive development of the Vector Synthesis Project took place at Aalto University in Helsinki, and in residencies at Cirkulacija2 in Ljubljana during 2017 (mentioned in section 4.7); at the Electronic Studio of Radio Belgrade in 2018 (discussed in section 4.11); and finally at the University of California in Santa Barbara in early 2019. During this time, I have strived to maintain a balance between the didactic and performative aspects of the project. Vector Synthesis has been performed more than twenty times in over a dozen different countries. I have held eight workshops in locations ranging from art universities to artist-run initiatives, and presented several lectures on the media archaeology of vector art and related issues — including a lecture on scan processing at the Pori Art Museum in Finland for the exhibition *Steina & Woody Vasulka: Art of Memory, Works from 1969 to 2000*. I have also given two keynote presentations based on my research for this project at conferences, the first being at Seeing Sound at Bath Spa University in the UK in spring 2018, and the second being at Vector Hack in

Croatia in autumn 2018, a conference which I co-organized as
discussed in section 4.12.

From the very beginning of the project, all of the
code I have written in Pure Data, along with various Python
scripts for converting 2D and 3D data from one format to
another contributed by Lee Montgomery of the University
of New Mexico, have been hosted on a public GitHub webpage
[https://github.com/macumbista/vectorsynthesis]. In addition
to publishing the code and hosting workshops, I have rallied
a user community of approximately 1300 people around the
project through extensive tutorials and help files written
within the library itself; through video documentation posted
on Vimeo [https://vimeo.com/macumbista]; and through sharing
information about the project with the LZX Video Synthesizer,
Pure Data, Video Circuits, and Vector Synthesis groups on
Facebook. In the following two sections, I will discuss the
Radio Belgrade residency and the Vector Hack conference in
detail, in the hopes that these two situations will illustrate
the breadth of the developmental, experimental, documentational,
didactic, communal, and performative elements involved in
this entire process.

RADIO BELGRADE RESIDENCY
4.11

Between 26 May and 03 June 2018, I undertook an
intensive residency at the Radio Belgrade Electronic Studio
with the goal of using their EMS Synthi 100 analog synthesizer
(figure XXI) with my Vector Synthesis software to create
a new set of truly hybrid digital/analog audiovisual synthesis
experiments. Only a few dozen of the massive Synthi 100
machines were made, and only two of them in Europe are
accessible to artists through residency programs; one at
Radio Belgrade and one at Contemporary Music Research Center
in Athens. The Synthi 100 incorporates 12 oscillators, eight
voltage controlled filters, three ring modulators, three
envelope shapers, three noise generators, two spring reverb
units, eight voltage controlled stereo-panning output channels,

a built in oscilloscope, and various other features, all interconnected by two 60 x 60 patch-pin matrices [EMS 1973: 3]. During my residency week at Radio Belgrade, I created three sketches and one finished work, and also compiled a short series of purely oscillographic experiments.

Mean Variance Brushstrokes [https://vimeo.com/272166951] was the first sketch of my residency. This video employs the Vector Synthesis library to make Rutt/Etra style scan processing of a saved image of a skull (a test image I commonly use for scan processing), which is then displayed on an XY display using audio signals. The video raster is created by the ramp oscillators of the Synthi 100, whose frequencies are controlled by the instrument's Random Voltage Generator. The luminosity of the pixels in the image being scanned controls the brightness and displacement of the oscilloscope beam. Additional modulations of the beam by audio signals create the other visual effects seen here. The signals are also run through the two spring reverbs, which are added to the raster signal and give the curved deformations seen in the video. The display monitor is a hacked Vectrex game console, and a version of the same audio signal sent to the monitor can heard in the audio track.

The second sketch is titled *Cubic Rotational Drone* [https://vimeo.com/272327635]. The cube seen in the video is created by reading the data tables for the three axes (X, Y, Z) in Pure Data with the external, analog signal of a ramp oscillator from the Synthi 100. Other Synthi 100 ramps are used to modulate the size of the cube and the rotations, all set at various near-harmonic relationships to the main oscillator. The Random Voltage Generator of the Synthi 100 makes small variations in the frequencies of those ramps. The lines are a bit rough due to the irregularities in the analog waveforms. Two signals (X and Y) are then sent to be displayed on the Synthi 100 oscilloscope, a Tektronix 5000 series modular rack.

Spomenik Surface Treatment [https://vimeo.com/272907790] is the third sketch of the residency. After an exciting visit to the monument to Partisan anti-Fascist fighters at Kosmaj, south of Belgrade, I decided to create a Modernist monument of my own from sound and light using the Vector Synthesis library to scan process

a photograph of the Kosmaj Spomenik, which is then displayed on a hacked Vectrex monitor using audio signals. The luminosity of a 3 × 3 pixel wide scanning area controls the brightness and displacement of the oscilloscope beam, with rotation and perspective added to the figure. The audio signal has been further processed after creating the image through the resonant low and high pass filters and the spring reverb of the Synthi 100.

Liquid Iron Lattice [https://vimeo.com/273041537] is the fourth work, which combines aspects of all the sketches I had previously produced. For this video, I created a simple 2D grid raster rotating in 3D space. I then applied to this grid a scan processed photograph of a simple architectural detail in the building in Belgrade where I was staying. The brightness values in this image push the 2D grid upwards, with a number of sine wave signals from the Synthi 100 responsible for the fluid motions of the grid. These signals were then displayed as vectors by my modified Vectrex monitor. They were also sent back into the filters and spring reverbs of the Synthi 100 for modification, and were then summed with the signals sent to the Vectrex, resulting in a variety of generative feedback effects.

EMS Synthi 100 Oscillographics [https://vimeo.com/277893072], the final video created, documents a series of audiovisual X/Y oscilloscope patches for the EMS Synthi 100, visualized directly from the signal outputs of the synthesizer on the built-in Tektronix 5000 series modular rack oscilloscope. They were patch-programmed to run autonomously without any human control. Most of them use two or three oscillators tuned to a close harmonic, and small changes in the frequencies (including temperature drift!) make large changes in the image and sound. A couple use the Synthi 100's low pass filters as well. All are based on Ron Pellegrino's oscillographic laser designs (Pellegrino 1983: 195-203). In addition to the videos, I left detailed instructions including a list of Synthi 100 patch matrix connections with the Radio Belgrade Electronic Studio, so that future visitors could reproduce my experiments.

VECTOR HACK FESTIVAL

My personal and academic research into experimental vector graphics systems culminated with the Vector Hack Festival [https://vectorhackfestival.com/] in October 2018. This festival sprung out of discussions Ivan Marušić Klif initiated with me in July 2017, when we both made the first public releases of our Max/MSP and Pure Data code libraries for displaying vector imagery on the oscilloscope using audio signals. Klif and I envisioned the event as a forum where artists creating experimental audio-visual work for oscilloscopes, vector monitors, and laser displays could share ideas, develop their work together, and form an actual community from the disparate artists working in this field, who otherwise only knew each other through the online world. We also curated a public program of open workshops and talks aimed at allowing young artists and a wider audience to learn more both about creating their own vector-based audiovisual works, and about the scientific and artistic history of these techniques from the 1950's onward, as well as organizing a rich performance program which demonstrated a diverse range of techniques and artistic approaches in action.

In total, we gathered a group of twenty-three participants, all working as researchers, teachers, developers, and performers in the field of experimental vector visuals, from across the EU, the USA, and Canada. The program was held between two very different locations in two different cities. The first half of the festival in Zagreb, with talks and performances oriented towards a larger public audience, was held in a large hall of the Nikola Tesla Technical Museum from the 2nd to 4th of October. We found it especially significant that this museum was also the site of the fifth and final *New Tendencies/Nova Tendencije* exhibition in 1973, which had focused on "constructive visual research, computer visual research, [and] conceptual art" (Rosen et al. 2011: 476). There, the keynote and subsequent presentations were very well attended by audiences of between 30-60 people each evening, while the biggest performance night featuring Robert Henke and Bernhard Rasinger drew approximately 300 people. At the second half of the event in Ljubljana, the Osmo/za venue was significantly smaller and therefore

the program focused more on discussion between the event participants alongside the evening performances from the 5th to the 7th of October. The event was organized locally by Ivan Marušić Klif, the Radiona.org Zagreb Makerspace, the Ljudmila Art and Science Laboratory, and Zavod Projekt Atol. Curatorial duties were shared between myself and Klif, with assistance kindly given by Chris King of the Video Circuits group.

One of the highest priorities of the program was given to the sharing of technical knowhow with a general audience in both a discursive and a participatory manner. In both cities, Jonas Bers and Philip Baljeu each gave practical electronics workshops focused on building the CHA/V, a "Cheap Hacky Audio/Visual" synthesizer based on the deliberate misuse of a Chinese VGA test pattern generator (Bers 2016), and the OGA, or "Oscilloscope Graphic Artist", a circuit developed by technology writer Mitchell Waite and published in *Popular Electronics* magazine (Waite 1980). Hansi Raber and Jerobeam Fenderson also each gave presentations on different aspects of their OsciStudio software, which may be the most well-known of the 'oscilloscope music' platforms, with Raber focusing on the freshly-implemented live coding functions of the application and Fenderson covering its artistic and performative use with a strong nod towards the computer gaming and demo scene.

The three other major coding platforms for audiovisual vectors, Pure Data, Max/MSP, and Processing, were demonstrated by my own Vector Synthesis library and Douglas Nunn's additional Pd research, Ivan Marušić Klif's REWereHere patch, and Ted Davis' XYscope library respectively. Equally important hardware approaches were elaborated by Andrew Duff and Bernhard Rasinger's discussions of analog modular synthesis for the Vectrex and ILDA laser display, Roland Lioni's examples using the Axoloti microcontroller DSP board, Joost Rekveld's self-built analog computers for the generation of vector-based HD video, and Baljeu and Bers' presentations of their own oscillographic and scan processing systems inspired by the Rutt/Etra video synthesizer from the 1970's and Mitchell Waite's circuits from the 1980's. Finally, Robert Henke gave an extensive tour through the progressive iterations of his

monumental Lumiere performance, along with details of the laser controlling software and hardware necessary to execute them.

The event also strived to provide a historical context for the contemporary activities it showcased, as well as cities in which we had chosen to work. We were very fortunate to welcome artist-researcher Darko Fritz, who provided a survey of vector-related works from the New Tendencies art movement, which was born in Zagreb and saw its most important exhibitions and publications come together there. And in Ljubljana, the artist and curator Ida Hiršenfelder presented a wonderful overview of Slovene computer art during the Yugoslav era, extending from the 1960's to the 1980's. Each of these talks was intended to provide a local artistic frame of reference for the visiting foreign participants, however much of the material was also new to many — particularly the younger generation of — local audience members as well.

From there, other keynote presentations dug into various particular technologies and their historical applications both in and outside of the art world. Rekveld set out an impressive display of early mechanical and electronic devices used to create physical analogies of real-world phenomena to provide real-time simulation and interaction for scientific and industrial engineering applications. I gave a window into my own research on the military development of computers as a means of simulating, predicting, controlling, and eventually annihilating unknown 'others', and where the legacy of these origins might be found in contemporary computer graphics. Researcher Stefanie Bräuer focused on a very specific historical setting, namely the use of technologies such as oscilloscopic and stereoscopic imagery in the 1950's films of Mary Ellen Bute, Hy Hirsh, and Norman McLaren which she described as marking a change in focus from mechanical to electronic means of image production in experimental cinema, while Chris King sought to bring together the developments of mechanical drawing machines with concurrent and subsequent experiments in video synthesis and vector graphics.

The majority of participants who gave workshops or talks, as well as laser artist Alberto Novello who could only join us for the last evening, also made performances demonstrating their self-made systems for a public audience. However, for me the most

exciting moments lay in the new configurations and collaborations which sprang up during the festival. The first of these collaborations was a sublime conversation between the ethereal sounds of Hrvoslava Brkušić and the geometric vectors of Douglas Nunn in Zagreb. This was closely followed by a completely spontaneous shared set by laserists Rasinger and Henke which illuminated the architecture of the Technical Museum hall with such power that I felt I could still see after images in the room the following day. Of note was the contrast between Henke's usual precision-high-tech approach, which he discussed just that afternoon as originating from the need to be taken seriously within the world of large-scale audiovisual installation and performance, and the relaxed, 'dirty techno' improvisational style he easily returned to for his duo with Rasinger in the evening of the same day.

Later on, in the more intimate settings of Osmo/za in Ljubljana, we focused on what we had been calling 'workgroups' throughout the festival. These workgroups were envisioned as a way of inviting young, local artists to interface with vector and video synthesis techniques for the first time and explore them towards the goal of an informal performance at the end of the festival. We took the extra step of inviting only women to these groups as a way of counterbalancing what I saw as a serious deficiency in female performers in our festival lineup, and of nurturing them into the larger scene of audiovisual vector artists from which we drew our international participants. Croatians Brkušić, who shared the stage with Nunn in Zagreb, and Vanda Kreutz, who presented an inspired solo improvisation arising from her meeting with the LZX Vidiot synthesizer, were joined in the workgroups by members of the Slovene noise collective Kikimore, which was founded in 2016 in Ljubljana out of an initiative focusing on the activities of women in the area of science, technology, and media art. I had given them a basic demo of the Vector Synthesis patches during a residency in Ljubljana in July 2017, and their enthusiastic response guarenteed that I would remember them when we began considering who we might invite. From their collective, Staša Guček took a masterclass in the art of audio-reactive video mixer feedback from Bers, and the trio of Sara Mlakar, Nina Orlić, and Barbara Poček ran the chaotic, noisy signals

from their lovingly-handmade electronic sound devices into the
laser system of Rasinger, laughing the entire time.

