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SIMULATED MEDIATION: A SONIC HISTORY OF MEDIATION, AFFECT AND DIGITAL AESTHETICS

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ABSTRACT - SIMULATED MEDIATION A SONIC HISTORY OF MEDIATION, AFFECT AND DIGITAL AESTHETICS - RYAN PAGE

This dissertation examines the intersection of mediation and simulation as aesthetic strategies, ideologies, and epistemologies, in relation to electronic music and commercial audio technologies. It explores the complex networks of influence between the avant-garde, popular culture and the tools for commercial sound production, such as software plugins, analog and digital emulations of circuits, and modular synthesizers. Throughout this document, the author outlines a philosophy and methodology for a poetics of simulated media applied to sound. Simulated mediation is the simulation of the aesthetic characteristics of media technologies. Simulation, within the context of this dissertation, is defined as the logical abstraction of perceptual information for the purpose of generating perceptually similar information. While there is a technical component to simulation, it is the relationship between the visual and aural output of a technical system and the object it represents that produces a simulation. The author explores the ubiquity of simulated media, as well as the potential for digital aesthetics outside of this framework. Through interviews with composers as well as instrument and effects designers, the author analyzes subjectivity in simulation and its relationship to nostalgia and the uncanny. The author concludes by examining various simulations, including tools they created, by applying the methodologies established therein.

This dissertation is dedicated to Sana Amini.

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INTRODUCTION:
MEDIA AS INSTRUMENTS/INSTRUMENTS AS MEDIA

I remember the first time I consciously considered simulated mediation. I was trying to describe a quality of light and found myself at a loss for words. I had a distinct memory of standing in the lobby of an apartment building with a set of stairs leading up into the darkness, a raised area underneath the stairs piled high with detritus, and various other details about the space. However, what I remembered most distinctly was the strange quality of the light; it looked as if it was filtered through television static. It had the texture of chalk or dust. I was aware that media produced affective experiences, at least in a vague sense, before this. I knew that cassette tapes seemed to bury the music I recorded onto them in noise and that—although I later came to admire their kitsch—digital emulations of analog guitar amplifiers sounded strange and unrealistic. These observations were never connected to the idea of simulation until I wrote down a description of this quality of light that I half-remembered.

I eventually realized that I was remembering a video game. The particular game, *Silent Hill 2* (Konami, 2001), continues to haunt my thinking about media. It is one of the first games to feature extensive, non-diegetic, simulated mediation in the form of simulated film noise. The visual and aural aesthetic of *Silent Hill* continues to influence the use of simulated mediation in games, television, and film. My Proustian nostalgia in recounting the quality of that light merged with the uncanny realization that this aesthetic only existed in virtual form. I had no understanding of how digital media functioned, which undoubtedly added to the sense of mystery. However, it was not just my lack of understanding that disturbed me; it was my certainty that I had perceived the scene. I recalled my vision processed through a filter of simulated film grain. One of the paradoxes of simulated mediation is that, despite its potential to draw attention to the constructed surface of media, digital interfaces train users to look and listen beyond mediation to the content within, and, as a result, mediation occupies a liminal space that constructs the aesthetic and affective gestalt that characterizes content.

This nagging sense of the uncanny began the line of inquiry leading to my current research. Simulation is often presented as an ontological challenge to "reality," as reported by the human sensory apparatus.[1] In the scores of fictional and philosophical accounts of simulation I read during my research, the vast majority take great care to dismiss or avoid addressing the contemporary art of simulation. The differences that distinguish simulation from human perception are presented as problems that the forward march of technological development will inevitably solve. This perfect simulation, then, will require philosophical intervention by virtue of the ontological crisis this instantiates.

My early experience with simulated mediation provoked a different line of thought: What happens if one rejects the idea of unmediated perception? More pointedly, what happens if one rejects the hierarchy of the real above the simulated? Finally, is it possible to provide a positive definition of simulation rather than

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[1] I will explore numerous examples of this later in the text.

defining it by what it lacks?[2] My memory ultimately consisted of “real” phenomena such as light and sound. What distinguished it were the processes used to construct the experience—the intentional and unintentional choices shaping the information I received. The constructed nature of simulations—the fact that they are explainable and reducible to binary logic—creates their uncanniness. My focus on the technical processes undergirding simulation is driven by my desire to highlight the uncanniness of simulation, not to “explain it away.” One of the necessary outcomes of this is my demystification of processes that are generally spoken of only in metaphor. Distinctions that initially appear to be insignificant may have far-reaching effects on the aesthetics and meaning of an artwork.

My theorization of simulation and the poetics of mediation bears a direct but nonlinear relationship to my art. While academic art praxis often consists of a recursive relationship between research and artistic practice, it is less common—within media studies or the humanities in general—for these to be interwoven to the degree I have within this dissertation. While I largely avoid addressing my music and software for the first four chapters, the writing remains focused on questions specifically related to my practices as a composer and instrument designer. I have never been entirely comfortable with my methodology as a composer, primarily due to the nagging sense that the way in which music is formalized—even within the context of experimental music—is incapable of capturing what I hear as the most

[2] This last question is influenced by the writing of Melle Jan Kromhout, whose work I will later discuss.

significant aspects of sound. The material properties of media that produce and transform sound, their cultural connotations, and their effect on sonic practices remain my principal interest. The theoretical framework presented herein represents an attempt at formalizing the relationship of aesthetics to simulation and expanding the framework within which I organize aesthetic phenomena. At the same time, acknowledging the subjective, personal associations with media technologies that inform the process of simulation[3] was also an essential component of the writing process.

The following work outlines strategies for analyzing musical instruments and tools for shaping sound from the perspective of a theorization of media rather than experimental music scholarship. I view technology—in the form of instruments and audio processing—as not only a form of knowledge production but a means through which knowledge is transmitted. Rather than flattening the wide array of forms through which knowledge passes into "text," I explore how each form of transduction, from electronic circuits to music and simulations, creates affordances that influence how this knowledge changes.

While it is not uncommon for musicologists to address the biographical or social context of a composer's oeuvre or even the relationship between a particular technology and a musical composition, an analysis of the aesthetics of a media technology—in both its musical and functional contexts—and its relationship to popular and experimental music is still somewhat rare. Composers and sonic artists

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[3] As well as the works of sonic art made with simulations.

have historically embraced consumer media technologies as both sonic and structural elements in their work. The field of musicology has, however, until recently, largely ignored the relationship between the limitations and biases of media technology and musical form. As Ezra Teboul notes, "Most studies of electronic and experimental music acknowledge electronics in the development of their object of analysis, but rarely engage with a systematic technical study of said objects."[4] This has changed extensively over the past several years with important contributions from scholars such as Teboul,[5] Madison Heying,[6] You Nakai,[7] Ted Gordon,[8] Kenneth McAlpine[9] and Melle Jan Kromhout.[10] The work of constructing a simulation, if it is possible to separate it from the music created with it, requires a different form of analysis, one that is perhaps better served by the techniques and methodologies of media studies. This offers an opportunity for those in adjacent fields such as science and technology studies, media studies, or sound studies, to develop an analysis that provides equal emphasis on music and "non-musical" sound. What can these forms of scholarship, without the need to respond to the historical methodologies of music, teach us about how technologically mediated music is received and how it is practiced? Conversely,

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[4] Ezra Teboul "A Method for the Analysis of Handmade Electronic Music as the Basis of New Works" PhD Diss. (Rensselaer Polytechnic Institute, 2020).
[5] Ibid.
[6] Madison Heying "A Complex and Interactive Network: Carla Scaletti, the Kyma System, and the Kyma User Community" PhD Diss. (University of California, Santa Cruz, 2019).
[7] You Nakai, *Reminded by the Instruments: David Tudor's Music* (Oxford University Press, 2020).
[8] Melle Jan Kromhout, "Noise Resonance: Technological Sound Reproduction and the Logic of Filtering" PhD Diss. (University of Amsterdam).
[9] Kenneth B. McAlpine, *Bits and Pieces: A History of Chiptunes*, Illustrated edition (New York, NY: Oxford University Press, 2018).
[10] Ted Gordon "Bay Area Experimentalism: Music and Technology in the Long 1960s" PhD Diss. (University of Chicago, 2018.)

what can the relationships of composers to media and media to instruments tell us about the nature of human interactions with technology generally? As Teboul notes,

> [M]odern discussions of technology in music seem to be concerned primarily with how things work (or can work, or should work) rather than who they work for, what they mean, and how they have been used for music.[11]

To this I would add that, given the assumed objectivity of the engineering and design processes for media technologies and musical instruments, not enough attention has been paid to the aesthetic judgments governing those decisions or their influence on the art made using these technologies. This issue is even more apparent in simulations of media. Perhaps because technologists present simulation as a derivative process, the problem of simulating an extant technology is often presented as purely technical. Simulation is treated as an outgrowth of mathematics or logic. As I will later show, the use of "expert listeners," used in the modeling process for commercial audio simulations, demonstrate the process' reliance on empirical observation and subjective taste.

In western culture, both media technologies and simulations are often treated as "black boxes," where the changes between input and output are known, but intervening processes are left undescribed. As I will later demonstrate, the marketing materials from music technology companies, such as Universal Audio and Arturia, emphasize the similarities between simulations and the original devices. Companies

[11] Ibid.

market these devices as convenient, "authentic"[12] replacements for bulky hardware. It does not benefit them to emphasize differences between a simulation and the simulated. However, when one accepts that a VCR and a VHS simulator impart the same aesthetic result, it is easy to overlook the internal processes that produce these results. The choice of what to retain, abstract, or expand is deeply personal and depends on the purpose of a simulation. While philosophers,[13] technologists,[14] science-fiction authors,[15] and filmmakers[16] have tended to emphasize the ontological difference between the simulated and the real, the functional differences are often more significant. A simulated VCR designed to impart the visual and aural aesthetics of VHS on prerecorded material may suffice for a content creator looking to create material with a similar visual aesthetic but is of no use to an artist trying to access documentation of their art in that format.

To understand the relevance of simulated mediation, one must first accept that the material properties of media restrict the range of possible aesthetic outcomes of said media. I refer to this as a "poetics of mediation." The use of media poetics raises

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[12] Roland Corporation, "Roland - SYSTEM-8 | PLUG-OUT Synthesizer," Roland, accessed April 5, 2022, https://www.roland.com/us/products/system-8/; Simon Gareste, "Arturia - Buchla Easel V - Buchla Easel V," accessed January 13, 2022, https://www.arturia.com/products/analog-classics/buchla-easel-v/overview; "AMS DMX Digital Delay & Pitch Shifter | UAD Audio Plugins | Universal Audio," accessed January 9, 2022, https://www.uaudio.com/uad-plugins/delay-modulation/ams-dmx-digital-delay-pitch-shifter.html.

[13] David J. Chalmers, *Reality+: Virtual Worlds and the Problems of Philosophy* (New York, NY: W. W. Norton & Company, 2022).

[14] Alan M. Turing, *The Essential Turing: Seminal Writings in Computing, Logic, Philosophy, Artificial Intelligence, and Artificial Life plus The Secrets of Enigma,* ed. B. Jack Copeland, 1st edition (Oxford : New York: Clarendon Press, 2004);

[15] Philip K. Dick, *Do Androids Dream Of Electric Sheep?*, New Ed edition (London: Gollancz, 1999); William Gibson, *Neuromancer*, 1st edition (New York: Ace, 1984).

[16] Lana Wachowski and Lilly Wachowski, *The Matrix - Standard Collector's Edition*, 1999; Cronenberg, David. *Existenz*, 1999. Alex Proyas, Dark City, 1998; Proyas, Alex. Dark City, 1998.

relevant questions regarding creativity, agency, and authorship: How does one consider the contributions of engineers to uses of technology that they, in many cases, could not have foreseen? What, if anything, does the technology itself contribute? What "slips through the cracks" when a design is transformed into a material object?

For particularly lossy communications technologies, such as early cellular phones, VHS tapes, AM radios, or wire recorders, the aesthetic effect is obvious. These are technologies that cannot produce the original signal without noticeable inaccuracies. For others, such as lossless PCM audio, the "sound" of the technology is less apparent. Regardless, it is precisely the limitations and biases that define media technologies and mediation itself. Media are defined, not only by the ways in which they diverge from each other but how they diverge from human sensory perception. Limitations to resolution or other forms of perceptible distortion and noise come to characterize media technologies.

These qualities are what make a simulation meaningful and are reflected to a greater or lesser degree in each of the works I examine. To simulate a VHS tape, one does not simply render images and sound. Instead, a simulation will recreate some or all of the aesthetic properties of VHS—such as lowered resolution, 4:3 aspect ratio, increased color saturation, subtle vibrato, and noise—that distinguish it from "unmediated" sound and vision. In offering a historical parallel between what I have dubbed "simulated mediation" and the broader "poetics of mediation," I aim to derive methodologies for producing new works of sonic art, and have included descriptions of these works as part of my dissertation research.

What I am proposing is the development of an aesthetics of simulated mediation. This form of scholarship overlaps with many of the concerns of software studies, for example, but a field of "simulation studies" will need to examine not only the technological framework or implementation of this framework via code but a mapping of the relationship between the interactive perceptual experience of the simulated object and the original from which this object is derived. This relationship cannot be described in terms of software; it exists between the digital object and the analog corollary. It is constructed by a human observer.

Rather than focusing exclusively on media art or music, I submit commercial products such as electronic musical instruments, synthesizers, audio software, and effects processors to the same examination process. Many of the pieces of media I have selected for analysis lay in the categorical interstices between tools, art objects, and commercial products. While this work will address individual composers, my focus is not on how composers develop their music in relation to previous composers' methodologies but how they have responded to particular technologies and, in turn, how these techniques influenced the development of new tools for creating music. By tracing the complex interplay between popular and experimental music, as well as commercial music production tools, I intend the following chapters to demonstrate the process by which the aesthetic assumptions embedded in technologies are reinscribed onto the broader culture. Recognizing the relationship between the world of art and commerce was necessary to understanding the reinscription of media technology in each context, and yet, it provoked considerable frustration and anxiety in my attempts to render each element properly. The simulations I describe lack the cache of experimental music compositions or the ubiquity of consumer media technologies. They are tools that are used to create commercial or amateur music. As new media scholar Soraya Murray notes,

> Within the American art history canon, the presence of technology—and its intrusion into high art—evokes quiet but persistent anxieties around its industrial-capitalist influences that purportedly erode the valuable essence (aura) of the original artwork by treading too close to the commercial.[17]

Mass-produced musical instruments and digital tools for music creation exist precisely within these interstices between art and commerce. While academic music institutions have embraced and, in some cases, developed music technology, there have also been boundaries defining which instruments and musical genres constitute appropriate uses of technology. Rather than appealing to esoteric values or objective aesthetics, I am much more interested in what values and aesthetic constraints have come to define a large portion of cultural practices during the past decade. I have selected particular technologies and simulation methods for what they tell us about the West's relationship to technology. If I understand nothing else about analog

[17] Murray, Soraya, "New Media Anxiety: Art History and the Problem of Modern Technology". PhD Diss. (Cornell University, 2007).

media, I know that their appeal extends beyond their efficiency as a means of distributing information. To be clear, I am not valorizing ideas simply because they are popular or using popularity as the sole metric for judging the value of a medium or musical concept. I am proposing that the relevance of understanding the aesthetics of media extends beyond any value one might attribute to aesthetics by itself.

While this project began as a means of understanding the process through which experimental techniques became subsumed into popular culture, I ultimately found that this question was far less interesting than how manufacturers design the tools used to construct popular culture. I enjoy popular music, and yet, I find the inability to escape it both disturbing and fascinating. There are certain sounds I have been exposed to so often—in supermarkets, in films, from the windows of passing cars—that I can no longer forget them. It is this involuntary aspect that makes popular sounds so powerful. The media used to situate or produce these sounds gain emotional resonances and semiotic relationships that artists and engineers seeking to recapture or complicate the affective properties of these media technologies will often exploit. As Devin Kerr—a DSP engineer I interviewed for this project—notes, "The medium becomes nostalgic. It has almost a scent memory of those formats and how they interacted."[18]

I am a composer who has experience with the production pipeline for popular cultural artifacts such as video games, as well as audio software and hardware. As a

[18] Kerr, Devin. *Goodhertz Interview*, 2021.

member of the larger electronic music and sound production community, I have access to and an understanding of the process for developing and deploying audio technologies. I have also had the opportunity to study or work with many of the composers referenced in this text. This has been enormously helpful in that my interactions with software and hardware developers provided me with insights into the relationship between a simulation of a media technology and the technology itself. Additionally, I may not have been as aware of the impact of media technologies on experimental music had I not performed pieces of music centered on media poetics. However, I cannot claim the objectivity that a scholar less invested in the practical use of this analysis might. For this reason, I have focused more on methods for understanding specific uses of simulation, rather than identifying broad tendencies of media—unless such a claim seemed unavoidable, given the evidence.

Another challenge of writing about the aesthetic, cultural, semantic, or semiotic aspects of technology is that not only does one inevitably run up against limitations to their knowledge, but the knowledge of their audiences. I intend this work to be legible to composers, musicologists, electronic instrument designers, and media theorists. However, I compiled the knowledge I drew upon to complete it from the peripheries of each of these fields. I adopt or expand upon methodologies developed by musicologists and composers of electronic music but articulate these techniques through media theory; a framework meant to address large-scale techno-cultural interactions. Simulated mediation lies in the interstices between media studies, music, perceptual psychology, and aesthetics. There are idiosyncrasies of language that make it challenging to address the problems of one field through the lens of another. However, in order to disrupt some of the binaries that haunt discussions surrounding technology, it will be necessary to understand the technological basis for certain distinctions that contribute to cultural reception. Readers will be informed, for example, about the difference between oscillators designed with digital signal processing (DSP) technology on standard microprocessors and those designed with field-programmable gate arrays (FPGAs), or voltage-controlled oscillators (VCOs) compared with digitally controlled oscillators (DCOs). If there is a difference between forms of media or synthesis techniques, I will attempt to express those differences. I debated including a glossary of terms but have instead opted to define terms within the text, given the extent to which terminology itself is examined in minute detail throughout. This has the added advantage of gradually introducing readers to fundamental concepts, which I can later expand upon or problematize.

Another challenge in preparing an analysis of a large number of code-based tools is that I did not have access to the underlying code. It is possible to describe the feature-set and glean the relationship of a simulation to a media technology by interacting with it or examining the labeling on the device. However, under these circumstances, any claims about the underlying system altering the sound will be educated guesses, at best. During the writing of this document, it became apparent that the best strategy was to restrict my analysis to simulations where the creators had either spoken publicly about their intentions or, more commonly, were willing to speak to me directly. I am incredibly grateful to have had the opportunity to talk to a wide variety of designers, composers, engineers, and artists. Without their willingness to discuss their design process—often in relation to their personal experiences with technology—my arguments would be robbed of urgency. Despite my conviction that simulation is a creative process that necessarily produces variations from fixed source material, I was consistently shocked by how different various simulations of the same medium were.

Chapter 1 defines the poetics of mediation. I present four different subcategories of mediation before considering the relationship of mediation to the twentieth-century avant-garde and post-war experimentalism—such as Steve Reich's discovery of phasing on mechanical tape and his subsequent incorporation of it into scored music for acoustic instruments. I consider how the form of a medium influences musical works composed using it and how classical information theory, as presented by Shannon, fails to account for this influence. I then address the relationship of media poetics to the ongoing debates surrounding determinism within media theory. Mediation is then contrasted with the prevailing assumption that music should be the actualization of sounds that have first been developed mentally by the composer. I conclude by addressing the role of failure and imperfection in mediation and the relationship of failure to agency within technology. I consider how intellectual gaps produced by failures may offer sites for resistance and art, but also how failure itself has been commodified and incorporated into products.

In Chapter 2, I examine the process of analog to digital conversion and the various aesthetic interventions necessitated by this process.[19] I argue that simulation practices begin with conversion processes, from analog to digital and digital to analog. Techniques such as the application of dither replace the sonic qualities that characterize the limits of digital information with sonic qualities that characterize the limits of analog information and thus introduce analog simulation into the most fundamental of digital processes. Dither replaces the sonic effects of quantization error—an error that results from the limits of resolution expressed in terms of bits—with noise, a limit to the resolution of analog media. One of the challenges in writing this chapter was to address the aesthetic relevance of something that is intended to be inaudible. I consider several works of art that explore the affective qualities of digitization, as well as tools such as bitcrushers that reintroduce the "errors" corrected within the conversion processes. This history of bitcrushers—tools for affecting the sound that intentionally decrease the sample rate and bit-depth of a signal—became particularly important to this discussion, as these devices are intentionally created to reproduce the types of artifacts that dither and anti-aliasing filters are used to eliminate.

One of the goals of this chapter is to establish a critique of immediacy, which is expanded upon in Chapter 3. Dither—which seeks to mask the aesthetic of conversion between digital and analog media—demonstrates the manner in which

[19] Chapter 2 is a response to a paper on the history of dither that I presented at the 2018 UCHRI Symposium on War Security and Digital Media.[19]

simulation is used to establish continuity with analog media rather than transparency or immediacy. I initially intended to focus this chapter on the poetics of digital media, only to find that simulation is deeply embedded within these poetics.

Chapter 3 contains a longer discussion of simulation, specifically through its relationship to remediation, immediacy, nostalgia, and the uncanny. I begin with an attempt to define simulation in the context of examining extant definitions and the concept's evolving character. I consider software simulations of analog and digital media in the form of plugins for digital audio workstations, guitar pedals, and rack effects units, as these are the tools that are used to produce the sound of mediation within popular culture artifacts such as films, television, and video games. I outline the process of hardware modeling as a means of exploring how differing methodologies articulate different conceptualizations of simulation, as well as problematizing various schema for simulation. For example, I explore how the search for an ideal subject of simulation belies claims of objectivity on the part of a simulation designer. The tolerances of parts in analog devices—the range of values associated with electronic parts such as resistors or capacitors—may produce different sonic results in each piece of manufactured equipment. Even if an engineer models a device by simulating each electrical component, they will still have to choose which device is definitive. I also consider the aesthetic and cultural reception of the simulation of analog media, in relation to the practices and beliefs of professional audio culture.

Interestingly, while nostalgia was consistently referenced by most of my interview subjects, the concept of the uncanny was largely absent from these discussions. Nostalgia was initially coined to describe what is now commonly referred to as "homesickness," but, over time, has taken on more neutral connotations related to a re-experiencing of past emotions. The uncanny remains closely associated with the uncomfortable "spectral" aspects of media.

Chapter 4 contains an extensive analysis of simulation in the Eurorack synthesizer format as well the commercial and social ecosystem centered around its production and use. Eurorack modules range from professional tools for music production to esoteric devices that lie somewhere between art objects, commercial products, and jokes. There are commercial modules that pass an electrical signal through dirt, create broken cables, derive random voltages from radioactive isotopes, produce sound from lasers passing through fans, receive and transmit shortwave radio, and a variety of other esoteric processes. The makers that I interviewed in the section on simulation in Eurorack synthesizers were often practicing musicians and artists, and consider the design of the modules they have developed an extension of that practice.

Chapter 5 focuses on several case studies in simulation within my own work. Since 2018, I have been working with composer and software engineer David Kant on commercial plugins for a software emulation of the Eurorack format called VCV Rack. Two of these modules are adaptations of designs we had previously prototyped in hardware, while another six were simulations of specific analog circuits. In addition, I consider *A Lambent Mirror for Remote Ontographies of Nested Infinities* a forthcoming four-channel autonomous sound installation from composer and sound artist David Dunn that uses the aforenoted modules.

I conclude by returning to an examination of immediacy as an ideology and how this contrasts with the lived experience of simulation. This dialectic produces different solutions, which I categorize as sampling and synthesis. I also explore the ubiquity of simulation and its sustainability as a cultural form. My analysis focuses on the relationship between this ubiquity and the use of mediation as semiotic or semantic information. I return to my previous critique of information theory before concluding with the observation that the poetics of mediation—even in its simulated form—is an implicit critique of the twin ideologies of control and immediacy that frame western expectations of technology.

The simulations evaluated in the following dissertation are not mass media, nor is each technology a means of distribution in the same sense as the telephone, radio, television, and the internet. Instead, these instruments and effects are the tools by which popular cultural artifacts are produced. The near-constant exposure to the popular sounds of previous decades—in film, television, and music—has heightened our awareness of the aesthetic effects of media technologies. Modern distribution and playback technologies emphasize the sonic artifacts of mediation such as noise, alteration of spectral content, and pitch modulation due to their relatively high definition. While consumer playback technology is not transparent—earbuds and cellular phone speakers impose radical filtering and distortion on the original sound—

definition has increased such that differences between recordings of various media technologies can be heard on the same device.

Simulation requires a new basis for analyzing aesthetics in media: one that draws upon insights from both media and music theory while incorporating the novel concerns raised by the realities of simulation. Many of the most fruitful areas for exploration and analysis have been ignored by those seeking to frame simulation as a purely ontological problem, or a field in which the methodologies and practices are purely technical.[20] Even in the most detailed emulation of a technical system, the ultimate means of judging a simulation designed for aesthetic purposes is a human observer. For this reason, simulation is constructed by personal subjectivity—rather than simply technique—as evidenced by the many anecdotes related to me by simulation designers.

[20] I discuss this pervasive tendency in Chapter 3.

CHAPTER 1:
DEFINING MEDIA POETICS

I define simulated mediation as the technical process of abstracting the aesthetic characteristics of a medium and isolating these characteristics from their dependence on the material properties of the original medium. The act of simulating a medium implies that certain qualities have been essentialized and that these essential qualities are necessary for the aesthetic, technical or social functioning of the simulation. This essentialization of the properties of a particular medium is made possible by a poetics of mediation. These poetics are not necessarily the result of conscious decision-making on the part of engineers and designers. Often, the poetics of mediation result from artists intuitively exploiting engineering compromises, especially those that result from medium-specific nonlinearities. How these poetics are interpreted and simulated depends on the software designer's familiarity with and interest in the aesthetic use of a particular technology.

There are at least four major types of mediation than can be distinguished:

1. The transference of media artifacts between media technologies: Transduction is the most basic form of mediation. It occurs when 35mm film is transferred to VHS, Laserdisc, DVD, and Blu-ray, to name one example. Analog to digital conversion is a special example, as I will demonstrate in Chapter 2. Were it not for the coinage from Grusin and Bolter, "remediation" would be

an effective term to describe this process. Post-war experimental compositions such as Alvin Lucier's *Quasimodo the Great Lover* (1970) or John Cage's *Variations VII* (1966) focus on this as a formal aspect of the composition, deriving the final sound from a concatenated series of mediations or parallel forms of mediation, respectively.

2. The use of the limitations of a particular technology to provide the formal characteristics of the work's composition: This form of mediation includes works such as Joan Jonas' *Vertical Roll* (1972), Alvin Lucier's *I Am Sitting In A Room* (1969), Nancy Holt and Richard Serra's *Boomerang* (1974), Steve Reich's *It's Gonna Rain* (1968), and Pauline Oliveros' *Deep Listening* (1990).
3. The appropriation of techniques from previous forms of media: The most ambiguous form of media poetics is the use of techniques or aesthetics previously rendered in other media. A new medium may be designed to enable the use of techniques developed in another form of media or artists may develop these techniques as part of their practice. An example of the latter is Clara Rockmore's use of vibrato and glissando to render discrete notes on the Theremin. These techniques have precedent in instruments without discrete frets such as the violin or cello, but acquire new importance in an instrument that lacks a haptic interface such as the Theremin.[1] Grusin

[1] Developed by Leon Theremin in 1928. The performer controls the Theremin by positioning their hands in relation to two antennae to control the instrument's pitch and volume. The closer the performer's hand is to each antenna, the louder or higher-pitched the sound becomes. The Theremin was unique at the time of its release, because performers did not need to touch the device in order to make sound.

and Bolter use this to describe how media technologies such as video "remediate" older technologies. It is challenging to determine which technology a simulation is borrowing techniques from, especially given that, according to Bolter and Grusin "immediacy dictates that the medium itself should disappear and leave us in the presence of the thing represented."[2] This makes their claims of remediation dubious in certain instances, as immediacy necessitates the appropriation of techniques accumulated by a variety of artistic and technological innovations, beginning with linear perspective in Renaissance paintings. For example, their claim that the video game *Doom* (id Software 1993) "remediates cinema" is difficult to justify given the variety of media technologies that employ linear perspective. [3]

4. Simulated Mediation: This refers to the intentional simulation of specific properties of media technology. Simulated mediation is differentiated from the appropriation of techniques from a particular media technology because the aesthetics of the underlying technology are recreated. This quality makes it somewhat easier to distinguish which technology has been referenced, as the limitations, aesthetic alterations and noises tend to be those that distinguish the technology. However, a designer may choose to abstract or generalize these properties such that the simulation can represent a range of technological devices or an amalgam of devices. In this case, explicit

[2] Jay David Bolter and Richard Grusin, *Remediation: Understanding New Media*, Reprint Edition (Cambridge, Mass.: The MIT Press, 2000), 6.
[3] Ibid, 47.

references to technology may refer to a particular use or cultural experience rather than the technology itself. Tom Majeski of Cooper FX did this when he used the name Generation Loss—the accumulative aesthetic effect of copying tape from other copies—for a guitar effect pedal. He describes his choice to name the pedal after this specific VHS artifact as "a stupid way to describe it, because VHS is just tape plus video, right? So, it should just be a tape emulator, but, the VHS thing, there's something to it. It's a bit more nostalgic than just saying tape."[4] In other cases, it may be necessary to examine a single, simulated property of a technology in the context of other forms of simulation, appropriated techniques from other media, or paratextual information in order to identify the media technology being simulated. Soraya Murray identifies Hideo Kojima's use of simulated camera focal length shifts in the video game *Metal Gear Solid V: The Phantom Pain* as a reference to the visual language of film. This "connects to the presumption of a pre-existing visual literacy of film and television in the player/ viewer."[5] Without an awareness of the film references and techniques used throughout the game, or Kojima's explicit admiration for cinema as an artform, this optical effect could be interpreted as a reference to many technologies, including still photography. It is the game's appropriation of filmic techniques that justifies this assessment. The simulation of a mechanism or property shared by

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[4] Majeski, Tom. *Cooper fx Interview*, August 2, 2021.
[5] Soraya Murray, *On Video Games: The Visual Politics of Race, Gender and Space* (London New York: I.B. Tauris & Co Ltd, 2017). 156-7.

> different media technologies requires contextualization to be interpretable. Simulation within a digital system is an alternate tendency to a poetics of mediation that intentionally engages with the limitations of a different medium than the one in which it is presented.

There may also be references to a technology without explicit representation of its aesthetics: this may include textual references to the use of a particular technology or a rendering of the physical properties of the technology. For example, a character in a film or novel may refer to calling another character on a cellular phone, or a video game may include a non-functional rendering of a guitar amplifier in the background. These references are not included within the poetics of mediation since they do not render the aesthetics produced within a medium. Put another way, representations of the outward appearance or references that do not attempt to reproduce the noise, distortion, interface, information structure, and affordances of a technology cannot be treated as an articulation of a poetics but a form of representation. However, these may be used to interpret and understand the "meaning" of a particular use of simulation.

The history of twentieth-century experimental music and sound art is deeply connected to the history of media poetics in sound. While natural reverberations and the natural resonant properties of aural media influenced western art music prior to the introduction of recording media,[6] it is clear that recording media influenced the compositional techniques of composers almost immediately upon its introduction:

> With the advent of recording technology in the late 19th/early 20th century in the form of the phonograph, new possibilities with regards to composition and performance were quickly discovered by some contemporary composers. While traditionally composers were limited to describing their music in notation form, focusing on pitch, rhythm, and meter, other parameters such as dynamics and articulation could not be described as precisely and were subsequently subject to the performer's interpretation. Indeed, composer Igor Stravinsky noted in his biography with regards to the player piano and gramophone that, in his view, recording technology offers means to impose "some restrictions on the notorious liberty . . . which prevents the public from obtaining a correct idea of the author's intention" and to prevent musicians from "stray[ing] into irresponsible interpretations of … musical text"[7]

It is difficult to overemphasize the effect of technologically enabled repetition on music. Walter Benjamin defined mechanical reproduction as the prevailing tendency of modern visual art. In music, the introduction of recording media presented a similar challenge to traditional western music practices. Much of the twentieth-century musical avant-garde responds to this challenge in some way: from the Cagean concept of indeterminacy—as opposed to the fixed determinacy of tape—to the "process" music of composers such as Alvin Lucier, Steve Reich, and Pauline Oliveros.

Experimental music is closely tied to process. Composer Steve Reich explains this in *Music As Gradual Process*, stating, "I do not mean the process of composition,

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[6] Thomas Wilmering, David Moffat, Alessia Milo, and Mark Sandler. "A History of Audio Effects." *Applied Sciences* 10 (January 22, 2020): 791. https://doi.org/10.3390/app10030791, p, 7.
[7] Ibid.

but rather pieces of music that are, literally, processes."[8] Reich differentiates this from traditional compositional processes in that they define the form and moment-to-moment aesthetics simultaneously. The process composer does not necessarily specify individual pitches, rhythms, harmonic relationships, or dynamics. Instead, they define a process that functions either automatically or with prescribed performer interventions. This form of music is more mechanistic in terms of compositional technique and the intended perceptual experience. It was the mechanism of the tape machine that influenced Reich's use of phasing in more traditional music practices. Reich admits that without the experience of hearing two tape machines moving slowly out of phase,[9] he would not have discovered this technique and further developed it for use in his music. However, an analysis solely focused on the role of technology in the development of this technique would miss important nuances of how Reich translated this technique from tape machines to the storage medium of notated music and the eventual realization by human performers, the relationship of phasing to time structures in western classical music or how Reich's combination of increasingly tonal music and phasing influenced the cultural reception of this technique across classical and popular music. While an analysis of the formal properties of the technology is necessary to understand this work, it is far from the only relevant object of study.

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[8] Steve Reich, *Writings on Music, 1965-2000*, ed. Paul Hillier (Oxford: Oxford University Press, 2004), 34-5.

[9] Phase, in this instance, refers to the relationship, in time, of one periodic signal to another. As the starting positions of these signals diverge from one another, we refer to sounds as moving "out of phase."

It may initially appear that the poetics of mediation are only relevant to experimental music or sound art and, therefore, of little relevance to understanding popular forms of music that affect the wider culture. However, with the vast majority of popular music written, produced, and organized on digital computers, it is common for the properties of the medium itself to be reflected in the structure of the composition. In this context, a theory of music that only looks at harmonic and melodic relationships will inevitably leave much of the aesthetically relevant material unexplored. McAlpine addresses the limitations of this musicological approach in *Bits and Pieces: A History of Chiptunes*:

> Stylistic analysis also doesn't paint a complete picture. Video game music is, at least in part, functional; just think of the 'attract mode' of many arcade games, nonplayable demos used to entice the quarters of prospective gamers like a midway caller drumming up trade for a ringtoss stall. It is a type of media music, whose form and structure is determined, to some extent, by factors that lie outside of the music itself: the constraints of the hardware, for example, or the need to balance the music with the gameplay.[10]

Following the model of communication articulated by Claude Shannon in *The Mathematical Theory of Communication*, the transmission of information is often presented as originating from an ideal source that is progressively degraded along a linear path to a receiver. Metaphors such as "windows" and "screens" emphasize that we are intended to look through technology to the content beneath it. Fallacious concepts such as the belief that greater information resolution in media leads to greater "immediacy" follow directly from this. As Michel Chion articulates, the

[10] Kenneth B. McAlpine, *Bits and Pieces: A History of Chiptunes*, Illustrated edition (New York, NY: Oxford University Press, 2018).

resolution or "definition" of a sound is potentially very different from its fidelity to the original audition:

> I am speaking of definition (a precise and quantifiable technical property, just like definition or sharpness in a photographic or video image) and not of fidelity. The latter is a tricky term; strictly speaking it would require making a continuous close comparison between the original and its reproduction, which normally would be quite difficult to physically arrange. Someone who listens to an orchestra on a sound system in his living room is not likely to be able to compare it with some orchestra playing at his doorstep. It should be known, in fact, that the notion of high fidelity is a purely commercial one, and corresponds to nothing precise or verifiable.
>
> However, it happens that today definition is (mistakenly) taken as proof of fidelity, when it's not being confused with fidelity itself. In the "natural" world sounds have many high frequencies that so-called hi-fi recordings do capture and reproduce better than they used to. On the other hand, current practice dictates that a sound recording should have more treble than would be heard in the real situation (for example when it's the voice of a person at some distance with back turned). No one complains of nonfidelity from too much definition! This proves that it's definition that counts for sound, and its hyperreal effect, which has little to do with the experience of direct audition. For the sake of rigor, therefore, we must speak of high definition and not high fidelity.[11]

These differences between fidelity and definition become evident when a simulation attempts fidelity to the qualities of a medium that limit its definition. To claim "immediacy" in any practical sense is to claim that the limitations of a medium possess perfect fidelity to the limitations of human perception—and, therefore, to also claim that one can objectively measure human perception. Since there is variance within the definition of human perception, "transparent" technologies tend to limit

[11] Michel Chion and Walter Murch, *Audio-Vision: Sound on Screen*, trans. Claudia Gorbman, 14th edition (New York, NY: Columbia University Press, 1994).

their definition slightly outside of this range. For example, the Nyquist frequencies[12] of standard digital audio distribution—22,500 and 24,000 hertz—exist within half an octave of the upper-frequency limit of the average listener's hearing. The aesthetic effects of simulated mediation are—to a certain extent—quantifiable and can be analyzed in a number of meaningful ways, such as comparing the spectral information, dynamics, and pitch of a sound before and after an effect is applied. However, as Chion notes, it is not simply the medium but standard audio production practices—and therefore cultural preferences—that dictate how audio is rendered. These aesthetic preferences often run counter to how "unmediated"[13] sound operates. Chion's example of the use of increased high-frequency emphasis demonstrates this.

Currently, the manipulation of affect through simulated mediation is ubiquitous; software plugins from Universal Audio, Eventide, Arturia, and other manufacturers simulate their own analog and digital hardware effects, social networks such as Instagram intentionally simulate the qualities of analog cameras, and video games simulate all manner of media.

Determinism

Within media theory, there remains considerable debate on the subject of agency and technology, expressed as a dichotomy between technological determinism and social

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[12] The upper limit of available frequencies before aliasing occurs. This concept is explained in greater detail in Chapter 2.

[13] Since sound must exist within a medium, my use of "unmediated" refers to sound that is heard without an intervening electronic medium.

construction. Put simply: this is a debate as to whether culture shapes technology or technology shapes culture, or to what extent the two are mutually influential. Generally speaking, this debate centers on communications media, especially those that find widespread, daily use. Media poetics, if not determinative, imply a certain level of agency on the part of the technology. It is, therefore, necessary to address this ongoing polemic. If media technologies themselves have poetics, it is through the limitation of potential choice. The poetics of mediation are the "determined" aesthetics of the medium. One could argue that this framing overemphasizes the influence a medium's limitations have on the artwork produced with that medium. Surely the artist selects the medium that best articulates their poetic ambitions, not the other way around? As Reich's work with tape demonstrates, the answer is both complicated and ambiguous.

Media historian John Durham Peters, offers an account of the origin of determinism in *''You Mean My Whole Fallacy Is Wrong'': On Technological Determinism*:

> Compared to other fallacies, technological determinism has a relatively recent birth. Since its origins in the 1920s, the ongoing odyssey of the concept was one of many battles with the ghost of Marx in the social sciences, especially with his question about how the means of production interact with relations of production.[14]

[14] John Durham Peters, "'You Mean My Whole Fallacy Is Wrong': On Technological Determinism," Representations 140, no. 1 (November 1, 2017): 10–26, https://doi.org/10.1525/rep.2017.140.1.10.

In Peters' account, the concept was initially put forward by "the cranky and brilliant American economic sociologist Thorstein Veblen"[15] to explain what he perceived as the increasing importance of machine technology.

> Like many others, Veblen both built on and criticized Marx, suggesting that the engine of social change was not solely economic production but also the scientific and technological know-how that guided and accelerated it. Engineers more than the proletariat were his revolutionary vanguard party. Technology for Veblen both shaped and was shaped by social forces; it was determined and determining.[16]

However, it was not Veblen whose name became most closely associated with technological determinism. Instead, media theorist Marshall McLuhan has come to symbolize the sins of determinism most clearly. McLuhan often spoke of technologies as agents of large-scale cultural change, "giving credit" for cultural shifts to forces seemingly outside of social control. His language was intentionally hyperbolic and metaphorical, making him the frequent target of criticism. McLuhan, whose writings influenced many of the early multimedia artists and composers, became, in Peters' words, "the poster child for technological determinism."[17] This debate reached a fever pitch when Raymond Williams published *Television: Technology and Cultural Form* (1974). In it, he criticizes McLuhan for presenting

> …an immensely powerful and now largely orthodox view of the nature of social change. New technologies are discovered, by an essentially internal process of research and development, which then sets the

[15] Ibid.
[16] Ibid.
[17] Ibid.

> conditions for social change and progress. Progress in particular is a history of these inventions, which 'created the modern world'.[18]

This discussion has found renewed relevance as the structure and mechanics of social media have come under greater scrutiny. Social media companies' public defense of their experiments in social engineering has primarily consisted of a denial of determinism and an appeal to the supposed neutrality of technology. However, the microblogging platform Twitter has admitted an "algorithmic" bias towards right-wing ideologies, and leaked documents from Meta reveal that many within the company felt that the platform was structured to spread hate speech and misinformation. An internal memo from Meta explicitly states, "The mechanics of our platform are not neutral."[19]

Returning to the question of whether or not the poetics of a particular medium determine the aesthetic outcome, it is difficult, even within my work, to say with certainty how much of my previous aesthetic biases determined my work with a particular medium. My development of aesthetic practices around the manipulation of laserdisc players provides an illustrative example. As illustrated in my master's thesis, *Ideology as Material Force*, my experiments began when I damaged a laserdisc copy of Ridley Scott's *Alien (1979)* while attaching a transducer to it for a realization of David Tudor's 1973 composition *Rainforest IV*. I was initially unaware

[18] Raymond Williams, *Television: Technology and Cultural Form*, 3rd Edition (London ; New York: Routledge, 2003).
[19] Dan Milmo and David Pegg, "Facebook Admits Site Appears Hardwired for Misinformation, Memo Reveals," The Guardian, October 25, 2021, sec. Technology, https://www.theguardian.com/technology/2021/oct/25/facebook-admits-site-appears-hardwired-misinformation-memo-reveals.

of how the technology worked, and out of curiosity, I attempted to play the disc. At the time I noted:

> Visible lines of distortion accumulated in each consecutive frame until the disc was unplayable. Through this intuitive experiment, I discovered a means of manipulating what was occurring on screen by blocking out or removing portions of the information the player was reading. Unlike digital media, the spatial position of the information I erased on the Laserdisc correlated chronologically and was mapped directly to the information displayed on screen.[20]

Part of the pleasure in composing works such as this—and presumably part of the potential value of observing the artwork—is derived from making the inner workings of a medium visible. To claim this practice is not "determined" by the nature of the medium is to claim, paradoxically, that the medium does not determine itself. Conversely, I was also informed by social practices around technology and music in selecting material for use in the work. What interested me in this composition was not so much the laserdisc technology itself but how the function and failure of the device itself interacted with the material I chose. It took a year of scouring thrift stores for laserdisc copies of films to find suitable material, which dovetailed with the creation of techniques and performance gestures to "act upon" the material.

When I asked Scott Harper, who makes videos exploring and promoting guitar pedals and synthesizers under the moniker Knobs,[21] about the "determining" aspect of

[20] Ryan Page, "Ideology as Material Force" (Oakland, CA, Mills College, 2013).
[21] Harper also developed Blooper, a complex looping device, in collaboration with Chase Bliss Audio. I will discuss this in greater detail within Chapter 3.

mediation, he expressed appreciation for the indeterminacy and restriction of potential choices that mediation brings to music:

> I know as a musician; I hate having way too many choices, and I hate when things work perfectly. Maybe lo-fi things build in one layer of breaking up the mundanity and inserting a bit of unpredictability, automatically, into music.[22]

While it is necessary to contextualize the poetics of media in relation to technological determinism and acknowledge the validity of these critiques, the discussion is better served by focusing on the distribution of agency in specific scenarios, rather than any attempt to define the nature of large-scale techno-cultural interaction. I am not developing a framework to explain how technologies come into existence or how they shape or do not shape culture. I am much more interested in understanding what particular design decisions in technological devices have to say about the designer's worldview and how these decisions are articulated in certain uses and reframed by certain users. The musical compositions and simulations that I examine are unique scenarios where a specific person has chosen a specific technology for a specific purpose. With that said, the question of agency with regard to technological objects remains a relevant concern, especially in relationship to the distributed agency that occurs when performers connect themselves to musical instruments.

[22] Harper, Scott. *Knobs Interview*. January 5, 2022.

Harper explicitly refers to the process of feedback between instrument and performer, when addressing the role of agency and instrumentation with regard to writing music:

> I think it's exhausting to have that burden on yourself all the time. Like, "it's me and my instrument, and we're going to make a beautiful song now." I don't know how that doesn't get exhausting. Never mind a person just starting out, but let's say you're 20 years into your musical career. Don't you need something?
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> It seems nice to have a bit of a feedback loop with your devices where they can inspire you to do something, and then you can use them.[23]

I have detailed the preceding processes as a means of articulating a common experience among musicians working with media that is often overlooked; we seek indeterminacy and novel processes derived from the inner workings of the medium, while at the same time, we seek to expose the underlying mechanics and impose our aesthetics upon them. In Harper's words:

> Far from being a point of shame, it's just always there. Sometimes it's screaming, and it's the reason the song exists, and other times it is more muted, but the technology is always part of the finished song.[24]

In some sense, this is the same relationship that any musician has with their instrument. Familiarizing oneself with the limitations and nonlinearities of an instrument is an essential part of learning to play an instrument. According to Harper, "The way that you think is limited or motivated by your instrument."[25] If we begin to

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[23] Ibid.
[24] Ibid.
[25] Ibid.

think of media in these cases as instruments that composers develop specific relationships with, it is perhaps possible to sidestep the question of technological determinism. There are also scenarios where the instrument may be more determinative than others. In some cases, design decisions have resulted in similar musical styles independently emerging in different cultures, as will be shown in the following discussion of the Roland TB-303 and its relationship to the Acid House genre.

While the degree to which a technology influences the aesthetics of a work will vary depending on the technology and the social context in which it is produced, there is a consistent tendency in the historical literature surrounding computer simulation to portray the medium as an infinitely malleable "blank canvas." This ideology continues to influence software tutorials for sound. Consider Andy Farnell's introduction to the Pure Data programming language in *Designing Sound*:

> [T]here is no correlation between creativity and ownership of equipment: as an artist gets more proficient the number of tools go down. [] You can often tell an extremely powerful tool by its Spartan appearance. It does not need to advertise itself. There are no flashing graphics or whizzbangs, just a command prompt or a blank canvas. What this is saying is "I am ready to do your bidding, Master."[26]

The problem with what Farnell is presenting is not only the potentially racist connotations of the term "master" in this context. Rather than an unfortunate choice of words, the master and servant relationship Farnell is outlining is an accurate

[26] Andy Farnell, *Designing Sound* (Cambridge, Mass: The MIT Press, 2010).

metaphor for the relationship with technology he is proposing. It is one in which a human agent projects their will onto technology to further their predefined goals. This design process is generated *a priori* and rendered ever-more perfectly by continuously refined technological aids. There is something seductive about the possibilities of a programming language such as Farnell's chosen language, Pure Data. Following Farnell's examples, it is easy to imagine the process of designing sound as strictly logical and mathematical, in Farnell's words, "following from first principles."[27] This is not to say that such a strategy is without merit. However, it is worth noting that however objective the process for generating the sound is, the means of evaluating the success of a model is always a subjective human observer or the conglomerate opinion of subjective observers. In an interview I conducted with composer John Bischoff, he describes an advantage of intentionally using the limitations of media as a means of avoiding the pitfalls of media transparency, "you avoid the risk of just assuming it's going to be the right basis for transforming some idea into reality."[28]

Composer Mark Fell articulates how this formulation fails to account for the development of many new forms of music and often leads to a mischaracterization of the actual processes of discovery. Fell recalls an interview with popular musician Thomas Dolby who expressed a desire for a synthesizer that would transform the music in his head into sound. He notes, "According to Dolby's model, the sound

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[27] Ibid.
[28] Bischoff, John. *John Bischoff Interview*. 12, Feb. 2013.

begins its life in his head, the technology then converts that imagined sound, as accurately as possible, into a tangible form."[29] He contrasts this approach with Acid House pioneers Phuture, who used the Roland TB-303, a monophonic synthesizer with a unique sonic character, to create a new sub-genre of techno. The TB-303, according to Fell, was "a more or less ignored little synthesizer known for its astonishingly bad imitation of the bass guitar."[30] However, its unique filter design and odd sequencer interface tended to produce interesting material, even if one did not know how to use it "correctly." Phuture's methodology mostly consisted of arbitrarily "turn[ing] the knobs"[31] of the TB-303 until they arrived at what became the characteristic sound of Acid House. Fell argues that

> If Phuture had rented a studio containing Dolby's synthesizer, we wouldn't have got the Acid House we are all so familiar with. And this is precisely because they did something with the 303 that they had not previously imagined. The music was not an expression of an idea starting in their heads.[32]

From Fell's perspective, music does not emerge whole-cloth from the composer's mind. Instead, ideas that composers could not have previously imagined arise from their openness to the aesthetic possibilities of new phenomena. One way of understanding this is the concept of the "technological frame." As Trevor Pinch and Frank Tocco note, "'Technological Frame'—like 'paradigm'—is a term that captures

[29]Mark Fell. "Collateral Damage: Mark Fell - The Wire." The Wire Magazine - Adventures In Modern Music. Accessed April 1, 2018. https://www.thewire.co.uk/in-writing/essays/collateral-damage-mark-fell.
[30] Ibid.
[31] Ibid.
[32] Ibid.

the way a whole series of practices, ideas and values get built around a technology. It includes both the ways technologies are produced and the ways they are used and consumed."[33] This frame informs the development of technology but is also informed by the technology's material properties and aesthetic limitations. While it is reductionist to derive all cultural outcomes in terms of the material properties of technology—particularly as these will vary in implementation—certain design decisions will increase the likelihood of particular outcomes to such an extent that they are eventually reinforced by cultural practices.

The aesthetic tendencies of the TB-303 were so strong that Charanjit Singh's *Synthesizing Ten Ragas to a Disco Beat*—an album released years before *Acid Tracks* from Chicago-based Phuture and within the cultural context of Mumbai—bears remarkable aesthetic similarities to the Acid House genre.[34] The technological frame still matters: *Synthesizing Ten Ragas to a Disco Beat* was a commercial failure that was largely forgotten until it was rediscovered in 2002,[35] while *Acid Tracks* was both successful and influential. While it is clear that the instrument and underlying technology influenced the sound and structure of the music—independently producing remarkably similar sounds on opposite sides of the planet—it is equally

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[33] Trevor Pinch and Frank Trocco, *Analog Days: The Invention and Impact of the Moog Synthesizer*, Revised Edition (Cambridge, Massachusetts London, England: Harvard University Press, 2004). 309-10.

[34] Stuart Aitken, "Charanjit Singh on How He Invented Acid House ... by Mistake," The Guardian, May 10, 2011, sec. Music, https://www.theguardian.com/music/2011/may/10/charanjit-singh-acid-house-ten-ragas.

[35] Louis Pattison, "Charanjit Singh, Acid House Pioneer," The Guardian, April 9, 2010, sec. Music, https://www.theguardian.com/music/2010/apr/10/charanjit-singh-acid-house.

apparent that cultural reception determined the modulation and spread of this idea. This sound, once popularized, was recreated on instruments other than the TB-303. For the video game *Streets of Rage 3* (Sega 1994), Yozo Koshiro and Motohiro Kawashima programmed the Yamaha YM2612 FM synthesizer in the Sega Genesis to simulate the squelching tones of the TB-303.[36]

Pinch and Trocco address the complicated influences of technology and culture by contrasting two differing examples of the technological frame,

> Hip-hop DJs use turntables for scratching, a use inconceivable to the engineers who first designed them. It was possible to tune Buchla's touch pads to the conventional scale and to retune Moog's to unconventional scales, but such reconfigurations—the making of new scripts—required specialized skills, and most users did not want to invest the time and effort.[37]

According to this example, Hip-hop DJs largely discarded the technological frame of the turntable, whereas the Buchla and Moog users were so affected by their respective frames that they produced very different types of music on each of these systems. These examples, intended to create a stark contrast, are not entirely accurate. Early DJs did not simply use technologies in unconventional ways—as Phuture used the Roland TB-303—they modified these technologies in ways that would be considered a form of engineering in other contexts. Djs not only altered turntables, but some, such as Grandmaster Flash, modified their mixing consoles by adding a potentiometer

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[36] "Yuzo Koshiro and Motohiro Kawashima's Streets of Rage 3 OST Is a Valuable Slice of Techno History," Fact Magazine, February 17, 2018, https://www.factmag.com/2018/02/17/streets-of-rage-3-soundtrack-review/.
[37] Trevor Pinch and Frank Trocco, *Analog Days: The Invention and Impact of the Moog Synthesizer*, Revised edition (Cambridge, Massachusetts London, England: Harvard University Press, 2004), 311.

that allowed them to hear the record they were cuing up in their headphones and crossfading that with the sound flowing out the speakers to create continuous breaks. While there is no evidence previous avant-garde uses influenced early Hip-Hop turntablism, composers such as Pierre Schaefer, John Cage, and Halim Abdul Messieh El-Dabh, made use of the turntable as a musical instrument nearly a half-century prior. The independent rediscovery of its by musicians as varied as DJ Kool Herc, Boyd Rice, and Christian Marclay points to the fact that the technological frame for turntables might have been considerably more oriented towards musical performance than Pinch and Trocco argue.

The use of non-traditional scales on Buchla instruments had little to do with a requirement of specialized skills. If this were true, users of the Moog 960 Sequencer would have faced the same issue: it is also unquantized.[38] Well-known Moog modular users such as Tangerine Dream composed in equal temperament on these unquantized sequencers. Numerous recordings of classical works on earlier electronic instruments such as the Theremin also exist. These instruments were considerably more difficult to play in tune.[39]

I draw attention to this to emphasize why a theorization of the cultural uses of technology should incorporate an awareness of the creative interventions necessitated by the limitations of that technology. My research methodology involves discovering

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[38] "Moog Archives," accessed January 12, 2022, http://www.moogarchives.com/m960.html
[39] Theremins were unquantized and could not store a set of preset voltages. Performers would have to move their hand to the exact position corresponding to a certain note and hold it there.

how artists and designers document their use of technology, and, when possible, interviewing them. In addition, I attempted to restrict myself to writing about technology that I have used. Without these limitations, it is easy to repeat tropes that may not acknowledge the contributions of communities historically ignored by academia. Corry Banks, the creator of Modbap Modular and BBoyTechReport, spoke about this experience when I interviewed him about the relationship of modular synthesis to hip-hop:

> A lot of these things that we use that are intrinsically, sort of "hip-hop" were not designed for us to be doing the things that we do with them, and just out of necessity, you have somebody like Flash that was—I don't know if he was an electrical engineer, or whatever the hell—he had enough know-how to modify these things and create the crossfader and all this kind of stuff. It was as simple to him as "I needed something to turn things off and on. I wanted that, so I made that." Then the turntable industry is built on that sort of thing.
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> …he doesn't get the credit that I think he deserves. I think most of us think he deserves credit for that. He should get frickin royalties from the Pioneers of the world.[40]

In contrast to the representation of DJ culture by Pinch and Trocco, Phuture's use of the TB-303, is often misrepresented as "breaking" or "misusing" the device. Phuture, who found unique properties of an unmodified instrument and used it in their music, were subsequently praised for using "monophonic bassline generators such as the 303 misprogrammed to beget Acid House"[41] as if writing a successful piece of popular music on a device was somehow form of misuse. Fell responds by asking,

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[40] Corry Banks. Corry Banks Interview. 2022.
[41] Prior, Nick. "Putting a Glitch in the Field: Bourdieu, Actor Network Theory and Contemporary Music." Cultural Sociology 2, no. 3 (November 1, 2008): 301–19. https://doi.org/10.1177/1749975508095614.

“Did Phuture manage to turn a dial further than it was intended to go? Was there a message on the front of the machine saying, ‘If you have the filter’s resonance turned up to maximum, please do not wiggle its frequency control, as you might inadvertently discover a new musical vocabulary?’”[42] Where Grandmaster Flash is uncredited for technological innovations, Phuture is presumed to have “broken” their instrument merely by playing it. In both cases, black musicians were subject to mischaracterization by white academics; what distinguishes these academic interpretations of the artists’ use of technology is their ideological position concerning technological determinism.

While a technological frame may offer a means of understanding how technology is used, it is necessary to understand both the frame of the technology itself, and parallel technologies with associated cultural practices. I find the concept of the technological frame useful. However, as these examples demonstrate, a frame is only capable of explaining cultural practices to the extent that it is contextualized within other cultural practices concerning technology. Furthermore, technological frames are constantly evolving due to new cultural conditions. At the time *Analog Days: The Invention and Impact of the Moog Synthesizer* was released, Pinch and Trocco's assertion that Buchla’s choices had largely relegated his form of synthesis to obscurity, at least in comparison to Moog’s designs, was largely correct. The subtractive synthesis model popularized in the Minimoog was enjoying a renaissance

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[42] Mark Fell, “Collateral Damage: Mark Fell - The Wire,”

in the form of "virtual analog" synthesizers—such as the Korg Microkorg,[43] Access Virus,[44] and Clavia Nord Lead.[45] This subtractive design, where one or more harmonically-rich oscillators pass through an amplifier and a filter to shape the sound, remains prevalent. However, at the time of writing, Buchla's designs have also become popular: Eurorack modules that follow the design of, or explicitly clone Buchla modules, such as the Make Noise Maths, are among the most popular modules in that format. According to the Make Noise website, Maths "builds on the tradition set into motion in the 1960's when Don Buchla adapted circuits found within analog computers for musical purposes."[46] Modern synthesizers, such as the Ashun Sound Machines Hydrasynth, incorporate low-pass gate designs first implemented in the San Francisco Tape Music Center Buchla system.[47] Popular musicians or bands such as Ryuichi Sakamoto and Nine Inch Nails, use Buchla synthesizers such as the Music Easel. Additionally, Arturia has simulated the Music Easel as a software plugin.[48] This cultural shift does not imply that the technological frame is an incorrect framework, but it is a framework whose implications for cultural reception are mostly dependent on external factors.

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[43] "MicroKORG - SYNTHESIZER/VOCODER | KORG (USA)," KORG Global, accessed January 8, 2022, https://www.korg.com/us/products/synthesizers/microkorg/.
[44] "Access Virus B & KB." Accessed January 8, 2022. https://www.soundonsound.com/reviews/access-virus-b-kb.
[45] "Clavia Nord Lead 3." Accessed January 8, 2022. https://www.soundonsound.com/reviews/clavia-nord-lead-3.
[46] "Make Noise Co. | MATHS (Classic) (Retired)." Accessed January 13, 2022. https://www.makenoisemusic.com/modules/maths-classic-legacy.
[47] Ashun Sound Machines. "Hydrasynth Keyboard." Accessed January 5, 2022. https://www.ashunsoundmachines.com/hydrasynth-key.
[48] Simon Gareste, "Arturia - Buchla Easel V - Buchla Easel V," accessed January 13, 2022, https://www.arturia.com/products/analog-classics/buchla-easel-v/overview.

Unending Failure

Theorists and historians of technology are quick to point to the political implications of serious and intentional design choices in technology, especially those developed for military or corporate use.[49] While there have been calls for understanding failure among historians of technology since the late 1950s,[50] there is less emphasis on the jokes and mistakes that find their way into successful products. Histories of failure are typically used to debunk myths of inevitable progress,[51] but what of the failures within successes? What happens when failure is crucial to success and widespread adoption of a technology? While projecting careful planning and rationality onto technocrats and engineers allows theorists to analyze and critique the "meaning" of particular engineering decisions, it leaves little room for resistance, except for altering, damaging, or avoiding the devices. As an alternative to this, I am influenced by "low theory," a concept first introduced by Jack Halberstam in his 2011 book, *The Queer Art of Failure*:

> Low theory tries to locate all the in-between spaces that save us from being snared by the hooks of hegemony and speared by the seductions of the gift shop. But it also makes its peace with the possibility that alternatives dwell in the murky waters of a counterintuitive, often impossibly dark and negative realm of critique and refusal.[52]

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[49] See: Langdon Winner, *The Whale and the Reactor: A Search for Limits in an Age of High Technology*, 1st edition (Chicago: University of Chicago Press, 1989).
[50] James S. Small, *The Analogue Alternative: The Electronic Analogue Computer in Britain and the USA*, 1930-1975, 1st edition (Routledge, 2013), 9-12.
[51] Ibid.
[52] Jack Halberstam, *The Queer Art of Failure*, Illustrated Edition (Durham: Duke University Press Books, 2011), 2.

Low theory draws from a variety of materials, and claims validity for forms of knowledge production and expression that lie outside of hegemonic institutional knowledge:

> Here we can think about low theory as a mode of accessibility, but we might also think about it as a kind of theoretical model that flies below the radar, that is assembled from eccentric texts and examples and that refuses to confirm the hierarchies of knowing that maintain the high in high theory.[53]

Failure, to Halberstam, serves as a way of opposing hegemony and as a counter-narrative to triumphalist narratives of queerness. If we do not acknowledge the mistakes, failures, and stupidity that influence technological development—we risk deifying the creators of technology. It is important to incorporate an understanding of failure into our analyses of technology and accept that the "cultural effects" of technology may not so much represent a conflict between the agency of consumers and engineers but with a technology itself that may contain many intellectual lacunae. Technological hardware, in particular, is influenced by so many disparate factors that a full accounting of the possibilities is often impossible. It is not necessary to reject the potential for freedom or agency on the part of humans interacting with or designing technology, to accept that this agency is often rejected in favor of copying proven techniques and preserving the status quo. Limitations of knowledge and resources, arrogance, manipulation, market monopolies, and fealty to authority may all lead to the reproduction of failure.

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[53] Ibid, 16.

The incidental aesthetic or cultural effects of a technology may have only a peripheral relationship to its intended purpose. From the perspective of an engineer, these effects may be irrelevant or represent a necessary concession that runs counter to their design. For artists, scholars, and those who are critical of the aesthetics of their environment, these effects still matter. These effects do not necessarily serve as an articulation of the designer's ideology but represent an excess—a liminal space that can be contested. This excess is also exploited by artists as a means of critique and experimentation.

In this sense, technological failings enable resistance to hegemonic forces of oppression. While resistance may consist of altering or "cracking" the media technology in question, the cracks almost inevitably exist before this intervention, readymade in the material properties of the technology.[54] As Caleb Kelly states:

> The practice utilizes cracks inherent in the media themselves— we cannot play a vinyl record without causing some damage to the surface of the disc—and leads to a creative practice that drives playback tools into territory where undesired elements of the media become the focus of the practice.[55]

Through the practice of "cracking" media, artists bring the abject, ignored elements to the surface for examination and aesthetic appreciation. Celebrating the failure of a

[54] Caleb Kelly, *Cracked Media: The Sound of Malfunction*, First Edition (Cambridge, Mass: The MIT Press, 2009), 4.
[55] Ibid.

technological apparatus constitutes a shift in perspective that may enable challenges to the hegemony of information theory.

However, failure is also a tool within late-capitalist production. Meta includes simulations of the failings of old cameras in its social network Instagram, not because it cannot process images through other means, but because one of the primary objectives of modern computing is the simulation of analog media. Failure may offer a way out of structured expectations, but what happens when failures become alienated, fetishized, abstracted, and commodified? What happens when the failure of a technology becomes the feature and not the bug? What is left as a site of resistance?

To name one example of a successful failure: The iconic sounds of the video game *Pong* (Atari, 1972) were created by connecting incidental audio-rate voltages from various parts of the extant circuit, such as the sync generator, to amplification.[56] According to Al Alcorn, the designer of *Pong*, his superiors at Atari had instructed him to synthesize the sounds of booing, hissing, and cheering crowds, but he lacked the knowledge to do so. The resultant sounds were determined by the operation of the device itself rather than any forethought or planning. Because *Pong* was successful, this sound influenced cultural expectations of what video game sound could be. Despite technological advances, these sounds—simple, usually square, waveforms

[56] Kenneth B. McAlpine, *Bits and Pieces: A History of Chiptunes*, Illustrated edition (New York, NY: Oxford University Press, 2018), 13.

with nearly instantaneous amplitude envelopes[57]—linger as part of video game culture. A sound, no matter how incidental, will persist if it becomes emblematic of a particular aesthetic.[58]

Another example of this phenomenon is the Prophet VS, a polyphonic synthesizer developed by Sequential Circuits in 1985. The Prophet VS combined the analog filters used in their flagship Prophet 5 synthesizers with four digital oscillators, which players can mix in real-time using a joystick. Film composers such as Alan Howarth, John Carpenter, Brian Eno, and Alessandro Cortini used the Prophet VS. Popular musicians such as Daft Punk, Aphex Twin, and Vince Clark are also known users. The process of developing the synth was described by ex-Sequential employee Chris Meyer, he notes:

> [N]one of us had any background in DSP or psychoacoustics; we had to make it all up from scratch. As it turns out, some of our ignorance paid off in taking paths that textbooks would have told us to avoid - for better *and* for worse.[59]

Meyer describes how he—along with engineer Tony Dean—began brainstorming ideas for how a synthesizer using sampled waveforms would work. This form of synthesis, known as wavetable synthesis, was previous used in previously

[57] While most synthesizers allow the user to set the rate at which the volume increases or decreases, producing envelopes that more closely matched those of acoustic systems, many early game consoles employed did not allow for this. The sound would rise and fall rapidly with a period of sustained sound between this.

[58] This does not mean that the presence of this sound in *Pong* made its acceptance inevitable: players could have decided they hated the sounds or arcade managers could have found the sounds distracting and turned them off. This aesthetic became associated with video games precisely because players found these incidental sounds appealing. Moreover, while the tone of the sound is incidental, the correlation of the amplitude envelope to the on-screen information is intentionally designed.

[59] "The Story of the Prophet VS" Accessed December 28, 2021. https://www.linkedin.com/pulse/story-prophet-vs-chris-meyer/.

manufactured devices, such as the PPG Wave and Korg's DW6000. Sequential Circuits acquired both of these for the purpose of better understanding how wavetable synthesis was implemented in commercially available devices. According to Meyer, their first two guesses were reflected in the design of the respective synthesizers, but they preferred the aggressive sound and low memory requirements of the Wave's implementation, which consisted of varying the sample rate to change the pitch of a short sample:

> This choice is the one place our ignorance paid off the most. Transposing a waveform way down in pitch causes strange upper harmonics - images of the original harmonic pattern - to appear if not "properly" filtered.[60]

Many artists and designers share Meyer's aesthetic preference for the sound of aliasing. Throughout the development process, a number of compromises and mistakes led to the introduction of noise, distortion and sidebands into the basic sound. The company could have mitigated some of these issues by producing another batch of the bespoke integrated circuits, but, given the expense they would have had to incur, the team chose a workaround that, according to Meyer, introduced "more noise and distortion"[61] than he initially intended.

While this offers a clear illustration of how failure informs the sound of successful musical instruments, in the context of this discussion, the most relevant feature of the Prophet VS is its simulation of failure. After hearing how an error in

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[60] Ibid.
[61] Ibid.

one of the prototype units "scrambled its patch memory, and was producing some of the most bizarre sounds as a result." Sequential Circuits founder Dave Smith requested that engineer Josh Jeffe implement a patch randomization feature to implement this effect. This feature, which has since been included on a variety of polyphonic synthesizers,[62] did not stem from the meticulous application of musical or acoustic principles but from observing and enjoying the sounds of failure.

With something as ineffable as the timbre of a synthesizer, it is worth acknowledging the limits of knowledge, even for "experts." When Dave Smith was asked by sound designer Richard Devine what gave the Prophet 5 its iconic sound, he answered:

> I don't think I could sit there and be specific about why the Prophet 5 sounds as good as it does. I could make up some stuff, and it would be partially true, but I think most synth designers would agree that, to a certain degree, the instrument is going to find a sound on its own. It is going to take itself somewhere. You can kind of steer it and kind of know what it is going to do, but it is going to be what it wants to be.[63]

This almost-animistic declaration is not uncommon among instrument designers. While it may be tempting to dismiss this as deterministic or disregard it as sentimental, Smith correctly identifies the relationship many engineers have with the complex, potentially indeterminate, affordances of each interacting technological element within their designs.

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[62] Most recently on the Ashun Sound Machines Hydrasynth.
[63] Sequential. *Prophet-5: One Year On, Part 2 Of 6*, 2021. https://www.youtube.com/watch?v=oMS-BHdZKDo.

The properties of a technological artifact may indicate potential uses, even if these properties were created unintentionally. Eric Persing, the sound designer of the Roland Alpha Juno 2, explicitly acknowledges that his part in the development of an electronic music trope was accidental. The "hoover" sound used by many techno artists arose out of a joke preset called "WhatThe?" that Persing created for the Alpha Juno 2. Unlike monophonic analog synthesizers such as the TB-303, polyphonic synthesizers use a digital system to edit, store and recall various settings for the oscillators, filters, envelopes, and low-frequency oscillators. These preset voltages determine the sound and operation of the synthesizer. In an interview with Mark Vale, Persing describes WhatThe? as "a really annoying sound with lots of pulse-width modulation."[64] The Alpha Juno synthesizers[65] were capable of providing a unique form of pulse-width modulation that could be applied to sawtooth[66] waveforms in addition to the pulse waves that are traditionally used for pulse-width modulation. Despite the fact that Persing did not intend to include WhatThe? in the Alpha Juno 2 factory presets, let alone imagine its use in popular recordings, WhatThe? was quickly adopted by artists. It is the lead melodic instrument on Joey Beltram's *Mentasm* and Human Resource's *Dominator*. In Persing's words:

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[64] Mark Vail, *The Synthesizer: A Comprehensive Guide to Understanding, Programming, Playing, and Recording the Ultimate Electronic Music Instrument*, 1st edition (New York City: Oxford University Press, 2014).

[65] There are two models of the Alpha Juno. The Alpha Juno 1 is a smaller 49 key synthesizer, whereas the Alpha Juno 2 provides 61 keys and features polyphonic aftertouch—the ability to perform changes to individual notes by altering the pressure applied to each key.

[66] Named as such because they resemble the tooth of a saw blade, sawtooth waves rise almost instantaneously before decreasing linearly for the rest of their duty cycle.

> I'd see people refer to it online: "Hoover this" and "Hoover that" and "Who's got the best Hoover?" I started doing research because I'm thinking we should probably include the "Hoover sound" in our current instruments. I find a website dedicated to "Hoovers" and posted there is a big picture of Roland's Alpha Juno 2, the coveted Hoover machine in Europe for trance and rave music because it can make this annoying sound. As I dug further I found that the "Hoover sound" comes from a factory preset in the Alpha Juno-2 called "WhatThe?" Then I realized I programmed the WhatThe? patch for Roland as a joke. [The "Hoover" preset] sort of sounds like a vacuum cleaner. The original sound wasn't intended to be anything but a joke and it ended up in the Alpha Juno-2's factory patch set![67]

Finally, iconic sounds may literally depend on the failure of electrical components. The Roland TR-808 is perhaps the most ubiquitous instrument in popular music. As I write this, I can hear the sound of an 808 kickdrum emerging from a distant car's subwoofer. After appearing on Afrika Bambaataa and the Soul Sonic Force's 1982 single *Planet Rock*, the drum machine became the de-facto form of percussion in hip-hop. Hank Shocklee, of pioneering hip hop collective Public Enemy, claims, "You cannot make a record without having that 808 sound."[68] In an interview for the documentary *808* (2015), Roland founder Ikutaro Kakehashi states that Roland was forced to cease production on the device because they could no longer source defective circuits:

> I used a defective transistor. In that time, they'd make 10,000 transistors; probably 2% to 3% were defective. This defective transistor made noises. It was rejected. Good ones were for sale, bad ones: throw away. I purchased these defective transistors; this is the sizzling sound source. Semi-conductor technology got better and

[67] Mark Vail, *The Synthesizer: A Comprehensive Guide to Understanding, Programming, Playing, and Recording the Ultimate Electronic Music Instrument*, 1st edition (New York City: Oxford University Press, 2014).
[68] Alexander Dunn et al., *808*, Documentary, Music (You Know Films, Atlantic Films, You Know Ltd., 2015).

> better. We could no longer buy the defective transistor. So, there was no way to come back![69]

The sound of the TR-808 is the sound of manufacturing failure. It was not possible for Roland to produce the device without it. In later drum machines such as the TR-909, short digital samples were used in addition to the analog sounds to produce its noise-based drum sounds such as the crash, ride, and hi-hats.

For all of the work of science and technology scholars, the narrative of rationally planned and executed—and therefore inevitable—technological progress is extremely difficult to dislodge from the popular imagination. These notions of progress are inexorably linked with digital computing. No other industry has seen such reliable progress in the ratio of cost to efficacy. The fact that histories of computing were initially written from the perspective of participants within that history adds to this narrative.[70] According to James Small, accounts of early computing "generally focus on successes, firsts and facts, and though often rich in detail, they adopt a distinctly narrow frame of reference. This results in a loss of historical contingency as well as context."[71] It unsurprising that technologists whose careers depend on public perception of them as competent and intelligent would emphasizes their successes and not their failures. The development of electronic musical instruments and audio processors—especially those with connections to countercultures, such as the modular synthesizers of Don Buchla—offer unique case

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[69] Ibid.
[70] James S. Small, *The Analogue Alternative: The Electronic Analogue Computer in Britain and the USA*, 1930-1975, 1st edition (Routledge, 2013), 5.
[71] Ibid.

studies precisely because the creators' descriptions largely counteract these teleological narratives.

While failure, randomness, and misunderstanding may not initially appear to be a productive starting point for analyzing or creating music, the influence of these imperfections is too widespread to ignore. As I will show, there is ample evidence that, despite appearances, the imperfections of media form the primary basis for the aesthetics of digital audio. There are, of course, many reasons to question the idea that the aural or visual alterations imparted by a particular media technology represent "imperfections." The noises and distortions of analog and digital media technologies are directly influenced by their physical properties and electronic configuration. The structures derived from media poetics are not determined outcomes. They are affordances that enable a variety of outcomes. When an artist engages with these poetics, they are effectively distributing agency between themselves and a technological object. The aesthetic outcomes of these processes are influenced by design decisions by the engineer or team of engineers that design them, and the artist's choices. The poetics of mediation imply that, rather than degrading a signal, media provide a structure within which composers and artists can formulate new sounds and musical forms.

CHAPTER 2:
THE POETICS OF DIGITAL MEDIA

A major issue in designing digital interfaces or hybrids is the apparent limitlessness of 'materials' – each thought has its own button. I do believe now that the instrument exists on the edge of its limitations – Those are not clear at first as the choices are vast, but eventually one needs to settle on a particular configuration, and play with its limits.

– Laetitia Sonami

Before considering how simulation functions within digital systems, it is necessary to detail the technical and theoretical processes by which digital systems are constructed. This foundation is required so that the reader can identify the cluster of traits that characterize digital simulation. By uncovering characteristics specific to digital media and how designers of digital audio systems obfuscate these characteristics through simulation, I aim to demonstrate the ubiquity of simulation and examine how cultural exposure to noise in analog media complicates any claims digital media has to transparency and immediacy.

Digital audio is produced through two distinct processes: the conversion of continuous signals into discrete binary information for later reconstruction or the application of algorithmic processes.[1] While the latter will be addressed in the following sections, I begin with the analog to digital conversion process. This conversion process is mirrored when digital information is converted back to analog. Aliasing and quantization error can occur in both processes and during the

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[1] Gareth Loy, *Musimathics: The Mathematical Foundations of Music*, vol. 2 (Cambridge, MA, USA: MIT Press, 2007), 9.

intervening stages of digital signal processing (DSP). In the popular imagination, the transformation of analog information into concatenated strings of "ones and zeros" and back holds a particular fascination. The first time this concept was explained to me, it struck me as vaguely miraculous that the immersive totality of sound and image could be expressed as concatenated logical statements. As early as the latter half of the 1960s, artists were producing interactive multimedia works explicitly addressing this process.[2] Michael Callahan's *Monologue to Digital Converter* (1967) uses sound to advance binary counters, providing an early form of real-time digital interaction:

> Monologue to Digital Converter was built in 1967 as a play on analog to digital. It consists of a VU meter (analog) and four decimal counting units (digital). The speaker serves as a microphone, picking up ambient sound. The level is indicated on the meter, and whenever a threshold is exceeded the counters increment. In was mounted on a wall and people would interact by speaking to it. Fifty years ago, digital was hardly in the public lexicon, and indeed, the counting units (IBM surplus) ran several hundred dollars each, so anything displaying digitals was uncommon.[3]

The artifacts of digital sound are both a potential impediment to the experience of immersion[4]—so often associated with digital media—and present aesthetic possibilities that are uniquely digital. Artists often utilize these "imperfections" of digital media to construct counternarratives to the widespread myth that digital systems can generate noiseless renderings of analog information. They are also ontological markers of the digital.[5] Aliasing and quantization error

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[2] Michael Callahan. *Michael Callahan Interview*, August 13, 2019.
[3] Ibid
[4] Immersion is a complex and paradoxical term. I will examine this in greater depth during my discussion of simulation in Chapter 3.
[5] "An example for a purely digital effect is the bitcrusher, a distortion effect that transforms the sound by reducing the bit-depth and sample rate of the input signal. The output sound is characterised by a

disrupt the illusion of perfect digital simulation, and force the listener to consider the distance between a representation and the represented. As later discussions will show, this is complicated by the use of techniques such as self-reflexive simulated mediation, which directs the users' awareness to the constructed nature of a representation, while at the same time, masking the ontological markers of digital media. In addition to fascination, the abstraction and simulation of analog signals may produce both a sense of nostalgia and uncanniness.[6]

Figure 2.1 Monologue to Digital Converter - Provided to the Author by Michael Callahan

The distinctions between analog and digital devices are contextual. Digital and analog systems are often defined in contrast to each other—analog systems as

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decreased bandwidth and added quantisation noise." Thomas Wilmering et al., "A History of Audio Effects," Applied Sciences 10 (January 22, 2020): 791, https://doi.org/10.3390/app10030791, 16.

[6] This particular quality of digital media will be discussed in Chapter 3.

continuous and digital systems as discrete.[7][8] For example, the resolution of an analog signal is typically defined in terms of noise rather than quantization error, which is associated with digital media. Moreover, according to Shannon, digital information transmission and reproduction can operate without accumulating noise along its transmission channel.[9] While a digital computer will inevitably contain analog and digital components, this distinction is not always presented as malleable in popular and academic contexts. In fact, there is no material difference between analog and digital components; their status as analog or digital is defined by their use within a circuit. The use of "digital" CMOS integrated circuits in analog synthesizer components such as the widely-adapted filter from the Electronic Dream Plant Wasp provides an example where this becomes aesthetically relevant. As German synthesizer manufacturer Doepfer notes regarding their adaptation of the Wasp filter, "This design 'abuses' digital inverters as analog operational amplifiers leading to distortions and other 'dirty' effects that generate the specific sound of this filter."[10] No practically available digital technology moves between two discrete states without brief continuous movement through intermediary states.[11] It is possible to derive a more accurate identification of an analog or digital circuit by examining its use.

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7 "Digital, n. and Adj." In *OED Online*. Oxford University Press. Accessed May 11, 2021. https://www.oed.com/view/Entry/52611.

8 Paul Scherz and Simon Monk, *Practical Electronics for Inventors*, 3rd edition (New York: Tab Books, 2013), 717.

9 Since each portion of the quantized digital signal is stored and transmitted as a single, identical bit—only distinguished by their position in relation to each other—any noise below the threshold for altering the state of that bit would not register in the received bit.

10 "A-124." Accessed March 17, 2021. http://www.doepfer.de/a124.htm

11 The question of whether this is theoretically possible is outside the scope of this discussion, as I have focused my analysis on extant circuits.

There are a number of stages involved in the analog-to-digital conversion process, such as low-pass filtering the signal, sampling discrete moments in time, quantizing the sampled information to the nearest bit, and eventually storing that information.[12] However, I will focus on the sampling and quantization stages as these have been the primary sites of artistic intervention. I will address the former technique first, mirroring the signal path of information as it is converted from analog to digital. While this process has been extensively documented elsewhere, I will reconstruct the conversion process in terms of poetics rather engineering principles or mathematics—although both of the latter fields will provide useful contextualization. Each element of analog-to-digital and digital-to-analog conversion has been the subject of artistic intervention and interrogation, and, therefore, it is relevant to explore the aesthetic assumptions embedded in these conversion processes. Finally, given the implications of the recontextualized processes for analog-to-digital conversion—as generative rather than simply transformative—I will consider how the rhetoric surrounding information theory has led to a mischaracterization of digital processes as objective and neutral.

While I use the terms "digital" and "analog" to characterize circuits and aesthetic outcomes, there is no agreed-upon definition for these words across all fields of study. Moreover, while there are aesthetic effects connected with digital media,

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[12] Gareth Loy, *Musimathics: The Mathematical Foundations of Music*, vol. 2 (Cambridge, MA, USA: MIT Press, 2007), 9.

these aesthetics may also be rendered in analog media.[13] A broader definition of digital aesthetics will include artworks or designs that digital media have influenced. In contemporary society, such a definition is so broad that it is almost meaningless. As Soraya Murray argues:

> The question remains as to whether there is such a thing as a "digital aesthetic," in the sense of the digital possessing unique, discernable qualities that isolate it from other media. Limiting the digital to art whose final form must be composed of illuminated pixels, binary code, digital sound, or electronic hardware are useful for structuring a specialization but ultimately under-represent the profound impact of art and technology. The digital has simply become too ubiquitous in western culture to disentangle it entirely and identify it discretely.[14]

Within the context of media poetics, the problems with defining digital media are twofold. First, properties that constitute digitality—such as discrete states—are unrealizable ideals that available hardware can only approximate. Secondly, the constituent elements of digital aesthetics—sampling and quantization—can occur independently. This means that the perception of digital aesthetics may include technologies that do not possess all of the qualities contained within a given definition of the digital. For example, celluloid motion pictures consist of discrete images but are considered analog due to the analog, electrochemical process of recording information in an individual frame. Despite this, the fact that these media are discrete and sampled means that they can produce "digital" artifacts such as visual

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[13] In fact, this is the typical way that listeners receive the aesthetics of the digital: by hearing a digital signal that has been converted back into analog information. It is possible to listen to unconverted digital information—by amplifying and transducing any point along a digital circuit before the DAC—but this is not a common practice. As mentioned earlier, Atari's *Pong* (1972) uses this technique.

[14] Murray, Soraya "New Media Anxiety: Art History and the Problem of Modern Technology" PhD Diss., Cornell University, 2007.

aliasing. Similarly, the “bucket brigade” delays common in early effects units sample discrete moments in time but are also commonly received as analog, despite audible aliasing. Conversely, DCOs—continuous systems without sampling artifacts that are nonetheless subject to the effects of quantization error[15]—and remain the subject of fierce debate regarding their ontological status.

Nevertheless, aliasing and quantization error have become iconic: depending on the context, they may evoke particular eras of console gaming, musical genres, digital error, signal corruption, and a variety of media-related artifacts. As early as 1995, Nicholas Negroponte lamented the continued presence of visual aliasing and its status as a visual synecdoche for computing;

> Unfortunately, the consumer has been trained to accept the jaggies as a given. We even seem to be turning this artifact into a kind of mascot in the same way that graphic designers frequently used that funny, magnetic readable font MICR, in the 1960s and 1970s to create an “electronic” look. In the 1980s and 1990s designers are doing this again by using exaggerated, aliased typography to mean “computerness.” Today there is no need for lines and characters to be anything less than print quality and perfectly smooth.[16]

While it was easy to identify and dismiss the practice of using aliased fonts as self-consciously retro—even in 1995—the material limitations of digital media persist in popular culture. Sample rate and bit depth reduction tools are offered as part of the most popular digital audio workstations (DAWs), such as Logic Pro X, Ableton

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[15] While the signals themselves are not subject to the sonic effects of bit reduction—the signal is continuous and unquantized, the available frequency resolution is determined by both the bit depth of the controller and the frequency of the master clock.

[16] Nicholas Negroponte, *Being Digital*, 1st edition (New York, NY: Vintage, 1996), 108.

Live, and Pro-Tools. They are also featured in synthesizer presets used to create popular music and soundtracks to popular forms of media such as video-games, television, and film. As I argue throughout, the simulation of mediation, noise, and failure continues to be the fundamental basis of the tools that artists use to create popular media at the time of writing. Dismissing these techniques as regressive, ultimately means dismissing most forms of mediated cultural expression.

Aliasing: What is on the Other Side of the Brick Wall?

Aliasing is not an exclusively digital phenomenon but applies to any system consisting of discrete time samples.[17] However, given that all digital systems are discrete, one must inevitably contend with aliasing when accounting for digital aesthetics. For a sampled system to function without aliasing, it must consist only of signals at frequencies less than half the sampling rate. If this limit, known as the Nyquist frequency,[18] is exceeded, it is not possible to reconstruct the original signal.[19] This results in ambiguity, and while the signal that crosses this frequency threshold will not be recorded, a new signal will be audible. This new signal's frequency is equal to the frequency of the original signal subtracted by the Nyquist frequency. To avoid audible aliasing, all signals above the Nyquist frequency must be removed. One method of accomplishing this involves using a low-pass "brickwall" filter to remove

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[17] I am speaking here of the media that are typically coded as digital.
[18] After Bell Labs researcher Harry Nyquist
[19] Curtis Roads, *The Computer Music Tutorial*, Edition Unstated (Cambridge, Mass: The MIT Press, 1996), 28-31.

these sounds. The technique of filtering sounds above the Nyquist frequency, known as band limiting, is a fundamental aspect of digital media and is the first stage of the process by which continuous signals are converted into binary logical states.

Consumer audio sample rates for compact disks and digital film are 44.1kHz and 48kHz, respectively.[20] Other consumer media, such as early video game consoles, were also capable of sample playback but at rates lower than compact disc audio. Human hearing can extend beyond 20kHz. Therefore, both consumer audio sample rates allow for very few inaudible frequencies below the Nyquist frequency.[21] This results in only a small amount of bandwidth in which a converter must transition from preserving information to the complete attenuation of the signal. The low-pass filters in synthesizers and mixing consoles typically attenuate frequencies in gradually increasing proportion, such that lower frequencies are attenuated by fewer decibels than higher frequencies. The amount of attenuation for a given range of frequencies is expressed in decibels per octave. The most common filter designs in synthesizers attenuate 12db or 24db per octave,[22] while mixing consoles and studio equalizers may offer even gentler slopes. By contrast, the analog antialiasing filters used in early analog to digital converters (ADCs) used slopes as sharp as 96db per octave to preserve as much information below the Nyquist frequency as possible without introducing aliasing.[23] These filters were not "transparent" and introduced other

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[20] Ibid.
[21] No more than a few semitones for those without significant hearing loss.
[22] Known as second-order and fourth-order filters, respectively. 6db, first-order filters are common on parametric equalizers.
[23] Gareth Loy, *Musimathics: The Mathematical Foundations of Music*, vol. 2 (Cambridge, MA, USA: MIT Press, 2007), 42-6.

effects on the signal, such as phase distortion in the higher frequencies. Listeners may perceive these early ADCs as having a “harsh” or “piercing” sound.

Many modern ADCs use oversampling to compensate for this, which involves sampling at a higher rate—typically a whole number multiple of the intended sample rate—and using a digital filter before resampling to the final sample rate. Digital low-pass filters of this type are both simple and sonically transparent.[24] Additionally, oversampling will lower the amplitude of the noise generated by quantization error because the noise is spread over a wider baseband of frequencies and the digital low-pass filter eliminates information in the higher frequencies. This results in a higher bit depth. Modern commercial audio interfaces offer sampling rates up to four times that of the standard distribution formats, while oversampling ADCs operate up to 128 times the base sample rate.[25]

While it is now possible to record without audible aliasing or phase distortion, aliasing remains present in music through various sample rate reduction tools such as bitcrushers, and through the continued use of older digital instruments built with more primitive digital conversion technologies. In addition, there remains debate as to whether the sample rates of consumer audio are adequate. Mastering engineer Bob Katz notes, “whenever I work at a very high sample rate, and then return to the ‘standard’ (44.1kHz) version, the lower sample rate sounds worse, although after a

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[24] Ibid.
[25] Bob Katz, *Mastering Audio: The Art and the Science*, 3rd edition (Burlington, MA: Focal Press, 2013), 312.

brief settling-in period, it doesn't sound so bad after all."[26] While I do not share Katz's perspective on the subjective sound quality differences between sample rates, it is important to note that the aesthetics of sample rates remain controversial within the professional audio industry.