Moments such as these workgroup performances went a long way
towards fulfilling the community-building goal Klif and I set out
during our first conversations, as well as towards that of bringing
new artists into this community with an enthusiastic welcome and
a wealth of new inspiration. After reading a draft of this text,
Jonas Bers pointed out to me how all the participants very quickly
got involved in the aspects of community building 'behind the
scenes' so to speak, by debugging each others' code; adding
features to their own systems by request; loaning, teaching,
troubleshooting, repairing, and modifying hardware; donating
printed circuit boards; coordinating workshops; creating content
for one another; and actively maintaining contact after the event
ended. Once the video documentation of the talks and performances
are online, we hope that the discussion they stimulate will grow
even larger and more inclusive of radically different approaches
to the medium. Our next ambition is to organize a followup to this
event, perhaps in 2020, which I would like to see go further in
directions we only touched on in this edition, i.e. more female
participants, more participants from outside Europe, more
participatory and entry-level workshop situations for local and
visiting artists, a deeper look into different approaches to
the laser display from both the established professional and
experimental artistic sides, a focus on the currently burgeoning
field of digital plotters and mechanical drawing devices, and a
new round of media archaeological excavations into the hidden
histories of vector technologies and the arts created by them.

4.13 FUTURE PLANS : THE ILDA LASER

One platform for future development of the Vector Synthesis
project are laser projectors following the ILDA control protocol,
which is used for many types of computer-controlled laser systems
currently manufactured. The ILDA protocol describes a system of
differential analog signals with 10V of potential (+5V to -5V) which

control the horizontal and vertical movements of the mirror galvanometers ('galvos'). These galvos direct the laser beam as it leaves the projector. Additionally, there are three inputs for the three independent red, green, and blue laser diodes which can be mixed to form variable colors. One input for the overall brightness of the laser beam exists, but is seldom used. Finally, there is an "interlock" input which forms part of the safety mechanism of the laser and requires a signal of +5V to keep a mechanical shutter open, allowing the laser radiation to be emitted from the device (International Laser Display Association Technical Committee 1999).

In regards to the speed of movement of the laser galvos, it is very unlikely that content for the Vectrex or similar vector monitors could simply be applied without modification to a laser projector due to an extreme difference in the signal frequencies which are possible. Because these galvos are electromechanical objects with mass and inertia rather than a beam of electrons bent electromagnetically in a vacuum, they are much more susceptible to damage from incorrect usage. While the bandwidth of a CRT can be measured in Herz, the speed of a galvo is expressed in the number of discrete Kilo Points per Second (kpps) it can display at a fixed angle of projection, often listed as 8 degrees. Signals which exceed the kpps rating of the galvos pose a number of risks: the image will be distorted; the galvos can be destroyed by overheating; and the galvo shafts and the mirrors mounted on them can be damaged or destroyed by mechanical stress. There is no exact correlation between kpps and Hz, as kpps depends very much on the size, complexity and angles of the figure being drawn — taking into account, for example, that the harmonics of a sharpcornered waveform may exceed the safe operating speed of the galvo. However, some basic slew limiting or low pass filtering of the signal, combined with the limiting of its amplitude, can serve as minimal protection for the laser hardware. (Larsen 2016). It should be noted that — unlike with the phosphorescent CRT monitors which have an innate image latency — any persistence of image depends entirely on the perceptual systems of the viewer, and so the lowest flicker-free frequency should be a bit higher than for a CRT. I have found frequencies close to 50 Hz to be optimal in terms of the smoothness of the

lines as opposed to the speed requirements of the galvos. In conjunction with this are the legally-mandated safety factors involved in laser projection, which generally prohibit slowly moving laser beams due to the risk of inflicting eye damage on members of the audience, or even starting fires if a beam is left stationary too long on a non-reflective object (Benner 2008). Most off-the-shelf, commercial software designed for creating ILDA laser shows incorporates an incredible amount of optimization in order to create figures whose lines, and particularly whose corners, are drawn within the speed parameters inherent in the kpps rating of the projector used—not too slow to provide a flicker-free visual experience to the audience, and not too fast to prevent harm to the projector itself.

The [vs-ilda] abstraction in the Vector Synthesis Library for this task accepts five channels of digital information created in Pure Data, corresponding to the ILDA channels X, Y, R, G, and B, and uses the sound card DAC hardware to deliver this as an analog signal to the laser. Within this abstraction, the signals which make up the laser image can be:

- scaled and translated on the X and Y axes;

- low-pass-filtered to certain ratings based on the kpps of the target projector;

- limited in amplitude by clipping both to prevent signals of damaging levels from reaching the laser galvos;

- limited to create safe 'zones' in the performance situation where the laser beam does not travel (for example, where the audience or other performers might be);

- and rotated on all three XYZ axes to compensate for the alignment of the projector in regards to the projection surface in a simialr way to the 'keystoning' features of a digital image projector.

As all of the ILDA inputs to the projector require a differential signal (in order to overcome the noise inherent in long cable runs), a further point which makes the MOTU UltraLite audio interface described in section 4.6 so attractive for this purpose is its balanced outputs. Ted Davis has published a very simple tutorial illustrating how one can wire these balanced

outputs to the DB-25 standard ILDA connector (Davis 2018a). Another option, if differential outputs are not available from one's audio interface, would be to use the Cyclops hardware module by LZX Industries. This EuroRack module, designed for use with analog modular synthesizers, produces a low pass filtered, diode-clipped, differential output from scaleable signal inputs for the X and Y channels; voltage control inputs and manual color controls for the red, green and blue channels of an RGB laser.; and manual control over the laser projector's safety shutter. Alternately, a large number of DACs designed specifically for use with lasers are also available on the market, such as the Etherdream, LaserBoy, RayComposer, Pangolin FB4, and the open source Helios DAC. None of these, however are designed to accept digital audio signals, instead accepting lists of points which the laser must track.

Concluding this speculation of upcoming developments, I recognize that the issues involved with using ILDA projectors require treating the laser as a unique tool for expression with its own media-specific considerations both technically and artistically, rather than using pre-existing content developed on CRT monitors. In particular, the scan processing capabilities of the Vector Synthesis Library, with their ability to utilize an arbitrary number of scan lines and frame rate, or use a lower bandwidth spiral scan rather than a sawtooth raster, present exciting opportunities in combination with the ILDA projector which deserve much deeper exploration in the future.

5.0 CONCLUSIONS

In reviewing my work over the last two years, as well as my efforts at conceptualizing and documenting it here in this paper, I have arrived at four areas where conclusions can be drawn regarding this media-archaeological re-enactment: in the relationship of Vector Synthesis to my historical research into the paradigms of vector graphics and early computing; in the success of Vector Synthesis in fulfilling the artistic goals I set out for myself; in a summary of the main technical aspects of experimental, audiovisual vector graphics as realized in the Vector Synthesis project; and in the progress of building a functioning community around the Vector Synthesis Pure Data Library.

5.1 HISTORICAL CONCLUSIONS

The second chapter of this paper raises some strong questions about the role which the ideologies which spawned specific technological artifacts may still have in shaping our use of the later iterations of these artifacts today. I do not believe that these questions can easily be answered either in the scope of this paper, nor in the scope of an abstract audiovisual performance such as Vector Synthesis. Regardless, these questions have informed my work on many levels. Key to my media archaeological research is the consideration of 'texts' from the eras most contemporary to the vector graphics technology I have chosen to reenact. That is the period of approximately 1960-1975, and by 'texts' I include not only written archive material, but also films, videos, performances, and sound recordings, as well as the devices themselves that made those artworks possible in the first place. Or as Turim and Nygren put it;

> [T]ools are not self-evident in their use or in their internal organization, and […] they require an activity not unlike that of reading. Tools themselves […] become texts, with an internal logic that is far from unproblematic.
>
> (Turim and Nygren 1996: 52)

While researching the Vector Synthesis project, I sought to place these historical 'texts' in relationship with more current concerns in media art and media studies, such as artificial intelligence, virtual reality, the marketing curve of technology, machine authorship, etc. I bring in these contemporary concerns as a way of creating the dialogs between past and present media espoused by Parikka, Huhtamo, Kluitenberg, Zielinksi, and others. While these 'texts' may not manifest themselves in the immediate outcome of a decidedly chaotic and non-narrative system such as the one I have designed, I have in sections 2.1 on technological determinism and 2.2 on techno-culture, as well as in much of chapter three on the historical artistic precedents to Vector Synthesis, strived to make clear their influence on the process which led me to those results here.

Rather than posit a deterministic view of media technology which ascribes a direct influence of machinery over the thoughts of humans, or a teleology leading from the primitive inventions of the past directly to the superior innovations of today, I would prefer to suggest a genealogical understanding that acknowledges the cultural, social, and economic conditions within which specific technologies were created as formative influences which can be carried within continued iterations of that technology as a kind of 'DNA'. This DNA can then go on to shape a technology's interactions with future cultural, social, and economic conditions. Such a genealogy suggests that our current state of affairs is derived from branches of thought which were followed in the past, but also that our reality could be quite different if other branches had developed instead. Or perhaps it even suggests that new possibilities can arise from recognizing and rewriting the genetic code by selecting for the more positive sets of influences and against the more negative or destructive ones. Barbrook takes just such a humanist position in his account of the trajectory from the 1964 World Fair to the Internet of today:

> "[T]he convergence of media, telecommunications and computing has not — and never will — liberate humanity. The Net is a useful tool not a redemptive technology. [I]t is humans who are the heroes of the grand narrative

of history. In the late-2000s, ordinary people have taken control of sophisticated information technologies to improve their everyday lives and their social conditions. [T]his emancipatory achievement can provide inspiration for new anticipations of the shape of things to come."

(2007: 264)

I have no illusions that my focus on discarded and obsolete technological platforms somehow erases my culpability in the ever-growing amount of electronic waste destined to become part of the geological record. Nor do I expect that the use of primitive graphics rendering techniques from the past, which serve no purpose to any contemporary commercial or military interests, sets me apart from other media artists who seek the cutting edge rather than the long tail of what techno-culture has to offer. My use of a modern laptop, a mobile smartphone, or a high speed audio interface all preclude such starry-eyed notions. However, I do hope that the small gesture of this media-archaeological reenactment does give other artists aspiring towards 'newness' and 'innovation' some pause for thought, wherein they might ask themselves; 'What is it that I am helping to bring into the world right now? What sort of ideologies demanded its creation? What will it be used for during the time when I am helping to drive its cultural engine, and where will it end up once I have discarded it? And is this a process worthy of my participation?'

5.2 ARTISTIC CONCLUSIONS

There is a wealth of computational art — Lissajous figures derived from pendulums, tuning forks, and mechanical geared wheels in motion; or similarly pristine and symmetrical electronic imagery generated by electronic tubes, transistors, integrated circuits, and generations of analog and digital computers — created from the middle of the 19th Century up until the last quarter of the 20th Century, whose purpose was to present idealized mathematical forms as natural beauty and universal truths (Taylor 2014: 66-67), a project which suffered greatly following the 1960's precisely due to its association with the military and totalitarian aspects of techno-culture (163). So perhaps we have arrived at a new

place in the history of art, a place where the perfectly harmonic and stable geometric figure no longer relates to the world we reflect in our art. Personally, I feel that it is the inharmonic, unstable, 'noisy' and 'glitched' elements introduced into the audiovisual process which communicate a more contemporary aesthetic, one that reflects the instabilities of the time we live in now, where concepts previously considered universal such as truth and identity have become conflicted and problematic. These 'imperfections' in my own work, which I choose to read as incidental subjectivities intruding on the mathematical perfection of the figure, are an attempt to separate it from the centralized symmetry, universalizing narratives, and techno-scientific legacy of simulation and control found in the oscilloscope and computer art of the 1950's and 60's.

In highlighting these imperfect turns on mathematical perfection, I believe that I have arrived at a very contemporary interpretation of vector graphics which is still highly influenced by their history. I would characterize the overall creative direction of Vector Synthesis in the following terms:

o   Signal-based images need not reproduce normal perspective, nor model physical reality accurately in order to be artistically evocative;

o   Therefore, although it derives imagery from two- and three-dimensional mathematical models, Vector Synthesis does not aim towards simulation or realism of any kind;

o   And, although Vector Synthesis can also process real-world imagery from a live camera or digitally stored videos and photographs, it remains deliberately nonrepresentational in the use of these images;

o   Additionally, Vector Synthesis does not attempt to utilize the narrative tropes of traditional cinema, which the games industry and many other aspects of new media art in the early 21st Century have inherited;

o   As such, Vector Synthesis in a 'non-functional' form of expression, in the sense that it does not try to fulfill an auditory or visual function within the framework of another art form, such as computer games, cinema, music videos, advertising, or electronic dance music.

In these ways, Vector Synthesis is a self-sufficient artwork whose primary goal echoes the goal stated by Larry Cuba in section 3.3 of this paper, which is to engage in "experiments and dialog with the medium" for their own sake in an unplanned, experimental, and improvisational setting.