Instruments such as samplers or ROM-based synthesizers play back digital audio information that has previously been recorded into the device's storage. In its simplest form, a sampler plays the recorded material at lower or higher sample rates, corresponding to the pitch of each note. Early samplers such as the CMI Fairlight, EMU Emulator, and Ensoniq Mirage[27] contained analog filters used to shape and remove aliasing from the sound. Users could set these filters to follow the notes of the keyboard, such that samples played at a lower sample rate would be accompanied by a proportional lowering of the cutoff frequency of the filter.[28] Because digital memory was expensive upon introduction, some of these devices—such as the E-MU SP-1200—limited the available sampling time to mere seconds. To sample longer material, producers would commonly sample vinyl LPs at 44 revolutions per minute, resulting in a higher-pitched sound with a shorter playback time, which allowed them

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[26] Bob Katz, *Mastering Audio: The Art and the Science*, 3rd edition (Burlington, MA: Focal Press, 2013), 25.

[27] Paul Wiffen, "Ensoniq Mirage (EMM Jul 1985)," Electronics & Music Maker, no. Jul 1985 (July 1985): 10–12.

[28] These filters are resonant and, therefore, they may also emphasize aliasing at the cutoff frequency. The frequencies at the cutoff point of a resonant low-pass filter are raised in amplitude in accordance with the amount of resonance. In this sense, analog systems may actively increase the perception of digital aesthetics.

to record sped-up versions of longer passages.[29] These recordings would then be played back at a lower pitch on the SP-1200, such that the original pitch and length were restored. This technique introduced noticeable aliasing. When combined with techniques used to mitigate noise and aliasing, this method of sampling produced a sonic aesthetic commonly associated with 1980s hip-hop and industrial music. As Corry Banks of BBoyTechReport and Modbap Modular related to me:

> It was almost a side effect of what you had available to you, but you leaned into it. I remember someone saying to me, “Yo, why is everybody trying to make everything sound like the [SP] 1200, we worked hard as hell to get that noise out of there!” This was somebody who was making big records in the ‘90s. At the same time, even when they mixed it in the studio to lessen that noise, it still became a bit of an effect, a bit of a layer.
>
> You’ve got this track that was sampled, say, into the SP-1200, and that thing gets layered into a reel-to-reel tape as separate tracks, and then you’ve got this compound tape saturation. You may run that through some A/D converters or through some analog mix-board. All of these things compound to create a sound.[30]

This particular sound is so sought-after, that in November 2021, Dave Rossum, the founder of E-MU, re-released the SP-1200 as a product from his latest company, Rossum Electro. According to Rossum, “the team determined that virtually all original components ought to be used in order to deliver the sound at the very highest standard of precision.”[31] This device features the same bit depth and sample

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[29] Abbey Road Institute. “Sampling: Its Role in Hop-Hop & Its Legacy in Music Production.” Accessed September 14, 2021. https://abbeyroadinstitute.co.uk/blog/sampling-role-in-hip-hop-and-its-legacy-in-music-production/.
[30] Corry Banks, *ModBap Modular Interview*, January 2, 2022.
[31] Rossum Electro-Music. “SP-1200.” Accessed December 19, 2021. https://shop.rossum-electro.com/products/sp-1200.

rate as the original but features increased memory. The Isla Instruments S2400, a sampler designed to replicate the interface and functionality of the SP-1200 and released in late 2020, despite possessing exponentially larger memory than the SP1200, offers a "classic" mode featuring 12-Bit, 26kHz sample rate recording.[32]

Aliasing is also an effect that is occasionally incorporated into analog emulations, especially if the simulation is intended to recreate the experience of listening to music produced during a time when aliasing was prevalent. Cooper fx's Tom Majeski incorporated aliasing into a pedal he designed to emulate the sound of VHS generation loss, not because aliasing is produced during the copying of VHS tapes, but because:

> … at the time, I was listening to a lot of music with the old 80s drums, 12 or 16-bit. They were low res, and that was also a big part of the Chillwave vibe that I was trying to go for. And yeah, of course, that was something that is not a part of VHS degradation, but it was still something I wanted to have in the palette.[33]

Aliasing also raises questions regarding the relationship between the materiality of digital media and the perception of the media artifacts. It has a complicated relationship to abstraction because the effect of the alias always demonstrates an "abstract" mathematical relationship—as in the case of the geometric patterns that occur with aliased images or the new waveforms introduced when multiple frequencies in the original recording exceed the Nyquist frequency—yet these patterns have an indexical and material basis. Aliasing patterns point to the

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[32] "S2400 – ISLA Instruments." Accessed September 14, 2021. https://www.islainstruments.com/products/s2400/.
[33] Tom Majeski, *Cooper fx Interview*, August 2, 2021.

physical limitations of real hardware and offer a view of the edges of a system where the limitations are often deliberately obscured. The sounds of aliased signals can be isolated to a single instrument, brought in and out of a recording in time with the music, or simply used to evoke the sonic aesthetics of a particular technology. The sound of intentional aliasing is audible alongside otherwise pristine recordings on Ludvig Forssell's soundtrack to the popular video game *Death Stranding* (Kojima Productions, 2019), to name one example.[34] While many of the effects of aliasing can now be mitigated to the point where they are imperceptible, the sound of aliasing cannot be unheard. Aliasing is now a sought-after effect, a recognizable marker of digitality.

A Silent Trembling: Digital Aesthetics and Dither

During the summer of 2012, Apple announced its increased pixel density, "retina" display Macbook Pro line of laptop computers at its annual Worldwide Developers Conference. Approximately ten minutes into the announcement, the video stream cut to a prerecorded promotional video; during the wonted voiceover from Chief Design Officer Jonathan Ive, he began explaining physical changes the company had made to the internal fan to reduce noise to the point of "near imperceptibility."[35] Ive states:

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[34] Forsell, Ludvig. *Death Stranding*. Mondo, 2020.
[35] "Apple Unveils next Generation MacBook Pro with Retina Display; Updates Other MacBook Models," Macworld (blog), accessed March 15, 2022, https://www.macworld.com/article/218044/apple_unveils_next_generation_macbook_pro_with_retina_display.html. accessed June 15, 2017, http://www.macworld.com/article/1167184/apple_unveils_next_generation_macbook_pro_with_retina_display.html

> Air is pulled into vents and propelled through sculpted cavities through fans with asymmetrically positioned blades. In most fans, the blades are positioned symmetrically, which creates a single, identifiable frequency.
>
> We positioned ours asymmetrically to spread the sound over a variety of frequencies, which makes it seem quieter and less intrusive.[36]

Upon watching this announcement, it struck me that Ive was describing a type of dither; the application of noise to reduce the periodic distortion of a digital audio signal. In the case of the fan sounds, there was no intended signal to be conveyed,[37] but the aesthetic goals remain the same. The length of each impeller blade of the fan differs so that the noise generated by the movement of air by each blade is distributed across the spectrum of audible phenomena rather than collecting around a center frequency to produce an identifiable tone.[38]

These asymmetrical blades are a uniquely psychoacoustic aspect of design. The engineers at Apple were not designing the fan based on the limitations of human physiology, as might be the case if they were to design a fan that produces noise at inaudible ultrasonic or infrasonic frequencies.[39] The purported advantage of distributing sounds across the audible spectrum is that listeners are less likely to

[36] the unofficial AppleKeynotes channel, *Apple WWDC 2012 - MacBook Pro with Retina Display Introduction, 2012*, https://www.youtube.com/watch?v=DX99JH-8n0s.

[37] Apple has previously and subsequently released fanless computers. Therefore, it is perhaps more accurate to state that that intended signal is silence. Thus, the fans are producing "noise" both in the sense of a "random" signal and an unintended signal.

[38] Philippe P. Herrou, Richard A. Herms, and Jesse T. Dybenko. *Fan having a blade assembly with different chord lengths*. United States US10422350B2, filed July 1, 2016, and issued September 24, 2019.

[39] This is precisely how noise-shaped dither functions; the energy is distributed to parts of the spectrum where human listeners are less sensitive.

perceive a band of quiet, distributed noise than a single periodic signal. This effect is partly due to a perceptual effect where higher amplitude sounds "cover" or "mask" sounds of lower amplitude. In its patent filing, Apple, Inc. claims that "by varying the chord length of the blades, the amplitude of the BPF is reduced and the acoustical tonal energy is spread across multiple frequencies, and the user may perceive less noise emanating from the fan assembly."[40] The average[41] amplitude may remain the same, regardless of whether the energy is distributed across the spectrum or concentrates around a particular pitch, but the listener will hear the distributed noise as quieter, and these sounds are more likely to be masked by sounds in the listening environment.

I begin with this example of mechanical dither to demonstrate that dither is an essentially analog process. There is nothing specific to the digital dithering process that cannot be accomplished by augmenting the quietest information—the lowest bit—with analog noise. Indeed, the noise of hardware dither used in analog to digital conversion is typically analog. What is uniquely digital about dither is the "problem" that it solves.

Understanding the function of dither brings us closer to deriving a technical basis for digital aesthetics. Dither is more than a technique for managing bit reduction. It is a design philosophy that extends across visual, aural, analog, digital,

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[40] Philippe P. Herrou, Richard A. Herms, and Jesse T. Dybenko. *Fan having a blade assembly with different chord lengths*. United States US10422350B2, filed July 1, 2016, and issued September 24, 2019.
[41] Using the root-mean-squared formula for determining average amplitude, for example.

and mechanical information systems. The efficacy of software dither is dependent on observations that are as much aesthetic and cultural as they are phenomenological. Dither also provides an insight into the socially constructed aspects of simulation and how these link to aesthetics.

Before proceeding further, it is necessary to define how dither functions in terms of computational and perceptual processes, how it relates to our conception of the digital, and why it is necessary for the creation of the experience of digital technology. When an audio interface[42] translates analog information into a digital form, this information is quantized to a set number of values. The resolution of this information is expressed in terms of bit depth, with each bit doubling the resolution with which an instantaneous sample can be expressed. When continuous analog information is encoded in binary, there is inevitably a difference between a measured value and what is ultimately recorded, because bit depth is, by definition, finite. The information below the threshold defined by the highest bit is registered as a "0" and is lost. In a 16-bit rendering of a bipolar signal, the lowest bit is the peak value divided by 32,767—approximately 96dB below peak amplitude.[43] Since the human perception of volume is approximately logarithmic, these errors are audible, especially with periodic signals, where the error is necessarily correlated to the audio signal. An analog dither increases the indeterminacy of the signal, but by combining noise with

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[42] Or any ADC
[43] Bob Katz, *Mastering Audio: The Art and the Science*, 3rd edition (Burlington, MA: Focal Press, 2013), 200-1.

the lowest bit of information, the average voltage of the noise will be offset by the value of the incoming signal, thus preserving information that would otherwise be lost.[44]

When audio plugins perform calculations that are expressed in greater bit depth than the original signal, quantization of information also takes place. A reduction in bit depth at this stage will also produce a distorted pattern related to the input signal. For complex signals, this will result in noise, but for simple, sinusoidal material, the result is audible distortion.[45] Depending on the noise floor of the environment that the listener occupies, the fidelity of the audio playback system, or the listener's hearing acuity, quantization error may be audible in audio up to 24 bits of resolution.[46] Software dither is considered an effective means of accounting for bit depth reduction because it is claimed that humans are especially attuned to hearing the addition of harmonics to a periodic signal. These patterns are considered less desirable and more noticeable than randomization of the least significant bit.

Dither decouples periodic distortion from the carrier signal. For non-periodic material, there may not be an audible difference, unless the dither noise has been shaped. Noise shaping allows an engineer to further tailor dither to human perception by distributing noise to the parts of the audible spectrum where "average" human listeners are least sensitive. As Andrew J. Oxenham notes:

> There is no direct relationship between the physical sound level (in db SPL) and the sensation of loudness. There are many reasons for this,

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[44] Ibid.
[45] Curtis Roads, *The Computer Music Tutorial*, (Cambridge, Mass: The MIT Press, 1996), 36-7.
[46] This is unlikely outside of a laboratory or professional studio setting.

> but an important one is that loudness depends heavily on the frequency content of the sound.[47]

Concentrating the already low amplitude dither in areas of lower frequency sensitivity will theoretically reduce its perceived loudness to the point of complete inaudibility.

I will show that there are complications to the theory of aural perception used to support the use of dither, and that the research undergirding it cannot be separated from the history of recorded media. Empirical research into hearing inevitably involves test subjects who have spent their lives listening and becoming acclimated to characteristic sounds of analog media technologies.[48] Given that noise is the limit of resolution in analog systems, it is unsurprising that the listeners in these tests are less aware of low-level noise and prefers it to inharmonic distortion. This preference is ultimately informed by one's taste and cultural conditioning. Katz makes it clear that he views low-level noise as the more musical of the two choices, "At 16 bits, dithering always sounds better than truncation, because inharmonic distortion is very unmusical."[49] Dither offers a counternarrative to claims that noise is inherently transgressive, as it is explicitly preferred by audio professionals to the "wrong" type of periodic signals.

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[47] Andrew J. Oxenham. "The Perception of Musical Tones" in The Psychology of Music, ed. Diana Deutsch. (San Diego, CA: Elsevier Press, 2013), 4.
[48] Despite the widespread adoption of digital media, analog noise is still audible on nearly any amplification system. The same is true for visual information, where analog noise is still the resolution limit for printed images.
[49] Bob Katz, *Mastering Audio: The Art and the Science*, 3rd edition (Burlington, MA: Focal Press, 2013), 207.

While dither is arguably inaudible on most commercial recordings, some forms of processing used in remixing or playing back a recording can render dither audible. Goodhertz DSP designer Devin Kerr mentioned this in an interview I conducted with him about Good Dither, an audio plugin he developed, to replace some of the potentially "nasty" sounds of the dithering process:

> Dither is really interesting because, in an ideal form, it should be purely technical. You should never hear the dither noise, but there are occasions where you do. Let's say you sample something from a record that already had dither on it; you have compressed it a ton, you distort it or something; now, all of a sudden, dither might easily be audible. So, one of the things we thought about when creating this was; if dither does become audible somehow, let's make this as pleasing as possible. Because there are some that are really nasty if they do become audible, it's like a squealing 20Khz tone or something. Even enough to be bad for your speakers or your ears.[50]

Kromhout suggests that "dither not only points to the structural limitation of digital sound but also suggests that noise is important for the way listeners relate to sound recordings more generally."[51] Noise is something that seems "natural" for recorded sound. However, by naturalizing our enculturated preferences as western listeners, we gloss over a fundamental fact about digital audio: it is constructed, from the outset, to simulate the analog. Our most hallowed cultural artifacts—especially those that remain prevalent in our culture through reuse in films, television programs, video games, and advertising[52]—contain audible noise. The uncanny distortion of

[50] Devin Kerr, *Goodhertz Interview*, 2021.
[51] Melle Jan Kromhout, "Noise Resonance: Technological Sound Reproduction and the Logic of Filtering" PhD Diss. (University of Amsterdam), 88.
[52] Such as the Beatles' discography, *Citizen Kane*, Reagan's Berlin Wall Speech, Motown, the "Amen" Break, Orch 2, the Vienna Philharmonic's rendition of *Also Sprach Zarathustra*, etcetera.

quantization error is swapped for the nostalgic hiss of analog tape. Chris Carter notes how both harmonic distortion and hiss can reintroduce some of the aesthetics of analog media into digital music making:

> I'm not a fan of bit crushing but I do like harmonic distortion and its variants, especially on digital material or anything that sounds too clean. That's the dichotomy of using digital but preferring a digital signal to sound more analogue. It's just a personal preference - I prefer a little distortion to warm things up a bit… even hiss sometimes, both of which can be good for disguising digital artefacts.[53]

Software dither offers an interesting challenge to the traditional assumptions surrounding noise as an aesthetic. It does not "bury" the distortions introduced by quantizing a periodic signal as a perceptual "masking" effect. Instead, it replaces the last bit altogether. As I have noted above, noise, much like randomness, has often been framed as a cultural signifier that is intrinsically ideological. What is or is not noise is determined by hegemonic forces that derive this determination from a very different perspective than that of an artist or composer.

Noise is not always subjective, as it is when it is employed in information theory or the vast majority of theoretical writing in the humanities surrounding the aesthetics of noise. When it is qualified, as in the case of Gaussian or "White" noise, it describes the objective qualities of specific phenomena. Acoustic white noise, for example, is the even distribution of random frequencies across the audible spectrum.[54]

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[53] Chris Carter, *Chris Carter Interview*, September 1, 2021.
[54] Eddy Brixen, *Audio Metering*, 3rd edition (New York, NY: Routledge, 2020), 37.

However, given that anything created by software *must be defined* in the code,[55] digital noise is generated procedurally from extent data. An indeterminate quality is defined by the listeners' inability to predict the relationship between one piece of information and the next. Different listening agents, including non-human listening agents such as software, will have different degrees of success in this prediction and thus what is determined to be "noise" will differ in each case. For example, some users of digital sleep aids claim to be able to hear a "loop" when the noise repeats, and prefer mechanical noise generators, such at the Marpac Dohm.[56] A "random" number generator created on any Von-Neumann architecture computer is necessarily determinate, and the process for generating said numbers involves applying a simple algorithm to one or more strings of arbitrary numbers. Digital encryption is defined by this perceptual indeterminacy; information will be perceived as noise by those without the data and methodologies necessary for decryption. The "noise" applied in software dither is the result of determinate algorithmic processes. It is a simulation of the random noise of tape hiss, a simulation that must be designed and shaped, even if it is meant to be inaudible. In my discussion with Devin Kerr, he confirmed this relationship between tape and dither:

> It's kind of interesting, the process of dither. How efficiently can you pack these 16 bits psychoacoustically? It's sort of trading-off one type of distortion for a different type of distortion. One that is more benign to us as humans, and we don't hear as a harmonic distortion, and you

[55] This is not to suggest that a programmer will necessarily know the outcome of deterministic code. Most programmers operate at a relatively high level of abstraction. The code, then, while defined, may be subjectively indeterminate.
[56] "The Sound of Silence - The New York Times." Accessed September 3, 2021. https://www.nytimes.com/2018/12/27/style/white-noise-machines.html.

can kind of push it to noise, especially when it is noise-shaped noise, which almost becomes like tape hiss.[57]

Figure 2.2 Greyscale, 1 Bit Threshold, 1 Bit Dither

Although the experience of dither is presented as, and largely is, a perceptual phenomenon, the question of whether low level noise is preferable to periodic distortion is also a question of aesthetic preference. Look at the images above. I experience both the second and third images as equally poor representations of the original image.[58] However, various cultural cues help create the impression that the dithered image is a more accurate transformation. Note the similarities between the noise contained in the dithered imaged and that produced by analog film or newsprint. Similarly, while our relative sensitivity to the distortion introduced by reducing the bit depth of an audio recording is, at least partially, a perceptual phenomenon, our relative insensitivity to low amplitude noise is also a result of our exposure to decades

[57] Devin Kerr, *Goodhertz Interview*, 2021.
[58] Images are reproduced here in their original size to avoid resampling at a higher bit rate and inaccurately portraying the conversion process.

of recorded music with a relatively high noise floor. This naturalization of mediation is part of a larger cultural environment in which digital simulations of mediation processes such as visual noise, tape saturation and chromatic aberration are employed to mask the aesthetics of a new medium with those of a previous one. Despite the rhetoric of transparency that defines the marketing and reception of new technologies, mediation and noise remain a significant aesthetic influence: phones that are marketed on the ever-improving specifications of their cameras are filled with applications for emulating the look of anachronistic film cameras, interfaces that can record with 32-bit floating-point at 192kHz come pre-loaded with emulations of analog tape machines.

Melle Jan Kromhout, in *Noise Resonance: Technological Sound Reproduction and the Logic of Filtering* notes:

> [T]he history of noise reduction and the continuous reappearance of noise and distortion in different forms and different places described in this first chapter suggests we should not, as the myth of perfect fidelity would have us believe, take noise as a byproduct of the recording and reproduction chain, to be eliminated, masked, reduced or filtered out at any costs. Instead, the observation that digital technology, which reduces the material noises of sound reproduction to unprecedented levels, is marked by the return of noise in the form of deliberately added dither retroactively puts any seemingly progressive account of sound recording and noise reduction in a different light.[59]

Dither is unique in that it utilizes noise to preserve the integrity of information—a statement that is paradoxical within the bounds of classical information theory. Since

[59] Kromhout, Melle Jan, "Noise Resonance: Technological Sound Reproduction and the Logic of Filtering" PhD Diss. (University of Amsterdam), 69.

the formalization of information theory by Claude Shannon, noise has been framed in opposition to information.[60] Noise—as defined by Shannon—is a transformation of information where the relationship to the original signal is indeterminate. As Shannon notes:

> If this function has an inverse — no two transmitted signals producing the same received signal — distortion may be corrected, at least in principle, by merely performing the inverse functional operation on the received signal.
>
> The case of interest here is that in which the signal does not always undergo the same change in transmission. In this case we may assume the received signal *E* to be a function of the transmitted signal *S* and a second variable, the noise *N*.[61]

This framing assumes a path from transmitter to receiver which, if not for the noise of the interstitial medium, would be perfectly communicated. "Our culture wants both to multiply its media and to erase all traces of mediation: ideally it wants to erase its media in the act of multiplying them."[62] as Richard Grusin and Jay David Bolter, eloquently note. The "trouble" according to Douglas Kahn "is that noises are never just sounds and the sounds they mask are never just sounds: they are also ideas of noise."[63] The various definitions of noise—from the colloquial to the scientific—are so varied that, in its most subjective sense, noise can encompass all sound. When a

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[60] This is ironic, given that, according to Shannon's schema, noise is also the richest form of information, as I will later discuss.
[61] Claude E. Shannon and Warren Weaver, *The Mathematical Theory of Communication*, 16th Printing edition (Urbana: The University of Illinois Press, 1971).
[62] Jay David Bolter and Richard Grusin, *Remediation: Understanding New Media*, Reprint edition (Cambridge, Mass.: The MIT Press, 2000), 5.
[63] Kahn, Douglas. *Noise, Water, Meat: A History of Sound in the Arts*. Reprint edition. Cambridge, Massachusetts London, England: The MIT Press, 2001.

sound designer speaks of noise, they will likely think of audio-rate[64] random signals. A second modern understanding, which has its roots with urban noise abatement research in the late nineteenth century,[65] and finds its apex in Shannon's work, defines noise in terms of volume levels of unwanted information.[66] These definitions can easily become associated with phenomena that are nearly the exact opposites of each other, as is apparent in the use of white noise machines to combat urban noise. Marie Thompson observes how the contradictions across various uses of "noise" render it both unclear and rigidly binary, stating "Noise, then, is simultaneously too vague and too 'segregationist'– it is too ambiguous with regard to what it signifies, and too rigid in the distinctions it requires."[67] Michel Chion proposes simply avoiding use of the term altogether because of its vagueness.[68] I share the frustration of Thompson and Chion: in order for the word "noise" to be comprehensible, it must defined in terms of the context in which it is used. Shannon's definition of noise is not vague, but it is segregationist; it is the material properties of the medium, defined in opposition to the message.

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[64] Signals between approximately 20-20,000 hertz.

[65] Emily Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America*, 1900–1933 (Cambridge, Mass.: The MIT Press, 2004), 145.

[66] Marie Thompson, *Beyond Unwanted Sound: Noise, Affect and Aesthetic Moralism*, Paperback edition (New York: Bloomsbury Academic, 2017).

[67] Ibid.

[68] Michel Chion, 'Let's have done with the notion of "Noise"', trans. James A. Steintrager, Differences, vol. 22/2 (2011), 240-8.

The noise inherent in mediation[69] is not necessarily random, and provides information to the listener, even if it displaces other forms of information.[70] In situations where the audio output of a medium is fed back into its input, the intrinsic qualities of a medium, manifest in its noise and nonlinearities, become apparent. A musician performing with a complex network of feedback in a mixing console is not degrading a signal, they are producing a signal from the network itself. Even in scenarios where there is ostensibly a predefined piece of information traveling along a linear path, such as a guitarist performing scored music in a studio, the timbre of the amplification or effects will inevitably affect how they play the written material. In my interview with Scott Harper of the YouTube channel Knobs, he went as far as to claim, "The way that you think is limited or motivated by your instrument." This claim is bolstered by the research of neuroscientist Andy Clark, who refers to the uses of technical apparatus to structure and enable new forms of thought as neurological "scaffolding."[71]

The present chapter is not a critique of information theory as it pertains to Shannon's internally published paper "A Mathematical Theory of Communication," I am not questioning its efficacy as tool for understanding, designing and improving communication systems. What I object to is the social effect of its retitling as *The Mathematical Theory of Communication* following its initial publication in the Bell

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[69] As well as the "noise" abstracted in Shannon's information schema.
[70] This ignores the central paradox of information: a completely random signal boasts the highest possible information content.
[71] Andy Clark, *Being There: Putting Brain, Body, and World Together Again,* Reprint edition (Cambridge, Mass.: A Bradford Book, 1998), 45.

Systems Technical Journal.[72] Shannon himself objected to the overly-broad application of this theory, stating:

> While we feel that information theory is indeed a valuable tool in providing fundamental insights into the nature of communication problems and will continue to grow in importance, it is certainly no panacea for the communication engineer, or, a fortiori, for anyone else. Seldom do more than a few of nature's secrets give way at one time. It will be all too easy for our somewhat artificial prosperity to collapse overnight when it is realized that the use of a few exciting words like information, entropy, redundancy, do not solve all our problems.[73]

The subjective phenomenon of noise is reframed in terms of its status as idealized, uncompressible information. This value-free definition of noise, creates an obvious paradox; purely random values—that is to say noise—represents the most information-rich form of communication. As Warren Weaver notes in *Recent Contributions to the Mathematical Theory of Information*:

> If noise is introduced, then the received message contains certain distortions, certain errors, certain extraneous material, that would certainly lead one to say that the received message exhibits, because of the effects of the noise, an increased uncertainty. But if the uncertainty is increased, the information is increased, and this sounds as though the noise were beneficial![74]

This is reflected in the problems that emerge from the twentieth century musical avant-garde's emphasis on complexity. Past a certain threshold, complex structures

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[72] James Gleick, *The Information: A History, A Theory, A Flood*, Illustrated edition (New York: Vintage, 2012), 222.
[73] Claude Elwood Shannon, A. D. Wyner, and Neil J. A. Sloane, *Claude E. Shannon: Collected Papers*, 1st edition (New York: Wiley-IEEE Press, 1993), 462.
[74] Claude E. Shannon and Warren Weaver, *The Mathematical Theory of Communication*, 16th Printing edition (Urbana: The University of Illinois Press, 1971), 19.

begin to appear as formless, unchanging noise. John Cage's incorporation of indeterminacy in his compositions can be seen as a reaction to this, as can his "silent" composition, *4'33"* (1952), which reverses the emphasis of signal over noise.

Noise[75] is present in all cultures, musical or otherwise,[76] and dither is merely one example of how noise can be appropriated to tame the aesthetics of information. A statement as all-encompassing as this may seem to require qualification by placement within a cultural or temporal context, but, with rare exceptions,[77] audible noise is a near-constant presence in daily life. Indeed, as I will later discuss, it is the ubiquity of noise as both a referent and environmental presence that makes dither so effective. The commercial availability of white noise machines for sleep or privacy offers another example of the practical use of noise to mask sound.[78] These electronic or electromechanical devices provide a means for environmental control. They are not used to generate affective states but to alter the listener's response to other discrete sounds. This is, perceptually, akin to lowering the dynamic range of a sound through compression, as, within limits, the ear becomes acclimated to sound of a consistent amplitude.[79] White noise machines mask quieter sounds, and listeners will perceive noises that are louder than the continuous noise as less intrusive than those experienced in a quieter space. Noise is not only ubiquitous but may also be may be

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[75] When defined as a sound consisting of clusters of inharmonic pitches at irregular intervals.
[76] If only through the ubiquity of environmental noise.
[77] Such as the anechoic chamber that inspired John Cage's celebration of quotidian noise, *4'33*" (1952). Cage famously claimed to hear noises from his own body within the space and concluded that sound was inescapable.
[78] "The Sound of Silence - The New York Times." Accessed September 3, 2021. https://www.nytimes.com/2018/12/27/style/white-noise-machines.html.
[79] With the caveat that compression does not mask quieter sounds as noise does.

one of the earliest perceptual experiences, for those that can hear. There is evidence that the reason the sound of white noise has a soporific effect on infants is due their familiarity with the soft noise of the womb.[80]

While noise is often framed as a subversive force[81] or an inherently radical political proposition, this ignores the mundane ubiquity of noise. As I write this, the inverter cooling the air in my house is generating noise concentrated below 600Hz, and if I listen carefully, I can hear the noise of the wind, filtered through my house at frequencies just above the inverter. I receive these sounds pleasant and bland rather than subversive or radical. Instead, it is the quasi-periodic sound of motorcycle engines accelerating past or the wail of sirens that shocks me out of my concentration on the present text. The subjective experience of pleasurable sound is unrelated to the objective randomness or complexity of a signal. The context in which noise is received inevitably influences its reception, as Douglas Kahn helpfully reminds us: "In a predictable world noise can promises something outside of the ordinary, and in a world in frantic pursuit of the extraordinary noise can promise the banal or quotidian."[82]

Technologies such as white noise generators, dither, noise-cancelling headphones, asymmetrical fan blades, and perceptual coding are technologies that

[80] "The Sound of Silence - The New York Times," accessed September 3, 2021, https://www.nytimes.com/2018/12/27/style/white-noise-machines.html.
[81] Russolo, Luigi, and Francesco Balilla Pratella. *The Art of Noise: Destruction of Music By Futurist Machines*. Erscheinungsort nicht ermittelbar: Sun Vision Press, 2012.
[82] Douglas Kahn, Noise, *Water, Meat: A History of Sound in the Arts*, Reprint edition (Cambridge, Massachusetts London, England: The MIT Press, 2001), 22.

embody the "domestication of noise."[83] This concept initially appears in Jonathan Sterne's *MP3: The Meaning of a Format*, as a way of describing technologies used to reduce or control noise, with MP3 compression as an outgrowth. Kromhout critiques this as a framing that "implicitly reaffirms the concept of noise 'as transgression or challenge' that Sterne claims to discard."[84] While Sterne accurately describes these practices as an attempt to control noise, the metaphor of "domestication" obfuscates the historical intervention of the futurists. Futurists such as Luigi Russolo framed noise in terms of violence and militarism, not as neutral observers of the "natural" properties of noise, but of polemicists agitating for an explicitly radical understanding and use of noise.

Likewise, in response to the formulations of noise presented as a violent political force by Attali, Russolo, and Hegarty, Kromhout asks

> Can we only account for the proliferation of noise practices in contemporary musical culture within an oppositional framework based on an inherently negative definition of noise? Or is it also possible to consider the musical importance and appeal of noise as something that contributes to the world of sound and music on its own terms—as a sonic phenomenon characterized by randomness and non- periodicity? Crucially, assuming such a different role of noise implies that its presence in music does not signify, or at least not *only* signifies, failure, transgression and disruption. Taking on this assumption, the key questions are as follows: how would it be possible to identify, and conceptually come to terms with an affirmative, perhaps foundational role for noise in contemporary musical practices; and how would it

[83] Mack Hagood, *Hush: Media and Sonic Self-Control*, Illustrated edition (Durham: Duke University Press Books, 2019).
[84] Kromhout, Melle Jan, "Noise Resonance: Technological Sound Reproduction and the Logic of Filtering" PhD Diss. (University of Amsterdam), 74.

> subsequently be possible to account for the ways in which noise, as an affirmative sonic presence, makes musical sense?[85]

This is an important question that directly relates to the question of noise within simulations. By explaining how noise functions as an affirmative force in the sonic arts, it is possible to come to a better understanding of why artists and designers look to mediation noise as a subject for simulation. As I have previously articulated, these concepts were well-established in experimental art and music before the use of dither in computing or the commercial application of white noise machines. The turn towards process in visual art, accompanied by a related interest in the noise of mediation, preceded the use of these techniques to produce sound.

Even works that initially appear to demonstrate Shannon's formulation often subtly undermine these principles upon closer inspection. On first glance, Alvin Lucier's *I am Sitting in a Room* is merely an illustration of Shannon's concepts. The performer reads a predefined script and subjects it to a mediating process, recursively. The content of the script describes a process that closely mirrors Shannon's models and diagrams:

> I am sitting in a room different from the one you are in now. I am recording the sound of my speaking voice and I am going to play it back into the room again and again until the resonant frequencies of the room reinforce themselves so that any semblance of my speech, with perhaps the exception of rhythm, is destroyed. What you will hear, then, are the natural resonant frequencies of the room articulated by speech. I regard this activity not so much as a demonstration of a physical fact, but more as a way to smooth out any irregularities my speech might have.[86]

[85] Ibid, 6.
[86] Lucier, Alvin. *I Am Sitting in a Room*. (Lovely Music, 1993).

However, the “content” of this work arises from experiences with the medium of the room, the microphone, the tape machine, speakers, as well as the composer’s own voice.[87] Furthermore, the final result of this process, “the natural resonant frequencies of the room articulated by speech” provide information to the listener. This information[88] provided about the room’s resonances does not reflect the supposed “content” of the message, but is indexical, aesthetic and interpretable information nonetheless.[89]

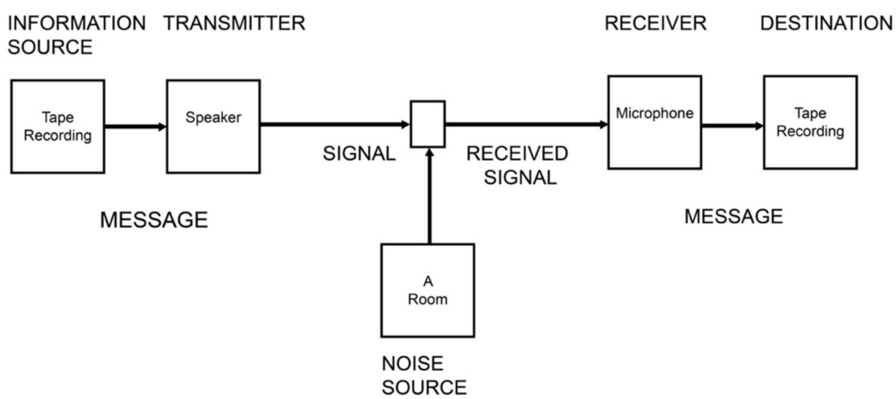

Figure 3.3 Shannon's diagram of information transmission adapted for Alvin Lucier's I am Sitting in a Room

While the proceeding works address the capability of mediation to produce information, they do not directly address the affective qualities of media. The affective properties of mediation are explicitly addressed by Richard Serra and Nancy

[87] Lucier had a stammer and was aware of the fact that his voice would have been considered an imperfect medium to convey text. His stutter is an asset in this work, as it reflects and is reflected by the text, further emphasizing the recursive nature of the work.
[88] While Lucier claims this is information about the room itself, this is much debated as the microphone, speaker, and tape were not “transparent” media and would also affect the resultant sound.
[89] This does not mean that the theory of communication posited by Shannon is incorrect, or inconsistent, but rather that his definition of information does not encompass all relevant interpretations of that word.

Holt in *Boomerang* (1974).[90] In this performance, Holt speaks extemporaneously while a delay system plays her speech into headphones that she is wearing, several hundred milliseconds after the original utterance. During the performance, both Holt's unaltered and delayed speech are audible to the audience. Her statements describe the experience of hearing her delayed voice, "Yes, I can hear my echo, and the words are coming back on top of me." The delay is not simply a system of altering her speech, it is part of the system that produces her speech aurally and semantically. When an artist willingly places themselves into a feedback loop with a medium, it is challenging to determine which aspects of mediation are producing these effects. These subtleties may be irrelevant in most circumstances, but become relevant in works focused on amplifying mediation recursively. In *Boomerang*, Holt performs the affective changes produced by mediation on both the aesthetic process, and her ability to respond to her own delayed voice, "I think that it makes my thinking slower." Holt does not specifically address the other changes produced by the delay system, such as changes to the timbre of her voice, but addresses the feelings and desires this produces, "the words keep tumbling out, because I want to hear them. I want to hear my own words flowing in on top of me." *Boomerang* shares performative transparency with *I am Sitting in a Room*, but more explicitly displays the relationship of authorship to process.

[90] "Boomerang | Transmediale." Accessed April 21, 2021. https://archive.transmediale.de/content/boomerang.

Figure 2.4 Nancy Holt performing Boomerang

The divergences from Shannon's model of information become more extreme in works such as John Cage's *4'33"* (1952) and Christian Marclay's *Record Without a Cover* (1985). Flowcharts mapping the path of information are especially tortured when applied to these works. In both instances, the information source, transmitter, signal, noise source, receiver and destination are collapsed into a single recursive loop. To be clear, the fault is not necessarily with Shannon, who was aware of Norbert Wiener's research into cybernetic feedback, for example, but the over-zealous application of his model to describe all communication systems.

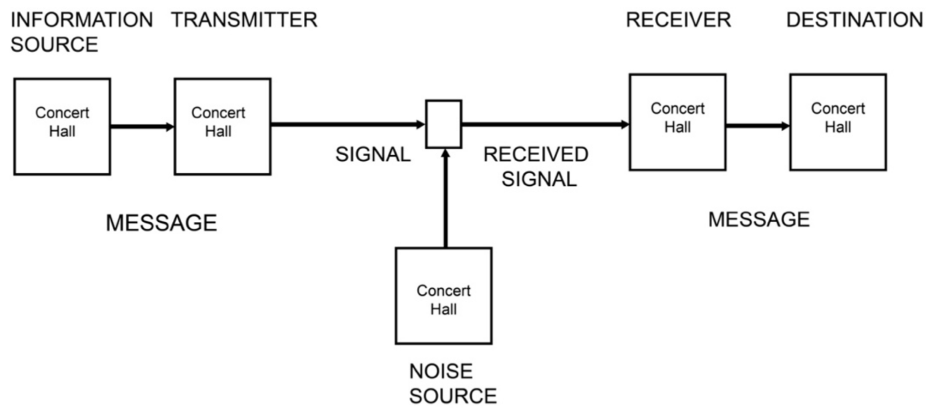

Figure 2.5 Shannon's diagram of information transmission adapted for John Cage's 4'33"

While the use of dither in digital audio and early digital images is linked to the experience of intersubjective phenomena, it is also a means of replicating a mechanical, analog system. The concept of dither originally derives from mechanical computers that were installed in planes delivering bombs during the Second World War.

> [O]ne of the earliest applications of dither came in World War II. Airplane bombers used mechanical computers to perform navigation and bomb trajectory calculations. Curiously, these computers (boxes filled with hundreds of gears and cogs) performed more accurately when flying on board the aircraft, and less well on ground. Engineers realized that the vibration from the aircraft reduced the error from sticky moving parts. Instead of moving in short jerks, they moved more continuously. Small vibrating motors were built into the computers, and their vibration was called dither from the Middle English verb "didderen," meaning "to tremble." Today, when you tap a mechanical meter to increase its accuracy, you are applying dither, and modern dictionaries define dither as a highly nervous, confused, or

> agitated state. In minute quantities, dither successfully makes a digitization system a little more analog in the good sense of the word.[91]

The application of the term dither in all of these instances implies a broad definition. In fact, the origin of the term in analog computing and the corollary process used in digital computers are only linked by the application of noise. The most revealing statement of this historical anecdote is the author's claim that dither "makes a digitization system a little more analog." The author is claiming that dither introduces an unsteadiness or trembling we associate with analog media. Like aliasing, distortion from quantization error is a mark of the specific point at which digital phenomena become distinct from their analog counterparts. Dithering and anti-alias filtering are attempts at the erasure of this difference. They represent an outgrowth of the rhetoric of immersion, a concept that can be traced back to American military necessities in the second World War. It is not surprising then, that this seemingly magical technique to more perfectly disguise the characteristic mediation of digital computers was literally created by the vibrations of warplanes delivering bombs.

It is worth returning to the association of noise with war. Starting with its use as a tool of the Futurists in creating a proto-fascist assault on bourgeois musical traditions, modern noise has been metaphorically linked to the sounds of war. The noisy vibrations of war machinery were literally manifest in the discovery of dither.

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[91] Ken C. Pohlmann, *Principles of Digital Audio*, Sixth Edition, 6th edition (New York: McGraw-Hill Education TAB, 2010).

However, rather than the violence of futurist noise, dither is used to soften the trace of technology upon a signal. The origin of dithering as an accidental discovery resulting from the use of mechanical computers in bombing campaigns betrays that it, like other cybernetic phenomena, is a direct outgrowth of the logic of war. Dither is a rhetorical tool in the language of simulation that disguises the digital by cloaking it in analog aesthetics.

The Bitcrusher: A History

While dithering and anti-aliasing are standard practices for commercial audio, it should be noted that, despite this consensus, "bitcrushing" effects are widely used as intentional effects to reintroduce quantization error and aliasing back into the signal. Digital Audio Workstations such as Logic Pro, Pro-Tools, and Ableton Live, synthesizers such the Dave Smith Instruments Prophet 12[92] or the Ashun Sound Machines Hydrasynth,[93] and samplers such as the Elektron Octatrack[94] include bit and sample rate reduction modules that the user can modulate in real-time for creative use. Tools that intentionally enable the user to reduce the bit and sample rate have a complex history of unofficial use—as was the case with the SP-1200—before they were incorporated into instruments and effects software.

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92 Sequential. "Prophet 12 Keyboard." Accessed January 5, 2022. https://www.sequential.com/product/prophet-12-keyboard/.
93 Ashun Sound Machines. "Hydrasynth Keyboard." Accessed January 5, 2022. https://www.ashunsoundmachines.com/hydrasynth-key.
94 Elektron. "Octatrack MKII (Black)." Accessed January 5, 2022. https://www.elektron.se/products/octatrack-mkii/.

The history of "bitcrushing" is complicated by the fact that these processes restore sonic attributes of digital audio that were always present. As should be clear, digital audio always requires quantization,[95] albeit at levels imperceptible to human hearing. Most computer-generated audio, from its inception until the mid-1990s, utilized bit depths and sample rates that introduced audible quantization error and aliasing. Although bitcrushers are relatively new tools for shaping audio, the sounds these devices are designed to produce have been present in computer music since the early experiments with digital sound at Bell Labs. The histories of aliasing and quantization error that I have outlined form a "pre-history" of bit crushing.

In addition to the ambiguous intentionality of bit and sample rate reduction, the terminology used to describe these phenomena is non-standardized. It is, in some cases, nearly impossible to determine the nature of an effect without access to the device itself. In Roland and Yamaha parlance, these techniques are grouped under the "lo-fi" moniker. Korg refers to the introduction of aliasing as "decimation." Dave Smith Instruments, now Sequential LLC, also uses the term decimate to describe sample rate reduction but use the term "hack" to describe bit depth reduction. The Access Virus series of synthesizers contain "bitreducer" and "ratereducer" effects. Perhaps the strangest bitcrusher is the Quantize + Flange algorithm in the KDFX effects module used in Kurzweil synthesizers, which combines bit reduction with a form of modulated delay known as flange.

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[95] Given that analog audio is continuous, even 64-bit floating point—a resolution far beyond the capabilities of human hearing—introduces some amount of quantization error.

The earliest reference I could find to the term "bitcrusher" is an effect included in Emagic's Logic 4 software, which was released in 1999.[96] While it is possible that an earlier coinage exists, it is very likely that this effect is responsible for bitcrusher's rise as the standard term for a combined bit depth and sample rate reduction processor. When E-Magic was acquired by Apple in 2002,[97] many of the effects from Logic, including BitCrusher, were used in the creation of Apple's GarageBand application. This meant that, among guitar amplifier and Yamaha DX-7 simulations, millions of consumers found themselves in possession of bit and sample rate reduction software under the BitCrusher moniker.

The earliest reference to sample rate reduction as an "effect" in a commercial synthesizer is in the manual for the Korg Trinity (1995). The manual states that decimation "creates a rough sound like a cheap sampler by lowering the sampling frequency." Another early instance of the intentional introduction of digital artifacts as an effect is the Waldorf MicroWave II (1997).[98] The MicroWave II was an eight-voice digital synthesizer that relied upon the use of digital "wavetable" oscillators. Wavetables are collections of samples of single-cycle waveforms that can be played back at user-selectable pitches, typically with the ability to interpolate between waveforms. The original MicroWave relied upon digital wavetables that were

[96] "Emagic Logic 4." Accessed August 16, 2021. https://www.soundonsound.com/reviews/emagic-logic-4.
[97] "Emagic - Company," April 13, 2003. https://web.archive.org/web/20030413192705/http://www.emagic.de/company/company/index.php?lang=EN.
[98] "Waldorf Microwave II." Accessed August 12, 2021. https://www.soundonsound.com/reviews/waldorf-microwave-ii.

processed by analog filters—much like a traditional "subtractive" synthesizer. The MicroWave II replaces these analog filters with filters created through digital signal processing. While the aliasing in the original Waldorf MicroWave and the PPG Wave 2.2[99] was a result of technological limitations, the MicroWave II includes an extra technological intervention to reproduce those limitations. The manual states,

> Usually, aliasing is reduced to a minimum by some magical mathematics, but here you can override this and listen to aliasing distortion just like in the dawn of the first digital musical instruments like the PPG Wave or the first MicroWave. Use a setting other than off for sounds that expressionally should have a digital character.[100]

It is worth noting, that this use of aliasing as an intentional aesthetic device, is specifically identified as a means of emulating earlier synthesizers. While the manual author acknowledges the "digital character" of the sound, this is not framed as a tool for creating new sounds, but as a means to simulate the nostalgic qualities of synthesizers the user might be "upgrading" from. The use of the aliasing effect as a tool for simulating the sonic properties of early digital synthesizers is reflected in the design of the aliasing effect, which can only be set to five fixed settings, and is not accessible through the modulation matrix—where it might have been modulated by the envelopes and LFOs to creative effect. Other contemporary synthesizers, such as

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[99] The reader may be curious about the relationship between Waldorf and PPG, as there appears to be continuity in both name and function between the PPG Wave synthesizers and the Waldorf Wave/MicroWave. The manual for the MicroWave II states, "In the late 80s PPG discontinued their work and therefore production of the Wave, but in the meantime Wolfgang Düren, now manager at Waldorf Electronics, initiated the rebirth of the Wave's technology. Based on an extensive cooperation contract with Wolfgang Palm, the Waldorf Microwave became the official successor of Wave technology in 1989."