TECHNICAL CONCLUSIONS
5.3

The Vector Synthesis method of sending vector imagery as audio signals to analog CRT and ILDA displays presents a number of characteristics which make it worthwhile for other artists to consider exploring. In the first place, these characteristics relate to the equipment necessary to realize audiovisual vectors:

o	These vectors are generated by a fairly low-bandwidth, audio frequency-range signals which can be produced by very common sound hardware and software, as opposed to video signals which can require much higher bandwidth and specialized devices to produce detailed results;

o	These vectors can be displayed on obsolete and discarded technical equipment which otherwise might remain in storage or be discarded, thus prolonging the useful life of these devices by many years;

o	If such commonplace and therefore inexpensive or even potentially free hardware can be employed, the need to invest in upgraded, 'cutting edge' equipment is negated. Likewise, if my Vector Synthesis library for Pure Data is used, all the software required for digital implementation is free of charge and can run on any computer. This is an important factor for novices, or for students and teachers in workshop situations;

However, they also relate to the results of the technique which are both seen and heard:

o
	As opposed to conventional raster graphics, analog vectors on a CRT monitor have a nearly infinite graphic resolution, constrained only by the size and sharpness of the beam in relation to the total monitor area (issues of signal bandwidth not withstanding, of course);

- o With the possibility of using both MIDI controllers and external audio signals as inputs to the system, control of the audiovisual figures produced by Vector Synthesis is highly intuitive, and the results immediately tangible;

- o And finally, Vector Synthesis maintains a direct, non-symbolic relationship between sound and image due to the fact that both are derived from the same signal.

Additionally, as mentioned in section 4.13, the potential of rendering scan processed photographic images or live video with the ILDA laser display, and being able to manipulate that projection in realtime with audio signals, has barely been explored outside the small community of scan processing enthusiasts I have worked with over the last two years. Such techniques would represent a significant development of the art form, and a novel approach which combines approaches from the dawn of the video art era with current technological capabilities.

5.4 COMMUNITY CONCLUSIONS

In keeping with my own belief that the highest creative possibilities come from the construction of one's own system rather than the use of another's, I resisted the urge to design the Vector Synthesis software as an end-user application with a full set of knobs to twist. Naturally, I do have a set of performance interfaces which I use in my live sets and to create videos, and the code library contains many simple examples which suggest uses for the tools I have programmed. However, beyond the performance itself, I intend the Vector Synthesis library as a set of building blocks for further customization, or as an artwork which requires active participation from the user in order to complete and fully realize. The code itself, as well as the overall concept, builds upon a great deal of historical work by others which I have recognized in chapter three, and upon contemporary work in both the hardware and software domains which I have

acknowledged as I described the functions of the library in the fourth chapter. To co-opt decades of influences and research and call it all my own does indeed seem arrogant. Therefore, I am proud to see the public release of the Vector Synthesis library as a unified, well documented body of code and media examples, following the example of Steina and Woody Vasulka and their generation of pioneering video artists. And I am equally proud to see it released with a non-restrictive, open source license in the spirit of Dan Sandin and others in the history of audiovisual toolmaking. My hope is that this fosters an active process of re-engineering by artists in the field, and honors the contributions and encouragement I received from the Pure Data and Video Circuits communities in particular.

6.0 BIBLIOGRAPHY

Anderson, Barbara, and Joseph Anderson. "The Myth of Persistence of Vision Revisited." *Journal of Film and Video*, vol. 45, no. 1, Spring 1993, pp. 3–12.

Arnheim, Rudolf. *Art and Visual Perception: A Psychology of the Creative Eye.* University of California Press, 2009.

Atkin, Emily. "The Environmental Case Against Bitcoin." *The New Republic*, Dec. 2017. *The New Republic*, https://newrepublic.com/article/146099/environmental-case-bitcoin

Bainbridge, Benton C. *Lisa Joy / Dueling Vectrexes.* 2016, https://www.youtube.com/watch?v=q3sKZA2r7qk

---. *Slate Projects Presents Rue Bainbridge: Scenes from Averard Hotel.* 2019, https://www.youtube.com/watch?v=rwUkqYGklQA

Baljeu, Philip. *ScanProcessor_Architecture_abstraction: NYC_001.* 2017, https://www.youtube.com/watch?v=BDyQVllHRgA

Barbrook, Richard. *Imaginary Futures: From Thinking Machines to the Global Village.* Pluto, 2007.

Barrett, Cyril. *Op Art.* Studio Vista, 1970.

Benjamin, Walter. "The Author as Producer." *Walter Benjamin: Selected Writings, Volume 2 (1927-1934).*, edited by W Jennings, translated by Rodney Livingstone, Belknap Press of Harvard University, 1934/1992, pp. 768–82.

Benner, William R. Jr. "Projector Connections." Laserist, 2008, http://www.laserist.org/laserist2008/projector-connections.htm

Bers, Jonas. *CHA/V. 2016*, https://jonasbers.com/chav/

---. *Memoriam (for Bill Etra).* 2017, https://www.youtube.com/watch?v=9A0NG9ij4g8.

Bier, Jess. "The Simple Societies of Complex Models." *E-Flux Architecture*, 2018, http://www.e-flux.com/architecture/representation/159207/the-simple-societies-of-complex-models/

Borrelli, Christopher. "Blueprints for 'Star Wars' Death Star Were Created at UIC." *Chicago Tribune*, 23 May 2017.

Boulton, Jim. "Bitworld." *Eye Magazine*, 2014, http://www.eyemagazine.com/feature/article/bitworld

Bowditch, Nathaniel. "On the Motion of a Pendulum Suspended from Two Points." *American Academy of Arts and Sciences Memoirs*, vol. 3, no. 2, 1815, pp. 413–36.

Bräuer, Stefanie. "Stefanie Bräuer." *VectorHackFestival*, 2018, https://vectorhackfestival.com/guests/brauer/

Brecht, Bertolt. "The Radio as an Apparatus of Communication." *Media Art Net*, 1932/2005, http://www.mediaartnet.org/source-text/8/

Burris, John. "Did the Portapak Cause Video Art? Notes on the Formation of a New Medium." *Millennium Film Journal*, no. 29, Fall 1996, http://www.mfj-online.org/journalPages/MFJ29/JBurrisPortapak53196.html

Bute, Mary Ellen. "Abstronics: An Experimental Filmaker Photographs The Esthetics of the Oscillograph." *Films in Review*, vol. 5, no. 6, July 1954.

Campaign to Stop Killer Robots. *Campaign to Stop Killer Robots*. 2018, https://www.stopkillerrobots.org/

van Campen, Cretien. *The Hidden Sense: Synesthesia in Art and Science.* MIT Press paperback edition, MIT Press, 2010.

de Campo, Alberto. *Science By Ear. An Interdisciplinary Approach to Sonifying Scientific Data.* Institute of Electronic Music and Acoustics, University for Music and Dramatic Arts, 2009.

Connolly, James, and Kyle Evans. "Cracking Ray Tubes: Reanimating Analog Video in a Digital Context." *Leonardo Music Journal*, vol. 24, 2014, pp. 53–56.

Crawford, Matthew B. *The World Beyond Your Head: On Becoming an Individual in an Age of Distraction.* Farrar, Straus and Giroux, 2015.

Crogan, Patrick. *Gameplay Mode: War, Simulation, and Technoculture.* University of Minnesota Press, 2011.

Crutchfield, James P. "Space-Time Dynamics in Video Feedback." *Physica*, no. 10D, 1984, pp. 229–45.

Davis, Ted. *DAC_ILDA Adaptor.* 2018, https://github.com/ffd8/dac_ilda

---. *LASER LETTERS II.* 2018, https://vimeo.com/274485191

---. *XYscope.* 2017, https://teddavis.org/xyscope/

Duff, Andrew. *Live Modified Vectrex & Eurorack Modular @ Y.U.M.A. Brighton Komedia 15/9/17.* 2017, https://www.youtube.com/watch?v=kzBtUrvw0Js

---. *Vectrex Minijack Input Mod.* 2014, http://users.sussex.ac.uk/~ad207/adweb/assets/vectrexminijackinputmod2014.pdf

Dunn, Fletcher, and Ian Parberry. *3D Math Primer for Graphics and Game Development.* 1st ed., Wordware Publishing, 2002.

Dziewanska, Marta, Dieter Roelstraete, and Abigale Winograd, editors. *The Other Transatlantic. Kinetic and Op Art in Eastern Europe and Latin America*. Muzeum Sztuki Nowoczesnej w Warszawie, 2018.

Edwards, Benj. "The Never-Before-Told Story of the World's First Computer Art (It's a Sexy Dame)." *The Atlantic*, 24 Jan. 2013, https://www.theatlantic.com/technology/archive/2013/01/the-never-before-told-story-of-the-worlds-first-computer-art-its-a-sexy-dame/267439/

Edwards, Paul N. *The Closed World: Computers and the Politics of Discourse in Cold War America.* MIT Press, 1996.

Etra, Bill, and Anton Marini. *V002 Rutt Etra 2.0.1.* 2008, http://v002.info/plugins/v002-rutt-etra/

Fenderson, Jerobeam. *Nuclear Black Noise.* 2013, https://www.youtube.com/watch?v=YqSvkNjWnnQ

---. *Oscilloscope Music.* 2016, https://oscilloscopemusic.com/watch.php

---. *Oscilloscope Music Tutorial 2: Setup* (Compression, DC-Coupling, Sampling Rate, Aliasing). 2017, https://www.youtube.com/watch?v=piZPIMYfq0c

---. O*scilloscope Music Tutorial 4: Sinewaves* (Harmonic Oscillation, Unit Circle, Additive Synthesis). 2017, https://www.youtube.com/watch?v=dJQCMw_Qb8A

Foote, Gareth. *Auto-Illustrator by Adrian Ward.* 2010, http://notfig.garethfoote.co.uk/auto-illustrator-by-adrian-ward/

Fox, Robin. *Backscatter.* DVD. Synaesthesia, 2004.

---. "RGB LASER SHOW." *ROBIN FOX,* 21 Mar. 2014, http://robinfox.com.au/rgb-laser-show/

Gagnon, Jean. "A Demo Tape on How to Play Video on a Violin." *The Emergence of Video Processing Tools.* Kathy High, Sherry Miller Hocking, and Mona Jimenez, editors. Intellect, 2014, pp. 309–22.

General Consumer Electronics. *Service Manual HP-3000*, Vectrex Arcade System. 1982, http://www.vectrex.de/wp-content/uploads/2013/06/Vectrex-Service-Manual.pdf

Gere, Charlie. *Digital Culture.* Expanded 2. ed, Reaktion Books, 2008.

Goldstine, Herman Heine. *The Computer – from Pascal* to von Neumann. Princeton University Press, 1993.

Gombrich, Ernst Hans. *Art and Illusion: A Study in the Psychology of Pictorial Representation.* Millennium ed., with A new preface by the author, Princeton University Press, 2000.

Goold, Joseph, Charles E. Benham, Richard Kerr, and L. R. Wilberforce. *Harmonic Vibrations And Vibration Figures.* Newton and Co Scientific Instrument Makers, 1884.

Haller, Robert A. "An Interview with Steina." *Buffalo Heads: Media Study, Media Practice, Media Pioneers, 1973-1990.* Woody Vasulka and Peter Weibel, editors. ZKM/Center for Art and Media Karlsruhe ; MIT Press, 2008, pp. 492–95.

Henke, Robert. *Lumière III.* 2017, http://roberthenke.com/concerts/lumiere.html

Hermann, Thomas, Andy Hunt, and John G. Neuhoff editors. *The Sonification Handbook.* Logos Verlag, 2011.

Hertz, Garnet, and Jussi Parikka. "Zombie Media: Circuit Bending Media Archaeology into an Art Method." *Leonardo,* vol. 45, no. 5, 2012, pp. 424–30.

Higgins, Hannah, and Douglas Kahn, editors. *Mainframe Experimentalism: Early Computing and the Foundations of the Digital Arts.* University of California Press, 2012.

Hocking, Sherry Miller. "The Grammar of Electronic Image Processing." *The Emergence of Video Processing Tools*, Kathy High, Sherry Miller Hocking, and Mona Jimenez, editors. Intellect, 2014, pp. 439–71.

Hoerr, Ethan. "A. Rutt-Etra Design." *A. Rutt-Etra Design*, 2017, http://rutt-cadetra.blogspot.com/2017/12/a-rutt-etra-design.html

---. *LZX Cadet-Based Scan Processor – Ernav K.* 2018, https://ernavk.wordpress.com/2018/02/13/lzx-cadet-based-scan-processor/

Hofstadter, Douglas R. *Gödel, Escher, Bach: An Eternal Golden Braid.* 20th anniversary ed, Basic Books, 1999.

Holzer, Derek. *Vector Synthesis*. 2019, https://github.com/macumbista/vectorsynthesis

---. *Vector Synthesis: What Are You Using for Your Own Vector Synthesis/ Oscilloscope Music Projects?* 2018, https://www.facebook.com/groups/ vectorsynthesis/permalink/953660184843556/

Hordijk, Rob. "Benjolin Schematics." *Electro-Music*, 2009, http://www.electro-music.com/forum/topic-38081.html

Houston, Joe. *Optic Nerve: Perceptual Art of the 1960s*. Merrell, 2007.

Huhtamo, Erkki. "Dismantling the Fairy Engine: Media Archaeology as Topos Study." *Media Archaeology: Approaches, Applications, and Implications.* Erkki Huhtamo and Jussi Parikka, editors. University of California Press, 2011, pp. 27–47.

IBM. *SAGE Computer Ad*. 1960, https://www.youtube.com/watch?v=iCCL4INQcFo

International Laser Display Association Technical Committee. *The ILDA Standard Projector.* Revision 002, International Laser Display Association, 1999.

Jimenez, Mona. "Preserving Machines." *The Emergence of Video Processing Tools.* Kathy High, Sherry Miller Hocking, and Mona Jimenez, editors. Intellect, 2014, pp. 567–94.

johncage.org. *John Cage Complete Works*. 2018, http://johncage.org/pp/John-Cage-Work-Detail.cfm?work_ID=79

Kagan, Andrew. "Ben F. Laposky: A Midwestern Pioneer of Absolute Light Form." *Arts Magazine*, June 1980.

Kittler, Friedrich A. *Gramophone, Film, Typewriter*. Stanford University Press, 1999.

Klif, Ivan Marušić. *REWereHere*. 2017, http://i.m.klif.tv/rewerehere/

Kluitenberg, Eric. "On the Archaeology of Imaginary Media." *Media Archaeology: Approaches, Applications, and Implications*. Erkki Huhtamo and Jussi Parikka, editors. University of California Press, 2011, pp. 48–69.

Knowlton, Ken. "Portrait of the Artist as a Young Scientist." *YLEM Journal*, vol. 25, no. 2, 2005, pp. 8–11.

Konopaska, Fred, and Jason Kopp. *Responses to Post by Derek Holzer in Closed Facebook Group "Vectrex, XY and Vector Monitors: The Technical Side."* 1 Aug. 2018, https://www.facebook.com/groups/Vectrex .XY.and.Vector.monitors.The.Technical.Side/permalink/1555327451226343/

Krauss, Rosalind E. *The Optical Unconscious*. 5. print, MIT Press, 1993.

Kreidler, Johannes. *Chart Music*. 2009, http://www.kreidler-net.de/english/works/chartsmusic.htm

Lancaster, John. *Introducing Op Art*. B. T. Batsford, Watson-Guptill, 1973.

Larsen, Lars. "Analogue Protection Filtering for ILDA XY/Galvos." *Photonlexicon Laser Forum*, 2016, https://www.photonlexicon.com/forums/archive/index.php/t-25301.html
---. "How a Video Oscillator Works." *Muffwiggler*, 24 Nov. 2010, http://www.muffwiggler.com/forum/viewtopic.php?t=25214&sid= 84479a1f9d1303f862ba0f01710ab0ee

Latour, Bruno. *Science in Action*. Harvard University Press, 1987.

Lioni, Roland. *Akirasrebirth*. 2018, http://www.akirasrebirth.com/

Lissajous, Jules Antoine. "Mémoire Sur l'Etude Optique Des Mouvements Vibratoires." *Annales de Chimie et de Physique*, vol. 3rd series, no. 51, 1857, pp. 147–232.

Lucier, Alvin, Gisela Gronemeyer, and Reinhard Oehlschlägel. *Reflections: Interviews, Scores, Writings = Reflexionen: Interviews, Notationen, Texte.* 1. Aufl, MusikTexte, 1995.

Mallary, Robert. "Computer Sculpture: Six Levels of Cybernetics." *Artforum*, no. May 1969, 1969, http://www.robertmallary.com/Commentary/artforum_09-1969.htm

Mann, J. Dixon. "An Improved Method of Projecting Lissajous' Figures on the Screen." *Nature*, vol. 18, no. 444, May 1878, pp. 24–25.

McLean, Asha. "Researchers Boycott Korean University over 'Killer Robot' AI Weapons Lab." *ZDNet*, 2018, https://www.zdnet.com/article/researchers-boycott-korean-university-over-killer-robot-ai-weapons-lab/

McLean, Donald F. *Restoring Baird's Image*. Institution of Electrical Engineers, 2000.

Medosch, Armin. *New Tendencies: Art at the Threshold of the Information Revolution (1961-1978)*. The MIT Press, 2016.

---. *Technological Determinism in Media Art*. Sussex University, 2005.

Menkman, Rosa. *The Glitch Moment(Um)*. Institute of Network Cultures, 2011.

Microsoft Workers 4 Good. "Hololens For Good, Not War." *@MsWorkers4*, 22 Feb. 2019, https://twitter.com/MsWorkers4/status/1099066343523930112

Minkowsky, John. "Design/Electronic Arts: The Buffalo Conference, March 10-13, 1977." *The Emergence of Video Processing Tools*. Kathy High, Sherry Miller Hocking, and Mona Jimenez, editors. Intellect, 2014, pp. 393–414.

Mohr, Manfred. *Manfred Mohr, Cubic Limit*, 1973-1974. 1974, https://www.youtube.com/watch?v=j4M28FEJFF8

Mordvintsev, Alexander, Christopher Olah, and Mike Tyka. "Inceptionism: Going Deeper into Neural Networks." *Google AI Blog*, 2015, http://ai.googleblog.com/2015/06/inceptionism-going-deeper-into-neural.html

Moritz, William. "Mary Ellen Bute: Seeing Sound." *Animation World Network*, vol. 1, no. 2, 1996, https://www.awn.com/mag/issue1.2/articles1.2/moritz1.2.html

New Mexico PBS. NMPBS *¡Colores!: Woody & Steina Vasulka*. 2013, https://www.youtube.com/watch?v=KgkOkeYHg_E

O'Hanrahan, Elaine. "The Contribution of Desmond Paul Henry (1921–2004) to Twentieth-Century Computer Art." *Leonardo*, vol. 51, no. 2, Apr. 2018, pp. 156–62.

Olson, Parmy. "Racist, Sexist AI Could Be A Bigger Problem Than Lost Jobs." *Forbes*, 2018, https://www.forbes.com/sites/parmyolson/2018/02/26/artificial-intelligence-ai-bias-google/

Optical Electronics Inc. *Applications of OEI 3-D Display Modules*. 2nd ed., Optical Electronics Inc, 1975.

Papadopoulos, Alexandre, Pierre Roy, and François Pachet. "Assisted Lead Sheet Composition Using FlowComposer." *Principles and Practice of Constraint Programming*, edited by Michel Rueher, vol. 9892, Springer International Publishing, 2016, pp. 769–85.

Parikka, Jussi. *What Is Media Archaeology?* Polity Press, 2012.

Patterson, Zabet. "From the Gun Controller to the Mandala: The Cybernetic Cinema of John and James Whitney." *Mainframe Experimentalism: Early Computing and the Foundations of the Digital Arts.* Hannah Higgins and Douglas Kahn, editors. University of California Press, 2012, pp. 334–54.

Pellegrino, Ronald. *The Electronic Arts of Sound and Light*. Van Nostrand Reinhold Company, 1983.

Pias, Claus. "The Game Player's Duty: The User as the Gestalt of the Ports." *Media Archaeology: Approaches, Applications, and Implications.* Erkki Huhtamo and Jussi Parikka, editors. University of California Press, 2011, pp. 164–83.

Prelinger, Rick. "On the Virtues of Preexisting Material." *Contents Magazine*, no. 5, 2013, http://contentsmagazine.com/articles/on-the-virtues-of-preexisting-material/

Raber, Hansi. *Oscilloscope*. 2015, https://oscilloscopemusic.com/osci.php

---. *OsciStudio*. 2016, https://oscilloscopemusic.com/oscistudio.php

Raymond, Eric S. *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*. Rev. ed, O'Reilly, 2001.

Reichardt, Jasia, editor. *Cybernetic Serendipity : The Computer and the Arts.* Studio International, 1968.

Roads, Curtis. *Microsound*. MIT Press, 2004.

Roberts, Fred S., and Barry Tesman. *Applied Combinatorics*. 2nd ed., CRC Press, 2009.

Rogalsky, Matthew R. *Idea And Community: The Growth of David Tudor's Rainforest*, *1965–2006*. City University London Music Department, 2006.

Rogers, Everett M. *Diffusion of Innovations*. 5th ed, Free Press, 2003.

Rosen, Margit, Peter Weibel, Darko Fritz, Marija Gattin, editors. *A Little Known Story about a Movement, a Magazine and the Computer's Arrival in Art: New Tendencies and Bit International*, *1961-1973*. ZKM/Center for Art and Media ; MIT Press, 2011.

Rudolf, Hank. "ETC's System." *The Emergence of Video Processing Tools*. Kathy High, Sherry Miller Hocking, and Mona Jimenez, editors. Intellect, 2014, pp. 473–84.

Sandin, Dan. *Triangle in Front of Square in Front of Circle in Front of Triangle*. Video Data Bank, 1973.

Sandin, Dan, and Phil Morton. *Distribution Religion*. Oct. 1978.

Schelling, T. C. "Dynamic Models of Segregation." *Journal of Mathematical Sociology*, vol. 1, 1971, pp. 143–86.

Sengmüller, Gebhard. *VinylVideo*. 2000, http://www.gebseng.com/03_vinylvideo/

Slater, Dan. "Chaotic Sound Synthesis." *Computer Music Journal*, vol. 22, no. 2, Summer 1998, pp. 12–19.

Spielmann, Yvonne. "Analog to Digital: Artists Using Technology." *The Emergence of Video Processing Tools.* Kathy High, Sherry Miller Hocking, and Mona Jimenez, editors Intellect, 2014, pp. 499–527.

---. *Video: The Reflexive Medium*. English ed, MIT Press, 2008.

Stallman, Richard S. "The GNU Manifesto." *Gnu.Org*, 2015, https://www.gnu.org/gnu/manifesto.en.html

Suominen, Jaakko, and Anna Sivula. "Retrovation – the Concept of a Historical Innovation." *WiderScreen*, 2016, http://widerscreen.fi/numerot/2016-3-4/retrovation-the-concept-of-a-historical-innovation/

Sweet, Neesa. "Animating the Death Star Trench." *The Very Best of Fantastic Films: The Magazine of Imaginative Media*, Feb. 1981, pp. 26–30.

Tasajärvi, Lassi, Mikael Schustin, Bent Stamnes, and Arttu Tolonen. *Demoscene: The Art of Real-Time*. Even Lake Studios : Katastro. Fi, 2004.

Taylor, Grant D. "The Soulless Usurper: Reception and Criticism of Early Computer Art." *Mainframe Experimentalism: Early Computing and the Foundations of the Digital Arts*, University of California Press, 2012, pp. 17–37.

---. "'Up for Grabs': Agency, Praxis, and the Politics of Early Digital Art." *Lateral 2*, 2013, http://csalateral.org/issue/2/up-for-grabs-early-digital-art-taylor

---. *When the Machine Made Art: The Troubled History of Computer Art*. Bloomsbury Academic, 2014.

Tilton, Homer B. *The 3-D Oscilloscope*. Prentice Hall, 1987.

Tung, Liam. *Google Employees Protest: "Stop Work on AI for Pentagon Drone Video Analysis". ZDNet.* 2018, https://www.zdnet.com/article/google-employees-protest-stop-work-on-ai-for-pentagon-drone-video-analysis/

Turim, Maureen, and Scott Nygren. "Reading the Tools, Writing the Image." *Steina and Woody Vasulka: Machine Media*, edited by San Francisco Museum of Modern Art, San Francisco Museum of Modern Art, 1996, pp. 49–64.

Turner, Felix. *Rutt-Etra-Izer*. 2011, https://www.airtightinteractive.com/2011/06/rutt-etra-izer/

Ulmann, Bernd. *AN/FSQ-7: The Computer That Shaped the Cold War*. De Gruyter Oldenbourg, 2014.

Vasulka, Steina, Woody Vasulka, Don Foresta, and Christine Carlut. "A Conversation between Steina and Woody Vasulka, Don Foresta and Christine Carlut." *Buffalo Heads: Media Study, Media Practice, Media Pioneers, 1973-1990*. Woody Vasulka and Peter Weibel, editors. ZKM/Center for Art and Media Karlsruhe ; MIT Press, 2008, pp. 498–507.

Vasulka, Woody, Steina Vasulka, Peter Weibel, and David Dunn, editors. *Eigenwelt Der Apparatewelt: Pioneers of Electronic Art*. Ars Electronica/The Vasulkas Inc., 1992.

Vasulka, Woody. "Five Lectures." *Buffalo Heads: Media Study, Media Practice, Media Pioneers, 1973-1990*. Woody Vasulka and Peter Weibel, editors. ZKM/Center for Art and Media Karlsruhe ; MIT Press, 2008, pp. 411–19.

Vasulka, Woody, and Charles Hagen. "A Syntax of Binary Images."
Buffalo Heads: Media Study, Media Practice, Media Pioneers, 1973-1990.
Woody Vasulka and Peter Weibel, editors. ZKM/Center for Art and Media
Karlsruhe ; MIT Press, 2008, pp. 420–37.

Vasulka, Woody, and Scott Nygren. "Didactic Video: Organizational
Models of the Electronic Image." *Buffalo Heads: Media Study, Media Practice,
Media Pioneers, 1973-1990*. Woody Vasulka and Peter Weibel, editors. ZKM/
Center for Art and Media Karlsruhe ; MIT Press, 2008, pp. 400–409.