[100] "Waldorf Microwave II." Accessed August 12, 2021. https://waldorfmusic.com/phocadownload/Microwave%202%20Downloads/Documentation/mw2_XT_XTk_eng.pdf

the Korg Trinity, do not have this limitation, and are capable of producing unique timbral changes by modulating the Nyquist frequency.

The manual further emphasizes nostalgia and continuity in another section addressing the included wavetables from previous Waldorf and PPG synthesizers:

> We have not forgotten the past: you can still find the original wavetables of the PPG Wave Computer (Wavetables 001…008), of the PPG Wave 2.2 (009…030) and of the classic MicroWave (031…64) in the Microwave II/XT/XTk, ensuring that you can still create all famous sounds of those times.[101]

Four months after the release of the MicroWave II, Yamaha released the MU100R.[102] This rack-mount synthesizer contained algorithms for bit reduction and aliasing, combined as a single "LOFI," or low-fidelity effect. The MU90R, an iteration released six months prior to the MU100R, lacked this feature.[103] In the MU100R LOFI effect, the sampling rate is adjustable from 44.1kHz[104] to 345Hz, while the bit depth—expressed in terms of word length—is variable from one to seven bits. Modern bitcrushers typically allow the user to reduce the audio information from 16 bits to a single bit and to shift the Nyquist frequency below several hundred hertz. These effects will also interact with each other, as the overtones introduced by bit reduction are more likely to cross the Nyquist frequency by virtue of their higher pitch than the original signal.

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101 Ibid.
102 "Yamaha MU100R." Accessed August 14, 2021. https://www.soundonsound.com/reviews/yamaha-mu100r.
103 "Yamaha MU90R." Accessed August 14, 2021. https://www.soundonsound.com/reviews/yamaha-mu90r.
104 The sampling rate of compact disc audio.

Although bitcrushers are relatively simple digital effects, there are differences that produce differing timbres, such as the choice of DACs or ADCs in the case of hardware bitcrushers. The processes for limiting bits and encoding into less-than-optimal[105] bit resolution each have unique properties and affect the sound in different, noticeable ways. Early digital phone systems used the μ-law codec to convert human speech—with its high dynamic range—into eight bits through nonlinear quantization.[106] With linear converters, the signal-to-noise ratio increases relative to the significance of each bit, making the least significant bit the noisiest. Given that human speech and hearing are logarithmic, much of the relevant information is encoded in the least significant bit in linear converters. Therefore, linear converters tend to be a poor match for audio at low bit depths. Many early commercially available 12-bit delays, such as the Lexicon PCM41, used companders in the signal path to reduce audible noise. A portmanteau of compressor and expander, a compander compresses the dynamic range of a signal before it is sampled at a bit depth where audio with a full dynamic range would lose salient information below the noise floor and expands the audio to its full dynamic range after it has been converted back into an analog signal.[107] The distortion produced by companding an audio signal creates a characteristic effect that is often associated with early digital audio devices

[105] The optimal resolution will vary depending on a number of factors, including the delivery medium, listening environment, and cultural expectations surrounding clarity and resolution. For the purposes of this discussion, I am speaking of any resolution in which the distortion introduced by quantization error is clearly beyond the limits of audibility.
[106] Gareth Loy, *Musimathics: The Mathematical Foundations of Music*, vol. 2 (Cambridge, MA, USA: MIT Press, 2007), 41.
[107] Ibid.

including the aforementioned phone and delay systems, as well as sampling keyboards such as the CMS Fairlight. Emilie Gillet of Mutable Instruments explicitly refers to this in a description of her implementation of 8-bit sampling in her Clouds eurorack synthesizer module:

> Note that Clouds' 8-bit is a lovely flavour of 8-bit: μ-law companding. It sounds like a Cassette, or a Fairlight - less hiss, more distortion.[108]

Additionally, there are features that may affect structural choices in the musical composition itself, such as the fixed levels of quantization in a traditional bitcrusher. Given that there are only 16 steps of quantization in a bitcrusher that reduces fidelity from 16 bits to a single bit, this means that the listener will hear discrete changes to the sound, even if they apply continuous modulation from an LFO, for example. If the composer does not want these discrete steps to be audible, these changes must occur when the sound is not audible, such as early in the onset of a note or by setting the device to a fixed bit depth. Instruments such as the Elektron Octatrack and the Dave Smith Instruments Pro 2 allow the user to tie the bit rate to particular steps in a musical sequence so that the fidelity of the music may change with each new musical note.

Other manufacturers have found means of introducing bit reduction that smoothly interpolates between states, explicitly as a means of solving this problem. For example, The Industrial Music Electronics Malgorithm MKII is a synthesizer

[108] "Mutable Instruments | Clouds." Accessed May 5, 2018. https://mutable-instruments.net/modules/clouds/alternate_modes/.

module[109] that uses “non-integer bit depth reduction”[110] to allow for continuous modulation between bit depths. This is consistent with the ethos of modular synthesizer design, where the continuous modulation of parameters is considered an important feature. I will discuss the aesthetics of modular synthesis in greater depth in Chapter 4. A Korg patent from 2016 describes a similar invention.[111] While the Malgorithm MKII product description refers to digital aesthetics, the Korg patent explicitly describes bit reduction in terms of the simulation of older media technologies:

> For example, from the clear sound quality of 16-bit quantization bit to the retro video game-like sound quality of 8-bit quantization bit, even if you aim to produce a sound signal that degrades seamlessly, the sound signal will deteriorate. Each time one bit progresses, the listener clearly hears the joint (border). Therefore, it is impossible for the listener to perceive an effect that the sound quality of the musical sound goes back to the past seamlessly.[112]

The reintroduction of bit and sample rate reduction as an effect must have inspired curiosity and bemusement from artists who had spent the past decades cautiously avoiding these sounds. In the manual for Degrader, a bitcrusher plugin designed by Cycling ’74, the author acknowledges the buyer’s potential confusion with self-aware humor.

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[109] A discrete component of a synthesizer that can be connected to other components via “patch” cables.
[110] “Industrial Music Electronics.” Accessed September 9, 2021. http://www.industrialmusicelectronics.com/products/1.
[111] 斉田一樹, Saida Kazuki, and 斉田一樹. 楽音信号変換装置、楽音信号変換方法、プログラム. JP2018060058A, filed October 5, 2016, and issued April 12, 2018. https://patents.google.com/patent/JP2018060058A/en?q=bitcrusher&assignee=Korg+Inc&sort=old.
[112] Ibid.

> If you're asking yourself, "why would I want to reduce the sampling rate and/or bit depth of a signal?" you might find that this plug-in isn't of much use to you. But try it anyway. You may find that this plug-in will save you hundreds or thousands of dollars by convincing you that you don't have to upgrade your audio converters to higher quality units quite yet.[113]

Digital aesthetics can also be heard where they are made inaudible, through filtering and dither. The lack of high-frequency material in much of popular music in the 1980s—often referred to as darkness—is an aesthetic born out of the need to filter out higher frequencies to avoid aliasing. Chris Carter described the effect that digital, sampled instruments had on the sound of the music he made with Chris & Cosey:

> The first digital synth we (Chris & Cosey) got was a Roland D-50. It was a fantastic synth and really shaped the C&C sound for years but it had horrendous digital aliasing in the upper audio regions - it was like birds chirping. It was so bad I sent the keyboard back to Roland as I thought it was faulty but they returned it with a polite letter informing me the aliasing was inherent in the new digital architecture. So we had to put this brand new digital synth through filters and EQ to reduce the sound of the digital aliasing. At the same time we got an Akai S900 which was a 12-bit sampler, with its own bit reduced issues. To get any decent sample times you had to restrict the sample rate down to 8 or 9k. Which at 12-bits sounds particularly crunchy. Almost overnight we'd gone from full frequency range analogue synths to lo-fi digital bits and aliasing. But that's OK because we were on the cutting edge of technology and actually making a lot of music - we just had to find some workarounds to get it sounding how we wanted.[114]

The bitcrusher is emblematic of the tension between novelty and nostalgia in both synthesizers and digital computing in general. Its evolution from a sound associated with a new and potentially undesirable technological limitation to a means

[113] "The Pluggo Plug-in Reference Guide." Cycling '74, 2003.
[114] Chris Carter, *Chris Carter Interview*, September 1, 2021.

of emulating the nostalgic qualities of older technology closely mirrors that of other forms of simulated mediation, including dither. Ironically, this digital form of distortion may be as familiar to listeners of a certain age and cultural background as tape hiss, given the extremely low sampling rate and bit depth of early sampled audio in consumer media technologies such as early personal computers and video game consoles. The persistence of aliasing and quantization error in modern music is now an aesthetic choice. That these sounds persist when inexpensive memory, storage, and network rates render the transmission and storage of high-resolution audio information trivial is a testament to their continuing aesthetic relevance and importance.

Conclusion:

While it is now possible to convert between digital and analog signals without any observable alteration of information, the sounds of digital mediation are embedded within our culture. I cannot say whether their continued relevance is dependent upon a desire to avoid the "hard" problems of simulation by intentionally exposing the simulation as a quantized or sampled system. It seems equally likely that as ubiquitous, "unintended" phenomena, they provide the sort of inspiration that 60Hz electrical hum provided to sound artists and composers such as La Monte Young, David Lynch, and Christina Kubisch. In another interpretation, interventions at the site of conversion between these states serve to investigate and antagonize the affordances of digital technology. It is an act of listening in defiance and directing our hearing towards what we are instructed to ignore. Bit and sample rate reduction techniques are interesting not simply because they expose the failings or material properties of the digital but because these sounds have been instrumentalized. They do not provide the "musical" distortion of overdrive or saturation and almost always lack a harmonic relationship to the original sound. This distinction may be part of bitcrushers' appeal; they are the sounds of the medium scraping up against a message, the revenge of the material upon the myth of a dematerialized digital sound.

By making elements of these processes audible, it is possible to remove some of the "magic" of digital sound and reframe how one conceptualizes digital media. Perceptual sleight of hand, such as dither—which seeks to mask the aesthetic of conversion between digital and analog media—demonstrates the manner in which simulation is used to establish continuity with analog media, rather than transparency of immediacy. At the same time, explorations at the site of conversion to and from digital media can render the naturalized sounds of digital audio uncanny. In one experiment, I used the Xaoc Drezno, a synthesizer module with individual outputs for each bit of an ADC, along with materials of various resistance, to create a crude DAC. By discovering the relative resistance of each object, it was possible to approximate each resistor in a DAC and reproduce the original signal, albeit very poorly. The act of visualizing and sonifying the normally invisible process of digital to analog conversion challenges the hegemonic belief that digital information is dematerialized. Dematerialization is a delusion that is accepted because it allows those who profit from the sale of new technology to promise transcendence.

CHAPTER 3:
SIMULATED MEDIATION – THE DIGITAL SIMULATION OF MEDIA

Whatever you now find weird, ugly, uncomfortable and nasty about a new medium will surely become its signature. CD distortion, the jitteriness of digital video, the crap sound of 8-bit — all of these will be cherished and emulated as soon as they can be avoided.

– Brian Eno

The process of abstraction itself, what is lost, is thereby involved in the elimination of noise. Noise in this way is the specific, the empirical… The interesting problem arises when noise itself is being communicated, since it no longer remains locked into empiricism but is transformed into an abstraction of another noise.

– Douglas Kahn

Digital computing is almost exclusively dedicated to the simulation of media. As I have previously shown, techniques such as dither and anti-alias filtering are used to bring digital media into aesthetic compliance with analog media. All digital media that can be seen or heard are, in a sense, simulations since they are constructed to simulate analog noise at perceptual limits. However, analog media are not the only subjects of simulation, as the limitations of early digital or hybrid systems are also the frequent subject of simulation in audio production tools. While digital simulation was extensively theorized in the wake of the commercial availability of personal computers in the mid-1980s, it is necessary that scholars reexamine the role of simulation in the aesthetics of contemporary culture. Not only are the limitations and possibilities of simulation embedded in nearly every form of new technology, the relationship between digital and analog media has also profoundly shifted.

Claus Pias identifies how the reaction within the humanities to its prior preoccupation with simulation has left fields such as media studies unable to respond to the profound effect simulation has had on the development of science:

> …we need to learn how to speak about it in new ways, for in view of the several thousand available books on the subject – and I am referring here exclusively to scientific simulations – the scholarly and practical significance of computer simulation cannot be overestimated. But despite this fact, computer simulation has not yet been reviewed from the standpoint of media history or the history of science. There are no more than a dozen or so essays on the epistemic status of computer simulation and even fewer history-of-science studies that have done exemplary work in providing an account of how the complexion of a single discipline has been changed by computer simulation in the course of the last fifty years. Briefly put, I believe that in computer simulation we can observe an epistemic shift of considerable magnitude – and which in the 1960s Joseph Licklider compared with the invention of printing in its impact on the sciences.[1]

If, as Pias later claims, simulation is supplanting theorization in science, this situation is more exaggerated in the arts, where assumptions about the affective qualities of media technologies are embedded in the code-based technologies used to produce aural and visual artworks. In fact, many of the components of simulations are themselves simulations. For example, the low-pass filters available in visual coding languages such as Max or Kyma are digital implementations of analog filter designs. I have used these designs in numerous simulations of analog media.

In the process of my research, I spoke to engineers from companies who have designed such simulations. Additionally, I constructed simulations of various media

[1] Claus Pias. (2011). *On the Epistemology of Computer Simulation*. Zeitschrift für Medien- und Kulturforschung. 2011. 10.28937/1000107521.

technologies as a means of understanding how different processes of abstraction alter the aesthetic results. In either case, my intention was to understand these methodologies as aesthetic processes and forms of knowledge production. To simulate a cassette tape is not simply to find a proper model to recreate a technical process, as the variety of objects created by my interviewees show. The designer of a simulation needs to decide which processes to reproduce and with what degree of granularity to reproduce them.

Consider the position of a young composer who has acquired a laptop computer containing the major DAWs and software plugin suites. Given that the laptop computer itself is presented and priced as a powerful media production device, they may choose to compose a piece of music with only the laptop computer. They might begin by selecting one of the thousands of available software instruments, either through the recognition of instruments that they have heard of, through the association of a visual aesthetic with a sonic aesthetic,[2] or simply through arbitrary selection. Having done this, more often than not, they will be presented with a window featuring an image of a hardware instrument developed between 1960 and 1998. They may recognize these instruments from album covers, or they may be entirely unfamiliar. The digital instruments may or may not sound similar to the instruments whose image and interface they have appropriated. This distinction will likely be meaningless since they have likely never used a Minimoog, Prophet 5, SQ-

[2] The use of wooden end cheeks is a clichéd signifier indicating analog or "vintage."

80, Synthi AKS, or DX-7—although, as I have previously mentioned, they may be familiar with those classes of sounds. Our hypothetical composer will likely not know the history of techniques associated with the object that has been simulated, nor will they be surprised at the techniques they have developed to exploit the unique characteristics of these simulations. The same will likely be true of the effects they use to process the sound. Having never used a Urei 1176, SSL mixing console, Pultec equalizer, or a reel-to-reel tape machine—the price of each piece of equipment far exceeds the price of the aforementioned laptop—they may develop an aesthetic preference for a field-effect transistor (FET) compressor emulation when compared with an optical compressor emulation while remaining unaware as to what any of these terms mean.

I present this scenario because the fact that most audio content is generated using simulations of equipment that musicians lack experience with raises a number of questions regarding their use of this technology: Does the use of these simulated compressors, guitar amplifiers, and tape delays roughly correlate to the use of their analog counterparts? Are these simulations commonly being used in a way that can be differentiated from the use of analog technologies? To what extent is the visual representation of simulated audio technology relevant to the eventual use? In order to discover the conditions under which modern sonic aesthetics develop, questions surrounding digital simulation loom large. How relevant are the specific properties of a medium, musical instrument, or audio processor to the aesthetics of a piece of music? Why is the simulation of the imperfections of analog media so prevalent? Is there a coherent aesthetic strategy that can be used to explore the unique properties of these simulations? Are digital media inherently nostalgic? Is synthesis a form of simulation? I do not intend to definitively answer these questions. I will, however, explore a variety of ways to frame these basic questions, especially in the context of historical examples and the results of my research and interviews. Just as the unique properties of media technologies are defined by their limitations in relation to an abstraction of human perception, the unique properties of simulation are always abstractions or divergences from the properties of a given medium.

Before exploring the methodologies and aesthetics of digital simulation in its various forms, it is necessary to establish a working definition of simulation. Perhaps even more so than the related terms digital and analog, simulation suffers from myriad ambiguous and contradictory definitions. I address this by outlining the aforementioned definitions before considering the specific case of digital simulation with an examination of component emulation and more general abstractions; two basic processes through which engineers create simulations.

Defining Simulation

When I speak of simulation, I am primarily concerned with the qualities that distinguish it from analog forms of representation or mediation. The ambiguities of simulation within the context of this dissertation are derived, at least in part, from the instability of the distinction between digital and analog.[3] However, in its pre-digital

[3] See Chapter 2.

form, the word is not only ambiguous but highly dependent on the intention of the simulator. The Oxford English Dictionary places the earliest use of the term in 1340 and defines it as "The action or practice of simulating, with intent to deceive; false pretence, deceitful profession."[4] This sense of falseness or inauthenticity carries through modern use, but deceit is no longer emphasized. An alternative definition dating back to 1870 describes simulation as a "[t]endency to assume a form resembling that of something else; unconscious imitation."[5] The emphasis is now on the appearance—versus essence—of the simulation. The observer's senses are now conspirators in the process of deception.

Media theorist Vilém Flusser emphasizes another aspect of simulation that is critical to understanding digital media in particular. Digital simulation is distinguished from prior forms of simulation in that it is reducible to logical abstraction. This changes the character of simulation in that a simulation generated in this manner must be determinate and knowable. It may also privilege a particular quality of its subject and thereby more efficiently render that trait or behavior:

> Simulation is a kind of caricature: it simplifies what is being imitated and exaggerates a few aspects of it. A lever is a simulation of an arm in that it neglects all aspects of an arm except the lifting function, but because it exaggerates this one function to such an extreme, it lifts much more effectively than the arm it is simulating.[6]

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[4] "Simulation, n.," in OED Online (Oxford University Press), accessed October 18, 2021, https://www.oed.com/view/Entry/180009.
[5] Claus Pias. (2011). *On the Epistemology of Computer Simulation*. Zeitschrift für Medien- und Kulturforschung. 2011. 10.28937/1000107521.
[6] Vilém Flusser and Mark Poster, *Does Writing Have a Future?*, trans. Nancy Ann Roth, 1st edition (Minneapolis: Univ Of Minnesota Press, 2011).

For the purpose of clarity, I offer my definition of the term: In the context of the following discussion, a simulation, if it is successful, is the production of an object, process, or concept that is perceptually similar to the simulated subject in one or more aspects, such that it is nearly or completely indistinguishable from these aspects of the simulated subject. Simulation is therefore subjective and explicitly linked to perception. Compression or abstraction of information often constitute a form of simulation, but it is also possible for a simulation to include greater complexity and information than the object it is simulating. For example, in my interview with Devin Kerr, he noted that he suspects his code for Vulf Compressor might be hundreds of times more verbose than the original.[7] The key distinction for simulation is the ontological difference between the simulation and the simulated.

Simulation—in its most extreme form as a phenomenologically invisible ontological difference—raises fundamental questions of being. If the first half of the twentieth century was defined by an anxiety about the lack of an objective system of morality, the post-war period is perhaps defined by a crisis of ontology. The fear is not just that one's sensory apparatus can be successfully deceived, but that essence and any material property that does not produce a perceptual distinction are irrelevant. Alan Turing's famous "imitation game" proposes precisely this, if a human subject cannot distinguish a simulated human from its "real" counterpart, we must

[7] Devin Kerr, *Goodhertz Interview*, 2021.

accept that computers "think."[8] David Chalmers aptly sums up the problem by noting, "If we're in a perfect simulation, it's hard to see how we could ever get evidence of that fact. Our evidence in the simulation will always correspond precisely to evidence in the unsimulated world."[9] In response to any potential evidence the reader might use to bolster their argument, he proactively warns that "any such evidence could be simulated."[10] More than eighty years prior, the protagonists of John W. Campbell Jr.'s *Who Goes There?* (1938) find themselves with the same recursive quandary when faced with alien creatures that could perfectly simulate the appearance and actions of human beings. The character Dr. Copper explicitly refers to this recursion as he attempts to determine who has been simulated and replaced by the alien:

> I know I'm human. I can't prove it either. One of us two is a liar, for that test cannot lie, and it says one of us is. I gave proof that the test was wrong, which seems to prove I'm human, and now Garry has given that argument which proves me human - which he, as the monster, should not do. Round and round and round and round and[11]

The large quantity of fiction centered around this anxiety is evidence of the pervasiveness and popular awareness of ontological fears.

Claus Pias claims that "the term »simulation« means the totality of various practices and widespread forms of knowledge that have been emerging since 1945

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[8] Alan M. Turing, *The Essential Turing: Seminal Writings in Computing, Logic, Philosophy, Artificial Intelligence, and Artificial Life plus The Secrets of Enigma,* ed. B. Jack Copeland, 1st edition (Oxford : New York: Clarendon Press, 2004).
[9] David J. Chalmers, *Reality+: Virtual Worlds and the Problems of Philosophy* (New York, NY: W. W. Norton & Company, 2022), 32.
[10] Ibid.
[11] John W. Jr Campbell and William F. Nolan, *Who Goes There?: The Novella That Formed the Basis of the Thing* (Somerset, Pa.? Rocket Ride Books, 2009).

through the new medium of computers."[12] While Pias presents a more complex position later in the article, it is worth taking this claim at face value, if only because it is representative of so much of the established understanding of computing. In fact, Richard Grusin and Jay David Bolter present a similar argument regarding media technologies "The true novelty would be a new medium that did not refer for its meaning to other media at all. For our culture, such mediation without remediation seems to be impossible."[13] I argue that while simulation encompasses much of modern computing practices, simulation is not necessarily limited to computing, nor is computing limited to simulation. For example, computer processes that generate control of analog systems are not always simulations of the analog but interfaces to it. While it is possible to think of digital communications protocols such as MIDI as simulated abstractions of the internal mechanics of instruments such as the acoustic piano, other protocols such as Open Sound Protocol (OSC) are not tied to previous interfaces or "ideologies."[14] It should also be noted that, before the availability of graphical user interfaces and high-level programming languages for microcomputers, artists and composers developed practices for computing outside of simulation.

John Bischoff, a founding member of the League of Automatic Music Composers and The Hub, described to me how using the limitations of the KIM-1

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[12] Claus Pias. (2011). *On the Epistemology of Computer Simulation*. Zeitschrift für Medien- und Kulturforschung. 2011. 10.28937/1000107521.
[13] Jay David Bolter and Richard Grusin, *Remediation: Understanding New Media*, Reprint edition (Cambridge, Mass.: The MIT Press, 2000), 271.
[14] "OSC Index," August 13, 2021. http://opensoundcontrol.org/.

microcomputer—as well as the challenges of programming the device—bypassed many of aesthetic challenges associated with simulation:

> The music really sounds like it's electronic. It's not like using electronics to sound like a piano and then running the risk of sounding like a crappy, fake piano—or that it's never going to be as good as the piano—and all the conundrums you get into trying to emulate other sounds in this supposedly perfectly plastic medium of electronics, which I didn't believe in and I don't think anyone around me believed in.[15]

Bischoff was interested in the poetics of the digital computer as it was, not in what it might—convincingly or unconvincingly—appear to be. This was not a computer synthesizing ideal waveforms because, as Douglas Kahn notes, "the computer he used (KIM-1) was a glorified motherboard that had to be programmed in machine code keyed in using a hexadecimal pad."[16] While there is some similarity between writing a musical score using sheet music and writing a program on a microcontroller to produce musical events, as McAlpine notes, "A musical score is an efficient way of communicating the macro elements of music, but it relies on a performer interpreting those high-level musical directions and imparting the sort of unnoted expressive nuances that truly animate it."[17] With microcontrollers, these nuances must be articulated as concatenated logic if these decisions are not abstracted away and Bischoff was working at a level of abstraction that was not far from the voltage levels of each logic gate and shift register. "Because Bischoff intimately knew the code he

[15] John Bischoff. *John Bischoff Interview*. Feb. 12 2013.
[16] Douglas Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the Arts*, First edition (Berkeley: University of California Press, 2013), 237.
[17] Kenneth B. McAlpine, *Bits and Pieces: A History of Chiptunes*, Illustrated edition (New York, NY: Oxford University Press, 2018).

authored and its relationship to each and every vibration in the speaker cone, he formed a palpable sense of everything between, that is, the signals coursing through the circuitry."[18] Bischoff was not focused on simply controlling the audio, however: he told me that he considered coding errors part of the aesthetic enabled by the KIM-1. This, then, represents a third path for musical computing, not as the generation of abstract mathematics and logic or the simulation of analog media, but a digital poetics akin to that of analog media in its use of the limitations and biases of the technology to produce aesthetic results.

Underlying the apparent contradictions between Pias' definition of simulation as the entirety of computing practices and my view of simulation as a subset of digital aesthetic activity is our subject of study. Pias is attempting to understand the epistemological changes brought about by the use of computer simulation in the sciences, while I am more interested in what simulation tells us about how artists and engineers understand and engage with media. Simulated mediation, as I define it, is by necessity a creative act because it requires the simulator to isolate what they believe are the salient perceptual aspects of the technology they are simulating. I see these choices as metaphorically linked to those of the representational artist, who must make myriad decisions as to how to represent the essential qualities of their subject.

[18] Ibid.

A second, implicit understanding of simulation is described by Pias as an empirical process of modeling which produces visual results that appear similar to a trained observer:

> This validation process, in any case, is comprised of the interplay of sensitivity analyses and model revisions. For example, this functions very simply through means of »curve fitting«; that is to say, you superimpose a graphically rendered system-behavior model, obtained by means of simulation run-throughs, onto the representation of an empirically obtained and rendered model of system-behavior. If the curves match, the simulation is considered accurate; but this would by no means imply that it is »true« in the emphatic sense of the word. (Especially since the comparative curve is only decipherable to the trained eye; but of course it is a mathematically loaded and graphically arranged construct – a historical invention.) Which means to say that we are not here dealing with a dualistic path to knowledge but with a differential one. The point is not to penetrate to the very rhyme and reason of things and thereby perhaps formulating »laws«, but rather, within the parameters of a kind of empirical exoneration, it is sufficient that two systematic contexts behave in a like manner – irrespective of the reasons.[19]

It is again worth noting the similarity to the process of creating representational art. In the wake of mechanical reproduction, in representational artworks, such as portraits, the fidelity of the artwork to its subject—photorealism—became less relevant than the ability of an artist to capture the perceived essence of their subject at a particular moment. In the same way that photography—as a technological and cultural endeavor—fundamentally shifted the aesthetics of representation, the practice of simulation has profoundly altered our understanding of ontology. The justification for the success of a simulation is not its ability to recreate the specifics of the data or

[19] Claus Pias. (2011). *On the Epistemology of Computer Simulation*. Zeitschrift für Medien- und Kulturforschung. 2011. 10.28937/1000107521.

whether the underlying assumptions of the simulation are realistic, but whether a human observer perceives the output of the simulation as similar to a rendering made from recorded data.

The challenges of defining simulation are not limited to questions of semantics or of defining what series of phenomena can be enclosed by this term. The problem with defining simulation is that it is, by definition, constructed to be something other than it is. A completely transparent simulation would disappear and become indistinguishable from what it is simulating. Moreover, a simulation may simply replace the object being simulated, and the definition or understanding of that object may be replaced by that of the simulation. This is true of modern cellular phones, which simulate telephone interfaces and have displaced telephones. A conventional telephone is no longer a "phone" in the current lexicon but a "land line" as distinguished from the networked computers that replaced it. Jean Baudrillard articulates a similar process referred to as the "four stages of the image." He illustrates the stages as such: "it is the reflection of a profound reality; it masks and denatures a profound reality; it masks the absence of a profound reality; it has no relation to any reality whatsoever: it is its own pure simulacrum."[20]

While simulation may be contrasted with the use of metaphors or analogs, the two are not necessarily mutually exclusive. A simulation may serve to highlight a metaphor, such as when the sound of a simulated radio is used to connote distance. A

[20] Jean Baudrillard, *Simulacra and Simulation*, trans. Sheila Faria Glaser, 14th Printing edition (Ann Arbor: University of Michigan Press, 1994), 6.

manufacturer may also introduce a simulation within an iteration of a previous technology by using simulated components in tandem with analog. This is true of hybrid synthesizers and samplers such as the Ensoniq ESQ-1[21] and the E-MU Emulator III[22]—where digital oscillators or samples of analog waveforms were merged with analog filters. The analog filters were replaced with digital simulations in later devices built upon the same technological base in the VFX[23] and Emulator IIIXS,[24] respectively.

Hardware Modeling

Having defined simulation in a general sense, it is worth considering the simulation processes specifically associated with modeling hardware effects processors. This process is less subjective than simulating the perceived "sound" of electronics but does not approach complete objectivity. To begin the process, one typically begins by either passing test signals through a device and measuring the effects on the signal at various device settings or starting from an extant schematic of a circuit.[25] In the case of the former, the designer will develop a set of transfer functions that match—to the best of their ability—the transformative characteristics

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[21] Tony Hastings, "Ensoniq ESQ-1 (SOS Aug 1986)," Sound On Sound, no. Aug 1986 (August 1986): 22–27.
[22] Chris Meyer, "E-Mu Systems Emulator III Version 1.21 (MT Aug 1988)," Music Technology, no. Aug 1988 (August 1988): 32–35.
[23] Paul Ireson, "Ensoniq VFX (SOS Jul 1989)," Sound On Sound, no. Jul 1989 (July 1989): 42–47.
[24] Julian Colbeck, "Emu Systems EIIIXP (SOS Feb 1993)," Sound On Sound, no. Feb 1993 (February 1993): 74–77.
[25] "Plug-in Modelling: How Industry Experts Do It," accessed October 20, 2021, https://www.soundonsound.com/techniques/plug-in-modelling-how-industry-experts-do-it?utm_source=social&utm_medium=post&utm_campaign=morning_post.

of the circuit at various settings. Unsurprisingly, this is most effective at modeling linear circuits that easily map to Shannon's model of information. For nonlinear circuits, this model begins to break down. Universal Audio Chief Scientist Dave Berner, in an interview with Sound on Sound, notes how it is precisely these nonlinearities that make analog hardware appealing:

> [A]nalogue equipment that exhibits high-bandwidth, non-linear behaviour presents the biggest challenges in creating accurate models. But it's often the sound of these non-linearities that makes the original analogue equipment so desired. Put simply, the more non-linear the behaviour, the more complex the physical model that's required, and the more processing power needed.[26]

While using a schematic as a guide and utilizing circuit modeling software[27] will often render a convincing simulation, this approach also presents challenges. Hardware units may not follow the schematic, and parts tolerances may vary considerably.[28] Furthermore, modeling the hardware at a component level is much more computationally expensive than simply modeling the sonic effects. Wave Arts President Bill Gardner, in the same Sound on Sound article, describes how even a relatively simple design such as the Fender Champ guitar amplifier demands extensive processing power:

> For example, our Tube Saturator plug-in has six circuit nodes in the non-linear portion, containing two 12AX7 pre-amp stages. This requires about 33 percent of a 2.8GHz P4, processing mono 44.1kHz samples; doubling the size of the circuit requires eight times the CPU. A complete tube amp, like a Fender Champ with 24 circuit nodes,

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[26] Ibid.
[27] This refers to software that simulates individual electrical components, which can then be combined to form functioning circuits.
[28] For example, a resistor labeled 10 kiloohms with a parts tolerance of 20% or 30% could be anywhere from 7 kiloohms to 13 kiloohms.

> would require 64 times the CPU — or about 20 CPU cores![29] However, CPU power will continue to increase. In the not-so-distant future we'll be able to model any vintage analogue gear by simply entering its circuit schematic and running it in real time. And, in many ways, these simulations will be better than the original circuit: exact component values, perfectly matched components, no noise...[30]

This is an interesting proposition because it assumes it is possible to ignore listening-based adjustments altogether. It requires the designer to first discover an archetypical device from which to base the model. Ignoring the specter of subjectivity that emerges with this choice, once this assessment has been made, the simulated amplifier will produce, without variation, the sound of that device. The lack of variation is an improvement from an engineering perspective, but it also reduces a probabilistic range of sonic material to a fixed set and, in doing so, may truncate aesthetic possibilities. In reality, a simulation designer must make an aesthetic choice as to what represents a "true" Fender Champ and what represents a less desirable version. The age of certain components may also introduce variations, such as when aged electrolytic capacitors produce a "duller" sound. Even if one has access to an amplifier or synthesizer used on a particular recording, it is impossible to determine what condition the device was in at the time of the recording without empirical listening. The act of determining the definitive version of a device is an aesthetic judgment. Dave Smith encountered a similar problem when creating the fourth

[29] A Mac Pro with 24 cores running at 2.7 GHz costs $11,999.00 in 2022, but there are signs that multi-core processors in that range will be considerably cheaper in the coming years. Apple's Mac Studio line of computers, released in 2022, contains a CPU with 20 cores and costs $3,999.00.
[30] "Plug-in Modelling: How Industry Experts Do It," accessed October 20, 2021, https://www.soundonsound.com/techniques/plug-in-modelling-how-industry-experts-do-it?utm_source=social&utm_medium=post&utm_campaign=morning_post.

revision of the Prophet 5, "We collected a number of Rev 3s and a Rev 2 and a Rev 1. I think we had up to five at one point, and they were all different! So, which one do you pick as a Rev 3?"[31] Although the audio-rate components are analog, Smith ultimately used digital control to simulate the variation between revisions and individual units. These are controlled by a continuous "vintage" knob that alters the behavior of the entire synthesizer on a per-voice basis.[32]

As much as the modeling process aims for objectivity, ultimately the means of evaluating a simulation is the subjective perception of listeners. These may be users who are familiar with music production, expert listeners known as "golden ears", the engineers and programmers themselves, or some combination of all three. While some designers embrace the goal of perfect simulation, others are more interested in using it as starting point for a simulation that relates to their own aesthetic interests. Devin Kerr of Goodhertz states:

> It's totally mining the past to create something new at the same time. It's both sides of it. That's the thing that excites me. We don't ever want to be a "carbon copy" company of which there are many. Where it's just, "we will recreate this exactly, go throw away your hardware, and use this." We just never want to do that. Even from an ethical perspective, it just feels distasteful to me.[33]

While it is theoretically possible to simulate any analog circuit to an arbitrary level of resolution using a digital computer, there are, at present, practical limitations that ultimately make the choice of analog or digital implementations of continued

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[31] Sequential. Sequential Prophet-5: The Legend Returns, 2020. https://www.youtube.com/watch?v=1acVKBsctrw.
[32] A "voice" in a polyphonic synthesizer is a single, complete sound generator. Each voice uses the same routing structure and basic timbre—unless the device is poly-timbral.
[33] Devin Kerr, *Goodhertz Interview*, 2021.

relevance to engineers. Despite the continually reduced cost of digital electronics, there are still many circumstances where an analog implementation is considered more cost effective and the digital version, unfeasible. As Stephen McCaul of Noise Engineering related to me:

> Analog computers simulate aspects of reality (like artillery shells) as expressed with equations. What we call an analog circuit is a physical analog of a system of differential equations (itself an analog!) where the parameters are represented by voltages. A digital computer is a discrete, deterministic linguistic processing machine. When applied to audio they have dramatically different strengths and weaknesses particularly when you start adding the cost and complexity of implementation in our modern world. With a lot of things are there is a clear winner (storing recordings: digital, simple distortion: analog). For some things there is a big gray zone and with modern embedded processors there are a ton of hybrid architectures that make a ton of sense (see almost any modern "analog" synthesizer).[34]

Aesthetic and Cultural Implications of Simulated Media

That the aesthetics of computing should be linked to simulation is, in terms of the vast majority of extant computing, obvious. The universal computer was designed as a master simulator. It was devised to recreate all other forms of logical and mathematical computing. Alan Kay and Adele Goldberg, inventors of the personal computer, referred to it as a “metamedium” capable of simulating all other forms of media.[35] However, admitting that the primary goal of computing is to simulate the failures of “inferior” media technologies flies in the face of how computers have been marketed and received, such that the instinctual reaction to my interest in the

[34] Stephen McCaul, *Stephen McCaul Interview*, 2019
[35] Alan Kay and Adele Goldberg, “Personal Dynamic Media,” in The New Media Reader (Cambridge, Mass: MIT Press, 2003).

simulation of anachronistic media has often been confusion or annoyance. Digital technology remains tied to notions of inevitable progress and the promise of greater clarity. Technology companies promise us that they have overcome the "mistakes" of earlier media technologies and that the latest consumable media will produce pure, unmediated experiences and greater immersion. The popular art being made on computers tells a very different story, one in which all manner of noise, distortion, saturation, filtration, smudges, dust, scratches, solar flares, aliasing, clicks, pops, discoloration, bleed-through, data compression, pixelization, data corruption, blurring, burn-in, jitter, phase variance, datamoshing, cigarette burns, clipping, and packet loss form the basic palette of tools. Digital emulations of synthesizers, analog and digital effects processing units and mixing equipment are used in every modern recording studio. Nearly all commercially and non-commercially released films, video games, music, and television programs, use some form of analog simulation. Apple's free DAW GarageBand is automatically installed on millions of computers each year and includes numerous simulations of tape delay, analog distortion, phasors, compressors, and pitch-shifters.[36] While it is widely accepted that these tools have changed the way music is produced, it is not always clear what role simulation actually plays for professional and amateur musicians or the music they make.

[36] Apple Support. "Add and Edit Effect Plug-Ins in GarageBand on Mac." Accessed January 4, 2022. https://support.apple.com/guide/GarageBand/add-and-edit-effect-plug-ins-gbndac55f7f8/10.4.4/mac/11.0.

Figure 3.1 Arturia Mini V: A simulation of the Minimoog

The success of a given simulation is ultimately dependent on how successfully it matches the subjective perception of one or more aspects of the object of simulation. This ambiguity is compounded by the subjective aesthetic goals and superstitious culture of audio production. Tara Rodgers notes the “occult-like habits”[37] of audiophiles, a description that can be as easily applied to audio production culture. There are many practices that are not easily explained but seem to “just work.” In some cases, such as the use of the notoriously bad-sounding Yamaha NS-10M speaker to audition mixes, the practice arises in the manner of a cargo cult, with producers using the tools of successful engineers without knowing why—only for later scientific testing to account for their use.[38] In other cases, no such explanation arises. As much as is understood about the human perception of sound, there remain gaps where speculation abounds, and manufacturers are willing to sell

[37] Tara Rodgers, “Tara Rodgers,” Sounding Out! (blog), accessed October 12, 2021, http://analogtara.wordpress.com.
[38] “The Yamaha NS10 Story,” accessed November 27, 2021, https://www.soundonsound.com/reviews/yamaha-ns10-story.

high-specification products, regardless of whether or not the merits of a particular product are proven to create appreciable results.

These practices may or may not produce audible changes to the sound by themselves, but they often affect the resulting sounds. Take, for example, the wooden end "cheeks" commonly associated with vintage synthesizers. Simulating the look of wood-grain in a digital emulation of an analog synthesizer will not affect the code that produces the sound, but it is a visual cue for the user. There are idiomatic performance techniques that musicians are more likely to use depending on the genre of music they are playing and the type of instrument they are using. Wood or simulated wood has certain aesthetic connotations that may be transmitted to the user. This was also true for the Minimoogs produced by Moog during the time the instrument was commercially available. As Tara Rodgers' research demonstrates, the iconic walnut wood paneling used to construct the early Minimoogs was a result of financial happenstance.[39] However, when this look became tied to musicians' expectations of the instrument, the designers chose to paint the later models to look like they were encased in walnut when cheaper materials became available. The type of wood casing on a commercial synthesizer is also unlikely to affect the circuits contained therein[40] but may affect how a user interacts with the instrument.

[39] Tara Rodgers, "Tara Rodgers," Sounding Out! (blog), accessed October 12, 2021, http://analogtara.wordpress.com.
[40] It is possible, for example, to imagine a scenario where the Minimoog oscillators, which are not designed to compensate for wide temperature variation, are affected by the insulating properties of the walnut, compared with metal, various plastics, or other types of wood, but this was not a factor in the design process or the cultural reception of the device.

Much like other forms of media, the reception of an instrument will result in different readings depending on the subject: a Minimoog player may find it easier to transition to an interface that features a similar look and layout, a musician who has heard of a Minimoog may have associations with the sound, or the user may not have any particular associations with the device but find the wood paneling evocative of a particular cultural moment. Websites such as Equipboard attempt to catalog the instruments used by particular musicians,[41] and the marketing materials for simulations from companies such as Universal Audio often promote these connections to the famous users of the original instrument.[42] Musicians may, therefore, seek out an instrument used by a performer they admire as a means of more easily emulating their sound. For other users, the aesthetics may simply register as "old" or "vintage." These associations may not affect the music a user creates with it, but it often does, at least in casual use. A user may choose to write material in genres associated with that instrument, for example. A simulation may also change how a musician understands the original instrument. As digital emulations of analog synthesizers are more common than analog synthesizers, this is the rule rather than the exception for young synthesists. Minimoogs were marketed on their ability to alter their timbre to reproduce the sounds of many instruments, but simulation renders

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[41] "About Equipboard | Equipboard." Accessed October 27, 2021. https://equipboard.com/about.
[42] "AMS DMX Digital Delay & Pitch Shifter | UAD Audio Plugins | Universal Audio." Accessed January 9, 2022. https://www.uaudio.com/uad-plugins/delay-modulation/ams-dmx-digital-delay-pitch-shifter.html.

the Minimoog as an "original" characteristic sound. This places it in an odd relationship where its "failings" become its value.[43]

Of course, this is not always true. Pitch instability may be a component of the character of the synth that is cherished, but it is not generally appreciated when it is impossible to play an instrument in tune. There are exceptions to this as well: Dave Smith Instruments includes a knob labeled "slop" on many of their synthesizers in order to emulate the instability of early analog oscillators by randomizing the pitch divergences between each voice to an increasing degree. While the Prophet 08 allows for only subtle divergences between voices,[44] later synths such as the Prophet 12,[45] Prophet 6, and Prophet Rev2 introduce greater modulation depth of the slop parameter after customers expressed frustration at being unable to make each voice deeply out of tune with the others. Regardless, it is the ability to control the amount of instability that transforms this "bug" into a feature.

When I spoke to Scott Harper about his work developing the Blooper pedal with Chase Bliss Audio, he pointed to the ability to "age" hardware in real-time as a feature that distinguishes modern audio devices:

> …being able to record those changes, being able to move between the past and the present is very cool and a very new idea—that it is possible, and that anyone would want to do that.[46]

[43] The added value over the simulation.
[44] "Prophet 08 Manual." Dave Smith Instruments, May 2010, 19.
[45] "Prophet 12 Manual." Dave Smith Instruments, March 2014, 16.
[46] Scott Harper. *Knobs Interview*. January 5, 2022.

While earlier digital devices such as the Waldorf Microwave II specifically framed sample rate reduction as a means of simulating the sound of older synthesizers, the ability to modulate the "age" of a sound is not a feature of earlier digital hardware.

Blooper belongs to a class of guitar pedals referred to as loopers.[47] It allows players to record into an audio buffer, modify the recordings in various ways, layer further recordings or modifications, and play the audio back. The user may record modifications to the audio that they perform by turning knobs associated with various parameters. Each parameter is associated with a form of altering magnetic tape. According to Joel Korte of Chase Bliss:

> That's kind of the line we drew for the modifiers. There's no reverb on there. It's inspired by tape. Speed changes, reverse, trimming the loop. We didn't want to make it a multi-effect—even though it is, kind of, we wanted to draw the line there.[48]

Many of the parameters can be assigned to different knobs by the user, but Korte and Harper assigned the "stability" parameter, a means of adding random pitch fluctuations and noise to the recorded audio, to a specific knob on the front panel. When I asked Harper about this, he said:

> It almost got to the core of the device itself. We're not changing the loop, it's more like we're aging Blooper. Is Blooper in its pristine, best working state, or is it 20 years old? I wanted that feeling to be obtainable on a knob. It wasn't based on anything specific that I had played.
>
> It's this concept, of… this is how we discussed it: is this brand new? Is it close to needing maintenance? When I described it to the engineer, it was like: with stability cranked all the way up, you should be afraid of

[47] The term itself refers to an audiotape that has been modified in such a way that it will repeat in an endless loop.
[48] Joe Korte. *Chase Bliss Interview*. December 12, 2021.

smoke coming out of it. If this was a piece of hardware, that's the point we're at here. That language was built in. It's the machine. That's why stability is different. It's not an effect, it's changing blooper as a whole.[49]

The simulation of aging electrical components within this device demonstrates an interest in creating continuous shifts between high and low fidelity sounds. As with the continuous bit reduction techniques I have previously discussed, the Stability knob is an attempt to disrupt the subjective experience of time by allowing for continuous movement between the simulated past and present. Stability is unique in that it is not an attempt to simulate the aesthetics of previous technologies but to age the simulated looping device and speculate about how it might appear in the future.

Figure 3.2 Blooper from Chase Bliss Audio and Knobs

[49] Ibid.

Remediation:

In contemporary media theory, simulations are often defined in terms of remediation, a concept introduced by Richard Grusin and Jay David Bolter in their *Remediation: Understanding New Media*. They define remediation as "the representation of one media in another."[50] Remediation is used to describe a wide variety of practices, from the use of visual metaphors in interface design to the translation of information from one medium to another. This concept originates in the work of Marshall McLuhan, who claims:

> [T]he "content" of any medium is always another medium. The content of writing is speech, just as the written word is the content of print, and print is the content of the telegraph. If it is asked, "What is the content of speech?" it is necessary to say, "It is an actual process of thought, which is in itself nonverbal." An abstract painting represents direct manifestation of creative thought processes as they might appear in computer designs.[51]

While this articulates a general tendency of media, it does not afford an adequately granular analysis of media aesthetics. Despite the status of *Remediation* as a foundational analysis of mediation and its continued influence on media scholarship, the term itself is too vague and contradictory. It is difficult, for example, to justify Bolter and Grusin's description of the use of linear perspective and moving images in video games as remediating cinema.[52] The use of moving image in games may just as

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[50] Jay David Bolter, and Richard Grusin. *Remediation: Understanding New Media*. (Cambridge, MA: MIT Press, 2003), 45.
[51] McLuhan, Marshall, and W. Terrence Gordon. *Understanding Media: The Extensions of Man*. Critical edition. Corte Madera, CA: Gingko Press, 2003, 1.
[52] Jay David Bolter and Richard Grusin, *Remediation: Understanding New Media*, Reprint edition (Cambridge, Mass.: The MIT Press, 2000), 47.

easily reference television or "unmediated" human vision. It is hard to imagine how the use of techniques shared by a variety of media can be identified as representing one medium over another without additional means of verification.

Grusin and Bolter admit there are distinctions between pre-modern media and digital simulation but argue that all media in Western culture is united by "denying the presence of the medium and the act of mediation."[53] It is true that the logic of immediacy is prevalent in both modern media and earlier forms of mediation, such as linear perspective in renaissance painting. It could even be argued that there is an intellectual through-line from Shannon's idealized "information" to the Aristotelian concept of the archetype. However, the tendency towards self-awareness, direct audience address, and conspicuous mediation is a tradition in Western art practices with a history as long as immediacy, as Bolter and Grusin themselves note. From the perspective of a scholar of modern art and popular culture, these tendencies are potentially more important, given the turn towards greater abstraction or embellishment in much of art after the invention of photography. Grusin and Bolter argue that hypermediacy does not necessarily detract from the experience of immediacy: the shakiness of handheld video camera footage or, in their example, the simulated cockpit display in a flight simulator may increase the experience of verisimilitude or the subjective sense of immediacy.[54] However, since it has been established that hypermediacy may also intentionally diminish the subjective sense of

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[53] Ibid, 11.

[54] It is not possible for these mediating effects to be literally immediate, so this sense of immediacy must refer to a subjective perception.

immediacy, it cannot be considered a unifying trait of digital and analog media. Moreover, the differences between the presence of a form of media in its original medium and a simulation can offer useful insights into the design of a medium or the rhetoric of an artwork.

Grusin and Bolter make a more compelling case for remediation when they claim that "this is all any new technology can do: define itself in relation to earlier technologies of representation."[55] As I have shown, this is true of most computing practices. The use of dither to replace the sound of quantization error with that of tape hiss is precisely that. However, this is not necessarily true for all media. Artists exploring the poetics of mediation focus almost exclusively on the unique aspects of new media technologies. This is also true outside of the avant-garde. While the forms of popular expression in new media may take the form of the reframing of older arts, they are just as likely to take on new forms, such as the emergence of record scratching or the "glitch" music created by intentionally overloading computer processors, or abrading the surface of compact disks.

Remediation is conservative in its framing. Presenting continuity between simulation and past forms of mediation allows one to identify its lineage but also threatens to gloss over what is new about digital simulation. To categorize the simulation practices that I am exploring under the broad category of remediation renders the sort of aesthetic practices covered in the current chapter invisible. These

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[55] Jay David Bolter and Richard Grusin, *Remediation: Understanding New Media*. Reprint edition (Cambridge, Mass.: The MIT Press, 2000), 28.

techniques have differing histories, technological infrastructure, cultural references, politics, and semiotics. It is impossible to analyze why an artist might use a particular form of mediation over another if computer simulation and analog reproduction are treated as equivalent.

To name a relevant example, the repurposing of discarded electronics for music through circuit-bending has a very different politics and environmental impact than the manufacture of new electronic devices using the same circuits or digital simulation. Circuit-bent devices and hacked devices, such as the hacked CD players used in Nicolas Collins' *Broken Light* (1992),[56] are modified consumer electronics that behave differently than their design specifications. As another example, the third revision of Laetitia Sonami's Lady's Glove used sensors from the Nintendo Power Glove to translate her performance gestures into data. This act of eviscerating the VR tool[57] and exposing its internal workings offered an implicit critique of the gendered ideology of immediacy. Sonami notes that the Lady's Glove was "a response to the heavy masculine apparel used in virtual reality systems."[58] The use of exposed components from consumer objects distinguishes Sonami's glove—with its focus on embodiment and gesture—from those developed by Lanier or later developments such as the Mi.Mu gloves, which focus almost exclusively on control.[59] Unlike

[56] Nicolas Collins, "CEC — EContact! 20.3 — Hacking the CD Player by Nicolas Collins," CEC | Canadian Electroacoustic Community, accessed April 9, 2022, https://econtact.ca/20_3/collins_cdhacking.html.
[57] Developed, in part, by Jaron Lanier.
[58] "Lady's Glove," LAETITIA SONAMI (blog), accessed April 9, 2022, https://sonami.net/portfolio/items/ladys-glove/.
[59] "MiMU | Home," accessed April 9, 2022, https://mimugloves.com/.

circuit-bent objects—rescued from planned obsolescence by circuit benders—many simulations require the latest consumer computing hardware, itself doomed to the cycle of obsolescence. Since, as Jussi Parikka notes, "approximately 250 million functioning computers, VCRs and cellphones are discarded each year in the United States"[60] the distinction is far from trivial.

While the physical interface of a device profoundly alters performance gestures and the resulting sound, the same can be said for novel uses of the physical properties of the instruments themselves: In 2013, I witnessed a performance in which composer Madalyn Merkey attached contact microphones to the body of an Oberheim Xpander, which amplified her performance gestures and real-time modifications to the sound by transducing vibrations using the instruments' interface. These differences were not confined to binaries of analog and digital or software and hardware. The difference between reusing code in an emulation and writing code, tabula rosa, to create a subjectively similar effect can have important aesthetic implications. Remediation glosses over the differences between mediation, modeling, translation, digitization, skeuomorphism, and simulation. For this reason, I avoid using the term "remediation," while considering the implications of "hypermediacy" and "immediacy" in relation to simulation.

Jonathan Sterne coins a similar term, "mediality," to describe "*a quality of or pertaining to media* and the complex ways in which communications technologies

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[60] Garnet Hertz, Jussi Parikka; *Zombie Media: Circuit Bending Media Archaeology into an Art Method.* Leonardo 2012; 45 (5): 424–430.

refer to one another in form or content."[61] Mediality, however, is less a means of explaining or categorizing phenomena than it is for identifying relationships. Unlike remediation, the question is not whether a variety of phenomena can usefully be grouped together but whether mediality articulates a distinguishing attribute of a particular medium. While references to the form or content of other forms of media are almost inescapable, media may possess varying degrees of mediality or express different forms of it.

Immediacy and Hypermediation

One of the simplest ways of understanding the failings of a technology and the anxieties surrounding it is to examine how it is marketed. Simulations are sold on their "authenticity," and advertisements promote new forms of mediation as immediate. As Andrew Ross notes, "[A]dvanced technologies are often sold on the premise that they can provide elemental experiences which are no longer possible through the technologies that they are seeking to supplant. According to this pitch, our current toys have formed an obstructive, mediating barrier that the new ones will leap over and restore access to the authentic stuff."[62] Ironically, this premise holds true, even when the "authentic stuff" is mediation. Simulations of anachronistic technologies are marketed as the "most authentic model of a true studio classic"[63] or

[61] Jonathan Sterne, *MP3: The Meaning of a Format* (Durham: Duke University Press Books, 2012), 9.
[62] Andrew Ross, *Music and Technoculture*, ed. René T. A. Lysloff and Jr Leslie C. Gay (Wesleyan, 2013), 379.
[63] "Lexicon 224 Digital Reverb | UAD Audio Plugins | Universal Audio." Accessed January 6, 2022. https://www.uaudio.com/uad-plugins/reverbs/lexicon-224.html.

"perfectly emulated".[64] While each new medium is marketed as more immediate and authentic, simulation of the artifacts of analog media is pervasive across all of popular culture. As early as 1996, Grusin and Bolter identified hypermediacy as an aesthetic philosophy. For them, immediacy is a design principle that aims for unmediated experience.[65] It is related to immersion in that both are intended to subjectively eliminate, or at least disguise, the frame of the medium.

Janet Murray, a contemporary of Grusin and Bolter, provides a clear explanation of immersion and its charms:

> The experience of being transported to an elaborately simulated place is pleasurable in itself, regardless of the fantasy content. We refer to this experience as immersion. Immersion is a metaphorical term derived from the physical experience of being submerged in water. We seek the same feeling from a psychologically immersive experience that we do from a plunge in the ocean or swimming pool: the sensation of being surrounded by a completely other reality, as different as water is from air, that takes over all of our attention, our whole perceptual apparatus. We enjoy the movement out of our familiar world, the feeling of alertness that comes from being in this new place, and the delight that comes from learning to move within it. Immersion can entail a mere flooding of the mind with sensation, the overflow of sensory stimulation experienced in the televisor parlor in Bradbury's *Fahrenheit 451*. Many people listen to music in this way, as a pleasurable drowning of the verbal parts of the brain.[66]

While Grusin and Bolter do not explicitly contrast immediacy and immersion, one implicit difference is the perceived sense of embodiment present in immersive

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[64] Morgan Perrier, "Arturia - Software Effects - Chorus Dimension-D," accessed January 6, 2022, https://www.arturia.com/store/software-effects/chorusdimension-d.
[65] Jay David Bolter and Richard Grusin, *Remediation: Understanding New Media*, Reprint edition (Cambridge, Mass.: The MIT Press, 2000), 21-2.
[66] Janet H. Murray, Hamlet on the Holodeck, Updated Edition: The Future of Narrative in Cyberspace, Updated ed. edition (Cambridge, Massachusetts: The MIT Press, 2017), 159-60.

simulations. To illustrate this concept, they quote Jaron Lanier, who claims that, in contrast to the experience of viewing photographs and video of dinosaurs or DNA via traditional media, one can "become" both through the immersive experience of virtual reality.[67] This particular example demonstrates many of the contradictions and absurdities of the rhetoric of immersion: it proposes that more detailed, true-to-life sound and visuals, along with greater interactivity, are all that is necessary to change one's sense of ontology to that of a dinosaur. While it may be tempting to dismiss Lanier's claims as dated or hyperbolic, the experience of immersion and embodiment remains the fundamental promise of virtual reality. VR, in this sense, is the practice of the ideology of immediacy rather than a specific technological medium. Commercial VR technology in the intervening three decades has focused almost exclusively on improved visual and aural experiences. The rhetoric has also changed very little since the 1990s, as evidenced by philosopher of neuroscience David Chalmers' recent book on the subject:

> What's distinctive about VR is that its virtual worlds are *immersive.* Instead of showing you a two-dimensional screen, VR immerses you in a three-dimensional world you can see and hear as if you existed within it. Virtual reality involves an immersive, interactive, computer-generated space.[68]

Despite the rhetoric of immersion and immediacy, the focus of VR technology has been monomaniacally focused on the senses that have already been colonized by

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[67] Jay David Bolter and Richard Grusin, *Remediation: Understanding New Media*, Reprint edition (Cambridge, Mass.: The MIT Press, 2000), 21-2.
[68] David Chalmers, *Reality + Virtual Worlds at the Problem of Philosophy*. (New York City, New York: W.W. Norton and Company, 2022).

media technologies. Chalmers admits that “much that matters is missing: proper bodies, touch, eating and drinking, birth and death, and more.”[69] However, he claims that these problems will solve themselves, seemingly through the inevitable forward march of technology:

> These temporary limitations will pass. The physics engines that underpin VR are improving. In years to come, the headsets will get smaller, and we will transition to glasses, contact lenses, and eventually retinal or brain implants. The resolution will get better, until a virtual world looks exactly like a nonvirtual world. We will figure out how to handle touch, smell, and taste. We may spend much of our lives in these environments, whether for work, socializing, or entertainment.[70]

Ignoring the fact that, for thirty years, little effort has been made to “handle” touch, smell, or taste in commercial VR, these predictions still read as anachronistic. They are the predictions of the future presented by post-war science fiction in works by Ursula K. Le Guin, Philip K. Dick, and, later, William Gibson. I suspect these arguments are meant for those who have already internalized these narratives. Projecting an idealized simulation allows him to address the crisis of ontology that has arisen in response to the potential realization of this ideal. What is lost in these assumptions about future VR is that the VR currently available present highly mediated experiences—with the creators of the critically acclaimed VR game *Resident Evil 7: Biohazard* (Capcom, 2017) going so far as to simulate the look of

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[69] Ibid.
[70] Ibid.

VHS tape and sending VCRs as promotional materials.[71] The VR "homes" Meta creates for its Oculus Quest hardware make no attempt at photorealism; they make use of the cheerful pastels and simplified geometry of cartoons. It is critical that our analysis of the present is not drowned out by the anxieties of an imagined future, even if such speculation is valuable on its own. It is important that we contextualize these fantasies about immediacy by examining current practices.

While Bolter and Grusin postulate that immediacy is rejected by academic theorists because it is "undertheorized,"[72] it strikes me that a more plausible explanation is that the conflation of improved audio or visual quality with immersion or empathy does not stand up to scrutiny. A medium cannot literally possess immediacy: "immediate" is defined as the lack of an "intermediary or intervening member, medium, or agent"[73] Moreover, the tools that produce affective experiences subjectively experienced as immediate are often those that mediate the user's experience and diverge from reality such as non-diegetic music, montage or unrealistic color grading. The improvement in one area of experience may only serve to emphasize the failings of another aspect of the experience. The "uncanny valley" addressed in the previous section is an example of this. To provide a more extreme example; latency between the movement of the VR user's head and the realignment

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[71] Philip Kollar. "Capcom Sent Us a VCR and Creepy Video Tape for Resident Evil 7." Polygon (blog), January 13, 2017. https://www.polygon.com/2017/1/13/14271370/resident-evil-7-vcr-capcom-promotion-promotional-tape-cassette.

[72] Jay David Bolter and Richard Grusin, *Remediation: Understanding New Media*. Reprint edition (Cambridge, Mass.: The MIT Press, 2000), 30.

[73] "Immediate, Adj., n., and Adv.," in OED Online (Oxford University Press), accessed October 27, 2021, https://www.oed.com/view/Entry/91838.

of the visual field in the virtual space may lead to nausea, an effect that may take the user "out" of the experience[74] more than a traditional viewing experience.[75]

Nevertheless, Grusin and Bolter are correct in emphasizing the desire for immediacy and immersion as a historical tendency and a widely-felt desire. The relationship of mediation to perception is one of constant struggle. Immersion and hyper-mediation correctly outline the dialectic tendencies of simulated mediation: a turn toward immersion consists of attempts to dissolve media into perception, and the failure to do so produces new forms of mediation and unacknowledged assumptions.

Nostalgia & The Uncanny

The requirement that a simulation must have an extant subject means that it must relate to the past in some way, even if it is the very recent past. With the simulation of media technologies, this relationship is further emphasized because of the way that the affect and aesthetics of individual media technologies come to be associated with particular eras and cultural experiences. This might include the visual noise, shifting of vertical alignment and discoloration of VHS tapes or the hiss, bandpass filtering, and random pitch modulations of audio cassettes. There are exceptions to the experience of simulated mediation as past, such as when television shows, films, or games simulate the interface of contemporary phones for aesthetic or practical purposes. However, the vast majority of production tools that simulate

[74] Whitson Gordon, "How to Reduce Motion Sickness in Virtual Reality," Wired, accessed January 8, 2022, https://www.wired.com/story/how-to-reduce-motion-sickness-virtual-reality/.
[75] Unless the intention is to simulate the experience of someone suffering from motion sickness.

media technologies recreate the aesthetics of anachronistic technologies. The presence of mediation artifacts in the technology of their childhood was an important aspect of the relationship many designers have with the simulations they created. Sean Costello describes this explicitly in a blog post addressing the new “LoFi” mode he created for Valhalla Delay:

> The deeper underlying inspiration for the LoFi mode was the low fidelity sounds I grew up with in the 70s and 80s. As a kid, I watched movies in school played on warbly 16mm projectors. In the 80s, I watched movies on VCRs, where the audio would hitch and wobble. I recorded vinyl records onto cheap cassettes, that would jam in my Walkman or car stereo. The tapes could be salvaged by prying them out and rewinding the spools with a pencil, but the tape would inevitably be chewed up and wrinkled, creating all sorts of wow and flutter. If you were a child of the 70s or 80s, you grew up in a lo-fi world.[76]

Scott Alexander Howard defines nostalgia in terms of perceived changes from the past, claiming, “Any adequate view of nostalgia will acknowledge that it involves a felt difference between past and present: the very irretrievability of the past is salient in the experience.”[77] He outlines two distinct forms of nostalgia.[78] Defined as “the poverty of the present,” nostalgia is the sense that the present is worse than the past in some way. This past may be a personal, such as the youth of the individual, or cultural such as a preference for the aesthetics, politics, and social moirés of a bygone era. The latter is especially true of simulations that emulate the iconic sounds or

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[76] Sean Costello, “ValhallaDelay 1.8.2 Update: LoFi Mode,” Valhalla DSP (blog), November 23, 2020, https://valhalladsp.com/2020/11/23/valhalladelay-1-8-2-update-lofi-mode/.
[77]Scott Alexander Howard, “Nostalgia,” Analysis 72, no. 4 (2012): 641–50.
[78] Alexander also identifies a third understanding of the term, a nostalgia characterized by a lack of awareness of the transience of the moment but dismisses it as a qualification, deeming that it “fails to capture the full range of genuinely nostalgic experiences”

visuals associated with a particular cultural moment, such as the characteristic compression of MP3 files or noise, bandpass filtering, and pitch instability of VHS tape. This form of nostalgia is best characterized by Linda Hutcheon, who emphasizes the relationship between the "the irrecoverable nature of the past" and the projection onto the past of an inverted present:

> The simple, pure, ordered, easy, beautiful, or harmonious past is constructed (and then experienced emotionally) in conjunction with the present – which, in turn, is constructed as complicated, contaminated, anarchic, difficult, ugly, and confrontational. Nostalgic distancing sanitizes as it selects, making the past feel complete, stable, coherent, safe . . . in other words, making it so very unlike the present.[79]

An additional category of nostalgia is what Howard describes as "Proustian nostalgia."[80] This form is typically experienced as a reaction to an external sensory cue, retrieved without mental effort. The nostalgia produced in this experience connects the affective experience of the present to that of the past in a fleeting but intense moment. The perceptual qualities of mediation may produce this feeling with greater clarity than information recorded at the moment of the experience, since this form of nostalgia is strongly linked to subjective, sensory experience.

The role of nostalgia changed when popular media redefined the past as an aesthetic that could be continuously revisited. For this reason, I suggest another form of nostalgia that seems to inform many simulations: the nostalgia experienced when

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[79] Linda Hutcheon & Valdés, Mario. (2000). *Irony, Nostalgia, and the Postmodern: A Dialogue*.
[80] Scott Alexander Howard, "Nostalgia," Analysis 72, no. 4 (2012): 641–50.

reviewing media, such as photos or videos of events. In this scenario, nostalgia may be experienced as a poverty of affect, where the emotional experiences, which cannot be recorded, become the object of nostalgic desire. Returning to the concept of immersion, this affective state—the sense of embodiment or "being" and all of the associated emotions present within it—is what is missing from immersive simulations or recordings. A clear example of this is the experience of listening to a favorite song and recalling the emotional experience of hearing it for the first time. This form of nostalgia is connected to the "poverty of the present," but it is not determined by the time that has passed since the original experience. Instead, the primary influence seems to be how often the experience has been repeated.

In simulation, we find a similar pattern, but rather than the past, it is the object of simulation that is irretrievable. There is a sensed ontological difference that can be difficult to articulate but persists as an affective state in situations of simulation. Simulations of media technologies that are intended to evoke nostalgia must overcome both this uncanny distance from their subject and the fact that, as Hutcheon explains, nostalgia is not a quality of the object itself but a subjective response to that object.

Grafton Tanner attributes modern nostalgia in the west to a desire to escape from the 21st century's atemporality:

> With unprecedented access to the Internet, the flattened desert where past, present, and future comingle, we find ourselves living in a state of atemporality, yearning for a time before the present. In the West,

> the time for which we pine is one before the twenty-first century, which arrived violently on September 11, 2001, and before the rise of the Internet. Capitalism knows this and exploits our collective nostalgia for economic gain, commodifying the very ghosts we clutch earnestly. All of this we do because the world we have found ourselves in runs on the motor of chaotic, neurotic capital that wipes away any meaning other than profit.[81]

While the desire to escape the trauma of September 11, 2001, informed the cultural experience of nostalgia generated in its wake, this explanation fails to account for many forms of modern nostalgia. The simulation of media technologies closely associated with post-9/11 and post-internet culture, such as the MP3 format, indicates that these were not singular catalysts. Perhaps this is explained by the fact that the COVID-19 pandemic has largely replaced 9/11 as the prevailing cultural trauma, which itself displaced, for many, the traumas of the presidency of Donald Trump. Trauma is also connected to a sense of the "poverty of the present," and recent historical traumas may have enabled a further devaluation. However, as nostalgia takes many forms, so do the reasons for creating nostalgic experiences. The internet may be an "atemporal" space in the sense that it is a repository of media as aestheticized history, but such repositories have been a historical reality long before the invention of the civilian internet. Any media that persists after the event it is recording represents an attempt to bring some sensory aspect of the past into the present. As Katharina Niemeyer observes in her introduction to *Media and Nostalgia: Yearning for the Past, Present and Future*:

[81] Grafton Tanner, Babbling Corpse: Vaporwave And The Commodification Of Ghosts (Winchester, UK ; Washington, USA: Zero Books, 2016).

> [N]ostalgia is not only a fashion or a trend. Rather, it very often expresses or hints at something more profound, as it deals with positive or negative relations to time and space. It is related to a way of living, imagining and sometimes exploiting or (re)inventing the past, present and future.[82]

It is, therefore, difficult to attribute an intensification of nostalgic practices—if that is how we choose to position the simulation of analog media—solely to the perceived atemporality of the internet.

While modern nostalgia is often presented as a result of late capitalism and an impediment to social or technological progress, it is also a way of challenging determinism and any argument that presupposes the inevitability of particular technological paths. Nostalgia—as a way of articulating a feeling of loss that one cannot rationally justify—allows one to reconsider what cultural hegemony has dubbed superfluous or worthless. Nostalgia is a means of critiquing immediacy and the ideology of transparency. Tom Majeski summarizes this sense that greater resolution and immediacy do not necessarily lead to improved aesthetics by stating, "We're losing the things that we like about technology as we get better at making technology."[83] Rather than being regressive or reactionary, nostalgic practices can enable us to better understand cultural practices surrounding technology. Accusations of nostalgic thinking are often used to promote narratives of inevitable progress or technological advancement. As Sherry Turkle notes:

[82] Katharina Niemeyer, *Media and Nostalgia: Yearning for the Past, Present and Future*, 1st ed. 2014 edition (Basingstoke, Hamshire New York: Palgrave Macmillan, 2014).
[83] Tom Majeski, *Cooper fx Interview*, August 2, 2021.

> Technology presents itself as a one-way street; we are likely to dismiss discontents about its direction because we read them as growing out of nostalgia or a Luddite impulse or as simply in vain.[84]

Nostalgia draws attention to the specific material properties of media that have been abstracted or ignored. Analog synthesizers are not simply abstract waveforms processed through ideal filters or waveshapers. The nostalgic processes for simulating these devices help us to recognize what it is about their differences from an idealized model that makes them aesthetically valuable to composers. As much as it would be preferable to isolate our engagement with the past from the irrational valorization of "tradition,"[85] unless we are willing to submit to an extreme form of logical positivism that rejects empirical experience, nostalgia will remain an important tool for understanding our relationship to the past.

While nostalgia is presented as a conservative tendency by Tanner, this incorrectly characterizes the relationship of conservativism to the past. The conservative position is to preserve current standards, aesthetics, or ethics, not to return to or revive those of the past. The Oxford English Dictionary defines conservative as that which "…conserves, or favours the conservation of, an existing structure or system; (now esp.) designating a person, movement, outlook, etc., averse to change or innovation and holding traditional ideas and values, esp. with regard to social and political issues."[86] A conservative preserves the past, only so far as the past

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[84] Turkle, Sherry. *Alone Together: Why We Expect More from Technology and Less from Each Other*. 3rd edition. New York: Basic Books, 2017.
[85] As seen in reactionary, neo-fascist political movements.
[86] "Conservative, n. and Adj." In OED Online. Oxford University Press. Accessed February 25, 2022. https://www.oed.com/view/Entry/39569.

persists into the present. By contrast, a return to the past may be conservative, radical, or reactionary. A distinction should be made between the continual repetition of past tropes in the present, and a radical or reactionary break marking the return to values regarded as distinct from our own.

Nostalgia's semantic origin is found in the German word heimweh—meaning "homesickness."[87] It is therefore unsurprising to find that the uncanny—another term that is closely associated with simulation—also has its roots in the home, as the "unheimlich" or un-home-like. As Sigmund Freud notes in his essay *The Uncanny,* the German word unheimlich, "is obviously the opposite of heimlich, heimisch, meaning 'familiar,' 'native,' 'belonging to the house'"[88] The pairing of these terms and their metaphorical application to simulated media implies a causal relationship; simulated media create a sense of homesickness precisely because they evoke the home, if only through their differences from it. This metaphor of home and its inaccessibility—the distance implied by homesickness, continues to be reflected in the terminology surrounding simulation. We are separated from the fantasy of immediacy by an "uncanny valley," again evoking the physical distance from home. It follows that critics who dismiss simulated media as nostalgic misunderstand something fundamental about digital computing. Digital media's success at resurrecting nostalgic technologies and its ability to provide continuity with current

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[87] "Nostalgia | Definition of Nostalgia in English by Oxford Dictionaries." Oxford Dictionaries | English. Accessed May 2, 2018. https://en.oxforddictionaries.com/definition/nostalgia.
[88] Sigmund Freud and Hugh Haughton, *The Uncanny*, trans. David McLintock (New York: Penguin Classics, 2003).

technology is, paradoxically, what enables its most radical and uncanny attributes: the more perfect a simulation becomes, the uncannier it appears.

Simulation is a common trope in literature dealing with the uncanny, especially in genres such as horror or weird fiction. In *Stone Animals* (2005),[89] Kelly Link describes a family that moves into a house where everyday objects slowly become "haunted" by a change in essence, without the difference becoming apprehensible to the senses. A bar of soap or a laundry basket suddenly feel "wrong" to the inhabitants. Link's short story—without explicitly referencing simulation—encapsulates its uncanniness. In *Stone Animals*, the uncanniness of the haunting makes the home "un-home-like." Again, this relates to the term's semantic origin. As Freud notes:

> Many people experience the feeling in the highest degree in relation to death and dead bodies, to the return of the dead, and to spirits and ghosts. As we have seen some languages in use today can only render the German expression 'an unheimlich house' by 'a haunted house'.[90]

As evidenced by the above quote, Freud associates the uncanny with death and a sense of horror. However, the ontological threat created by perfect simulation is not the existential threat of traditional horror. For Freud, the horror of the corpse is not

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[89] Link, Kelly. "Stone Animals" in *Magic for Beginners*. (Northhampton, MA: Small Beer Press, 2005) 67-114.
[90] Sigmund Freud and Hugh Haughton, *The Uncanny*, trans. David McLintock (New York: Penguin Classics, 2003).

that it reminds us of our own death but that it threatens the ontological status of the human. It reduces human "essence" into a soulless, mechanistic force.

Simulation occurs at the junction of the familiar and unfamiliar; it is the generation of something familiar and known by unfamiliar means.[91] Mediation has historically been a site of the uncanny, and theorists such as Jacques Derrida have used the uncanny as a means of understanding the affect of media. In a broader sense, the uncanny is connected to the recording, storage, and reproduction of media technologies because the uncanny is associated with the elimination of time.[92] Reading Freud, along with Nicholas Royle's analysis of Freud's essay, I was struck by how much the uncanny seemed to represent the affective experiences of encountering media technologies. The literature of the uncanny roughly follows the introduction of various media technologies. *Der Sandmann* (1816) appeared as the experiments leading to photography were being developed and, perhaps more importantly, as optical telegraphy emerged as the first modern communications protocol in Europe. Hoffman was interested in the emerging technology of the magic lantern, having staged a "private phantasmagoria" with a hidden device at the home of a relative.[93] The experiences of disembodiment, detached voices, dismemberment, extended consciousness, the persistence of the voice and image of the dead, projection in space or time, and other spectral phenomena are not unique to the

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[91] Royle, Nicholas. *The Uncanny*. Illustrated edition. Manchester: Manchester University Press, 2003, 1-9.
[92] Ibid.
[93] Andriopoulos, Stefan. *Ghostly Apparitions: German Idealism, the Gothic Novel, and Optical Media*. New York: Zone Books, 2013.

affective experience of modern media technologies, but the emergence of these experiences as part of quotidian, daily life, is. It is this aspect—the combination of the familiar and the strange—that defines the experience of the uncanny. Royle's introduction to the uncanny could easily have been written about simulation or mediation:

> It is a crisis of the natural, touching upon everything that one might have thought was 'part of nature': one's own nature, human nature, the nature and reality of the world. But the uncanny is not simply an experience of strangeness of alienation. More specifically, it is a peculiar commingling of the familiar and unfamiliar. It can take the form of something familiar unexpectedly arising in a strange and unfamiliar context, or of something strange and unfamiliar arising in a familiar context.[94]

The connection between mediation and the uncanny is especially evident in the divergences from the transmitted "message".[95] As Grafton Tanner notes:

> To witness a "haunted" electronic medium is to confront the uncanny with all its gaps. When we listen to a warped vinyl record or examine the visual traces on the blank screen of a finicky television, we are immediately struck by the characteristics of their ghostliness because their malfunction, actual or perceived, indicates a rift between them and their carried messages. The horror then arises from electronic media's propensity to glitch and malfunction, throwing us (the users) into a sudden state of disarray. The analog electronic media of prior decades were particularly prone to presenting ghosts. Unlike the sleek, liquid form of digital media, early radio and television for instance channeled information through a low-definition interface, while static and poor resolution interrupted the flow of sound and image. When the radio signal gives out and another channel comes through cloaked in fuzz and static, it is as if the radio has acted entirely on its own and, most unsettlingly, is more prone to malfunction than maybe we think.[96]

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[94] Royle, Nicholas. *The Uncanny*. Illustrated edition. Manchester: Manchester University Press, 2003, 1.

[95] As I have shown, this framing is not universal, but does color how many of us experience mediation.

[96] Grafton Tanner, *Babbling Corpse: Vaporwave And The Commodification Of Ghosts* (Winchester, UK ; Washington, USA: Zero Books, 2016).

The Victorian aesthetics of ruination and decay expressed in the epistolary horror novel have been extensively theorized, as has the relationship between early media technologies and spectral, ghostly phenomena. Simulated mediation, despite its close relationship to mediation, and its relevance to the aesthetics of the science fiction, fantasy, and horror genres, maintains an ambiguous relationship with the uncanny. While simulations of human beings are often uncanny, simulations of media technology may render these "ghosts" of mediation as familiar and nostalgic by providing order and the ability to render these "glitches" within a preexisting aesthetic framework. The promise of a VHS generation loss effect pedal is that it makes "unwanted" artifacts such as random modulation of pitch, the introduction of noise, aliasing, and bandpass filtering controllable by the user, "without the need for a broken VHS player."[97]

The uncanniness of simulation is not felt most strongly in its perceptual divergence from reality but in its imperceptible differences. Tom Majeski of Cooper fx shared my ambivalence about the status of glitches and artifacts, "The uncanniness is the technology that's letting you do the things that DVD or VHS did, right? I wonder what was more shocking to see; the weird parts or the new format in general?"[98] It is now understood that the effects of mediation are not necessarily registered by listeners until years of experience with the aesthetics of a format.[99] The

[97] Cooper fx. "Generation Loss V2." Accessed October 26, 2021. https://www.cooperfx.com/product-page/generation-loss-v2.
[98] Tom Majeski, *Cooper fx Interview*, August 2, 2021.
[99] Thomas Lund and Aki Mäkivirta, "On Human Perceptual Bandwidth and Slow Listening" (Audio Engineering Society Conference: 2018 AES International Conference on Spatial Reproduction -

sense of the uncanny seems to indicate a gap between the information received and our capacity to consciously understand that information. This is because formats have historically been designed around subjective testing methodologies with limited timescales:

> Using traditional subjective testing, it has proven difficult to argue clearly in favor of higher data-rates than 48 kHz/24 bit linear PCM per channel [93]. The same kind of tests, however, have also been used to promote lossy data reduction, where most audio information is discarded, though many interested in sound today notice warbling "space monkey" artefacts and collapsed imaging across platforms, be it broadcast, YouTube, music streaming or phone. That kinds of artefacts might be felt more gravely now as more listeners have become "experts", than when the codecs were originally tested.[100]

This is also perhaps why we feel that new forms of media are more immediate; we are not yet fully acclimated to the aesthetics of mediation until long after they are "new". Research into listening practices on longer timescales poses a significant challenge to the argument that the simulation of media is inherently nostalgic—as there is necessarily a large time delta between the introduction of a new media technology and a listener's ability to perceive what is unique about it.

When I spoke to Chris Carter about his work with the industrial music groups Throbbing Gristle and Chris & Cosey, he suggested that the simulation of analog and digital effects processors had less to do with nostalgia and the uncanny than it does with maintaining continuity with the quality of the original designs:

> Partially I would put it down to the cyclic nature of music production trends. The popularity of both 'analogue sounding' and 'vintage digital'

Aesthetics and Science, Audio Engineering Society, 2018), https://www.aes.org/e-lib/browse.cfm?elib=19621.
[100] Ibid

> seems to be waning and recurring more often, and as silicon and software gets more powerful, then emulation becomes more convincing and authentic sounding. I could be wrong but I think there's a possibility that newer generations of musicians and producers are using vintage digital software emulations simply because they sound good, maybe not so much for nostalgia. Unlike some older musicians and producers who are possibly using the same software with a nostalgic attachment to the original hardware - and also because it sounds authentic. And that's certainly the case with myself and Cosey. We still have some of that older digital hardware but because we didn't want to take it on the road to perform live shows with, we opted for software solutions. The audience cannot tell the difference.[101]

This is an interesting suggestion because it turns the conversation back to aesthetics and associations. If a musician is attracted to an aesthetic embodied in a particular instrument or is drawn to the sound of a particular genre, a simulation of digital or analog media may be the only viable way of achieving that. Rather than evoking a sense of the "poverty of the present" or as a sensory cue to evoke a previous experience, an older piece of technology might simply provide particular sonic characteristics that are difficult to achieve otherwise. This approach is less centered on the poetics of mediation than a personal aesthetic articulated by media. While engineers such as Devin Kerr and Tom Majeski were clear that nostalgia was an important aspect of some of their designs, their taste and aesthetics would often override fidelity to the past. The complexity of this relationship is ultimately what makes the study of simulations such a rich entry point into understanding a culture's relationship to its past.

[101] Chris Carter. *Chris Carter Interview*, September 1, 2021.

Generation Lossy: Simulated Media/Simulated Formats

In audio effects, simulated mediation is the rule rather than the exception. As Thomas Wilmering, David Moffat, Alessia Milo, and Mark Sandler note, “While the emulation of established analogue devices in the digital domain remains an active field of research, the majority of digital audio effects rely on signal processing principles and existing audio effects developed in the analogue domain.”[102] The majority of audio effects are based on devices that were explicitly designed for use in a recording studio. However, other effects simulate communications technologies, especially analog technologies such as cassette tapes, vinyl records, VHS, or analog radio that have been largely superseded by digital forms of transmission and distribution.

Figure 3.3 Left to Right: Cooper fx Generation Loss Version 1, Chase Bliss Generation Loss, Cooper fx Generation Loss Version 2

[102] Thomas Wilmering et al., “A History of Audio Effects,” Applied Sciences 10 (January 22, 2020): 791, https://doi.org/10.3390/app10030791.

The Cooper fx Generation Loss is a guitar pedal that simulates the sound of media that has been copied across multiple generations of VHS tape. Cooper fx typically manufacturers their pedals in small batches and has struggled to keep up with the demand for their devices. "Generation Loss refers to the decrease in sound quality and introduction of noise and sound artifacts each time a copy is made on magnetic media such as tape."[103] The pedal has been produced in three[104] distinct iterations: the original unit, a version designed in collaboration with Chase Bliss Audio, and a second revision in the original form factor. An electrically erasable programmable read-only memory (EEPROM) based on Generation Loss is also available for Arcades, a cartridge-based pedal that allows the user to swap effects algorithms by inserting and removing cartridges. According to Majeski, the version 2 Generation Loss pedal is the most accurate representation[105] of the wow and flutter associated with audio submitted to a recursive process of copying on analog tape:

> The first one was seven years ago at this point and I had very little knowledge of electronics, and coding, and stuff. So I kind of whipped it together, but I knew enough to do what I did there. It certainly wasn't very authentic, whereas I feel like with the new one, it is a lot more so. And some people are mad about that, because they liked the old one better. I don't know. Personally, I just wanted to get that sound as right as I could.[106]

All versions of the device use a Spin Semiconductor FV-1 integrated digital signal processing (DSP) circuit. Released in 2006, the device is common in guitar

[103] "Generation Loss V2," Cooper fx, accessed October 26, 2021, https://www.cooperfx.com/product-page/generation-loss-v2.
[104] When I spoke to Joel Korte of Chase Bliss Audio, he mentioned that he and Majeski are working on a fourth iteration of the pedal.
[105] Tom Majeski, *Cooper fx Interview*, August 2, 2021.
[106] Ibid.

pedals,[107] as it provides a relatively simple integrated DSP platform containing two integrated audio-rate ADCs and DACs, as well as three control inputs for use with potentiometers. Programs for the FV-1 are either written in an assembly language called SpinASM or a higher-level programming environment called SpinCAD.[108] Spin Semiconductor describes the FV-1 as a "complete reverb solution in a single IC."[109] While the device was designed to create artificial reverbs, it is also possible to use the device for delay, pitch-shifting, and filtering applications. The latter two are the basis for Generation Loss. The FV-1 was also used in the Chase Bliss Dark World reverb pedal, which includes an algorithm created by Majeski and based on the Generation Loss. In fact, according to Joel Korte, the Chase Bliss version of the pedal was inspired by a hack of Dark World from pedal designer Ryan Worthley, which substituted the FV-1 firmware from that module with that of the Generation Loss.[110] When I spoke to Korte, he mentioned that Worthley "posted a picture of it and people really liked it. With me and Tom [Majeski], we're really down to work with each other, but it seems like we need something to make it happen, so we started texting because of that."[111]

Each model uses a random modulation source to alter the pitch of an incoming signal, which is then sent through adjustable low-pass and high-pass filters. The Gen

[107] "The Revolutionary Chip Inside Your Favorite New Delay and Reverb Pedals," reverb.com, November 8, 2019, https://reverb.com/news/fv-1-chip-history-5-pedals.
[108] Ibid.
[109] "Spin Semiconductor - Products." Accessed October 29, 2021. http://www.spinsemi.com/products.html.
[110] Chase Bliss Audio. "Generation Loss." Accessed October 29, 2021. https://www.chaseblissaudio.com/generation-loss.
[111] Joe Korte. *Chase Bliss Interview*. December 12, 2021.

parameter reduces the sample rate of the signal. In Generation Loss and Generation Loss V2, the noise parameter, which determines the level of noise added to the sound, is assigned to its own continuously variable knob, while in the Chase Bliss version, it is relegated to a three-way switch that selects between none, mild and heavy.

While there are ostensibly three versions of the pedal, there is also an iterative change after the first 50 units that allows the user to switch between two implementations of the noise circuit. In the first version, the noise is applied post-filter, which means that any filtering of the high or low frequencies in the input signal will not be applied to the noise added to the circuit. This modification is applied by removing an integrated circuit from a socket and replacing it with another. This change was implemented in the production units starting in May 2018, three years after the original pedal was released. While this alteration is relatively simple, it can produce complicated changes to the resultant sound as the noise will also interact with other pedals or processors the performer uses. This also brings the simulation model closer to the manner in which the interacting media of VHS and VCRs function, as much of the noise in the resultant signal arises from the stored media, which is then filtered by the audio circuits within the playback medium.

Despite ending production as recently as 2016,[112] VHS has been superseded by nearly every other form of available media in both audio and visual quality during its nearly fifty years in production. Unlike vinyl records, it is not defended as a

[112] Mark Walton, "Last Known VCR Maker Stops Production, 40 Years after VHS Format Launch," Ars Technica, July 21, 2016, https://arstechnica.com/gadgets/2016/07/vcr-vhs-production-ends/.

superior quality format to its digital successors, even by enthusiasts. Despite this, it remains both a popular format for collection and simulation. There are dozens of VHS filters on the Apple App Store, and applications such as Rarevision VHS – Retro 80s Cam list celebrity users and feature thousands of reviews.[113] While VHS tapes and VCRs remain accessible, it is unclear whether the interest in VHS simulations stems from a nostalgic familiarity with the format or exposure to the format through simulations appearances in other media such as film. When I asked Majeski about this, he suggested that there might be important aesthetic qualities of VHS outside of cultural context or nostalgia, stating:

> There's definitely been a resurgence, like we were just talking about. So, it has even become familiar to people who don't know what a VCR is. Maybe that's part of what it is. We were never part of the tube amp era, but we still recognize that that's an awesome sound. Maybe there's something that, even more than the experience, there's just something that clicks in our brain when we hear it.[114]

Scott Harper, who created a promotional video for the Chase Bliss Generation Loss, suggested that the aesthetic of VHS might be responsible for the current interest in VHS nostalgia, rather than the inverse:

> It's almost like it succeeds in spite of that. Many of us don't think back to our childhoods too fondly, but there are these cool characteristics that come with VHS audio, for example. It still makes us long for a time that, maybe we didn't even love.[115]

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[113] App Store. "Rarevision VHS - Retro 80s Cam." Accessed October 29, 2021. https://apps.apple.com/us/app/rarevision-vhs-retro-80s-cam/id679454835.
[114] Tom Majeski, *Cooper fx Interview*, August 2, 2021.
[115] Scott Harper. *Knobs Interview*, January 5, 2022.