Vector General, Inc. *Vector General Graphics Display Reference Manual*. 1972.

Waite, Mitchell. *Projects in Sight, Sound and Sensation*. Howard W. Sams
& Co, 1974.

---. "The Oscilloscope Graphic Artist." *Popular Electronics: Electronic
Experimenter's Handbook*, 1980, pp. 21–25.

Warren, Tom. "Bitcoin Mania Is Hurting PC Gamers by Pushing up GPU
Prices." *The Verge*, 30 Jan. 2018, https://www.theverge.com/2018/1/30/
16949550/bitcoin-graphics-cards-pc-prices-surge

Whitney, John Sr. *A Personal Search For the Complementarity of Music and
Visual Art*. 1992, https://www.youtube.com/watch?v=uunwKF7AUkc

---. *Digital Harmony: On the Complementarity of Music and Visual Art*.
Byte Books, 1980.

Williams, Raymond. *Television: Technology and Cultural Form*. Routledge, 2003.

Yalkut, Judd. *Open Circuits: The New Video Abstractionists*. 1973,
http://www.vasulka.org/Kitchen/K_Audio.html

Youngblood, Gene. *Expanded Cinema*. 1st ed, Dutton, 1970.

---. "Calculated Movements: An Interview with Larry Cuba." *Video and the
Arts Magazine,* Winter 1986, https://people.well.com/user/cuba/VideoArt.html

---. "Interview with the Vasulkas." *Buffalo Heads: Media Study, Media
Practice, Media Pioneers, 1973-1990*. Woody Vasulka and Peter Weibel,
editors. ZKM/Center for Art and Media Karlsruhe ; MIT Press, 2008,
pp. 442–55.

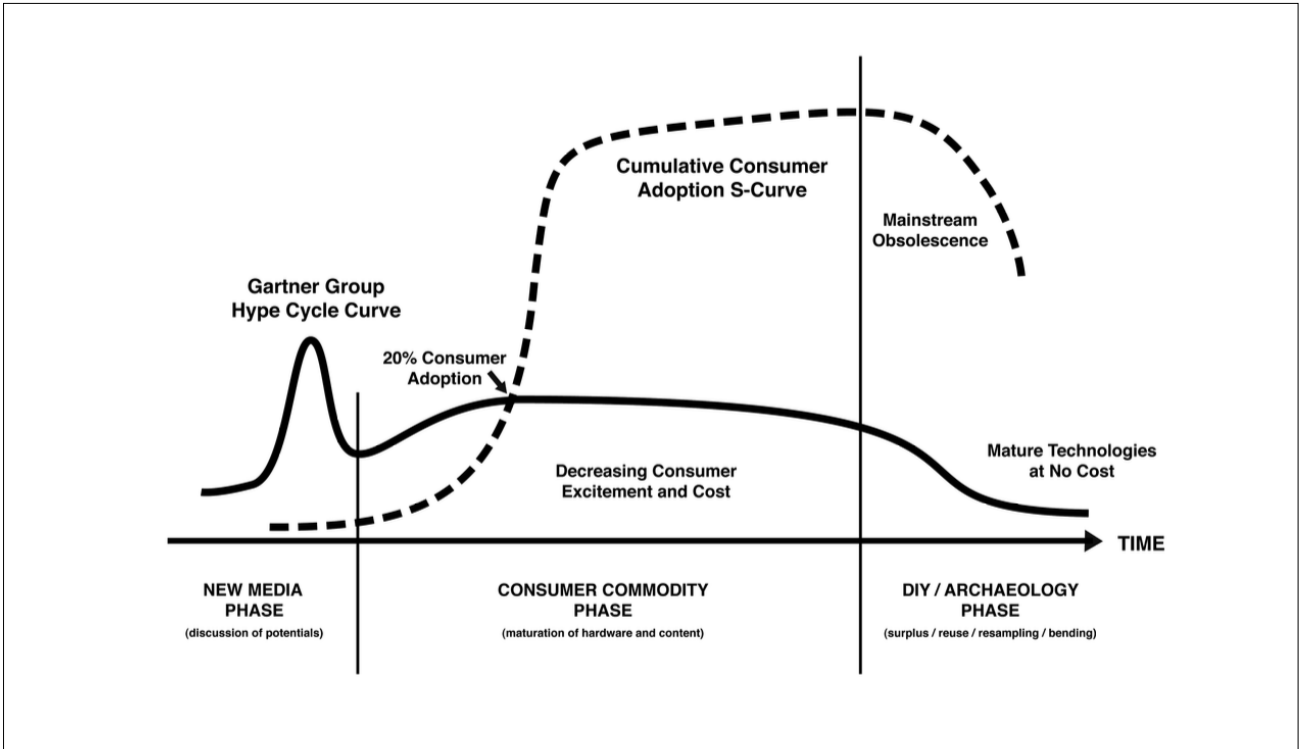Zielinski, Siegfried. *Deep Time of the Media: Toward an Archaeology of*
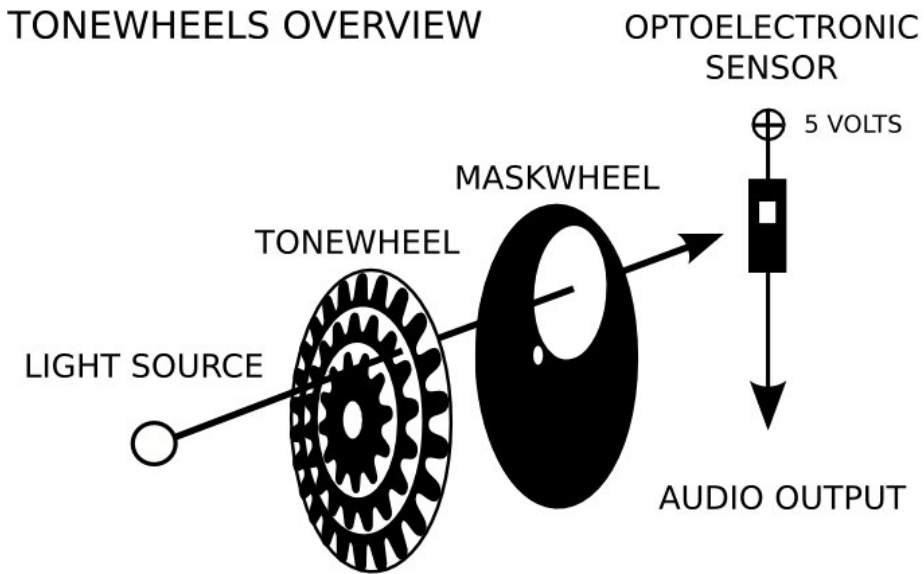
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Figure I
The Semi Automated Ground Environment system.
Brochure cover, detail (Stromberg-Carlson Corp.,
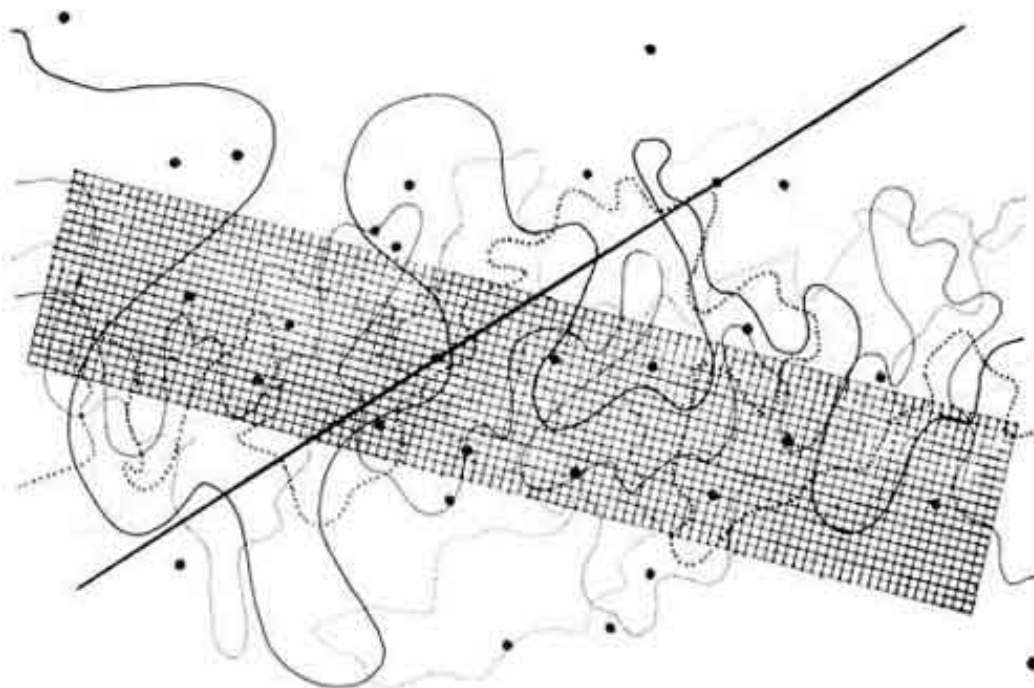*Multi-Purpose Military Displays*, 1960).

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Figure **II**
Garnet Hertz, *Phases of media positioned in reference to political economy* (Hertz and Parikka 2012: 428).
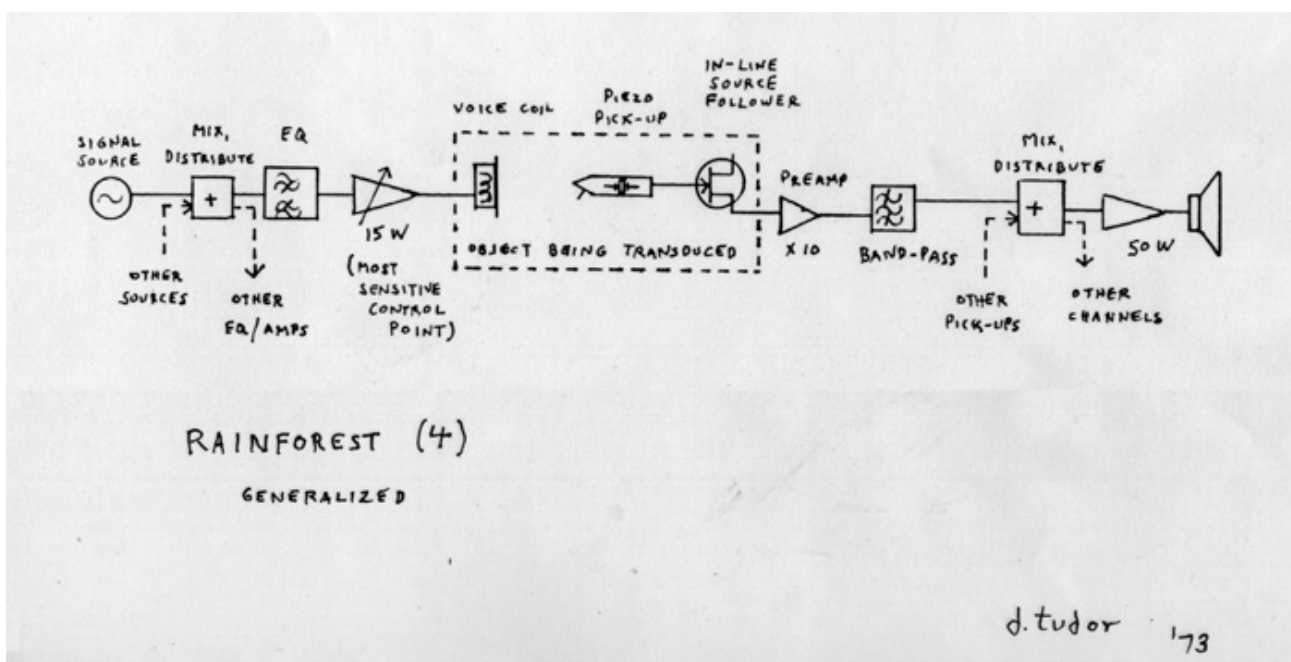

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Figure **III**
Derek Holzer, Tonewheels system, 2010.