Even if a musician is intimately familiar with a particular media technology, the divergence of a simulation from the medium it is simulating may be so extreme that it leads to new sonic possibilities. The "Vinyl Sim" effect on Boss' SP-303 sampler is one example of this.[116] Hip hop producers such as J Dilla, Madlib, and Flying Lotus used Vinyl Sim as a stereo bus compressor for samples taken from vinyl records. Rather than using Vinyl Sim to emulate the sound of vinyl, these producers discovered a unique form of compression that shaped the sound of their music. The creator of Vinyl Sim could not have known how this effect would be used: at the very least, the design, features, and naming indicate otherwise. At the same time, the sound of these records would have been different if Vinyl Sim had not existed. The innovative and novel effect would not have been possible without a "failure" to accurately simulate the experience of listening to vinyl. Vulf Compressor from Goodhertz is particularly unique in that it is a simulation of Vinyl Sim—itself a simulation of another media technology. Devin Kerr, who designed Vulf Compressor, celebrates the perceived divergence from the aesthetics of vinyl:

> I assume the [SP] 303 Vinyl Sim was supposed to sound like vinyl… I assume… It's called the Vinyl Sim. It sounds nothing like vinyl! Not even in the same ball-park. I mean, it has dust and… noise: sounds that most people just turn off. That designer, I assume accidentally, designed an incredible compressor! How did they do that? I'm sure it's very elegant too, I'm sure it's ten lines of code or something, and we're spending thousands of lines to sort of model parts of it. I would love to know the story behind that.[117]

[116] "Vinyl Sim." Accessed September 17, 2021. https://goodhertz.co/tonal/vinyl-sim/.
[117] Devin Kerr. *Devin Kerr Interview*, 2021.

Like the early digital reverberators that have been subject to myriad simulations, it is possible to better understand the salient features of the effect—compared to its analog counterparts—by examining both its use and the features that were carried over to subsequent simulations. None of the iterations of Vinyl Sim claim to simulate every characteristic aspect of vinyl records. Some characteristic traits of vinyl records, such as monophonic bass and high-frequency attenuation that increases as the needle reaches the center of the record, are not included. Instead, Vinyl Sim allows the user control of three parameters: Compressor, Noise Level, and Wow Flutter[118] (sic). While each of these is represented in Vulf Compressor, the additional controls provide insight into which features are considered relevant to the user. Noise is given the least attention in the interface; aside from a small button on the panel that turns noise on or off, a slider on the far right is the only other direct control of the noise parameter. Wow and Flutter[119] features its own mix slider, a depth control for pitch modulation, a slider to determine phase divergence for the pitch modulation oscillators used to alter the left and right portions of the stereo signal, and a drop-down menu with three options for LFO speed.[120] By far the most full-featured part of Vulf Compressor is, as indicated by the name, the compressor. Aside from controls affecting the input and output volume, there is a compression percentage, separate controls for attack and release times, a switch to apply equal compression to each

[118] Boss Corporation. *Boss SP-303 Dr. Sample Owner's Manual*. 2001. http://lib.roland.co.jp/manual/en/dl_06-10290/SP-303_e4.pdf

[119] In this particular case a simulation of the faster and slower pitch modulations that occur when a vinyl record is placed off-center or when the record itself is physically warped

[120] 33.3, 45, and 78 rotations per minute, respectively.

stereo channel, a slider to determine the amount that the compressor's behavior is determined by an audio source other than the input, a switch to listen only to the external side chain, a slider for adjusting the frequency emphasis of the side chain, and a slider for controlling the digital reference level. In addition to these features, Vulf Compressor includes controls for various "LOFI" parameters, which introduce harmonic distortion and aliasing.

Ironically, within my mixes, I have come to rely upon Vulf Compressor's simulation of the pitch modulation of vinyl records to introduce chorusing or stereo widening effects rather than the using compressor itself. This method of introducing greater or lesser pitch shifting at rates associated with the speed of vinyl records and then shifting the phase of this effect by 180 degrees in the right channel as compared to the left is not a technique that I would have thought to use without this expanded vinyl simulation.

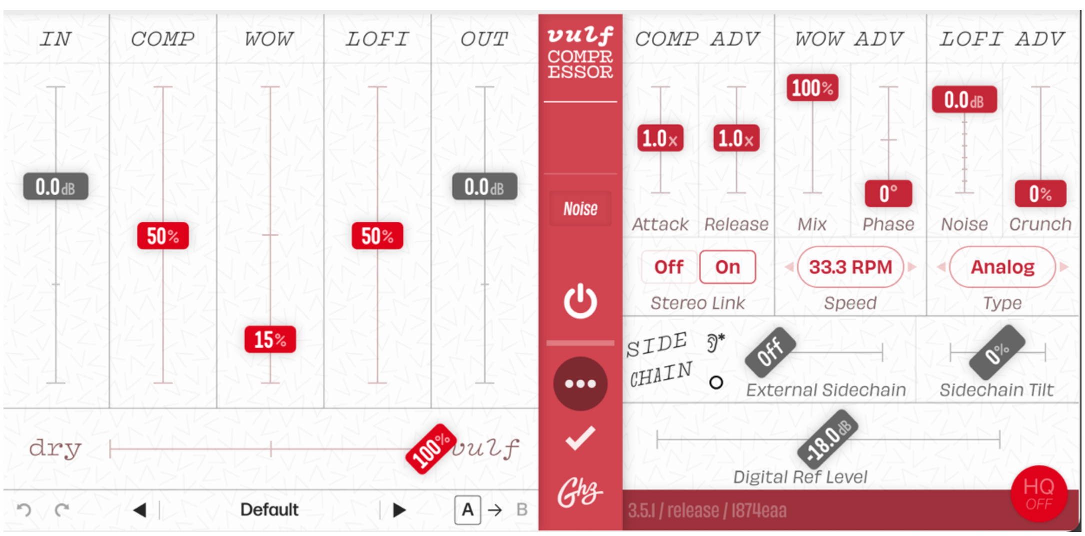

Figure 3.4 Visual interface for Goodhertz Vulf Compressor

While Vinyl Sim continues to be available as an effect on Roland[121] products,[122] later versions of this effect are considered inferior by some users, and online discussions regarding the various perceived differences abound. It is unclear whether or not these changes were intended to better emulate the sound of vinyl records, but it is worth noting that it is the sound of this particular simulation that has become iconic, not the concept of vinyl simulation itself. Devin Kerr experienced the aesthetic value of mistakes and divergences in simulation while iterating versions of Vulf Compressor:

> I mean certainly there are lots of stages after you do your best to capture something or model it. With that algorithm, there's lots of things you can tweak about it. You don't have to follow reality exactly. So, there's another creative opportunity where it's like "well actually we're going to deviate here because we think it's cool." This happened a lot with Vulf Compressor, which also started from a hardware model and then did that deviation thing. I remember a moment in that one, calling Jack from Vulfpeck and asking him, and I was very torn between the reality part and this incredible sound I had found while I—I think I had made mistakes when modeling it or something. Something was wrong with the release [of the compressor] or I just hadn't gotten around to the release behavior yet. And I called, Jack, and I ask him. I said "this is a really horrible decision to make" and I sent him some samples. He said "Oh man, this sounds so cool."
>
> There's the preset, called vacuum-pumped, that's only in Vulf Compressor. You can't even come close to something like that with the hardware. And it's exactly that: there's something in the release behavior that's not like it would have been. If you were the full "lab coat" and "we must model this" and you're not open to these mistakes, or deviations, or the creative stuff that happens, that sound wouldn't exist. I think it's one of the coolest parts of Vulf Compressor.

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[121] Boss is a subsidiary of the Roland Corporation. Ikutaro Kakehashi founded both companies. The Roland SP-404 product line is considered the successor to the Boss SP-303.

[122] Roland Corporation. "Roland - SP-404SX | Linear Wave Sampler." Roland. Accessed September 30, 2021. https://www.roland.com/us/products/sp-404sx/.

> It's hard because you're trying to be precise and exact in some cases, but you're also trying to be open to chance, and mistakes and errors.[123]

Since true randomness cannot be produced within software, it is often these moments of human "error" that allow for novel processes to emerge. As modern DSP allows for processing at bit depth and samples rates far in excess of the limitations of human perception, professional audio production technology is less influenced by the material constraints of underlying computing technology and must simulate mediating effects. This led Kerr to speculate that, "maybe there will be nothing to come back to, nostalgia-wise"[124] for current audio production technology.

In another vinyl simulation from Modbap Modular, called Wax 2, pitch modulation takes precedence over compression. This stems from Modbap Modular founder Corry Banks' experiences observing the material properties of a record change due to the heat of an intense summer day. He related the experience that led to this design in an interview I conducted with him:

> With Wax 2 I was thinking about the warble but more intense. I can remember very specifically back in the day, growing up in Chicago, we'd have block parties. DJs would set up on a porch, or maybe or a sidewalk or on the street. The whole street would be blocked off. As I think back, I'm like "those DJs were always set up under trees. Big ass shady trees." I didn't really think about it, but if I see it in my mind, those dudes were always in shady areas.
>
> There was one particular time where this DJ was on a porch and it was a really bright porch. It was weird, he wasn't on the front of the house where the block club party was going on, but his speakers were. I remember looking up, and it was very hot, it was very sunny on that

[123] Devin Kerr. *Devin Kerr Interview*, 2021.
[124] Ibid.

> porch, and the music got weird. Not that he played weird music, but the actual music that he was playing started to sound weird. He started complaining, "My fuckin' records are warping!"
>
> He was in the sun! He was in direct sunlight. It was so damn hot that the records were warping. This was back in the 80s when all the families knew each other. All the families didn't act like family, but all the families knew each other. We were in his back yard, to meet with his younger brothers. It was a point where I always liked to watch the DJ. He started complaining about his records warping and I was like "Oh… is that why it sounds like that? Is that why it started sounding weird?" I thought he was doing some new technique! It was the 80s, lots of things were new.[125]

According to Banks, all of the available vinyl simulations were distinct enough to warrant him purchasing and using three different versions:

> The reality is, obviously I have several Per4mers sitting right here, I have the Vulf Compressor on my computer and I have the Warped Vinyl HiFi. That's probably not unusual for anybody that has a certain aesthetic in mind, to have some combination of those devices and even other devices too. You definitely hear the difference. There's a clear difference.[126]

For many of the DSP programmers I spoke to, the ability to deliver clear audio without uncontrollable artifacts was almost considered a detriment to creativity. Kerr describes this tabula rosa state from which modern DSP emerges as "lifeless" and views the process of emulating the limitations of older formats as a means of adding "life" back into the sounds. Kerr specifically noted how the research process for a simulation of the Alesis Midiverb II led to new and inspiring sounds:

> The MegaVerb is our 80s inspired reverb. Every time you work on one of these you feel like Sherlock Holmes: kind of going through

[125] Corry Banks. *Corry Banks Interview*. 2022.
[126] Ibid.

> whatever information is available at the time. And the designer of that original reverb is no longer alive, but he had written a bunch about how it works and done some interviews about some of the insane technical limitations they were up against. These really cheap adders. How ram was so limited, so they're packing all these delay lines in 10-bit registers.
>
> Versus recreating some of that in a modern digital reverb, where everything we do is 64-bit. Reducing it to 10-bit in places with weird, cheap dithers sounds incredible. It just has life. Kind of like what you were saying earlier: now with extremely high-quality digital it is fully transparent. It clearly is more transparent than our hearing can accept, basically. So, you're starting from nothing, which has very little life, I guess, and you can choose now to add it back in. It's totally different than, say, pre-2000, where, no matter you do, you're getting stuff.[127]

Reverb is unique among the standard effects available in DSP in that it is always a simulation. While many delays, filters, and EQs are simulations of analog hardware, with reverb, even in analog electromechanical hardware such as spring or plate reverbs, the intention is to simulate the resonant characteristics of acoustic space. The crafting of unique resonant spaces—from the bodies of acoustic instruments to the architecture of concert halls—has historically been an important aspect of musical articulation. It is perhaps for this reason that artificial reverberators are often prized for their divergences from "realistic" reverberant spaces.[128] Another reason that "dirtier" less physically accurate reverbs may be of interest is that physically modeling reverberations in real-world spaces remains out of reach for most personal computers as of the time of this writing. Much like dither noise is used to mask bit

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[127] Ibid.

[128] Jonathan Sterne, "Space within Space: Artificial Reverb and the Detachable Echo," Grey Room 60 (July 2015): 110–31, https://doi.org/10.1162/GREY_a_00177.

depth limitations, artificial reverbs use randomization to simulate the complexity of real-world spaces. As Jonathan Sterne notes:

> At one level, the turn to randomization is akin to surrendering in the face of overdetermination: so many things are happening in so many different ways that they cannot be calculated or captured by any modern computing device. But here, the human dimension is crucial: artificial reverb uses time delays and filters to simulate sounds' movements through space, but their ultimate goal is to produce a particular kind of perceptual effect, not to map a space.
>
> Reverberation orients a subject, gives the feel of a space without tracing it directly. Through different kinds of statistical behaviors and degrees of randomness, digital reverbs simulate the reverberation of a variety of physical spaces and devices, but they do so by mimicking effects, sharing an aesthetic heritage with their mechanical predecessors, even if their operational protocols are entirely different.[129]

Like other forms of simulation, artificial reverbs exploit the limits of human perception to create the aesthetic result of more complex behavior with a simpler underlying process. Sean Costello—who has developed plugins that simulate the characteristics of early digital reverberators such as the Lexicon 224—helpfully points to the fact that:

> None of this is real. None of it is modeling a real room. That's still several orders of magnitude beyond what this [points to laptop] can do. Modeling every reflection in a room in real-time would just be prohibitive. No one is doing that in real-time.[130]

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[129] Ibid.

[130] Seattle Music Machine Salon, Sean Costello (Valhalla DSP) on Reverb Design, March 2019, 2019, https://www.youtube.com/watch?v=aJLhqfHrwsw.

While it is possible to capture the sound of a real-world space using convolution, that snapshot remains essentially static and fixed to a single point of origin, even if the reverberation is captured at multiple locations. Simulating the characteristics of early digital reverbs is much more processor-intensive than an equivalent algorithm rendered in the available resolution on modern computers. Costello, when asked why it was so difficult to simulate hardware reverbs with considerably smaller computing power, responded by stating that:

> One thing is that, the amount of CPU is not necessarily proportional to the quality of the algorithm. I'd say, in the Valhalla Vintage Verb, in a given algorithm, about half of the CPU is being applied to the cruft. You have to do work to make it sound like a 16-bit algorithm with a 12-bit converter. You have to emulate that stuff. I guess I could program in 16-bit fixed point, but… I'm not going to do that. I'm not going to be programming in 'MMX' or whatever that is. So, there's a lot of work trying to emulate these artifacts. [131]

Jonathan Sterne has suggested that "[i]f there is such a thing as media theory, there should also be a format theory."[132] Much like my earlier objections to remediation, Sterne objects to the collapsing of what he regards as disparate categories. Formats dictate the operation of a medium and define certain aesthetic properties of that medium. Examples of formats include the various sizes and speeds of vinyl records or MP3. While the 45-rpm record format does not change the medium itself—the record player remains the same—important aspects of the received aesthetics are determined by the format. Like the poetics of mediation, the aesthetics of formats are largely dictated by their imperfections and limitations. The

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131 Ibid.

132 Jonathan Sterne, *MP3: The Meaning of a Format* (Durham: Duke University Press Books, 2012).

aforementioned 45-rpm record is defined by the relatively small amount of audio that can be stored on it, as well as the speed at which imperfections such as pitch modulation from physically distorted or “warped” vinyl or “clicks and pops” from dust and scratches occur. For this reason, some simulations of media, such as Vulf Compressor, offer simulations of the differing formats as well. While less common than simulated media, plugins that simulate formats without simulating the enclosing medium, are available. These are unique instances of simulation that occur within the same “medium” as the format that is being simulated.

While there is a tendency within audio cultures to characterize digital audio as “clean” or “clinical” in contrast to analog audio, a more important distinction, from the perspective of music and sound design, is that of “lossy” or “lossless” formats. Lossy formats accumulate artifacts when subjected to repeated mediation, while lossless formats do not. Historically, repeated mediation within lossy formats has been an important aspect of the aesthetics of experimental works such as Alvin Lucier’s *I Am Sitting in a Room* (1969)[133] where the performer’s voice is recursively subjected to reverberation. The work is structured by the effects of mediation, as an extremely reverberant room will quickly replace the performer’s voice with the room’s resonant frequencies, and the work will subsequently end sooner than a performance in a room where the mediating effects of reverberation are less strong. While all analog media are lossy, digital information is capable of lossless transmission and compression. However, popular formats such as MP3 are lossy, and

[133] Alvin Lucier. *I Am Sitting in a Room* (Lovely Music, 1993).

the recursive application of the MP3 compression algorithm inspired the development of a Goodhertz plugin called Lossy:

> In June of 2014, producer & friend-of-Goodhertz, Tyler Duncan, wanted a certain drum fill to sound like the year 2001 — that is, like a low bitrate digital mp3 ripped from KaZaA.
>
> We understood him immediately. Since the dawn of the second recording format, mankind has longed for the aesthetic imperfections of the previous recording format.
>
> "Would a bitcrusher do?" No, Tyler didn't have 8-bit in mind. He wanted lossy digital audio: streaming music on a 56k modem, an mp3 ripped from a CD-R, light jazz music streamed over a cellphone, a YouTube video uploaded in 2007. What if a plugin could degrade digital audio and simulate those quintessential compressed sounds in realtime?
>
> So we built Lossy: artifacts of heavily compressed audio in a highly tweakable realtime plugin.
>
> Goodhertz asks: are you ready to nostalgize the beautiful harmonics of heavily compressed digital audio? Are you ready to enter the underwater cathedral?[134]

Although the origin story that Goodhertz present appears to indicate that the plugin was developed to create the sound of a particular drum fill, Devin Kerr corrected this when I spoke to him "I think he actually ended up just manually converting it back and forth from MP3 for his record, because I'm pretty sure that needed to come out way before we could build a plugin to do it."[135] Since it was possible to create this sound by specifying certain aspects of the compression algorithm—such as bit rate—and recursively applying this process, the value of Lossy lies elsewhere. As with

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[134] "Lossy, by Goodhertz." Accessed October 29, 2021. https://goodhertz.co/lossy/.
[135] Devin Kerr. *Devin Kerr Interview*, 2021.

sample rate reduction and bit crushing, Lossy parameterizes and provides real-time control over what was previously a fixed artifact. Previously, if one wanted to hear the effects of MP3 compression, it was necessary to take an existing audio file and perform the conversion offline using software before auditioning the sound. Software such as Apple's Music allow for the adjustment of bit rate—a parameter that determines the amount of compression applied to the file and the size of the file relative to the length of the track—sample rate, and high-pass filtering, but these parameters do not exhibit a linear relationship to the sonic results. While, on modern computers, this conversion can be completed in a matter of seconds, this must occur upon every parameter change. In addition, it brings this processing into the environment of a digital audio workstation, where the user may make adjustments to the compression while the affected and unaffected tracks within a mix are audible. The real-time monitoring made possible by Lossy allows users to sculpt the way that these compression artifacts affect their sound with a level of precision that is impossible with non-real-time MP3 encoders. Additionally, the ability to modulate parameters in real-time makes performing changes to the algorithm a possibility. It is also possible to use Lossy within a feedback network—something that is impossible with offline conversion. Lossy expands upon the poetics of the MP3 format—bringing it closer to a medium.

According to Kerr, MP3 had been an important consideration when he was working professionally as a recording engineer:

> I used to work as an engineer, so I used to think a lot about MP3 as a delivery format. And it's just kind of fascinating, and it's fascinating

> that we're still using it, even now, for Spotify or something like that. It's strange. I remember visiting Bob Clearmountain's studio one time, and he had this sign in the middle of the mix desk, "all of your blood sweat and tears will be compressed down to a shitty MP3" It's like a little mantra there.[136]

Lossy features five different effects that originate within MP3 and other lossy audio formats. "Standard" uses a perceptual model of hearing to remove information from an audio recording. This mode is intended to reproduce the artifacts of the MP3 format, especially when it is pushed to an extreme. Kerr said that he consulted the published literature to develop a basic model and asked himself, "well, what if I was making MP3 from scratch?" He developed a prototype of the plugin from this premise, which, according to him, "sounded exactly like MP3."[137] "Inverse" consists of the information removed in the "Standard" algorithm. This is, according to the perceptual model, the information humans are least likely to hear. "Phase Jitter" simulates "imperfect clocking" by producing phase distortion. The latter two modes, "Packet Loss" and "Packet Repeat," simulate the various ways in which lossy formats handle the loss of information. Packet Loss reduces the amplitude of short, arbitrary sections of incoming audio. Packet Repeat fills these gaps with repetitions of the previous sound. According to Kerr, these modes were inspired by examining the "realistic" MP3 he had developed and asking, "what if we make it unreasonable in a bunch of different ways and break it in a bunch of different ways?" The "speed" and "amount" knobs change their function depending on the algorithm and are scaled

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[136] Ibid.
[137] Ibid.

differently to each. For example, in Packet Loss, when the "amount" parameter is set to 100%, the audio is silenced, but in Standard, the sound remains fully audible, albeit with significant artifacts.

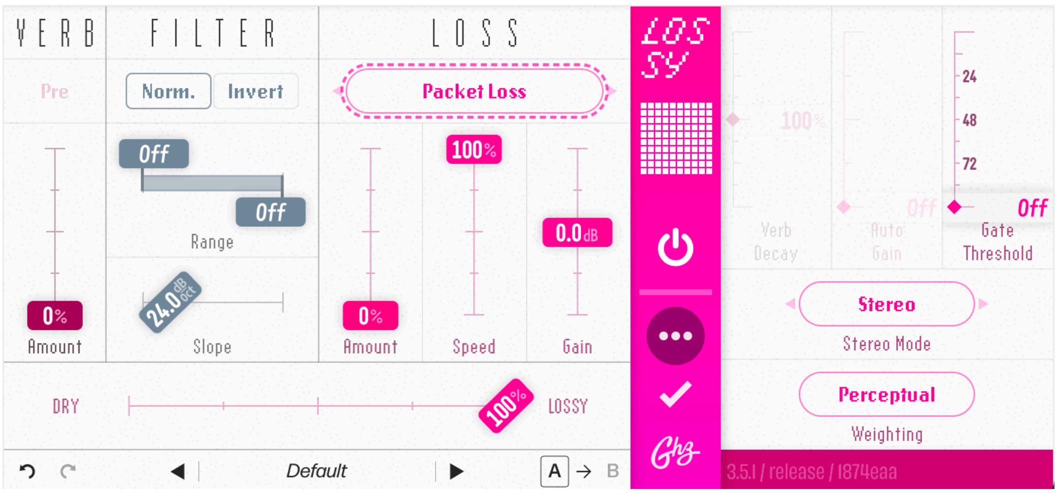

Figure 3.5 Visual interface for Goodhertz Lossy

In addition to the lossy format algorithms, the plugin also contains a reverb and a filter. These were added in response to empirical experimentation with the prototype. Kerr mentioned that he often used reverb in conjunction with Lossy because it "really give it a lot to chew on." The reverb can be applied prior to or after the lossy algorithms.

It should be clear from this description that, like the other forms of simulated mediation discussed previously, simulated formats—at least in the context of commercial audio software—are created in response to the aesthetic and cultural uses or associations with a technology. Rather than a "neutral" rendering of the MP3 format, Lossy is designed to emphasize the limitations and failures of lossy compression technologies.

It is tempting to think of music and music technology in a sort of closed feedback loop, where designers are influenced by the music they listen to, and composers are in turn influenced by the possibilities of new technologies. This was largely borne out in the interviews I conducted: every piece of technology—according to the developers—was either influenced by music, previous media technologies, or both. From this perspective, media theory and media histories have had very little influence on the development of new musical technology. However, when I examined pieces of music referenced in my interviews with instrument designers, I often discovered explicit references to media theory. When I asked Devin Kerr about Stern's *MP3: The Meaning of a Format*, he was interested but had not read the book. However, in a blog post about the design of Lossy, Goodhertz co-founder and art director Rob Stetson mentions that the "Inverse" mode of Lossy was influenced by *The Ghost in the MP3*, a project by Ryan Maguire that makes the sounds that are "lost" through MP3 compression audible. According to Maguire, "In the work presented here, techniques are considered and developed to recover these lost sounds, the ghosts in the MP3, and reformulate these sounds as art."[138] The work is influenced by Stern's writing and cites both *MP3: The Meaning of a Format* and *The MP3 as Cultural Artifact*. This suggests that the path that knowledge takes is more complicated than the above model and emphasizes the important role that

[138] Ryan Maguire. "The Ghost in the MP3," 2014.

experimental music and media art often take in translating research into actionable knowledge.

Conclusion:

It is tempting to critique the aesthetics of nostalgia as the uncritical worship of the past. There is a broad consensus that nostalgia deserves condemnation, rendered in critiques from political and social positions as different as Graften Tanner and South Park. There is a fear of the feedback loop: this is the ouroboros Tanner references by titling his book *The Circle of the Snake*. According to this theory, culture has become a snake that has swallowed its tail, endlessly reproducing and consuming itself. Feedback, however, is not a simple process of replication. As any modular synthesist knows, some of the most complex and unpredictable behavior occurs with feedback. It is feedback that leads to the complexity of mathematical chaos and the stark, simple tones in the final iterations of Alvin Lucier's *I am Sitting in a Room* (1969).

The musical avant-garde, starting with Italian Futurists such as Luigi Russolo, is exceptionally anti-nostalgic. The Futurists not only called for new instruments to replace what they determined to be an outmoded orchestra but the destruction of music in totality. This was echoed by calls from composers such as Pierre Boulez for the destruction of previous musical and artistic forms and traditions. Ironically, it is feedback, specifically feedback using media technologies, that has sustained the musical avant-garde since the beginning of the post-war period.

While it is possible for a feedback system to find equilibrium: endlessly producing exact copies of itself or minor variations—such as the quasi-sinusoidal states of a chaotic oscillator or the sustained tones of microphone feedback—it is also possible for feedback to produce continuous variation and complexity. In the experience of making music with feedback systems and in observing the production of simulations, I have seen both tendencies manifest. If we only examine the similarities between a simulation and its subject or overemphasize the continuity between them, we risk losing sight of what is unique about simulation in this cultural moment. To stake out a moral position in opposition to all practices of simulation by admonishing nostalgia is to reject nearly all digital forms of cultural expression. Moreover, this position, ironically, ignores much of what is new about post-modern culture.

I do not, in 2022, hear Vinyl Sim from the SP-303 as a realistic simulation of the aesthetic qualities of a vinyl record. What I hear is the limitations of DSP technology in 2003 merged with the aesthetic proclivities of a designer. Scholars cannot continue to operate under the illusion that simulating previous technologies must only represent a regurgitation of the past. To do so is to repeat the mistakes of the twentieth-century avant-garde, a position that is ironically quite nostalgic in its broad assertions and sweeping rhetoric. The poetics of simulation offers a framework for understanding these practices for what they are; a creative act inscribing the subjective perception of a designer onto a technological form.

While simulation is a complex human activity with myriad forms, it is possible to isolate basic characteristics associated with various forms of simulation. Perhaps the most common feature of simulation, in the modern sense, is perceptual equivalence. I have shown that this is complicated by the fact that simulations of natural phenomena, such as reverb, are often mediated by another form of simulation. This occurs when a digital reverb is processed by a software dither that simulates analog tape or the input of a reverb features simulations of the analog saturation, filtering, and compression found in early digital reverbs. Given that human perception differs, and the relevance of a given property of a media technology will be more or less relevant to particular uses, simulations provide a means of understanding the reception of a media technology within a particular culture. The same is also true for cultural reception: as we understand the reception of media technologies and their cultural uses, we gain insights into what informs the design decisions made within simulations. Nearly every simulation discussed was influenced by a piece of music: Generation Loss was inspired by Neon Indian and the soundtracks to educational videos,[139] Megaverb "wouldn't exist if *Stranger Things* hadn't existed,"[140] the Chase Bliss CXM1978 draws inspiration from Vangelis' soundtrack to *Blade Runner* (1982).[141] The process of feedback from the development of the Lexicon 224, with all of its constituent electronic components, to Vangelis' soundtrack to Blade Runner, and finally the CXM-1978 from Meris and Chase Bliss, is incredibly complex and

[139] Tom Majeski. *Cooper fx Interview*, August 2, 2021.
[140] Devin Kerr. *Goodhertz Interview*, 2021.
[141] Joel Korte. *Joel Korte Interview*, 2021.

non-linear. The path from design to schematic to hardware to music to design to schematic to hardware does not produce an exact copy but a mapping of subjective impressions onto technical practices.

Rather than being inspired by the technology itself, these designers were drawn to the technologies after discovering their association with a particular piece of music. Even if ones accepts that "the medium is the message," one must, in turn, also accept, as Stuart Hall observes, that each message will be received differently by differing subjects. By tracing the technological, musical, and academic pathways through which knowledge is transferred to a simulation, one gains a greater understanding of simulated technology as a cultural object, as well as a greater insight into the function of simulation as a techno-cultural process.

CHAPTER 4:
VIRTUAL MATERIALITY: SIMULATED MEDIATION IN THE EURORACK SYNTHESIZER FORMAT

There is a tension between nostalgia and novelty in Eurorack-format modules that is related but not limited to that of digital computing. This is especially true of modules that simulate analog media. Eurorack modules are often hybrid objects that process signals digitally but interface with analog signals. The transmission of audio and control information as analog signals in modular synthesizers complicates established means of understanding and classifying analog and digital media. In doing so, this complex ecosystem offers examples of the myriad forms of media poetics. Working from interviews with Eurorack programmers and designers, as well as my experiences as a scholar and practitioner, I detail in the following chapter how the fuzzy boundaries and material implications of modularity enable and constrain our understanding of simulation.

One of the goals of this dissertation is to examine how the process of abstraction in simulations of media can be understood as a creative intervention distinct from the design of the original medium. A module that simulates analog media is never a neutral translation. Salient properties must be abstracted and then modeled. How designers implement these abstractions will alter the aesthetic outcome to varying degrees. To better understand mediation and the diverse cultures of simulation in modular synthesis, I spoke to several programmers and designers of prominent Eurorack modules so that they could detail their practical and theoretical approaches to transferring technical and artistic concepts across devices.

It is not the intention of this chapter to improve or problematize conventions for classifying media. Instead, I will examine how the aesthetic use of simulation influenced the design of Eurorack modules and how these abstractions provide initial conditions that alter aesthetic outcomes. By examining the abstractions used in simulations, it is possible to determine what the designer considered the salient properties of the object they were aiming to simulate. Examining a simulation provides an insight into how media are understood and depicted in popular culture and received within engineering culture.

What is now commonly referred to as Eurorack was established in 1995 by German synthesizer manufacturer Doepfer as the "A-100 Series," a proprietary format of analog, voltage-controlled synthesizer modules. The modules occupy three rack units in height[1] and feature 3.5-millimeter TS jacks for patch interconnections. This makes the format considerably smaller and more portable than the Moog, Synthesizers.com, or MOTM formats[2] and makes the use of Eurorack hardware more feasible as a live performance tool. Whereas the larger format synthesizers are aesthetically, mechanically, and electronically compatible with early predecessors,[3] the Eurorack specifications are broad and unenforced. There is no central consortium

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[1] Approximately 4.4 centimeters
[2] Synthesizers.com, MOTM, and Moog occupy five rack units and use 2.5-millimeter TS cables to create connections.
[3] The current Moog and Serge-format synthesizers are essentially extensions or revivals of the early modular synthesizers under their respective brandings.

or governing body that establishes standards—such as there is with MIDI—and none of the specifications of the A-100 series published by Doepfer can be relied upon to predict the form or function of a particular module. There are two distinct standards for 1U "tile" modules that make certain cases and modules incompatible with each other,[4] to name one example. There have even been instances of modules within the format damaging each other through normal use.[5]

Modular synthesizers are distinguished from fixed-architecture polyphonic or monophonic synthesizers in that each of the components are independent of the others and interface through temporary connectors such as cables or pins. A modular synthesist may compose music prior to "patching" and create the functionality they deem necessary for that music, or they may adopt a variety of ad-hoc configurations. The modules may be organized in such a way that various parameters of the patch—such as the pitch, rhythm, amplitude, and timbre—of various elements evolve over time without human input. This form of patching is commonly referred to as "generative." While modular synthesizers have more flexibility than most fixed-architecture synthesizers, they typically lack patch memory, making it difficult to move between a variety of timbres in a live setting. Some synthesizers, such as the Dave Smith Instruments Pro 2, Novation Peak, Moog One, Waldorf Quantum, and the Arturia Matrixbrute include modulation matrixes that rival the flexibility of

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[4] Intellijel. "1U Technical Specifications." Accessed August 16, 2021. https://intellijel.com/support/1u-technical-specifications/; "1U Tiles – Pulp Logic." Accessed August 16, 2021. http://pulplogic.com/1u_tiles/.
[5] WHIMSICAL RAPS. "RUN: A Word of Warning." Accessed June 29, 2021. https://www.whimsicalraps.com/pages/run-a-word-of-warning.

modular synthesizers, but this feature does not change the audio signal path to the extent possible within a modular synthesizer.[6] The Eurorack format is more flexible than fixed architecture synthesizers but lacks globalized presets and patch recall since these connections are made via the physical interface.

Initially, the only available Eurorack modules were approximations of extant analog synthesizer components, such as the transistor-ladder filter designs found in Moog designs or the state-variable designs popularized by Tom Oberheim's eponymous brand of synthesizers, but the format has expanded to include thousands of digital modules, in addition to the proliferation of a variety of analog designs.[7] This association with early analog synthesizers often codes the cultural reception of Eurorack as nostalgic. Despite this, contemporary Eurorack modules often feature the same embedded microcontrollers found in common consumer electronics and generate sounds using modern digital signal processing techniques rather than analog methods.

In addition to standard microcontrollers such as the PIC18F221 found in Harvestman modules, the Atmel AVR series found in Arduino-based modules, and the ARM series processors common to most contemporary digital modules, there are also application-specific integrated circuit (ASIC) DSP devices such as the SPIN FV-

[6] It is not possible, for example, to change the whether an analog filter comes before or after the effects section.
[7] Chris Carter. "Doepfer A100." Accessed June 14, 2021. http://chriscarter.co.uk/content/sos/doepfer_a100.html.

1 found in Erica Synths Black Hole DSP[8] and the Tiptop Audio Z DSP,[9] as well as field-programmable gate array (FPGA) circuits used in modules such as Intellijel's Rainmaker[10] and Shapeshifter.[11] Each processor has its own limitations that are reflected in the final sound or functionality of the module. For example, FPGA-based modules typically have high sample rates for audio processing and are capable of rendering waveforms with harmonics far above the Nyquist frequency of ARM-based processors but are more difficult to program. Arduino-based modules have the advantage of USB interfaces for firmware updates and a widely used, high-level programming language that users may alter but lack the processing power of the other options and are typically limited to control-rate signals.

As a composer creating music using modular synthesis systems, it is challenging but necessary to come to terms with the aural and functional limitations of these simulations. For example, a user may be asked—via associated paratexts such as marketing materials, manuals, design choices, or naming conventions –to think of a module as a tape loop, despite the fact that manipulating the audio in ways similar to tape will result in sounds specific to digital audio, such as aliasing. A "tape" module may digitally simulate the mild compression, saturation, low-pass

[8] The Sound Parcel. "Erica Synths Black Hole DSP 2." The Sound Parcel. Accessed November 17, 2021. https://thesoundparcel.co/products/erica-synths-black-hole-dsp-2.
[9] "Interest in Valhalla Z-DSP Cartridges? - MOD WIGGLER." Accessed November 17, 2021. https://modwiggler.com/forum/viewtopic.php?t=40264.
[10] Intellijel. "Shapeshifter." Accessed November 17, 2021. https://intellijel.com/shop/Eurorack/cylonix-shapeshifter/.
[11] Intellijel. "Rainmaker." Accessed November 17, 2021. https://intellijel.com/shop/Eurorack/cylonix-rainmaker/.

filtering, and wow and flutter of analog tape,[12] it could include analog circuitry to recreate this effect,[13] or may simply refer to the manner in media is stored and accessed.[14] In other cases, tape is simply an interface metaphor for a digital audio buffer that makes no attempt to reproduce any of the characteristics of analog tape machines or tape. In addition, these modules may also provide controls unavailable on analog tape, such as the ability to change the pitch of recorded material at fixed intervals, or start and stop playback at arbitrary points, while remaining synchronized to other musical material.

The most distinctive characteristics of modular synthesizers are patchable analog inputs and outputs for audio and control voltages. If a module processes or generates digital information, it is usually converted back into a continuous analog signal before it interfaces with the rest of the system. One exception to this is Musical Instrument Digital Interface (MIDI)—a digital control system that rose to prominence in 1984 and has remained ubiquitous on electronic instruments ever since. Some modules feature standard 5-pin DIN MIDI ports, although others use 3.5-millimeter TS or TRS jacks with the same physical characteristics as the analog inputs and outputs. Although this is incompatible with the analog signal also sent via a 3.5-

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[12] Strymon. "Magneto - Four Head DTape Echo & Looper Eurorack Module." Accessed June 29, 2021. https://www.strymon.net/product/magneto/.

[13] Instruō. "Instruō - Lúbadh." Accessed August 16, 2021. https://www.instruomodular.com/product/lubadh/.

[14] "The Phonogene is a digital re-visioning and elaboration of the tape recorder as musical instrument. It takes its name from a little known, one of a kind instrument used by composer Pierre Schaeffer." "Make Noise - Phonogene," March 12, 2013. https://web.archive.org/web/20130312123152/http://www.makenoisemusic.com/phonogene.shtml.

millimeter cable, the potential confusion is mitigated somewhat because the flow of MIDI information requires that only a signal port is needed for each of the respective inputs and outputs. It is extremely uncommon for a Eurorack module to lack any form of analog interface unless the module is intended as an "expander" for an extant module. These expander modules are connected to a host module via a ribbon connector and may perform additional tasks or provide additional controls. While the interconnection of analog signal paths remains fundamental to the experience of using modular synthesizers, all modern formats offer digital modules. Eurorack, as the most widely-used format, is populated by a wide array of digital modules that simulate the properties of various analog media.

In the culture surrounding hybrid objects such as polyphonic synthesizers, discussions often begin with the assumption that there are strict demarcations between analog and digital components. There are acrimonious debates in online forums[15] regarding the ontological status of synthesizers, with "pure" analog synthesizers more highly prized than hybrid synthesizers. In practice, this distinction is artificial, even when the audio signal path is entirely analog. Polyphonic "analog" synthesizers will typically incorporate microcontrollers to parse MIDI data, allocate voices, and route modulation sources. Even if one ignores the digital control system implemented in analog synthesizers in favor of defining "analog" in relationship to the audio rate signal path, complications remain. Digitally-controlled oscillators

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[15] "The DCO Is Purely Analog (Not Just Hybrid)...PROOF - Gearspace," accessed March 15, 2021, https://www.gearspace.com/board/electronic-music-instruments-and-electronic-music-production/830163-dco-purely-analog-not-just-hybrid-proof.html.

(DCOs) such as those utilized in Roland's Juno and JX[16] series of synthesizers perform analog wave-shaping on digitally-controlled subdivisions of a master clock, resulting in oscillators with discrete frequency relationships and continuous waveforms.[17] The oscillators in DCO-based synthesizers combine properties that are typically associated with both digitally generated oscillators and voltage-controlled oscillators. In a modular synthesizer, digital oscillators output analog signals, which can be processed by any number of analog waveshapers and processors. In many cases, this renders the resultant signals indistinguishable from those produced by a voltage-controlled oscillator. This is further complicated by the fact that the perception of analog and digital aesthetics is highly informed by the listener's prior experience of cultural practices involving synthesized music. A listener may associate a simple waveform that continuously glissandos between wavering pitches with the analog sounds of early science-fiction films and the "glass-like" timbres of through-zero frequency modulation and aliasing with the digital synthesizers used in the popular music of the 1980s, but neither sound is an inherent property of analog or digital synthesis.

By focusing on the unit of the module and its status as an individual object, I aim to highlight its precariousness: modules are dependent on external input to perform basic tasks and are therefore difficult to define outside of their relationship to other modules. Each module is part of a larger system for producing sound. In this

[16] Namely, the Juno 6, Juno 60, Juno 106, Alpha Juno, JX-3P, JX-8P, and JX-10 synthesizers.
[17] Thea Flowers, "The Design of the Roland Juno Oscillators - Thea Flowers," accessed March 23, 2021, https://blog.thea.codes/the-design-of-the-juno-dco.

context, the process of defining how simulation functions presents challenges. Many modules are engineered to achieve broad functionality, with their use dependent on how the user connects the various inputs and outputs. For example, Maths, from North Carolina-based manufacturer Make Noise, can function as a filter, slew rate limiter, low-frequency oscillator, mixer, logic gate, gate to trigger converter, and a variety of other applications, depending on how it is patched.[18] The information received into the devices' analog inputs also changes the functionality, often in drastic ways.[19] In an analysis of simulation in the context of modular synthesis, it is critical to examine which properties the designers abstracted from analog media and the methods they used to reproduce these properties in both internal mechanisms and external means of interaction.

In addition to examining the ambiguity created by the patching interface, it is necessary to consider which properties have been recreated using discrete components, integrated circuits, or microcontrollers. For example, Mutable Instruments' Streams combines analog VCA and VCF circuits with digital control signals provided from an ARM Cortex-M3 microprocessor.[20] In one mode, a simulation of a vactrol—an electronic component that combines a light-emitting diode (LED) with a photoresistor—is used to turn the module into a dual low-pass

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[18] "Make Noise Co. | MATHS."

[19] A four-quadrant multiplier can act as a VCA and modulate volume when a unipolar envelope is applied to an audio signal, whereas a bipolar audio-rate signal will result in amplitude modulation when modulating another audio-rate signal.

[20] "Modules – Streams – Specifications | Mutable Instruments," February 7, 2015. https://web.archive.org/web/20150207030252/http://mutable-instruments.net/modules/streams/specifications.

gate. When analyzing the device, one must combine an analysis of the code with an analysis of the schematic to properly examine the aesthetic choices made in the process of simulation.

If a manufacturer uses harvested integrated circuits from extant digital synthesizers, such as many of the modules developed by manufacturer ALM/Busy Circuits,[21] the potential added cost and difficulty these parts bring to the manufacturing process offer some indication of their importance to the design. There are a variety of reasons a designer might seek to use extant circuits. Manufacturers that use components from consumer electronics such as the Commodore 64 and the Sega Genesis often market their modules based on the nostalgic connection potential users feel for these deprecated technologies. In other cases, the manufacturers I spoke to were ambivalent on the relevance of these circuits. For example, Tom Whitwell of Music Thing Modular described his choice to use discrete logic integrated circuits rather than microcontrollers in his Turing Machine modules as "pure 'mojo' ridiculousness."[22]

When examining the current field of widely-available Eurorack-format synthesizer modules, it becomes apparent that many of these modules are simulations of analog media. In some cases, these are simulations of analog synthesizers, but in many instances, the modules are simulations of communications media such as ¼" tape, compact disks, radios, and components of video game consoles. Some of these

[21] "ALM - ALM011 Akemie's Castle." Accessed August 16, 2021. https://busycircuits.com/alm011/.
[22] Tom Whitwell, *Music Thing Modular Interview*, January 8, 2021.

modules more closely resemble works of art than they do musical instruments. For example, ERD, a small Eurorack manufacturer, created the Earth Return Distortion - Raven Edition, a device that sends the incoming signal into soil extracted from the gravesite of author Edgar Allen Poe.[23] Another module, SIR (Susceptible, Infected, Recovered) simulates a shift register in its model of viral transmission. Similarly, some modules are created as gags. Manufacturer 2HP briefly sold a simulated "cat" module, which included sampled recordings of a variety of feline sounds that can be played at various speeds.[24] Modules such as these are often sold in limited, numbered sets. However, many of the most widely used modules, such as Make Noise's Morphagene and Music Thing Modular's Radio Music, are also designed to simulate aspects of the functionality of the media they emulate. While the simulation of deprecated media technologies is not unique to Eurorack, software plugins such as Goodhertz's Lossy and guitar pedals such as Cooper FX's Generation Loss simulate MP3 artifacts and VHS generation loss, respectively[25]—the interleaving of analog and digital information in Eurorack is distinctive, as is the ability to alter parameters of the simulation at audio rates.

While the poetics of mediation have historically had little place in musicology, there is abundant evidence it has been an important aesthetic

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[23] "ERD Modular Eurorack Series 2020," accessed January 15, 2021, http://www.1010.co.uk/org/ERD.html.
[24] Anatomy, Synth. "2hp Cat Oscillator Is Back with a Partner Module for the Ultimate Meow Experience." SYNTH ANATOMY (blog), October 28, 2021. https://www.synthanatomy.com/2021/10/2hp-cat-is-back-with-a-partner-module-for-the-ultimate-meow-experience.html.
[25] The nearly ubiquitous tendency towards simulating analog media remains relevant to the discussion of the particular implementation of simulation in the Eurorack format.

consideration in both experimental and popular music. Compositions such as Alvin Lucier's *I am Sitting in a Room (1969)* and *Quasimodo the Great Lover (1970)*, Max Neuhaus' *Radionet* (1977), Maryanne Amacher's *City Links* (1967), and John Cage's *Radio Music* (1956) are notable examples of experimental works where mediation informs structural elements of the music. Popular musicians and soundtrack composers have also adopted these techniques. Consider the soundtrack to *Doom* (Bethesda Softworks, 2016), a video game that sold 3.6 million copies in the year of its release. In a video posted to *Doom* composer Mick Gordon's YouTube channel, he claims:

> I came up with this idea of breaking sound into its kind of bare-bones components, which are sine waves and noise. I then pulsed rhythms of sine waves and noise through vast arrays of analog equipment. So, the idea here was not to use the analog equipment as an effects processor, even though that's sort of what it's made for. I am using the equipment to corrupt the pure sine waves and noise.[26]

The use of the word "corrupt" in this context explicitly refers to the alteration of information as it passes through a medium. In the video, Gordon can be seen using a 12U[27] modular system. While he refers to the equipment that he uses to process the signal as analog, the patch he is using also contains a number of digital modules, including digital emulations of analog equipment such as the Dave Smith Instruments Character module.

[26] Mick Gordon, *DOOM: Behind The Music Part 2*, 2016, https://www.youtube.com/watch?v=1g-7-dFXOUU.

[27] 12U describes the dimensions of a modular synthesizer's housing: for a 12U modular synthesizer case, there are four rows of modules. Each row is three standard rack units tall.

The design of a simulation blurs the boundaries between scientific and aesthetic practices: to what extent is a simulation a scientific model or an aesthetic abstraction with intentional divergences from reality? What is the relationship between these perspectives on simulation and the perception of verisimilitude? These questions should be considered an essential part of understanding the function of simulation in a given module.

The Make Noise/Soundhack Erbe-Verb: A Meta-Reverb

The Erbe-Verb is a module coded by Tom Erbe and designed in collaboration with Make Noise, a prominent Eurorack manufacturer.[28] It is ostensibly a digital reverberator, but is capable of synthesizing sound without external input. In operation as a reverberation device, it receives a monaural audio-rate signal which is then sent through a delay feedback network, as well as a series of all-pass filters, before entering an analog mixer where it is combined with the original signal and is sent to the stereo output. Rather than the traditional reverb function of creating an artificial "space" for incoming sounds, Erbe-Verb is a malleable effects system designed to morph between many reverb types. As Erbe notes:

> Most reverb processors are used as the last effects device, the room that one places an instrument in. Although the Erbe-Verb supports this use, I wanted it to be more fully integrated into a synthesizer voice. For this reason, all parameters are fully modulatable, designed to be controlled by common control-rate signal generators such as envelope

[28] "Make Noise Co. | Erbe-Verb." Accessed August 16, 2021. http://makenoisemusic.com/modules/erbe-verb.

> generators, low-frequency oscillators and envelope followers. Each note, moment, or gesture can have its own resonant character.[29]

The module features a front panel with nine parameters that the user may adjust using potentiometers and control voltage inputs. While it is possible to produce an approximation of physical spaces by setting the parameters on the front panel or by modulating it with external control voltages, it is not the primary purpose for which the module was designed. As Erbe stated in an interview I conducted with him:

> I had a bit of a reaction to previous reverbs, since reverb is really almost totally a digital development, where almost all of the good devices are digital devices. Especially because of the economy of how things got developed at first, everything was sort of a "patch-like" system. You have a patch, then you go to another patch, and then maybe you dive down and tweak a few variables, and then maybe save another patch. Then you're just refining all these little models. So, one of the main motivations was to make something that was not like that at all.[30]

A traditional digital reverb either approximates the reverberation of sound in a physical space of a given size and shape by simulating the reflections given by walls positioned in a particular relationship to a source or simulates mechanical reverberations created by plates or springs by emulating the reflections in those devices. In either case, the approximations may diverge significantly from the physical space or mechanical reverberation technology. Many of these divergences are considered aesthetically appealing by musicians and engineers. As Jonathan Sterne notes in his essay *Space Within Space: Artificial Reverb and the Detachable*

[29] Tom Erbe, "Building the Erbe-Verb: Extending the Feedback Delay Network Reverb for Modular Synthesizer Use," 2015, 4.
[30] Erbe, Tom. *Tom Erbe Interview*. 2021.

Echo, "Reverb devices achieve canonical status not because of their realism or their particular operational characteristics but because of sonic signatures that they impart to notable passages in notable recordings."[31]

Figure 4.1 The Erbe-Verb Front Panel

Many of the commercially available artificial reverbs articulate the size of a reverb algorithm in terms of the physical length of a space and are meant to model the dimensions of a room in which that quality of sound could be achieved mechanically, from simple energy dissipation as sound waves reflect off surfaces. While there is a size parameter on the Erbe-Verb, there are no markings to indicate how each knob

[31] Jonathan Sterne, "Space within Space: Artificial Reverb and the Detachable Echo," Grey Room 60 (July 2015): 110–31, https://doi.org/10.1162/GREY_a_00177.

position correlates to a specific distance. Erbe describes the range of the size parameter in the Erbe-Verb as extending from four inches to over four hundred feet. The extreme range of sizes, the relatively coarse control offered by the single turn potentiometer of the size parameter,[32] as well as the lack of numerical feedback, make specifying an exact room size by hand unfeasible in this particular system. Instead of simply mediating the incoming sound by a specific set of parameters to create the impression of the sound reverbing in a real space, as a traditional reverb might, the Erbe-Verb's design encourages the musician to perform extensive modifications of the sound in real-time.

The module provides voltage control of the size, speed, pre-delay, absorption, modulation depth and type, filtering, decay, and mix of the reverb.[33] The control voltage input for the size parameter allows for audio-rate modulation—providing automated, real-time alteration of the simulated space. This parameterization allows for modulations that would be physically impossible in a real space and creates significant alterations to the input signal. In contrast, contemporary digital Eurorack reverbs such as the Æverb from Audio Damage or the Halls of Valhalla card for the Tiptop Audio Z-DSP[34] offered fewer control parameters, and sonically-relevant parameters such as size were either unavailable or fixed to specific algorithms.[35]

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[32] It should be noted that the position of a knob does not correlate to a linear increase in size. Erbe intentionally emphasized the ranges he found to be interesting.
[33] "Make Noise Co. | Erbe-Verb." Accessed August 16, 2021. http://makenoisemusic.com/modules/erbe-verb.
[34] Tiptop Audio. "Z-DSP." Accessed April 21, 2021. https://tiptopaudio.com/zdsp-ns/.
[35] The Tiptop Audio Z-DSP is a platform for digital signal processing based on the Spin FV-1 signal processor. The user purchases cartridges with various effects loaded onto the cartridge's ROM.

Internal feedback featured in the Erbe-Verb's digital signal processing allows the module to function as a synthesis voice without external input; the medium becomes the message. Erbe specifically recalls an instance of this, when composer Alessandro Cortini created a patch that modulated the size parameter at audio rate to produce cymbal like timbres.[36]

The Erbe-Verb is an extreme example of what Jonathan Sterne describes when he notes that "an artificial reverberator is more aesthetically akin to a musical instrument than a building."[37] While the continuous control of certain reverb parameters is not dissimilar to reverb pedals or controllers such as the LARC for the Lexicon 224, the ability to smoothly interpolate between reverb types is unique, as is the incorporation of voltage control for every parameter.

The implementation of voltage control adds to the Erbe-Verb's instrumentality. Voltage control allows the user to map reverb parameters onto various performance-oriented controllers or sequencers. In traditional rackmount and pedal reverbs, internal low-frequency oscillators (LFOs) are mapped to set parameters. Parameters such as "size" must be adjusted manually. An engineer creating a reverb intended to approximate the acoustic properties of a space, or a particular class of reverb hardware, such as plates or springs, would not be incentivized to provide the user with the ability to continually modulate the reverb

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[36] Erbe, Tom. "Building the Erbe-Verb: Extending the Feedback Delay Network Reverb for Modular Synthesizer Use," 2015, 4.
[37] Jonathan Sterne, "Space within Space: Artificial Reverb and the Detachable Echo," Grey Room 60 (July 2015): 110–31, https://doi.org/10.1162/GREY_a_00177.

size simply because natural and mechanical reverbs do not continually alter their size. The Erbe-Verb draws upon the aesthetics of continuous parameter modulation common in modular synthesis and connects this with an abstraction of established reverb types. Even reverb systems that incorporate MIDI control do not allow the user to route audio-rate modulation, following the limitations of the MIDI specification. Erbe claims that his goal was to "develop knobs that had a large amount of space in them"[38] and that "my criteria often was often to go a little bit too far in each direction."[39] The decision to provide a wide range of values for each parameter meant that the scaling of the incoming voltage from the potentiometers and control voltage inputs became an important aesthetic consideration. He notes, "The knobs do not make sense in any sort of way, except that I wanted to make them feel good when you perform on them. I think that's what led me to that idea of avoiding any presets; to make something that was quite performable."[40]

Classifying the Erbe-Verb is difficult. It is not an attempt to simulate a room or a specific class of reverbs. Instead, Erbe has extracted aesthetic properties from previous reverb models and abstracted these properties into a malleable reverb capable of approximating many reverb types and interpolating between them. While it is possible to describe the Erbe-Verb as a tool for simulating various reverb types, this fails to account for the emphasis on interpolation and performance. The Erbe-Verb is more accurately described as a meta-reverb instrument that abstracts various

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[38] Tom Erbe. *Tom Erbe Interview*. 2021.
[39] Ibid.
[40] Ibid

parameters of historical reverb algorithms and incorporates them into a modular synthesis environment.

ModBap Modular: "Everything is vinyl"

ModBap Modular was founded in 2020 by Corry Banks, a hip-hop producer and journalist who previously created the blog BBoyTechReport. Banks designs the modules in collaboration with Ess Mattisson, who is responsible for programming and engineering the modules. According to Banks, he created ModBap "to create things with the intention of Hip-hop, with the intention of that kind of beat-driven music, but in technology."[41] Throughout my interview with Banks, he emphasized the importance of providing tools designed for the purpose of making hip-hop, since, in his view, "a lot of the stuff that we use as ours, in this genre, in our culture to make this music, none of it was designed for us to do what we do."[42] The word "modbap" is a portmanteau of modular synthesis and boom-bap. Boom bap is a subgenre of hip-hop characterized by minimalist production with an emphasis on the kick and snare within a sequence or loop. The word itself is onomatopoeic, with "boom" and "bap" originating from beatboxers' vocalizations of kick and snare sounds. According to ModBap Modular's website:

> The term was created by Banks as a denotation of his experiments with modular synthesis and boom-bap music production. From that point forward, a movement was born where like-minded creatives built a community around the idea of Modbap.[43]

[41] Banks, Corry. *ModBap Modular Interview*, January 2, 2022.
[42] Ibid.
[43] Modbap Modular. "Our Story." Accessed February 12, 2022. https://www.modbap.com/pages/about.

Banks has released two modules, with another currently in development.[44] ModBap Modular's first release was the Per4mer, a multi-effects unit featuring four simultaneous effects that the user can trigger in real-time using four arcade-style buttons mounted to the front panel. The aforementioned effects are delay, reverb, "glitch" (a short sample of the audio input repeated indefinitely), and tape stop. In addition to the performable effects, Per4mer features eight "color' processors and a compressor. The color processors were designed to impose the aesthetics of sampling and mediation on real-time synthesized sounds. While the "classic" and "lofi" modes emulate early 12-Bit and 8-Bit samplers, respectively, Banks designed Wax and Wax2 to replicate different characteristics of vinyl records.

> I think one of the things people don't think about when we mention issues with sampling—the copyright stuff is one thing—the other big thing that is maybe not as obvious is that when I was sampling a lot from vinyl, I would always get to a point where I wanted to embellish a little more, I wanted to go a little further with that certain pocket that they were in. Sometimes I felt like there was only so far I could take it.
>
> So when it came to Per4mer, I was thinking in that sense. That gives you an idea of where my head was when I was making Per4mer. I wanted performance effects, but I also wanted this aesthetic that I could have the vinyl sound and technique, or the sampling sound and technique with original melodies and original music, and still have that feeling. And it kind of becomes its own thing, but if you go deep enough into it, it can be indistinguishable from "yo, where'd you get that sample from?"[45]

[44] Banks, Corry. *ModBap Modular Interview*, January 2, 2022.
[45] Ibid.

` Figure 4.2 ModBap Modular Per4mer

ModBap's next release was Osiris, a wavetable oscillator featuring a unique fidelity parameter inspired by the earliest personal computers capable of sample playback, such as the Commodore Amiga and Atari ST series. According to Banks, it was important that Osiris was capable of producing high-fidelity audio so that the user could shape the sound to their liking.

> The oscillator runs at 96kHz, it's just a very clean, pristine sound, but then, being able to dial in more of the character, more of this musical degradation, that was really important.[46]

The fidelity parameter introduces phase jitter, as well as bit and sample-rate reduction. These effects are based on algorithms Mattison developed to emulate the

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[46] Ibid.

Commodore Amiga, as well as experiences Banks had with Atari computers in recording studios. According to Banks "I remember the sound was very specific, and it was great for hip hop."[47]

Banks told me he wanted his modules to be accessible to newcomers, especially those that might otherwise feel alienated by the notorious difficulty and lack of documentation prevalent in Eurorack. For example, the manual for Per4mer is 47 pages long[48] and features numerous illustrations detailing the installation of the module, block diagrams describing the signal flow and charts pertaining to the LED color associated with each effect. According to Banks:

> That was a big thing for me because I had a goal of introducing Eurorack to more hip-hop producers and first-time Eurorack users. It feels odd to say that. I don't think I voice that too often, but that was a goal of mine. If I am saying, "I'm all about hip-hop, and I want to be the voice of hip-hop in everything I do and design these things from that perspective. I already knew that it would be a lot of first-time users coming in. So, I thought that the documentation had to be easy to get into and accessible.[49]

Many of Banks' customers are new to Eurorack or uninterested in it as a platform aside from his creations. Banks intentionally designed Per4mer to send and receive line-level signals and sells a Modbap Modular-branded 20HP case[50] designed by 4MS Company[51] so that producers could use Per4mer as a stand-alone effects processor.

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[47] Ibid.
[48] Manuals for modules are often short or non-existent.
[49] Banks, Corry. *ModBap Modular Interview*, January 2, 2022.
[50] Modbap Modular. "Modbap20 Powered Eurorack Case." Accessed February 19, 2022. https://www.modbap.com/products/modbap20-powered-Eurorack-case.
[51] 4MS is a Chicago, Illinois-based Eurorack Manufacturer.

The simulations of media in Per4mer and Osiris should be understood within the context of their tailoring instruments to produce hip-hop. As a genre distinguished by its emphasis on repurposing and altering recorded media, the history of hip-hop is marked by explorations of the limitations and possibilities of media technologies, from turn-tables to samplers. The simulations in Per4mer are influenced by the gestures of disk jockeys and producers developed for these technologies, such as scratching records or performing tape stops. Like many of the other designers I interviewed, Banks' simulation practice was focused on reproducing an aesthetic experience rather than emulating components because "at the base level of everything, you're going for a sound."[52]

Radio Music: A Digital Emulation of Radio Aesthetics

Music Thing Modular is a small London-based Eurorack company founded by Tom Whitwell, a programmer, designer, hardware engineer, and former assistant editor of *The Times*. Unlike Make Noise, Whitwell does not manufacture the modules he designs. [53] Instead, he furnishes kits including printed circuit boards (PCB), front panels, and the electronic and mechanical parts necessary to build his modules. The circuit designs, PCB layouts, and code are released under Creative Commons licenses and are available for use or modification.

52 Banks, Corry. *ModBap Modular Interview*, January 2, 2022.
53 Mylar Melodies, *WHY WE BLEEP PODCAST 001*.

Radio Music is a sample player in the Eurorack format that emulates some features of radio, such as multiple channels of synchronized audio that are accessible by "tuning" to a particular "station." [54] It plays audio-rate samples that the performer alters via two knobs and a single momentary button on the front panel, as well as respective control voltage and gate inputs. Whitwell did not design the hardware interface to resemble a radio, nor did he attempt to reproduce the characteristic static, distortion, interference, or low-level noise of analog radio. However, he did preserve some of the basic interactive features of radio. The user selects "stations" by adjusting a potentiometer on the front panel in a manner that roughly approximates tuning into various radio stations on an analog radio. Whitwell was initially inspired by Donald Buchla's experiments with voltage-controlled analog radio, as well as John Cage's *Radio Music* (1956), [55] which gave the module its name. Whitwell explains that he decided to transition from a voltage-controlled analog radio to a digital emulation after attempting a performance with this analog prototype in an electrically insulated room.

> I found somewhere on a forum that there was a very cheap German radio kit you could buy that had the particular components in it so it could do voltage-controlled tuning. So, I bought that kit, made it into a little module, and I had a CV sequenceable radio. Where I am here in South London, there's quite a lot of interesting, weird radio stations around, you know, there are pirate stations, there is stuff on the broadcast spectrum that is kind of interesting. So, I made this thing, and it worked really well. It was really interesting doing that. I then went to Brighton. There's a modular meet-up in Brighton every year, and I went down to that. It is held in the university there, and this year it was held in a room that was essentially a Faraday cage, and the room

[54] Tom Whitwell, *Music Thing Modular Interview*, January 8, 2021.
[55] Ibid

> has got lighting gantries all over it. So, I went in and plugged in this thing I was going to show everyone, and there was just nothing there.
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> Obviously, that was a kind of an amazing thing to happen; to go, and my radio module doesn't produce any audio, but it was a little bit annoying, and so at that point, I thought, "okay, there is they should be a way of doing this." So, it's the same joke, the same sort of gag, but it works in a more reliable way.[56]

The module uses a Teensy 3.1, which is an ARM Cortex-M4 development board[57] that can be programmed with a bespoke audio programming language called Teensyduino.[58] The Teensy provides micro-USB connections as well as low-resolution analog-to-digital converters (ADCs) and one high-quality digital-to-analog converter (DAC). It is considerably easier to reprogram and write new firmware onto the Radio Music than many other digital modules due to its available USB connectivity. Whitwell mentions that the fact that Radio Music was "hackable" was something he only became aware of after releasing the module, but that this became "an important and interesting part of it."[59] This, along with the considerable resources and encouragement provided to the user base by Whitwell meant that a number of alternate firmwares were created for the Radio Music by its users. Whitwell hosted many of these on the official Music Thing Modular GitHub repository, further increasing their circulation. While the initial firmware was programmed by Whitwell, the current official firmware was created by Martin Wood-Mitrovski, a customer with

[56] Ibid.
[57] "17 Things to Know about the Music Thing Radio Music Module." Accessed January 12, 2021. https://musicthing.co.uk/pages/radio.html.
[58] This language borrows extensively from the Arduino programming language, as indicated by the name.
[59] Tom Whitwell, *Music Thing Modular Interview*, January 8, 2021.

no affiliation with the company. As Whitwell noted in my interview with him, "My only real brief [for the outside programmer] with that firmware was that you could use it exactly as it was beforehand, without using any other features, and as far as I know, it does that."[60]

Figure 4.3 Radio Music Module

The degree to which Whitwell incorporated external modifications into his existing product strongly suggests that he was less interested in the specifics of simulating radio than he was in abstracting specific attributes as part of a sampler design. He confirmed this when I spoke to him, stating:

> With the Radio Music, there are ways that you could much more explicitly reproduce a radio. You could have it so that you could tune between stations. You could have it so that you could have it untuned, and it would make the sound of an untuned radio. And I suppose I partly thought that would be difficult, so I didn't do it. And also, I think it comes back to skeuomorphism as well somehow. Having a

[60] Ibid.

> sampler that behaves in the way it switches between stations or audio files in this slightly odd way, to me, felt fine. Whereas trying to simulate—you could imagine having FM/AM/Shortwave switch and simulate the going between them—that to me feels very skeuomorphic and kind of like rendering a wooden surface in your VST plugin. It felt like that would be kind of weird. And so it feels a bit like you are giving somebody too much of the answer.[61]

Whitwell did, however, provide a library of suggested sound files, including many recordings of government radio propaganda, lectures by philosophers and artists he admired, field recordings, and other long-form sounds. These suggested files were distinct from the preset patches and samples typically burned into the ROM of various samplers in that they were optional. However, this library of sounds became an important feature of the module because, in the initial firmware produced by Whitwell, users had to convert their files into the RAW format through a somewhat tedious process before transferring these files to the module. This made it difficult for users to transfer large numbers of small files onto the device, as the bit and sample rate conversions that enabled the translation to this format were error-prone. Rather than converting their own files, many users relied upon the available libraries that Whitwell created. When comparing the Radio Music to One, a nearly identical module manufactured by Tiptop Audio, Whitwell was quick to point out, "I don't imagine it comes with hour-long recordings of North Korean radio stations."[62]

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[61] Tom Whitwell, *Music Thing Modular Interview*, January 8, 2021.
[62] Tom Whitwell, *Music Thing Modular Interview*, January 8, 2021.

Figure 4.4 The Tiptop Audio One - A sampler with nearly identical design and controls to the Radio Music. It was released three years after the Radio Music, and contains more “traditional” samples.

Given the highly abstract relationship between the Radio Music and radio, it might be tempting to conclude that this connection is superficial. Other media such as television or tape loops could be used as a metaphor for the interface. In this regard, the context in which the Radio Music is presented is important. While there are now many pre-built or used Radio Music modules available for purchase online from independent builders, the module was originally only available as a kit. This meant that in order to build and test the device, users would necessarily come into contact with Whitwell’s commentary on the module, suggested readings from Alvin Lucier, John Cage, and Robin Rimbaud, as well as the curated audio recordings. At the very least, a builder must spend time examining the PCB in order to determine the placement of electrical components. When they do, they will find explicit references to John Cage, [Karlheinz] Stockhausen, Akin Fernandez, Don[ald] Buchla, Nicholas Collins, John Peel, Max Neuhaus, UbuWeb, and Resonance FM amongst the labels for resistor values and diode orientations. The curation of suggested content does not determine the module's use, but it does offer strong cues to the user. These samples are also audible in the most popular video tutorials on the module,[63] furthering their association with the device.

Another distinguishing feature of the Radio Music is its emphasis on the use of long-form audio recordings. According to Whitwell, "One 32gb micro SD card can store about four-and-a-half days of audio in the normal Radio Music format."[64] Samplers have, historically, tended to allow for polyphonic articulation of relatively short recordings. While the expense of random-access memory was the primary reason that early samplers did not allow for longer sampling times, [65] there were other complications preventing the use of longer samples, such as the challenge of synchronizing longer files. Sample manipulation becomes difficult with longer sample times, and it becomes difficult to control the time and pitch relationships between sustained non-periodic material beyond a few seconds. Even periodic material will often fall out of sync unless it is arrhythmic or manually synchronized. Most commercial samplers require that a key or pad remain depressed in order for the

[63] Future Music Magazine. *Modular Monthly: An Intro to DIY Eurorack & the Radio Music*, 2016. https://www.youtube.com/watch?v=9g2Q0esgBuk.
[64] "17 Things to Know about the Music Thing Radio Music Module." Accessed January 12, 2021. https://musicthing.co.uk/pages/radio.html.
[65] The E-MU Emulator and the Ensoniq Mirage—two early professional samplers—each had 128 kilobytes of memory, approximately two and six seconds of sampling time, respectively.

sound to continue playing. Audio on the Radio Music begins playing as soon the module receives power, without requiring a gate or trigger from external modules. While it is possible to reset to the beginning of the file by pressing the reset button or sending an external gate into the reset input, there is no way to stop the file from playing. Users can control where the file starts, but the resolution of the ADC prevents precise control of the position in longer files.

Radio Music is a module that cannot be defined by its functionality and interface alone. Judging from these on their own, the connection to radio is quite tenuous. However, the way that the device is situated and the performance practices Whitwell encourages by framing the building and sampling process in terms of radio art weigh heavily on its reception and use. While the musician using the device is free to ignore this information, Whitwell himself considers it to be an important aspect of the instruments he builds. During my interview with him, he claimed that,

> I always want to have some sort of story, or, I suppose, not always, but generally, I want to have some sort of narrative. For me, the narrative around the thing is important.[66]

By providing longer samples and making it difficult for the user to operate it as a traditional sampler, Whitwell encourages the user to consider simultaneity, something that many of the composers he cites were invested in as a compositional strategy. The user of Radio Music is expected to use the module as a source of indeterminate material for processing. By synchronizing all audio "stations", Radio Music allows

[66] Tom Whitwell, *Music Thing Modular Interview*, January 8, 2021.

the user to consider the dynamic relationship of various unrelated recordings over time, much like the performer of Cage's *Radio Music* (1956). It is this connection to the performance practices of radio in experimental music that makes the Radio Music legible as a simulation.

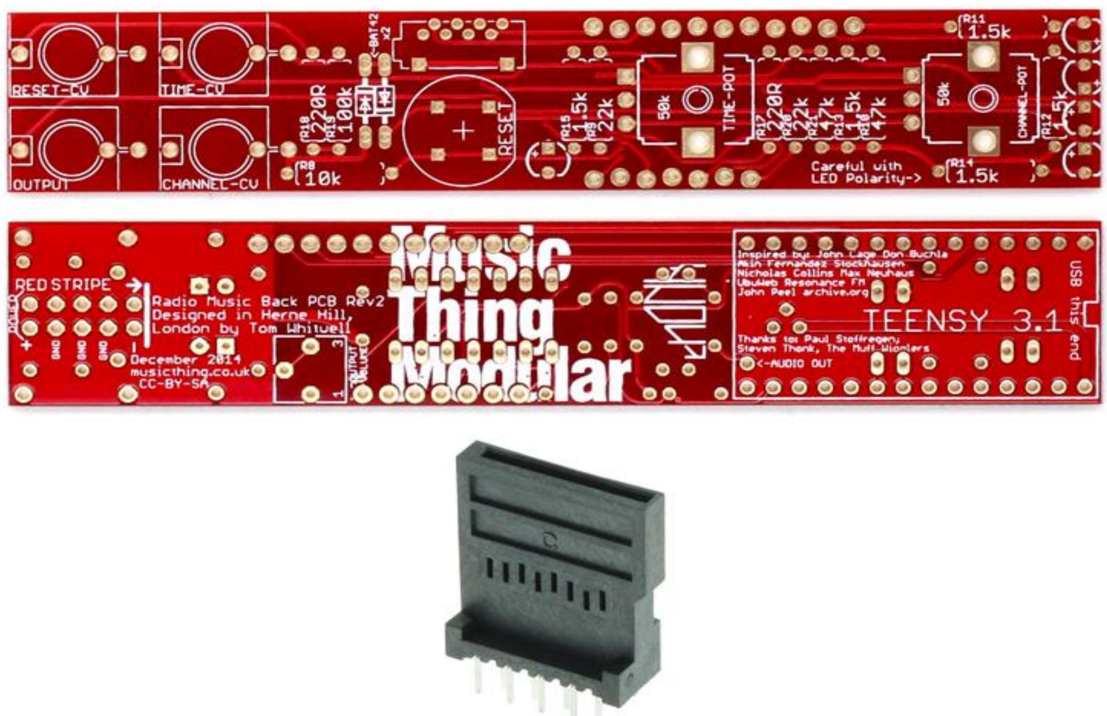

Figure 4.5 The Radio Music PCB contains explicit references to John Cage, [Karlheinz] Stockhausen, Akin Fernandez, Don[ald] Buchla, Nicholas Collins, John Peel, Max Neuhaus, Ubu Web, and Resonance FM amongst the labels for resistor values and diode orientations.

Atari Cyberpunk Consoles: Abstracting Game Console Sound Generators

While communications or storage media are commonly used as the basis for Eurorack modules, the digital circuits used to synthesize audio in video-game consoles have also been simulated. Like the other forms of media discussed in this essay, simulated game console synthesizers are typically used to expand the functionality of the original design. When the integrated circuits are available for purchase, manufacturers often incorporate them into the modules. London-based manufacturer ALM Busy Circuits used the MOS Technology 6581/8580 SID[67] and the Yamaha YMF262[68] in its SID Guts and Akemi's Castle modules, respectively.[69] Special Stage Systems, a Providence, Rhode Island-based company, released the Oscillographic Block, which contains the Texas Instruments SN76489AN used in many Sega and Neo-Geo home consoles.[70] According to the manual for Akemie's Castle, "Using an original chip gives a very authentic and special sound."[71] The author later cautions,

> [U]sing an original chip imposes some limitations, some of which become more apparent with such direct control. Expect some 'stepiness' and potential low level clicks when changing certain parameters. It is only possible to modulate parameters up to low audio rates. The chip will alias and even distort if pushed hard enough in certain settings - care should be taken. One can quickly go from rich tonal bliss to crushing noise. It is a beast, but one that can be tamed. Embrace and enjoy these limitations.[72]

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[67] Most notably used in the Commodore 64.
[68] Notable for its widespread use in Soundblaster cards for gaming on personal computers.
[69] It should be noted that the SID Guts does not function unless the user provides their own SID integrated circuit. Due to the limited availability of SIDs, users may choose to use the SwinSID—a modern hardware recreation—creating another layer of ambiguity regarding the status of the module as a simulation. Another module, Fizzle Guts relies on deprecated, bespoke circuits from the Casio FZ-1.
[70] ModularGrid. "Special Stage Systems Oscillographic Block." Accessed January 13, 2021. https://www.modulargrid.net/e/special-stage-systems-oscillographic-block.
[71] "ALM - ALM011 Akemie's Castle."
[72] Ibid.

When Noise Engineering designed the Ataraxic Translation, they used the same synthesis methodology as the Atari Pokey sound generator but implemented it on a modern processor and extended the original design's capabilities.

> It's a 16-bit tuneable LFSR [linear feedback shift-register] oscillator.[73] This circuit/algorithm was ubiquitous in 1970s games because it's digital and with very few gates you can make a lot of different sounds. The Atari 2600 is the most popular version of this. It has a 6 bit and a 5 bit LFSR that can modulate each other. The Zorlon Cannon[74] is the same algorithm though it allows the user to include configurations that produce non maximal galois sequences. But.. it is just a bunch of xor [exclusive or] "gates" (software in this case) that you can configure the feedback paths on.
>
> The process was pretty simple... My coworker was sick of me bagging on his Eurorack modules so he called my bluff and told me to make my own. He in particular wanted a properly tunable 2600 oscillator (you can't actually tune the Atari 2600 to any proper scales). So, over the weekend, I made him a prototype which became the AT.

Aesthetics of Digital and Analog Systems

There was a clear consensus among those I interviewed that while there are valid reasons to be attracted to anachronistic forms of media, particularly analog media, they were less interested in exact simulations of older media than appropriating the aspects they found aesthetically appealing and musically meaningful. These conversations occurred against a backdrop of analog fetishization in the professional audio industry and the synthesizer hobbyist community. The importance of the

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[73] Stephen McCaul, *Stephen McCaul Interview*, 2019.
[74]A linear feedback shift register (LFSR) module that provides control and audio rate output. An LFSR is a series of gates arranged to delay information one bit at a time. The Zorlon Cannon was developed by Scott Jaeger and released by his company, The Harvestman, in 2008. A revised version of the Zorlon Cannon was released in 2012. Like the Ataraxic Translatron, the Zorlon Cannon also contains oblique references to the Atari 2600 ecosystem, specifically *Yars' Revenge* (Atari, 1982), a popular game for that system..

particular characteristics of analog media varies depending on the use case and, more generally, context. A company focused on marketing its products to professional musicians will likely have less interest in emulating a particular medium's limitations than they will in extending its functionality. As Kris Kaiser from Noise Engineering notes, "most professionals we talk to don't care whether things are digital or analog, they care what the product does."[75] In addition, because these modules are products that are meant to provide value to the musicians that use them, tension may arise between the designer's aesthetic instincts and the desire to appease customers. Tom Whitwell addressed this tension in relation to his decision to use discrete CMOS logic chips to design the Turing Machine, Music Thing's shift register-based sequencer,

> You sort of think, "obviously, you could do it quite simply with a straightforward microprocessor. I imagine you could do it at audio rates because the CMOS chips don't go that far. If you try and do it at like 10,000 hertz, it won't work. It goes up to—I don't know—a couple of thousand hertz. For me, it just doesn't seem interesting, doing it like that - but that is pure "mojo" ridiculousness. There's no customer end value for that.[76]

Questions such as this point to the ambiguous status of modular synthesizers now that it is possible to emulate all of the components of a modular system on a laptop computer. The software suite VCV Rack simulates the look and functionality of Eurorack, albeit with a suggested design language that replicates modern computer interfaces' flat designs. Many manufacturers offer free versions of their modules in the VCV Rack language, including an adaptation of Whitwell's Turing Machine. One

[75] Kris Kaiser, *Kris Kaiser Interview*, 2019.
[76] Tom Whitwell, *Music Thing Modular Interview*, January 8, 2021.

of the VCV brands, Audible Instruments, shares the interface and code of the Mutable Instruments Eurorack modules. There was a sense among those I interviewed that the differences between analog and digital media were not necessarily inherent properties of either medium but instead reflected the design principles of most commercially available analog emulations. A programmer may determine that oscillator pitch fluctuations, filter saturation, noise, and non-linearities in various components' frequency response are not worth simulating.[77] Idealized circuits are often simpler to program and consume fewer resources than those that simulate circuit components at greater degrees of granularity. In my interview with Stephen McCaul, he addressed these design choices in regard to a stigma toward digital modules:

> You do still hear complaints but they are often valid and interesting. Someone we talked to recently was lamenting how accurate his clocking was in the box which is one reason he likes modular because it was actually much messier which made it sound more human to him. Once you unpack this from "digital sucks analog is better" (which is somewhat the way it was originally presented to us in that discussion) you see that he has a very specific and very valid reason for his preference that really has nothing to do with it being a computer or circuits or digital or analog but it is how we as a society have taught people to oversimplify this.[78]

The examination of Eurorack modules offers unique challenges compared to either the study of mass media or analysis of complete musical instruments. Analyzing the relationship between Eurorack modules and the media they simulate offers a constructive means of studying the design principles and aesthetic choices made by

[77] Audible pitch drift is not necessarily a feature of analog, voltage-controlled oscillators. The Prophet 6 and OB-6 VCO-based synthesizers from Sequential respectively include "slop" and "detune" parameters that introduce random pitch fluctuations.
[78] Stephen McCaul, *Stephen McCaul Interview*, 2019.

their designers and programmers. I have outlined these designers' specific processes for abstracting various forms of media to establish a methodology for contextualizing the modules' effect on the music created with them. While the choices made in designing a module do not determine specific aesthetic outcomes, designers use these decisions to direct the musicians' use of the devices. In some modules, such as the Radio Music, the designer's choice to emulate a particular medium forces the user to avoid particular interactions while simplifying others, such as the playback of files over an hour in length. In others, such as the Ataraxic Translatron and the Erbe-Verb, the module's sonic character is difficult to avoid.

The simulated reverbs, radios, and video-game consoles in Eurorack-format modules form only a small subset of simulated media. They do, however, offer some of the most complex examples of simulation, given their hybridity and interconnectivity. While Eurorack modules themselves are not widely used by the general public[79] these designs have an outsized influence on popular culture due to their use by soundtrack composers such as Hans Zimmer, Trent Reznor, Mick Gordon, Michael Stein, and Kyle Dixon. Additionally, Eurorack offers unique challenges to the study of simulation that complicate the study of less complex simulated media such as those found in software plugins or guitar pedals. Like the internet ecosystem in which they are promoted, discussed, and sold, Eurorack modules represent and reflect a complex relationship with culture, one that is at once

[79] Most manufacturers I spoke to were not comfortable providing sales figures, but the general estimates I was provided with were between four to five figures.

highly referential and personal. Eurorack, more so than any previous modular synthesis format, is a global phenomenon with a startlingly diverse range of products and personalities. Given that the range of professionalism, musical and philosophical interests, cultural backgrounds, and personality types are reflected in module design and functionality, Eurorack offers a rich opportunity for examining how culture becomes embedded within technology.

CHAPTER 5:
EXPERIMENTS IN SIMULATION

Magus Instrumentalis

Since 2016, I have been experimenting with systems for storing, recalling, and interpolating through complex states of audio modulation and feedback. My earlier music and installation work—in particular, *Ideology as Material Force* (2013)—the multimedia composition created as part of my master's thesis research—incorporated empirical experiments with the poetics of media with feedback. While this performance system featured bespoke electronics in the form of audio and video mixers and "hacked" analog media technologies such as VHS and Laserdisc, I quickly shifted my focus to configurable modular systems. The performance system I constructed for *Ideology as Material Force* was unreliable due to the instability of many of the modifications and the age of many of the media playback systems and media. It became clear that a small-format modular system was the best solution to achieve stability and portability with potential for the same aesthetic results. I eventually settled on the Eurorack format due to the lower cost, wide variety of modules available, connectivity, and compatibility with multimedia—including video modules. The variety of USB audio and MIDI interfaces available in Eurorack meant that I could incorporate the control and audio processing systems I had designed in Pure Data, Max, and Kyma into the complex hybrid networks I was creating in the modular system. While a hybrid system involving integrated computer control and feedback between the computer and modular synthesizer provided enormous flexibility, it was often unwieldy and the interface unintuitive. It was at this point that I began to design Eurorack modules for use in my work.

This work represents a parallel process to my academic research into media and, as it became a collaborative project, is less clearly indicative of my aesthetic proclivities than other music or designs that I have completed since beginning my dissertation research. However, it is also the work most informed by this research. In particular, my theorization of simulation and the affective properties of analog media directly influenced the collaborative design process of a morphing preset controller known as the Ars Memorium and a later suite of simulated analog modules. The Ars Memorium was designed in collaboration with David Kant with additional design input from Mustapha Walker. From the manual:

> The Ars Memorium, at its core, is a voltage source with state memory and recall. It is capable of producing 16 arbitrary functions at once and providing two-dimensional interpolation between saved states. All of its functions are mapped to X and Y coordinates—allowing for a wide range of audio applications, including patch preset design and interpolation, LFOs with user programable shapes, sequences with an arbitrary number of steps, precise recall of complex feedback patches, dense Xenakis-esque glissando, quadrophonic panning and many other forms of linked, user-defined modulation.[1]

Modular synthesis systems offer extreme flexibility but are notoriously difficult to control, and it is often impossible to recall the state of a patch once a change has occurred. Many of the early compositions I created with the modular synthesis system I assembled consisted of the real-time reconfiguration of feedback systems. In many

[1] Magus Intrumentalis. *Ars Memorium*. Santa Cruz: Magus Instrumentalis, 2020. https://magusinstrumentalis.com/wp-content/uploads/2020/10/Ars-Memorium-Manual-V.1.0.pdf

instances, the audio would be routed through a matrix mixer which could duplicate and attenuate each signal across multiple outputs. This allowed for the creation of complex feedback networks, especially when each audio stream was processed by nonlinear circuits. Since small changes to each parameter in these patches would alter how the other parameters responded to change, it was often impossible to return to a particular "state." These states continually evolved but tended to occupy circumscribed territory in terms of timbre and envelope. Much of the challenge of composing and performing in this way stemmed from the difficulty of transitioning from one "interesting" sound into another. These changes required that I manipulate the routing manually, and it was not generally possible to return to past system states.

In 2017, I began having discussions with another composer, David Kant, about his work simulating analog chaos. Digital emulations allow for precise recall and control but are processor intensive, given the recursive processing. These observations about the advantages and limitations of analog and digital media led to a design for an analog matrix mixer with digital recall and interpolation. We decided upon a matrix of four rows and four columns because of the relative ease of mixing four quad voltage-controlled amplifiers (VCAs) using available integrated circuits such as the Coolaudio V2164 D and because this was the maximum number of channels we were capable of deriving from commercially available DACs, without compromising on resolution or including parts that were prohibitively expensive. I created several early mockups in Adobe Photoshop to pitch my ideas for the module before moving to a vector-based design to enable the production of laser-cut panels, which I outfitted with interface components. This prototype allowed us to experiment with ergonomics and, later, became a means of housing the analog controls while we began experimenting with ways to parse and clean the data generated from each of the control potentiometers.

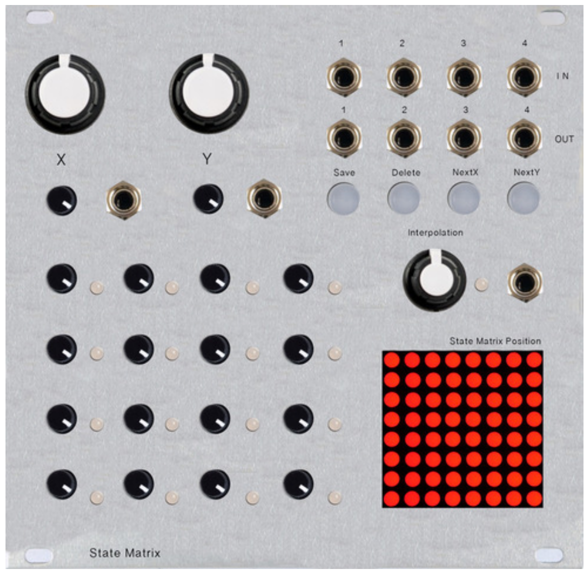

Figure 5.1 Ars Memorium Photoshop mockup

The design underwent several modifications based on empirical experiments with this "dummy" interface. We developed an informal hierarchy of interface components to organize the physical placement of knobs and, later, "hidden" functionality embedded in a menu accessed via the screen. The highest level of priority was given to what we determined to be "performance" controls. Perhaps the most important of these were the X and Y potentiometers. These are what the user interacts with to perform real-time interpolations by navigating through both dimensions of the matrix. The performance elements were placed below and to the left of the majority of the cables—with two exceptions. This design assumes that navigation through the matrix will be controlled externally when the player connects cables to the "X" and "Y" control voltage inputs. While the controls remain functional as offsets, performance using the knobs is more difficult in this scenario, as the cables will extrude from the section of the case where players would normally rest their hands.

Below the performance controls in the hierarchy were the programming elements. The user is provided with front-panel access to the 16 potentiometers that control the 16 outputs in "Edit" mode. However, these are clustered closer together than the performance controls as the expectation is that the user will manipulate these controls to discover interesting states within the patch for later recall, rather than performance gestures that potentially require a greater surface area.

There are also functions that the user is likely to change only a small number of times within a session. These include saving and loading collections of patch states—referred to as plots, setting the output voltage range, and changes to the data visualization. The decision to allow the user to save collections of states was based on our experiences using the module in multiple compositions within the same performance. Differing plots allow for varying forms of interpolation, producing dramatically different collections of morphing sound. The user may also save "stock" mappings of various functions onto the X and Y inputs. We created an option for voltage offsets to bypass the need for extensive patching to match the voltage ranges of various Eurorack hardware. Finally, given that the voltage associated with each knob is decoupled from the position of the knob on the front panel in interpolation mode, we elected to provide a visualization of the state of each knob.

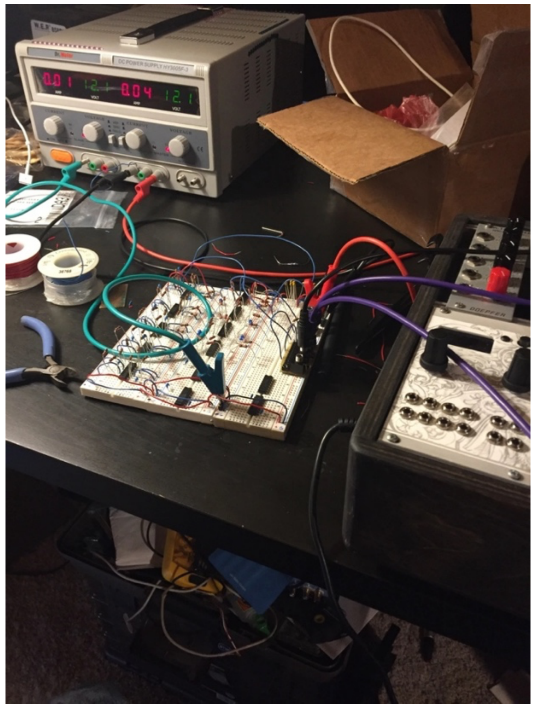

Figure 5.2 VCA Matrix breadboard prototype

I began the analog circuit design by modifying available schematics and assembled a working prototype of a VCA matrix on a breadboard. For the central processor, we selected an ARM Cortex-M3 and used two interleaved eight-channel DACs. The analog control input used a multiplexer to route the voltage passing through the eighteen potentiometers into the device's single ADC. By early 2019 we had working prototypes of the analog control system, the CV outputs, and the VCA matrix and had tested each component in conjunction with the others. However, the fragility of the system made rapid prototyping challenging, and by the summer of 2019, we elected to move to a software platform as a means of developing the interface and functionality of this system. We selected VCV Rack—a popular environment that emulates the look and functionality of Eurorack—as the development platform in order to maintain continuity in our design.