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Figure IV
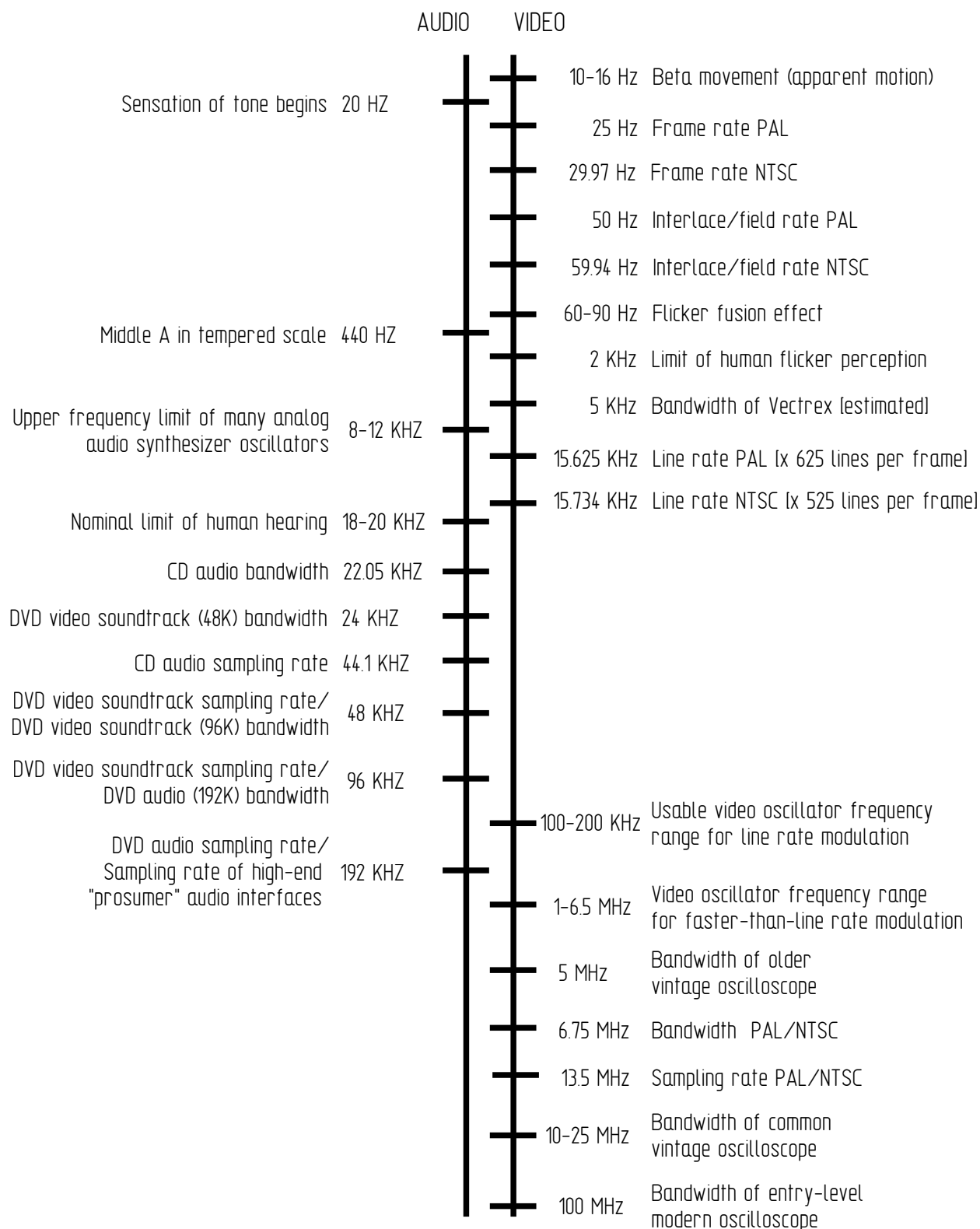John Cage, *Fontana Mix*, 1958 (johncage.org. 2018).

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Figure V
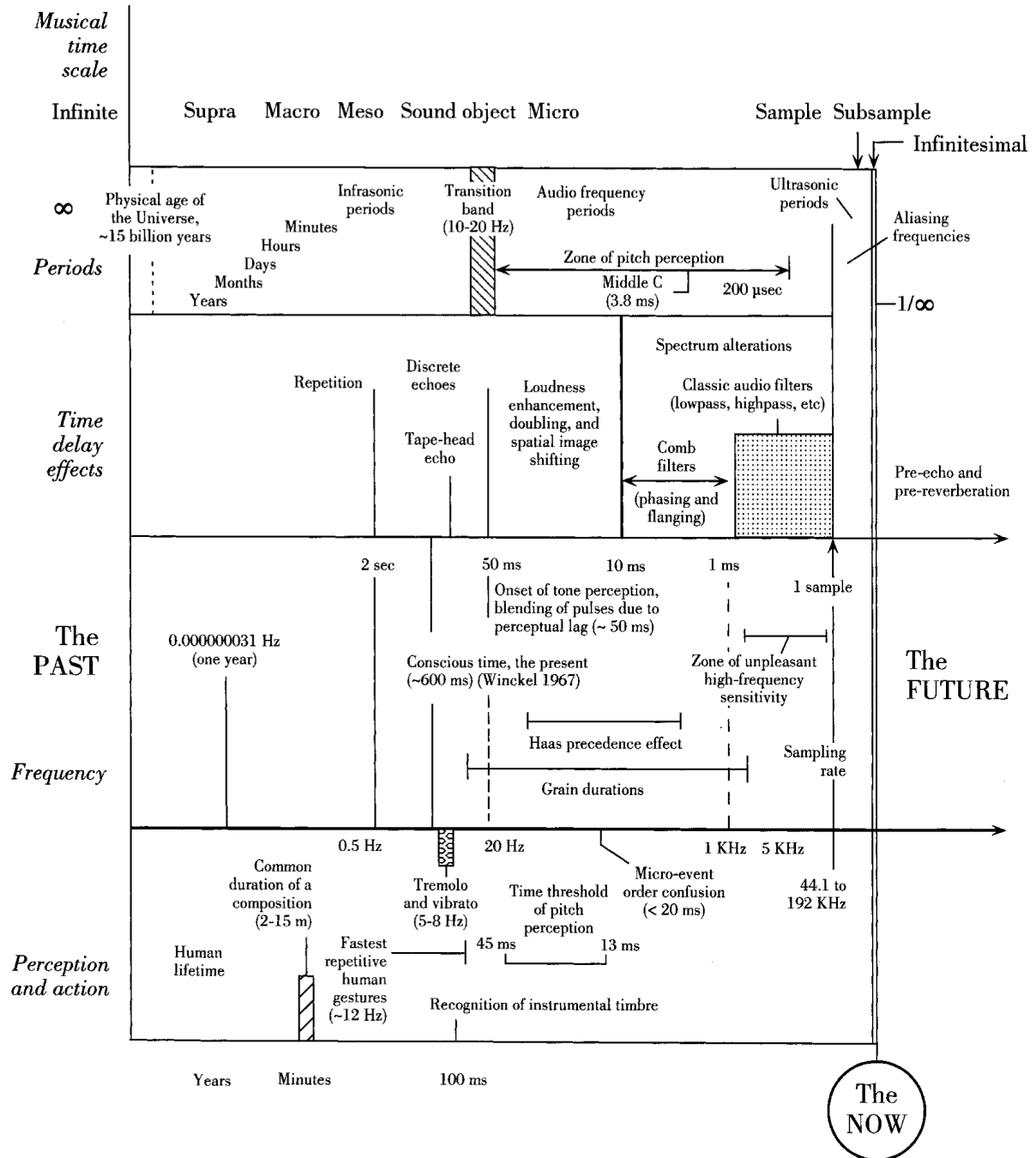David Tudor, *Rainforest* 4, 1973 (Rogalsky 2006: 202).

A Comparison of Frequencies and Bandwidths of Audio and Video Signals
(not to scale)

AUDIO   VIDEO

|		
	10-16 Hz	Beta movement (apparent motion)
Sensation of tone begins 20 HZ	25 Hz	Frame rate PAL
	29.97 Hz	Frame rate NTSC
	50 Hz	Interlace/field rate PAL
	59.94 Hz	Interlace/field rate NTSC
	60-90 Hz	Flicker fusion effect
Middle A in tempered scale 440 HZ	2 KHz	Limit of human flicker perception
	5 KHz	Bandwidth of Vectrex (estimated)
Upper frequency limit of many analog audio synthesizer oscillators 8-12 KHZ	15.625 KHz	Line rate PAL (x 625 lines per frame)
	15.734 KHz	Line rate NTSC (x 525 lines per frame)
Nominal limit of human hearing 18-20 KHZ		
CD audio bandwidth 22.05 KHZ		
DVD video soundtrack (48K) bandwidth 24 KHZ		
CD audio sampling rate 44.1 KHZ		
DVD video soundtrack sampling rate/ DVD video soundtrack (96K) bandwidth 48 KHZ		
DVD video soundtrack sampling rate/ DVD audio (192K) bandwidth 96 KHZ		
	100-200 KHz	Usable video oscillator frequency range for line rate modulation
DVD audio sampling rate/ Sampling rate of high-end "prosumer" audio interfaces 192 KHZ	1-6.5 MHz	Video oscillator frequency range for faster-than-line rate modulation
	5 MHz	Bandwidth of older vintage oscilloscope
	6.75 MHz	Bandwidth PAL/NTSC
	13.5 MHz	Sampling rate PAL/NTSC
	10-25 MHz	Bandwidth of common vintage oscilloscope
	100 MHz	Bandwidth of entry-level modern oscilloscope

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Figure VI

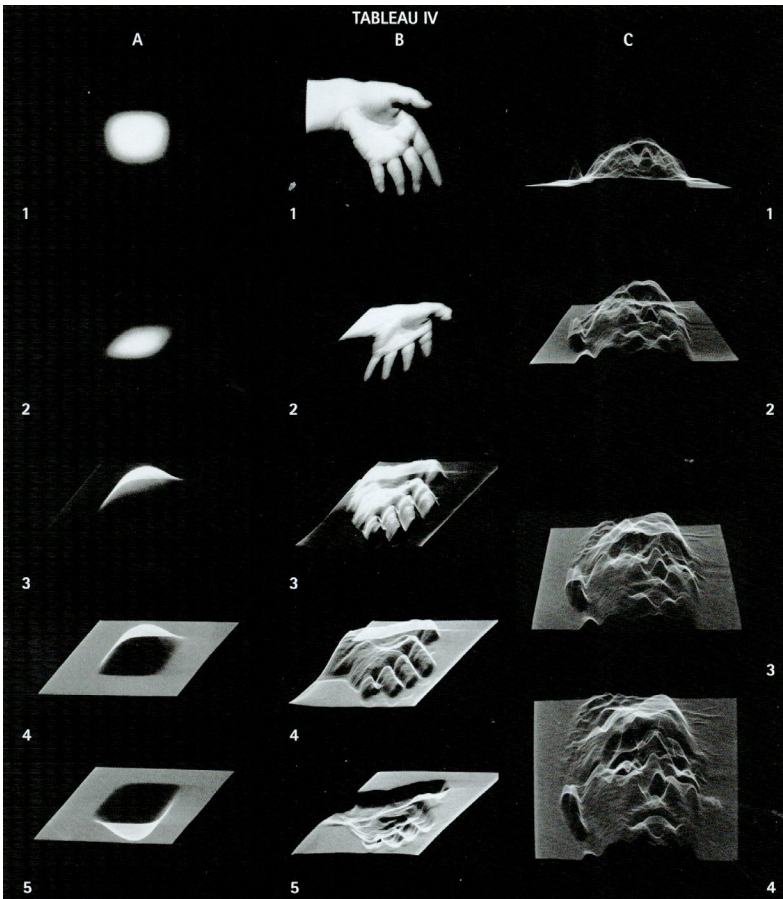A comparison of frequencies and bandwidth of audio and video signals.

Figure VII

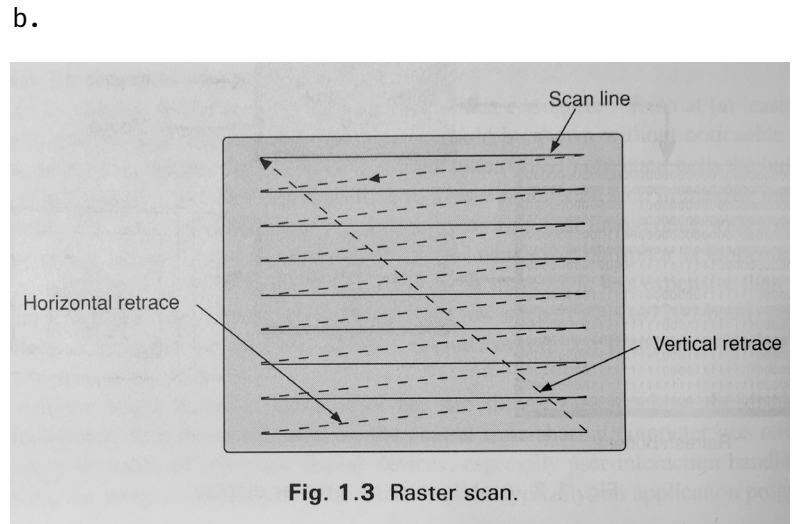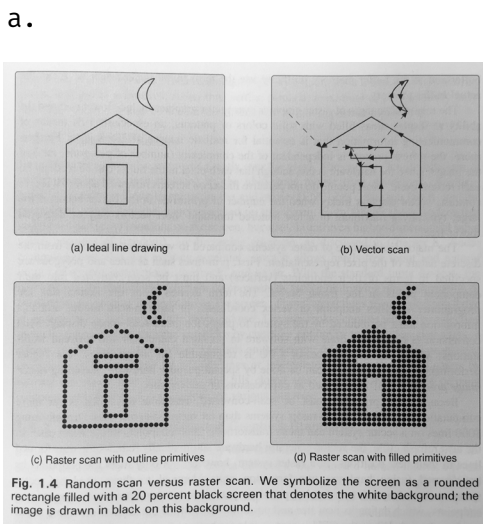Curtis Roads, *Time scales of music* (Roads 2004: 5).
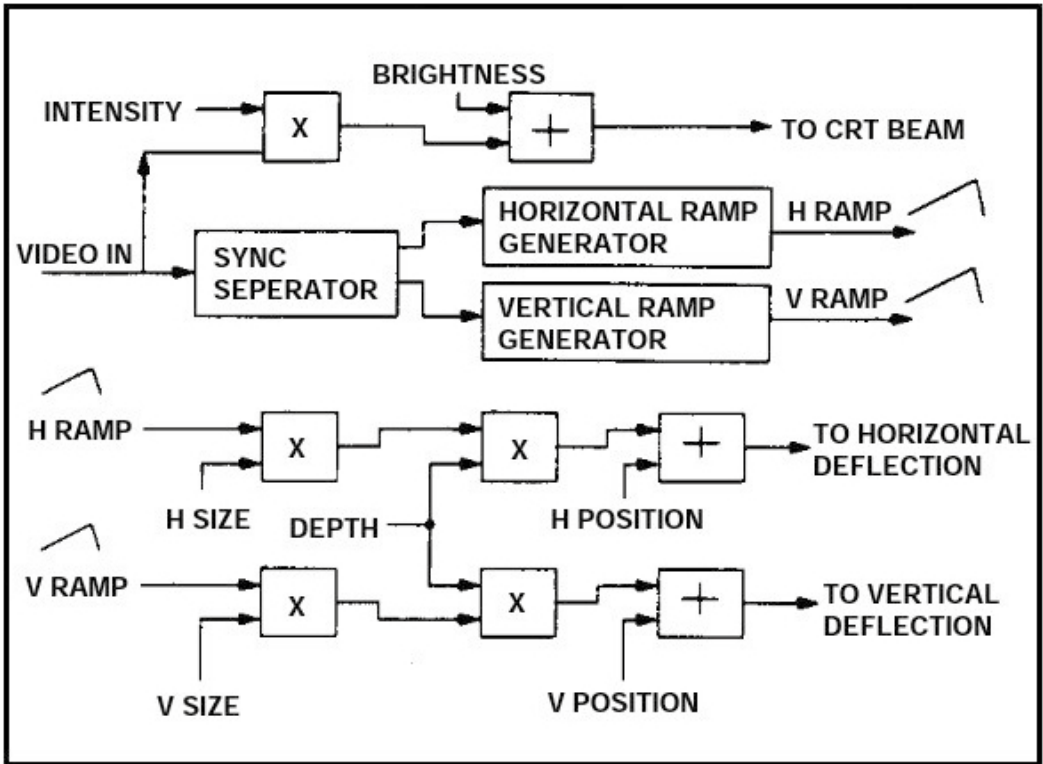
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Figure VIII
Rutt/Etra Synthesizer block diagram (Vasulka et al 1992: 139).

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Figure IX
Woody Vasulka and Scott Nygren, *Didactic Video* (2008: 408).

phase / frequency ratio	0°	45°	90°	135°	180°
1 : 1					
1 : 2					
1 : 3					
2 : 3					

......

Figure X

Lissajous figures.

a.

b.

(a) Ideal line drawing

(b) Vector scan

(c) Raster scan with outline primitives

(d) Raster scan with filled primitives

Fig. 1.4 Random scan versus raster scan. We symbolize the screen as a rounded rectangle filled with a 20 percent black screen that denotes the white background; the image is drawn in black on this background.

Scan line

Horizontal retrace

Vertical retrace

Fig. 1.3 Raster scan.

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Figure XI

a. Vector vs raster graphics systems, b. Video raster (Foley, James D., et al. *Computer Graphics: Principles and Practice.* 2nd ed, Addison-Wesley Publishing Company, 1990. pp 12-13).
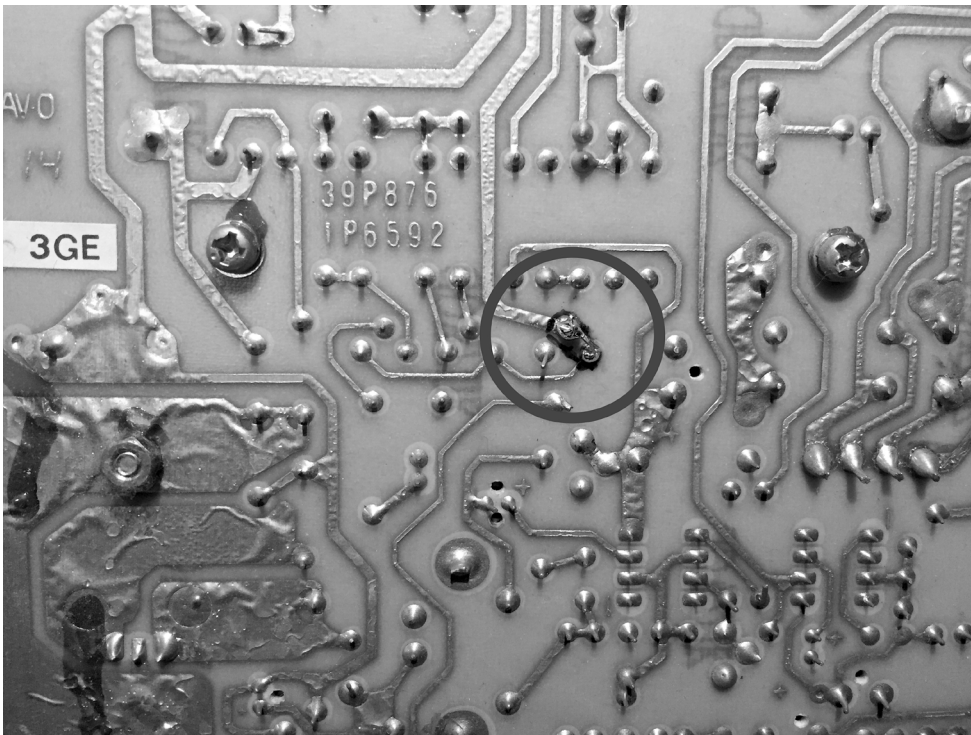
......
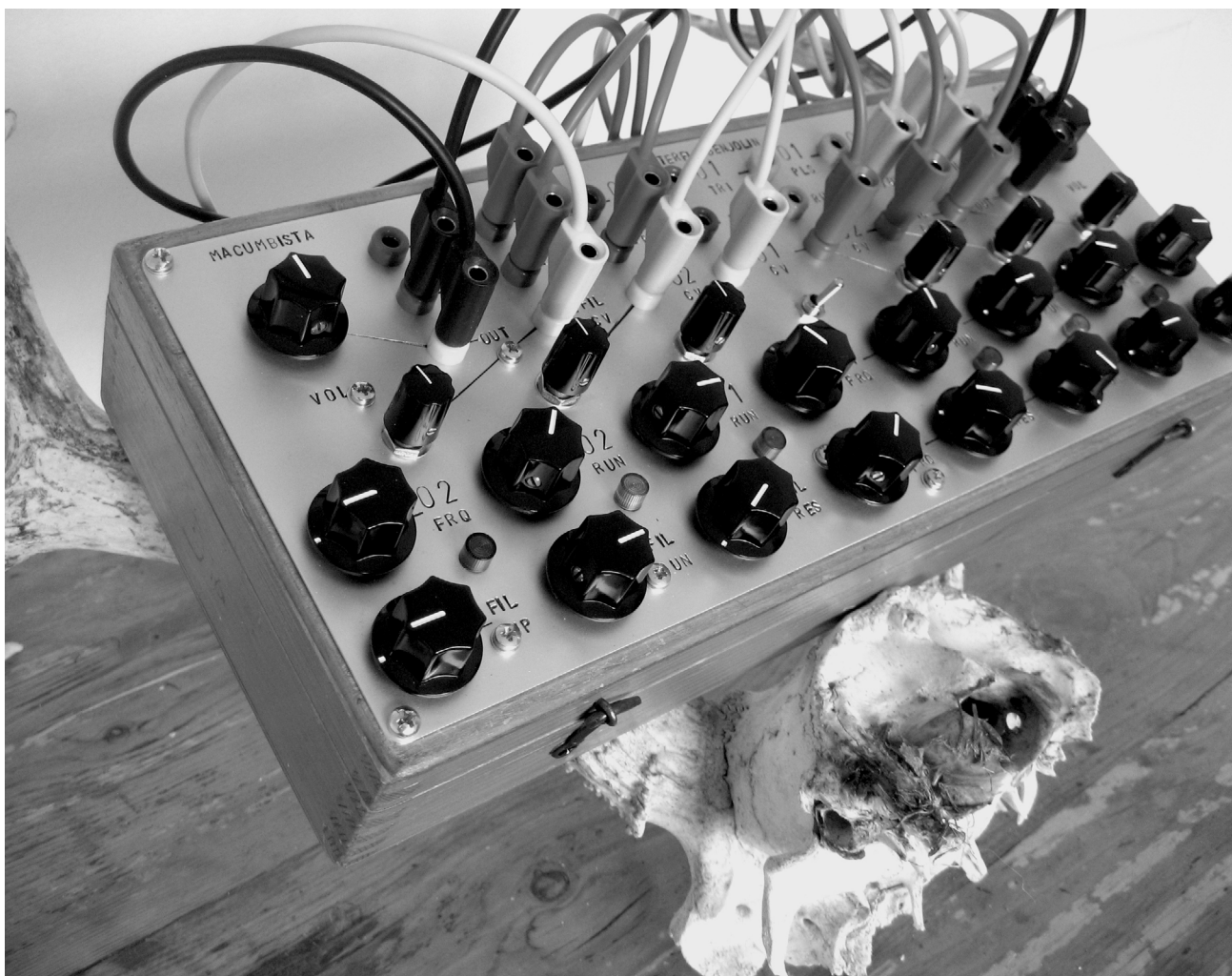
Figure XII

Derek Holzer, self made Benjolin synthesizer, 2014.

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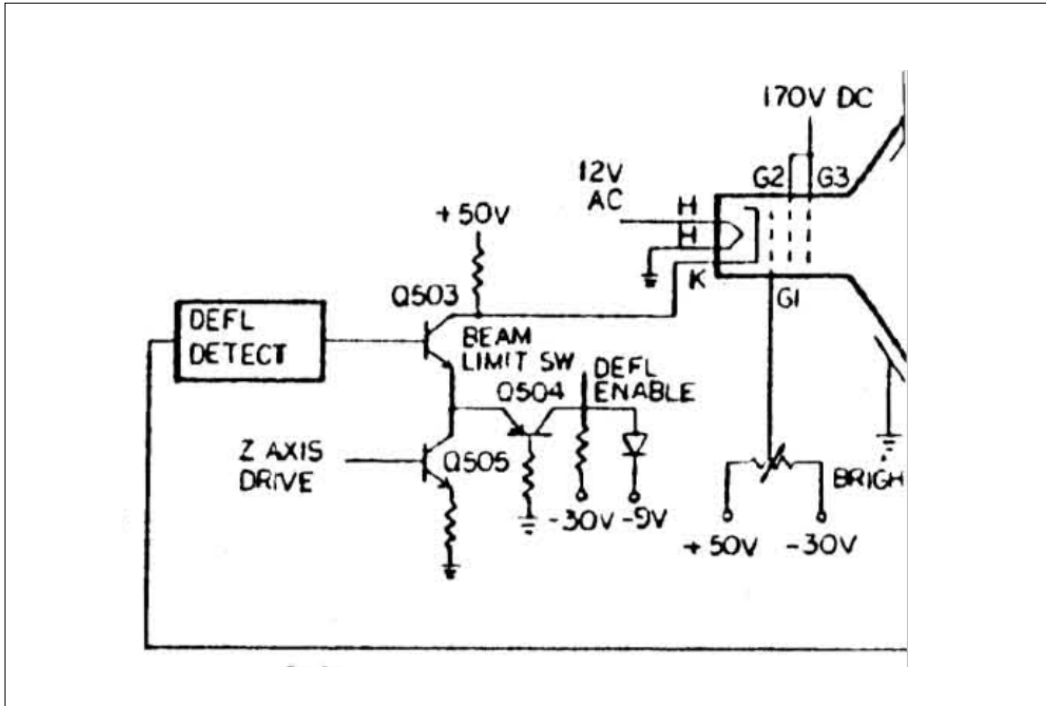
Figure XIII
Vectrex "spot killer" schematic (General Consumer Electronics 1982: 29).

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Figure XIV
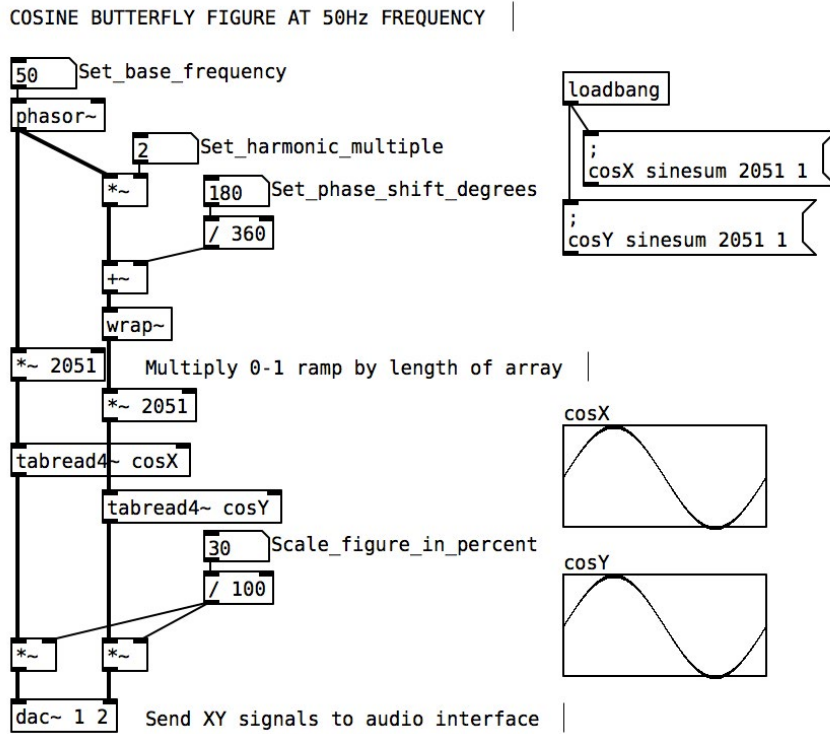Vectrex "spot killer" modification.

NAME	AUTHOR	URL	PLATFORM	INTERFACE	INPUTS	OUTPUTS	OPEN SOURCE	YEAR
Oscilloscope Music	Jerobeam Fenderson	http://oscilloscopemusic.com/maxforlive.php	Max/MSP	GUI, Live timeline	MIDI	Audio (2ch)	Patches	2016
OsciStudio	Hansi Raber	http://oscilloscopemusic.com/oscistudio.php	Open Frameworks	GUI, timeline, livecoding	Audio, MIDI, Blender, OBJ, SVG	Computer display, Audio (2ch)	No	2016
XYscope	Ted Davis	http://teddavis.org/xyscope	Processing	Coding	Audio, video camera, font, + others via Processing libraries	Audio (2/3ch), ILDA	Yes	2017
REWereHere	Ivan Marušić Klif	http://i.m.klif.tv/rewerehere	Max/MSP/Jitter	GUI, patching	Audio, video camera, MIDI, video/image file	Computer display, Audio (3ch)	Patches	2017
Vector Synthesis	Derek Holzer	http://github.com/macumbista/vectorsynthesis	Pure Data	Patching, GUI	Audio, video camera, MIDI, OSC, video/image file	Audio (2/3/5ch), ILDA (planned)	Yes	2017

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Figure XV

Overview of existing audiovisual oscillographic software.

COSINE BUTTERFLY FIGURE AT 50Hz FREQUENCY

```
50   Set_base_frequency
phasor~
     2   Set_harmonic_multiple
*~        180   Set_phase_shift_degrees
          / 360
     +~
     wrap~
*~ 2051   Multiply 0-1 ramp by length of array
          *~ 2051
tabread4~ cosX
          tabread4~ cosY
               30   Scale_figure_in_percent
               / 100
*~        *~
dac~ 1 2   Send XY signals to audio interface
```

```
loadbang
;
cosX sinesum 2051 1
;
cosY sinesum 2051 1
```

cosX

cosY

......

Figure XVI

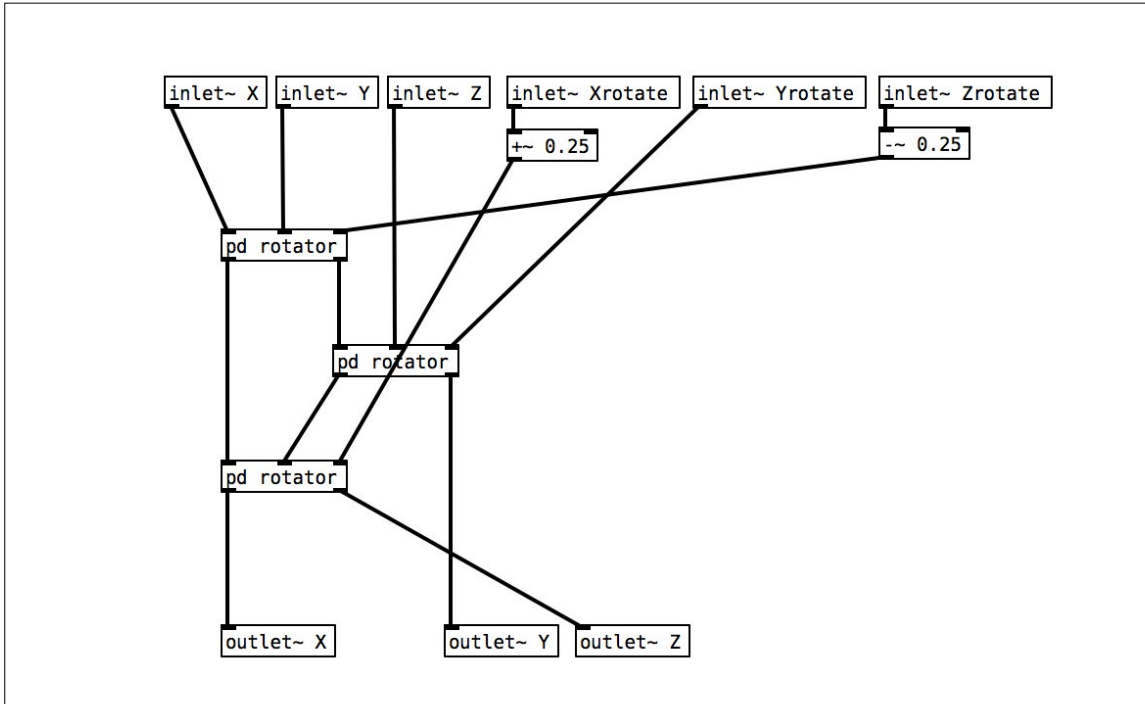Phase-locked, phase-shifted, and harmonically multiplied sawtooth waves.
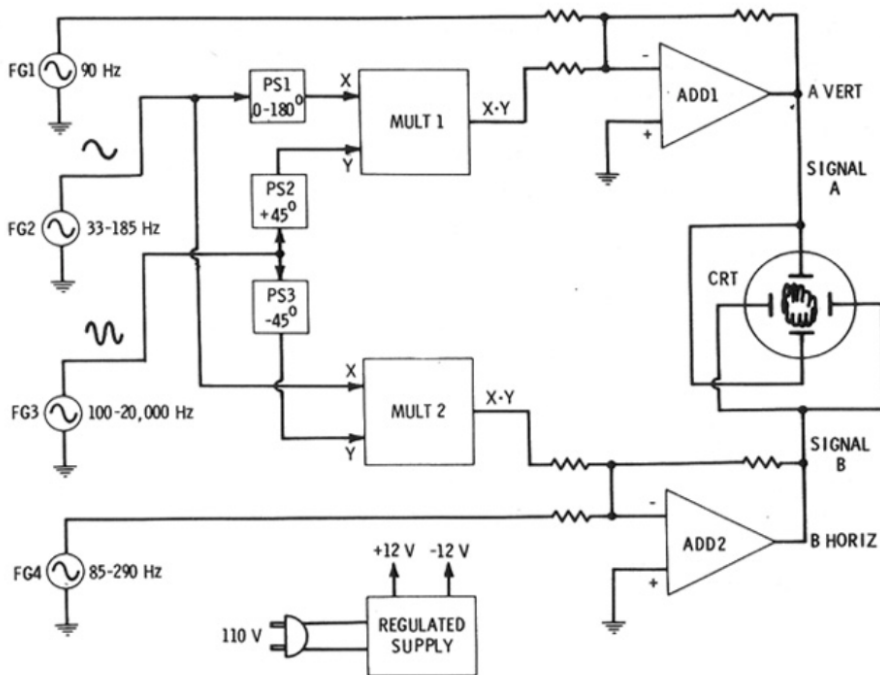
Fig. 1-8. Syntheshape block diagram.

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Figure XVII

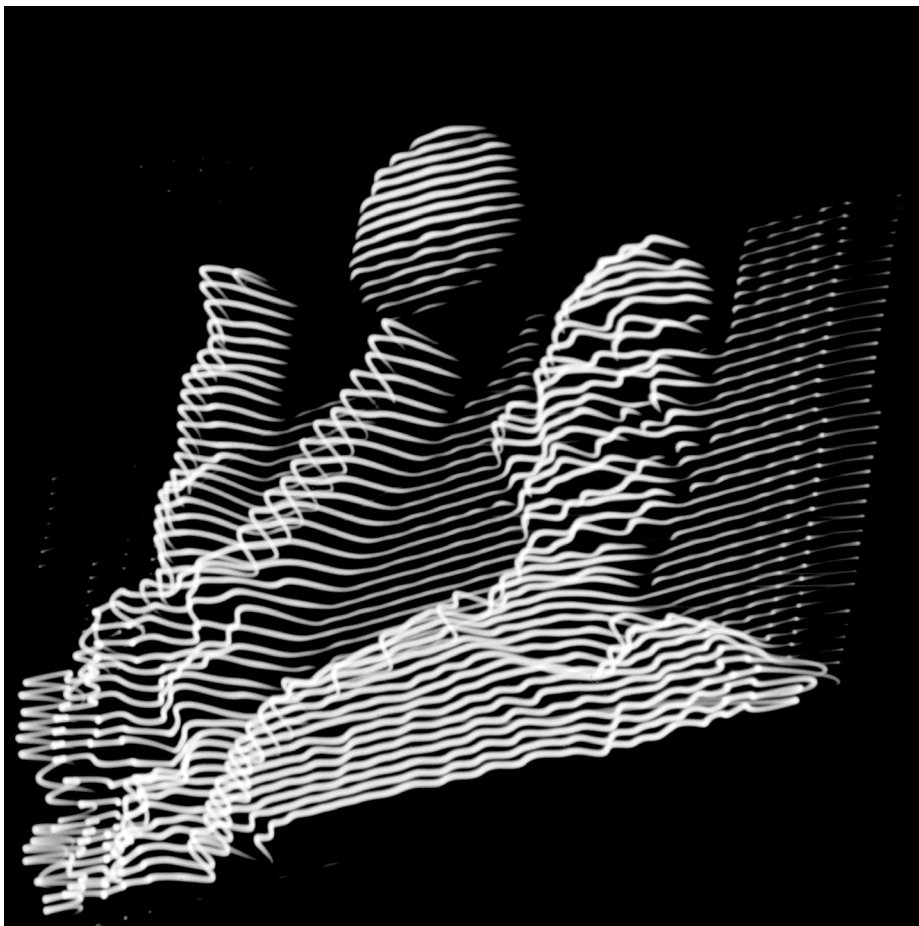Mitchell Waite, *Syntheshape* (Waite 1974: 13).

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Figure XVIII
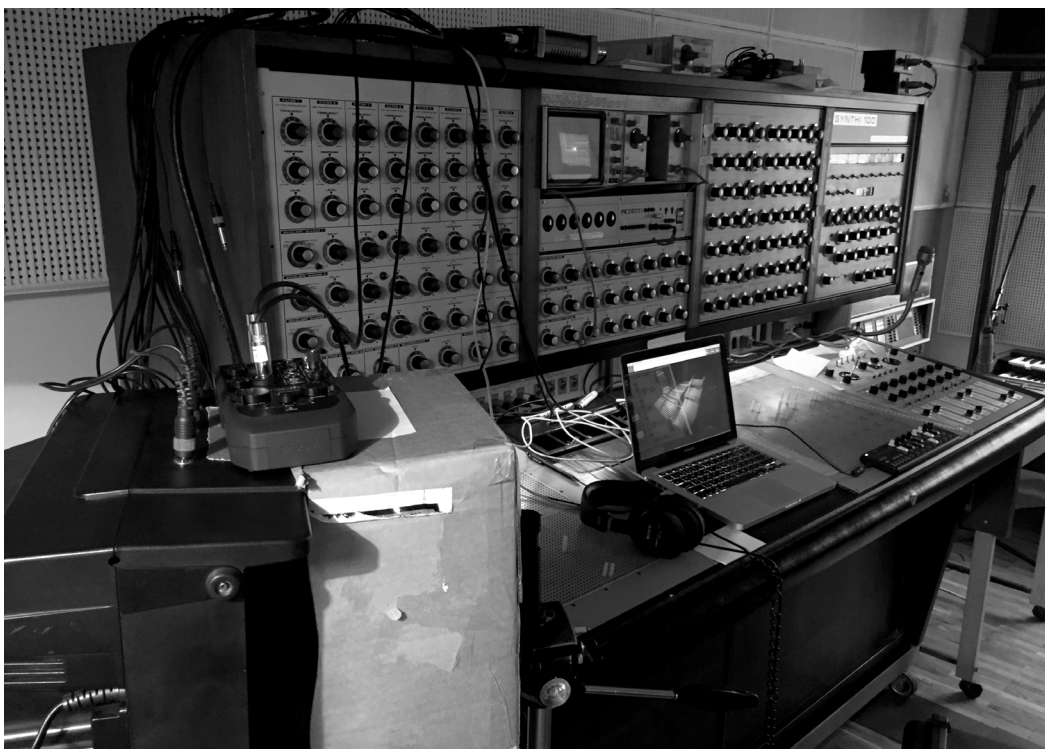3D rotation matrix.

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Figure XIX
Derek Holzer,
2D scan processed
image, 2017.

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Figure XX
Derek Holzer,
3D scan processed
image, 2017.

......
Figure XXI
Radio Belgrade EMS Synthi 100 analog synthesizer, 2018.