VCV Rack is a simulated Eurorack environment created by Andrew Belt in 2017 and is currently available as both a stand-alone application and a software plugin for digital audio workstations.[2] Belt compares the model of modular synthesis to that of UNIX computing, where small but robust modules interact to construct more complex systems. Like Linux and BSD—two Unix-like operating systems—the application is free and open source. The software is designed to look and function like a modular synthesizer, although the module designs are intentionally flat and simplified.[3] The VCV Rack specification for panels is proportional to the Doepfer specification for Eurorack modules, which are three rack units in height and whole number increments of horizontal pitch in width. Independent developers are encouraged to "Design panels as if you are designing hardware."[4] In addition to the design, modules in VCV function similarly to their Eurorack counterparts. The user constructs "patches" by connecting a number of modules through virtual patch cords. These cords pass signals between modules, allowing for control of various parameters. The user typically starts a patch by adding modules—which are selected from a menu system, before making the interconnections. Like Eurorack, control and audio information are undifferentiated within the application, and some modules may

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[2] "VCV Manual - About VCV," accessed November 12, 2021, https://vcvrack.com/manual/About.
[3] The design shifted slightly towards the skeuomorphic with the introduction of VCV 2 in late 2021.
[4] "VCV Manual - Panel Guide." accessed December 16, 2021. https://vcvrack.com/manual/Panel.

be used in a variety of ways, including the creation of both audio-rate and control-rate signals. Audio is processed at a single sample delay. This means that it is possible to perform recursive operations by patching the output of a signal path back into its input without obvious artifacts. VCV Rack includes many simulations of Eurorack modules from manufacturers such as Mutable Instruments, Music Thing Modular, Befaco, nonlinearcircuits, and Instruo.

While VCV Rack is marketed as a direct substitute for Eurorack synthesizers, there are a number of differences. Aside from the aforementioned flat appearance of most modules, there are a number of major differences that alter the experience: Within the software, the user may access options pertaining to the module's function by right-clicking it and checking or unchecking options from within that menu. There are Eurorack equivalents to this: modules such as Mutable Instruments' Clouds use button combinations to enter into alternate modes, for example. However, this means of engagement makes use of the unique advantages of graphical user interfaces, such as drop-down menus.[5] In addition, some modules may operate polyphonically—passing multiple streams of information along a single patch cord, which can be broken out for individual processing by dedicated modules. VCV Rack is also primarily designed for ASCII keyboard and mouse interaction. It is not possible, for example, to turn multiple knobs at once using the mouse, which is a performance technique used by many modular synthesists. Users interact with knobs by clicking

[5] There are Eurorack modules with screens and graphical user interfaces. The distinction is that the GUI remains a distinct layer, common to all modules in VCV.

and dragging the cursor, which makes typical performance gestures such as modulating the cut-off frequency of a low-pass filter more difficult. However, performance controls can be mapped to external MIDI control surfaces, allowing the user to interact via potentiometers, sliders, and other forms of physical interface. A final notable difference is that users of VCV Rack may bring as many copies of a module into a patch as computing power allows.

Following the change to VCV Rack, we made a number of decisions that significantly changed the nature of the device. Due to the fact that the new design was fully digital, we removed the integrated VCA matrix and converted that design into a separate module. We felt that a device with sixteen control voltage outputs would provide a better means of interfacing with analog audio systems. This change meant that the Ars Memorium could still provide voltage control if the system output was sent to a DC-coupled interface. In addition, the module's functionality enabled the control of parameters other than the routing of signals through a pre-defined matrix. This resulted in other applications for the device, such as preset saving and recall for Eurorack synthesizers, as well as polyphonic synthesizers over MIDI. While this undermined the original goal of creating a self-contained Eurorack system with state recall, it enabled new uses and allowed us to build a mature software system, which we are currently transitioning back to hardware.

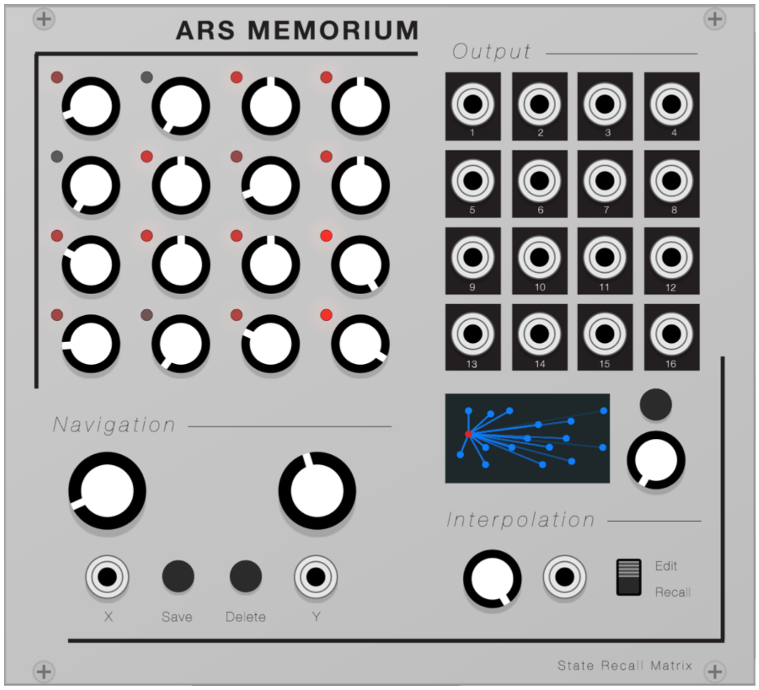

Figure 5.1 Ars Memorium interpolating between 16 states

The final software design functions in the following manner: First, the user creates a VCV patch by connecting audio and control rate signals to produce sound—typically by processing one or more signals through one or more channels or by creating recursive connections between signal processors. This may involve various delays, reverberation units, filters, distortions, and other means of processing signals. The user then connects the outputs of Ars Memorium to the control voltage inputs of these processing and control modules. In doing so, the user may alter the sound of the "patch" by setting various parameters while Ars Memorium is set to "edit" mode. When the user has decided upon a state that they intend to store, they can navigate to a position in the two-dimensional matrix by altering the position of the X and Y knobs—or by setting the position via the control voltage inputs for the X and Y positions—and clicking the save button. Once the user has created two or more "states," the user may switch the module from edit to "recall" mode. In recall mode, the module will interpolate between these states:

> In Interpolation, states are located in a two-dimensional interpolation space according to their (x, y) coordinates. State recall and interpolation are performed using Inverse Distance Weighting (IDW), which weights neighboring states inversely proportional to their distance from the recall position. Neighbors that are located outside a given interpolation radius are zeroed and do not contribute at all. Interpolation is the primary intended functionality of the module.[6]

Our goal when designing this module was to connect intuitive sonic experimentation with the ability to save, recall and therefore structure the sounds found within this intuitive framework. In addition, the interpolation between adjacent allows the user to observe the relationship between fixed "preset" sounds as the Ars Memorium slowly shifts between them. Interpolation between idiomatic sounds of genres or various synthesis tropes—especially those within a simulation—alters the perception of these tropes by destabilizing their status as fixed objects.

While we intended the Ars Memorium to provide a novel means of manipulating a relatively large number of parameters rather than simulating analog media, we chose to create a simulation of the VCA matrix I had previously designed for the hardware implementation of the Ars Memorium. This module, which was later named Enochian Tablet after a device created by noted renaissance alchemist John Dee, features 16 control voltage inputs correlating each of the four inputs to each of the four outputs in a matrix configuration. This works in such a way that an increase

[6] Magus Intrumentalis. *Ars Memorium*. Santa Cruz: Magus Instrumentalis, 2020. https://magusinstrumentalis.com/wp-content/uploads/2020/10/Ars-Memorium-Manual-V.1.0.pdf

or decrease in control voltage inputs 1 through 4 correlates to the first input signal passing through to the four respective outputs to a greater or less extent, with the second, third, and fourth signal inputs correlating to control voltage inputs 5-8, 9-12, and 13-16, respectively.

Given that recursive digital signal processing required greater computational power—which is one of the primary benefits of utilizing a recursive analog system—we opted to design a simulation that approximated the functionality of the analog matrix without emulating the components of that system. This initial version, which abstracted the functionality of the original design considerably, ran into issues that led us to simulate more granular features of the device. In particular, early versions of the module would generate a large DC voltage offset when used recursively. This issue was anticipated because, without some form of AC coupling or saturation, small amounts of DC current would be multiplied indefinitely. While the obvious solution was to high-pass filter the sound to block this current, this prevented non-recursive DC voltage matrix mixing, which was a potential use case we did not want to undermine. For this reason, we both offered DC filtering and an emulation of analog saturation as selectable options for the user. Due to the fact that we intended the module to be a functional substitute for a later analog implementation, we included these options in a “right-click” menu rather than include extra switches on the face of the module itself.

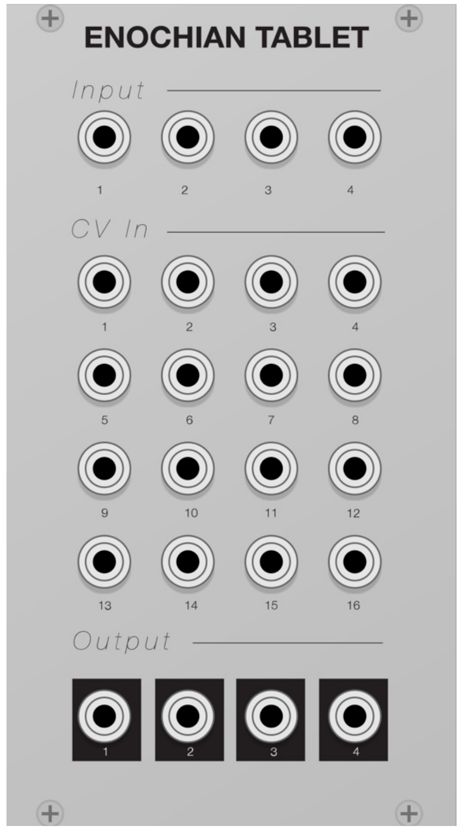

Figure 5.2 Enochian Tablet: VCA matrix

Madness Suite

Parallel to our work on the Polymaths Suite, we began the development of what later became the Madness Suite. This set of modules included a low-frequency chaotic oscillator, an audio-rate chaotic oscillator, a saturating mixer, a vactrol simulation, a low-pass gate, and a simulated analog computer. The design of our audio-rate chaotic oscillator Azathoth[7] derives from early experiments translating code into VCV Rack that Kant created for research purposes to model circuits from composer David

[7] Named after a deity dwelling at the center of chaos in Howard Philip Lovecraft's pseudomythology. Each module in this set refers to Lovecraft's fiction.

Dunn's *Thresholds and Fragile States* (2010). Two other modules, Eibon and Nyarlathotep, are modifications of circuits used in Dunn's chaotic synthesizer. In addition to this, we included Shoggoth—a module that includes many features of modules within the Serge modular system, without simulating any specifical module—as well as Hastur—a simulated vactrol—and Yog-Sothoth—a low-pass gate. Like the other forms of simulation that I have previously discussed, I will examine the ways that these simulations diverge from their analog precursors.

Prior to beginning work on this set of modules, Kant had extensively studied both the electronic and philosophical underpinnings of *Thresholds and Fragile States*. He has also recently documented his experiences analyzing and modeling the work in the essay *Measuring Infinity: Autonomy in David Dunn's Thresholds and Fragile States*.[8] It is the intention of this essay to consider how these designs were repurposed or modified to fit within a simulated Eurorack ecosystem, rather than to restate what has been well-documented elsewhere. However, to fully contextualize what was produced in our collaboration, it is worth summarizing Kant's research praxis with regard to the aforementioned work by Dunn, as well as providing a brief overview of the salient features of Dunn's composition and performance system.

Thresholds and Fragile States represents a culmination of Dunn's experiments with cybernetics, nonlinear systems, and chaos theory. According to an essay Kant created in collaboration with composer and researcher Madison Heying,

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[8] David Kant, "Measuring Infinity: Autonomy in David Dunn's," Conference on AI Music Creativity, July 2021, 9.

upon the discovery of nonlinear science, "Dunn's work shifted away from interacting directly with environments and towards modeling them by building nonlinear systems using electronics."[9] As Dunn's compositional process shifted towards an environmental model, he created electronic systems that allowed him to create sounds aesthetically akin to the emergent complexity of the sonic environment. This generative framework is now a common feature of popular and academic electronic music. The systems of dodecaphony, serialism, indeterminacy, and, later, process-music can be understood as attempts to introduce autonomous elements into music. However, the cybernetic relationship between the performer, composer, and electronic system in *Thresholds and Fragile States* distributes agency in a manner more comparable to David Tudor's feedback instruments.[10] Due to the complexity and orthogonal controls, the performer/composer acts as both a listening agent and an influence on the chaotic system that produces the sounds, rather than specifying the exact sounds.

The emergent complexity of an interconnected system of control and audio information is what first attracted me to analog modular synthesis and, later, chaotic circuits. Before I began my study of modular synthesis, my music was either written for traditional instruments, created with acoustic feedback, or procedurally programmed in visual programming languages such as Max or Pure Data. Early compositions such as *Etude for Nine Kinetic Sound Objects* (2010) consisted of

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[9] Madison Heying and David Kant, "The Emergent Magician," Sound American 19, accessed December 1, 2021, http://archive.soundamerican.org/sa_archive/sa19/theemergentmagician.html.
[10] Ibid.

primitive, algorithmic abstractions of environments. These early works were intended to run autonomously, often modeling simplified lifecycles for sound-generating entities and incorporating real-time data into the models. Modular synthesis offered the possibility of integrating the long-form autonomous processes I had been constructing within my algorithmic compositions, with the unpredictability, sonic complexity, and the intangible "organic" quality afforded by feedback and analog processing. When creating algorithmic compositions, there was very little that surprised me; the better I became at programming, the more determinate the results became. By contrast, the more that I understood about modular synthesis, the more it became possible to program complex, unpredictable feedback networks of semi-stable states.[11]

As previously mentioned, the Ars Memorium was designed to allow the user to save, map, and recall these states within a simplified two-dimensional matrix. Because feedback systems amplify minute changes, the interpolations of control voltages performed by the Ars Memorium do not often result in the linear interpolation of discrete sounds. Moreover, since these states are often highly dependent on initial conditions—with the character of the sounds changing over time—the speed with which the interpolations occur may also affect the sonic results on a moment-to-moment basis. While the Ars Memorium can be used in conjunction with a DC-coupled interface to produce control voltages—or through commercial

[11] I later found that low latency digital software, such as Kyma and VCV Rack, enabled similar complexity.

MIDI to control voltage converters—an obvious use for the device is to control complex feedback networks within VCV Rack itself. As a system designed to produce nonlinearity and feedback, Dunn's chaotic synthesizer from *Thresholds and Fragile States* seemed a natural choice. This process was greatly simplified by Kant's previous modeling of the electrical components used in Dunn's work. However, the translation of a bespoke, personalized synthesizer to a series of modules within the VCV Rack standard—intended for use in conjunction with the standardized set of modules we had already produced—created many challenges and required a number of alterations.

The two chaotic oscillators offer many of the same features but operate within different frequency ranges. As the chaotic attractors do not correlate to the same range of frequencies, we intentionally eschewed the volt-per-octave standard of frequency control used by most Eurorack and VCV format modules. Instead, the range of possible frequencies is approximately 31.25Hz to 2kHz for the audio-rate oscillator and 0.004Hz to 250Hz for the low-frequency oscillator.[12] These ranges vary depending on the characteristics of each chaotic attractor. There are outputs for the three dimensions of phase space in which the chaotic signal is rendered. Both modules have manual and voltage control for both the frequency and the chaotic attractor. The chaotic attractor can also be fine-tuned via an additional knob. The control input for the chaotic attractor passes through an attenuator, while the knob for setting the chaotic attractor acts as an offset. For Azathoth, the audio-rate oscillator,

[12] In both instances, this refers specifically to sinusoidal waveforms.

there is a parallel/series switch to the right of the chaotic attractor selection knob. This switches the signal path of the control voltage input on the chaotic attractor between a series and parallel resistor connection. Series is the normal operating mode — the modeled resistors add together on the control voltage input. The parallel mode operates similarly to a minimum function and will shut off the output unless the user manually adjusts the chaos knob or introduces a signal into the frequency input.

Hastur is a simulated vactrol. Vactrols are an early implementation of voltage control, also known as optocouplers. They consist of a photoresistor and a light source, typically an LED. When voltage is sent into the LED, it increases the amount of light it emits and controls the amount of signal which can pass through the photoresistor. This allows an engineer to replace the potentiometers in circuits with vactrols to enable a simple form of voltage control. While there are more sophisticated forms of voltage controlled analog signal attenuation, such as the use of operational amplifiers, modular synthesizer manufacturers such as Make Noise, Verbos Electronics, Doepfer, L1, Mystic Circuits, Tokyo Tape Music Center, Takaab, Meng Qi, and many others employ vactrols in their modules, because of the unique envelope shapes they produce. Due to the electrochemical properties of photocells, near-instantaneous changes in voltage will be slewed, with longer slew times for decreasing voltages. By passing a trigger through the LED, the vactrol will attenuate the sound with an envelope that is useful for synthesizing percussive and plucked string sounds.

While there are Eurorack modules that allow for vactrol control of other modules, such as the Deopfer A-101-9 Universal Vactrol module,[13] these are designed to semi-permanently modify other modules through soldering. Hastur was created to expose the vactrol simulation to a variety of applications. One use is to place Hastur between a control voltage source and a VCF or VCA. This allows the user to apply vactrol envelopes to a variety of filter or amplifier types. It may also be used as a nonlinear waveshaper.

Related to Hastur is Yog-Sothoth, a low-pass gate emulation. A low-pass gate combines a voltage-controlled low-pass filter with a VCA, allowing the user to attenuate the higher frequencies in tandem with the overall amplitude. Combined with the vactrols typically employed to allow for voltage control, it is possible to use a low-pass gate with a gate or trigger source rather than a traditional envelope to control the dynamics and harmonic structure of the sound. While this technique is primitive when compared to frequency modulation or physical modeling methods used in later synthesizers, the nonlinearities within each section of the circuit allow for complex behavior to emerge.

To create this module, we began with a prototype filter design which was converted into a VCV module. This allowed for experimentation with various parameters in combination with other modules and real-time comparisons between each option. Many of the parameters included in this prototype were not intended for the final product but allowed us to exchange saved VCV patches with the module

[13] "A-101-9." Accessed November 14, 2021. https://doepfer.de/A1019.htm.

configured in particular ways to make determinations about what values we were going to use for each parameter in the final design. One example of this was the "maximum" frequency of the filter: if the filter passed frequencies above 8kHz, it was possible for the resonance to alias at many of the available sample rates.[14] We considered incorporating an anti-aliasing filter into the design but found that the maximum frequencies of many of the analog low-pass gates we tested were less than 8kHz. Other controls that were specific to the prototype included a shape control for the resonance, a "self-modulation" parameter that added even harmonics, and a post-filter saturation setting.

This development process within a modular synthesis environment also allowed us to use modules we had previously developed to define the values of each operational parameter. We used Hastur's unique ability to apply vactrol characteristics to various sections of the circuit and discover envelope shapes that we felt best suited the sound of the low-pass gate. We experimented with applying simulated vactrols to the linear frequency and amplitude controls as well as an exponential input that controlled both. While it was possible to include a vactrol simulation for each input, this added to the use of processing time and diminished the ability of the user to introduce audio-rate modulation of these parameters. Ultimately, we decided that the best results were obtained by applying the vactrol exclusively to the linear frequency input of the filter. While we removed many of the available controls from the Hastur implementation of the vactrol simulation, we included a

[14] VCV Rack offers up to 16X oversampling, or a sample rate of 768kHz

“Vactrol Envelope” knob to allow the user to shape the attack and decay curve of the simulated vactrol—providing the user with a means of simulating a wider variety of low-pass gate designs. This particular control was created by examining the response curves on vactrols in extant modules and interpolating between them.

A Lambent Mirror for Remote Ontographies of Nested Infinities

Much of the preceding dissertation concerns determining what properties, if any, could be identified as characteristic of digital media and how simulation is incorporated into digital aesthetics. I have shown how these distinctions become problematized in modular synthesizers that include analog interfaces for the control and processing of audio-rate signals. While I had intuited during the writing process that the intermingling of digital simulations and analog signals—especially in a configuration where audio-rate information interacts recursively between a large number of points—was capable of producing unique aesthetic results, I had not found examples of this in significant compositions, until recently.

A Lambent Mirror for Remote Ontographies of Nested Infinities is a forthcoming four-channel autonomous sound installation from David Dunn that consists of an analog Eurorack modular system interfacing with two computers running VCV Rack. While the work is not in its final form, Dunn anticipates both an installed version using four coaxial speakers and a single subwoofer, as well as a binaural rendering used for streaming purposes. The work plays continuously without interaction from the composer or external sensors for environmental input. The

Eurorack modules interface with the computers through DC-coupled interface modules such as Expert Sleepers ES-3, ES-8, and ES-9, which allow for audio and control-rate signals to be passed between a computer and the modular system. According to Dunn,

> At its heart are five Magus Instrumentalis virtual modules (3 Nyarlathotep and 2 Azathoth). Most of the complex sounds are generated by the two audio rate chaotic oscillators (Azathoth).[15]

These simulated analog chaos modules interface with the physical Eurorack modules to produce the sounds of the installation. Due to the high sample rates and small buffer sizes achievable with VCV Rack, it is possible for audio rate modulation to pass bidirectionally from the Eurorack system and the simulated modules without noticeable sonic effects. However, the 96kHz sample rate specification of the Expert Sleepers ES-8 and ES3—the audio interfaces used to connect these systems—and the minimum processing block size of 64 in VCV results in a 1.4-millisecond delay upon sending and returning the signal from the interface—which can produce audible effects in feedback configurations. In the screenshots Dunn provided for me, no audio-rate feedback connection appears in either VCV patch.

[15] David Dunn, "The Use of Your Modules," December 9, 2021.

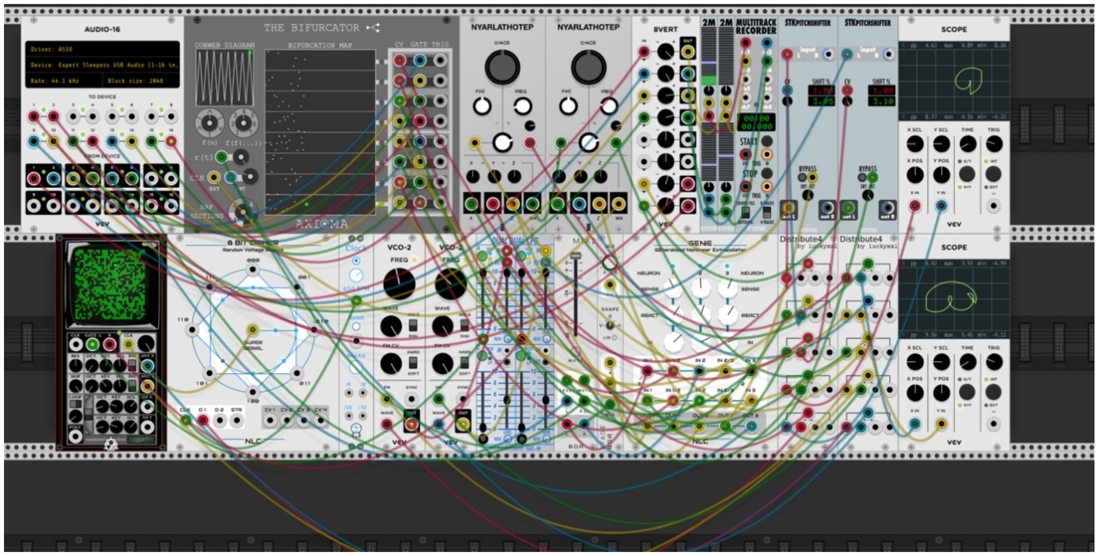

Figure 5.3 VCV Patch 1 for David Dunn's *A Lambent Mirror for Remote Ontographies of Nested Infinities*

Dunn decided upon the use of Azathoth to produce the majority of the sonic material because of "the tightly truncated attractor that allows such fast switching between complex states."[16] This shifting between complex states is a fundamental element of the work: both of the overlapping voices do not retain pitch or timbre characteristics for longer than a few seconds at a time, often shifting within fractions of a second. The waveforms are frequently sinusoidal—foregrounding the harmonic relationship between the two voices at moments. However, the frequent pitch changes and shifts into unpitched sounds direct the listener's attention to the processes that give these sounds form. Despite the musicality of the work, the piece ultimately emphasizes the processes directing the sound-producing agents and how these might relate to the complexity of environmental sound.

[16] Ibid.

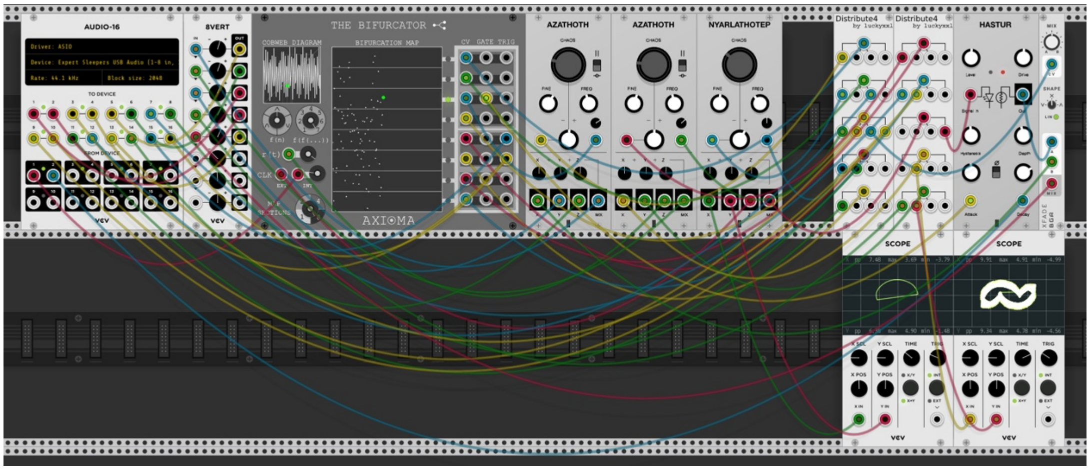

Figure 5.4 VCV Patch 2 for David Dunn's *A Lambent Mirror for Remote Ontographies of Nested Infinities*

Conclusion

Given my earlier observation that simulations are best understood as a reflection of both the designer and the technology, I feel compelled to assess the modules I took part in designing from this perspective. The process of designing the Polymaths and Madness suites offers a characteristic illustration of the complexities of simulation. Some of the designs grew out of projects that had begun long before my involvement. While we designed some of the modules to emulate the electrical properties of analog systems, still others were abstractions of the functionality and sound of extant module designs. Often, I was able to verify Kant's code in direct comparisons with the circuit designs that the modules were based on, while in the case of some modules—such as the Model 110 low-pass gate in the San Francisco Tape Music Center Buchla system—I was forced to rely on my memory of the device. Unlike other projects where I have developed simulations, I did not write or inspect the DSP code—my work consisted of developing the interface and functionality while exchanging ideas with Kant. These exchanges took the form of written and spoken conversation, “issues” on the software development host Github, audio recordings of relevant sounds, and patches using prototype versions of the modules.

My attention to the minutia of the development process for simulations raises the question of what extent these details become relevant in understanding the music made with these systems. In the case of Dunn’s *A Lambent Mirror for Remote Ontographies of Nested Infinities,* the modules are derived from circuits with Dunn’s handmade chaotic synthesizer. However, the implementation of properties distinct to the simulation reflects the performance practices and aesthetic interests of both Kant and myself. For example, the “tightly truncated attractor” that Dunn found inspiring was implemented in the earliest VCV prototypes and is reflective of Kant’s interest in providing immediate control of a variety of single and double scroll chaotic attractors. However, some of the features, especially those that conform to the expectations of Eurorack design, were a result of my intervention. For example, early versions of the design lacked an external frequency control input. Kant added this control upon my suggestion, based on my understanding of how a chaotic oscillator would be utilized in a modular system. Nyarlathotep—the low frequency chaotic oscillator—was similarly created based on both Kant’s audio-rate design and my experiences using low-frequency, fixed-attractor, chaotic oscillators in the Eurorack format such as the nonlinearcircuits Sloth.

How does one attribute agency in these circumstances? I do not believe one can fully appreciate Dunn’s work only by listening to the sonic outcome—it is antithetical to the nature of the work to do so. The sonic content continually changes. One does not listen for a carefully chosen organization of pitches, amplitudes, and timbres but for the possibilities that are contained within a system. As a listener, I can hear sonic elements I first observed in Kant's early prototypes, I also hear sounds that are a result of my work to bring these ideas into conformity with Eurorack standards, and finally, I can hear both Dunn's earlier works such as *Thresholds and Fragile States*, as well as his interest in the properties of a new formulation of chaos with unique properties only possible in a digital implementation. My large-scale work *IX* (2022), which also uses Nyarlathotep to structure the sonic content of the work, is similarly influenced by the intellectual history of the module. Simulation, much like chaos itself, is best understood as a nonlinear information system.

CONCLUSION:
AN AESTHETICS OF SIMULATION AND FAILURE

Two conflicting ideals inform the development of media technology: one of immediacy and one of accommodating imperfect realities. The seductive myth of the digital computer promises it will imbue programmers with God-like powers to compose idealized worlds out of abstract logic. However, these abstractions produce an uncanniness or lifelessness that often highlights the limitations of the medium used to render these abstractions. To simulate the complexity of the analog world, programmers must collect data from it (sampling) or abstract features of it in increasingly complex ways (synthesis).[1] There is a certain exhilaration associated with the latter method. Corry Banks from Modbap Modular described this experience as "seeing into the matrix,"[2] referring to a scene in the 1999 film in which the protagonist Neo sees the data that literally[3] makes up the world around him for the first time.[4] This feeling of having captured some small part of the underlying structure of reality stems from the relationship that connects a simulation to its object. This connection has as much to do with understanding human perception as with technology, especially when simulating sounds rather than modeling electrical components.

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[1] Recursive neural networks represent an attempt to combine both methods in an automated system.
[2] Banks, Corry. *ModBap Modular Interview*, January 2, 2022.
[3] While it is also inarguably a visual metaphor, the filmmakers display lines of code occupying the space where objects had previously been—making the metaphor literally true in the diegesis of the film.
[4] Lana Wachowski and Lilly Wachowski, *The Matrix - Standard Collector's Edition*, 1999.

The cultural domination of simulated analog media began with the introduction of personal computers, digital synthesizers, and game consoles in the late 1970s and has grown in prominence ever since. The use of digital synthesizers to simulate analog instruments remains ubiquitous in popular music. Beginning in 1978 with the New England Digital Synclavier,[5] Yamaha's implementation of phase modulation synthesis became the dominant means of simulating analog instruments, before sample-based workstations, such as the Korg Trinity, superseded this method in the late 1980s. By 1986, a single preset from the phase modulation-based Yamaha DX7[6] was featured on 61% of pop, country, and R&B number 1 singles featured on the United States Billboard charts.[7] This preset, designed to replicate the sound of an electric piano, is but one of many simulations included in the device that have been used on popular recordings. Simulations of media technologies form the basic toolset for composers and sound designers. They appear in most films, popular music, and video games. It is difficult to over-emphasize how pervasive these sounds are.

One of the anxieties I experienced while preparing the preceding document was the distinct sense that simulated mediation and nostalgia would soon recede in relevance. Despite the prevalence of simulated mediation, there were many times I found myself asking if it would remain a useful means of characterizing media. I can

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[5] New England Digital licensed phase modulation synthesis technology from Yamaha.
[6] The DX7 employed six sine wave oscillators, referred to as operators, that the user could configure in 32 different signal and modulation routings or "algorithms" in Yamaha's parlance. This modulation architecture, when combined with the complex envelopes in the synth, meant that it was possible to design complex timbral changes akin to acoustic instruments.
[7] Megan Lavengood, "What Makes It Sound '80s?," Journal of Popular Music Studies 31, no. 3 (September 3, 2019): 73–94, https://doi.org/10.1525/jpms.2019.313009.

recall when the non-diegetic simulation of analog media felt novel and uncanny. At present, it is so ubiquitous that individual instances of it fade into background noise. It is easy to imagine that, given its near ubiquity, simulation of the "failures" of previous media technologies has lost its relevance as an aesthetic or semantic intervention. When I interviewed Scott Harper, who has reviewed a number of "lo-fi" guitar pedals for his YouTube channel Knobs, he expressed a similar sentiment:

> These lo-fi sounds they're very popular. Aside from your typical overdrive, they're right there up there with the most popular effects. I wonder if, in five or ten years, that these sounds become so commonplace that we stop thinking about them as nostalgia and making things sound old again, and they just become another texture. They become another way of listening to sound, and that nostalgic aspect goes away, or whether that's always going to be attached to them.[8]

As digital media reach levels of clarity that extend far beyond the limits of human perception, one might assume that new media technologies will cease to influence aesthetics. However, such an assumption underestimates the tenacity of failure, especially in communications media. Failures to communicate, meet expectations, account for real-world conditions, or understand the basic product abound. Well-designed systems may account for sub-optimal conditions, but these solutions are never perfect. During the course of writing this dissertation, all communications within the University of California system became remote due to the COVID-19 pandemic. As my teaching duties were transferred to Zoom, I became

[8] Harper, Scott. *Knobs Interview*. January 5, 2022.

intimately familiar with a variety of newly significant “imperfections,” chiefly the dynamic time-stretching of audio that occurs during gaps in the received information.

As the percentage of our mediated interactions increases, so does our ability to hear the specifics of mediation. During my interview with Devin Kerr, he recalled requests from engineers in professional studios for a plugin to recreate the “Twitter lossy snare compression sound"[9] or the sound of the iPhone 4’s internal microphone. The attraction to these sounds is not limited to audio professionals: I was recently delighted to discover a friend’s preference for the sound of a pop song played at 175% of the original speed through YouTube’s time compression algorithms. While it is conceivable that the simulation of media will become less prevalent, it is unlikely that those who remain interested in mediated or low fidelity sound will find future media lacking.

I will now return to the poetics of media in sound, expressed as a distribution of agency between humans and media. Scholars as disparate as Marshall McLuhan, Donna Haraway, Andy Clark, and Bruno Latour have argued for various forms of distributed agency between humans and technology. While the image of the cyborg conjured up by discussions of the fusion of human and machine is often radical,[10] by focusing on the mundane aspects of techno-cultural interaction, I emphasize the historical continuity of musical interactions with technology. I suspect that part of the reason for Marshall McLuhan’s continued popularity among musicians stems from

[9] Kerr, Devin. *Goodhertz Interview*, 2021.
[10] Such as the screaming, melting, bleeding “metal fetishist” of *Tetsuo: The Iron Man* (1989), to name one example.

the fact that extending one's consciousness into a technological object is an essential aspect of performing with an instrument. An instrument imparts its form onto the music it helps to create. Moreover, new forms of instrumentation inform the creation of new forms of music. Extended techniques expand upon the accepted uses of an instrument but do not change its fundamental physical limitations. While composers and improvisers may modify their instruments, this is, definitionally, an engagement with the instrument's limitations, even if one regards this as an attempt to overcome them. Even hacked or circuit-bent instruments cannot overcome every limit of the original devices.

The model Claude Shannon developed for the transmission and reception of information ultimately fails to account for mediation as a generative, creative process. The compositional techniques of western classical music—a set of practices that have had a stranglehold on the teaching of music in the United States—follow the model of information theory: the composer uses the written score as a message that is imperfectly transmitted by the performers before it is received by an audience. Simulations of analog media result from designers' attempts to recreate or extend the information generated by mediation. There would be little point in simulating media if mediation only distorted or obfuscated the intended message. As I have shown, mediation may enhance the definition of information, provide additional semantic or semiotic information and, subjectively, improve the aesthetic experience of the received information. Rather than focusing solely on the ontological crises brought about by perfect simulations, it is essential to acknowledge that, within the arts, the distinction between the "real" and the mediated is evaluated in terms of aesthetics and not of ontological status.

Within the past decade, critical music scholarship has begun to acknowledge and overcome the limitations of information theory. Authors such as Ezra Teboul,[11] Madison Heying,[12] You Nakai,[13] Ted Gordon,[14] and Kenneth McAlpine[15] have written about musical form in relation to the technological and formal properties of instruments. Theorists such as Jonathan Sterne have written about the aesthetic and cultural reception of media technologies, formats, and instruments. My contribution to this discussion is to lend equal weight to the aesthetic contributions of mediation to the specific sounds that qualify as music and "nonmusical" sound within the general media ecosystem. Musical practices, while relevant, are far from the only sonic practices worthy of study. Nor is music the only subject worthy of critique. As the earlier example from Michel Chion shows, listening practices for film often center around a contradictory and fallacious understanding of fidelity.

The study of simulation is a means of analyzing both the cultural reception of mediation and the means through which it is abstracted. Simulations are marked by inherent differences from the objects of simulation, and these divergences lead to differing functionality and, in the case of musical use, differing music. While

[11] Ibid.
[12] Madison Heying "A Complex and Interactive Network: Carla Scaletti, the Kyma System, and the Kyma User Community" PhD Diss. (University of California, Santa Cruz, 2019).
[13] You Nakai, *Reminded by the Instruments: David Tudor's Music* (Oxford University Press, 2020).
[14] Melle Jan Kromhout, "Noise Resonance: Technological Sound Reproduction and the Logic of Filtering" PhD Diss. (University of Amsterdam).
[15] Kenneth B. McAlpine, *Bits and Pieces: A History of Chiptunes*, Illustrated edition (New York, NY: Oxford University Press, 2018).

“remediation” correctly identifies that representation, recreation, and simulation are cultural activities that connect new forms of media to previously hegemonic technologies, the differences in how each technology renders media are equally relevant. To understand modern cultural practices surrounding electronic music and the sonic arts, it is necessary to avoid exclusively analyzing media technologies as vessels for information. I am not claiming that the form of mediation is the only information expressed. The poetics of mediation are not only the aesthetics of the medium itself—although, in autonomous systems where feedback is employed, this might be the case—but how these properties interact with or construct other forms of media.

Simulation exposes these poetics as the salient features of the simulated media technology and the simulation designer’s relationship to that technology. Tom Majeski’s Generation Loss pedals and their variable aliasing, or the Packet Repeat mode of Goodhertz’s Lossy, extend beyond the technology they were explicitly simulating but connect to cultural experiences the designers related to VHS and MP3, respectively.

While there are notable exceptions to the use of digital computers for simulation, it remains the dominant mode of aesthetic expression in computing. Practices such as dither demonstrate that modern computer interfaces exhibit this tendency at the most basic levels of information processing. While such practices are often dismissed as nostalgic or regressive, they are not only of great interest to the designers, engineers, and manufacturers I spoke with but continue to influence the sounds of popular culture. Rather than breaking immersion, modern consumer virtual reality products use the look of simulated film or VHS tape to immerse users in an "analog" aesthetic. Despite the marketing of greater transparency and definition by companies such as Meta, immediacy is a false promise. Simulated mediation cannot be dismissed as nostalgic; it is a means of abstracting and representing individualized and social experiences with technology. Sound cannot exist in a vacuum; it requires a medium. For sound, there is no "listening beyond" media.

One of the most significant influences on my artmaking and worldview is the appreciation I have for the poetics of unintentional sound. In a speech for the 14th International Conference on New Interfaces for Musical Expression, the sound artist Laetitia Sonami recalls how the development of her instrument, the Lady's Glove, altered her desires as a maker. She connects the invention of instruments focused on control to imperialism, stating, "We so want to explore and dominate an unknown, yet leave it behind as soon as it becomes domesticated. Dreams of control turn into dreams of chaos."[16] Simulations seem to abstract away much of this chaos, and yet the anecdotes I have collected tell a different story, one in which the uses of simulation extend far beyond the intentions of the designer. These simulations of media technologies offer interfaces to the entire spectrum of audible sound, and it is impossible to know the results of every form of interaction. As an artist working in sound, I often wonder how simulations can serve as readymade or autonomous

[16] EAVIgoldsmiths, NIME2014 Goldsmiths: Laetitia Sonami Artistic Keynote: DREAMS OF CONTROL, DREAMS OF CHAOS, 2016, https://www.youtube.com/watch?v=nEkufXDb-Ro.

systems. Is exposing the failures of a simulation more interesting than allowing it to function properly? Rather than answering and thus domesticating these questions, the preceding dissertation documents the uncanny lacunae within simulated media as spaces for artistic endeavor. At a moment of inescapable neoliberal optimization, an aesthetics of simulation and failure offers one of the last sites of resistance.

APPENDIX:
MAGUS INSTRUMENTALIS MANUALS

Ars Memorium

Introduction:

The Ars Memorium, at its core, is a voltage source with state memory and recall. It is capable of producing 16 arbitrary functions at once and providing two-dimensional interpolation between saved states. All of its functions are mapped to X and Y coordinates—allowing for a wide range of audio applications, including patch preset design and interpolation, LFOs with user-programmable shapes, sequences with an arbitrary number of steps, precise recall of complex feedback patches, dense Xenakis-esque glissando, quadraphonic panning and many other forms of linked, user-defined modulation.

Most modular patches have several "sweet spots" where the settings line up just right to produce the sound you are looking for. Historically the problem has been how to return to these spots once you have moved on to another sound. The Ars Memorium solves this problem by saving the state of each of its control voltage outputs into a two-dimensional matrix. This allows the user to not only recall the most interesting settings for a patch but also to position these settings in a meaningful spatial relationship to each other and morph between these to produce new, interstitial states.

Despite all the complexity it is capable of producing, the Ars Memorium is based on very simple principles: the user saves states in Edit Mode by organizing them in a two-dimensional space using the X and Y knobs and interpolates between them by the same process.

One analogy is a preset system in a traditional synthesizer. Presets are an ordered list of settings about things such as the frequency cutoff of a filter, the shape of the ADSR envelope, etc. When the user selects a new preset, they are instantaneously taken to the new sound. The Ars Memorium "morphs" between the two sounds. Many of the example patches for controlling traditional synthesizers over MIDI CC are a useful starting point for understanding why this is unique.

Another way of thinking about this is to compare it with automation in digital audio workstations (DAWs). In DAWs, automation tracks allow you to set the value of various plugins at various points in time. The Ars Memorium is, by comparison, extremely non-linear—allowing the user to move through the saved plot at whatever pace they choose.

Front Panel:
Take a look at the front panel. You will notice a 4 x 4 array of knobs in the top left. Each of these knobs relates to a single output, the 4 x 4 array of jacks on the right contains outputs related to the corresponding knob so that the top left knob controls the top left jack, etc. Each of the 16 control voltage sources can be programmed to a set "state" via the associated knob. The output range of the 16 control voltage outputs is set to 0-10 volts by default. The input range of the "X" and "Y" control voltage inputs is 0-10 volts.

In Use, Understanding Edit and Recall Modes:
Examine the switch in the bottom right corner. When it is flipped up, the module is in Edit Mode; when flipped down, it is in Recall Mode. In Edit Mode, the indicator LEDs above the knobs are red. In Recall Mode, these LEDs are blue.

In "Edit Mode," the control voltage output directly reflects the position of the knobs—making it a static voltage source. Try it for yourself. Unless you need 16 fixed offset generators, this may not seem useful. However, below the 4 x 4 grid of knobs, you will see two larger knobs marked X and Y. Give them a twist. Between the "X" and "Y" inputs, there are two buttons labeled "save" and "delete ."Click the save button. Now repeat the process. You will notice that there are now two additional dots on the screen to the right of the "X" and "Y" knobs; these are the location of your saved states. If you need to delete your last state, simply press the "delete" button. Before we test this out, you will need something to control using the Ars Memorium. The pitch of an oscillator is a good first choice because it is very clear what the modulation is doing.

Now switch the module into Recall Mode via the switch on the bottom of the module. Then begin turning the "X" and "Y" knobs, and you will notice that the closer you are to a particular point, the closer the output voltage is to the state you save. Again, this may not be particularly interesting with one source, but play around with multiple outputs and saving multiple points in the matrix. You will very quickly find that it is quite intuitive to map everything you want to control about your sound to a function generator in the Ars Memorium.

Keeping track of whether you are in edit and Recall Mode is fundamental to understanding the module. With this in mind, let's compare these modes directly. The primary purpose of Edit Mode is to program your patch and find interesting sounds.

Where you would normally find a sound by setting the value of knobs on the module itself, when using the Ars Memorium, you use the CV inputs on whatever module you are using to control these values instead, with each value you want to control mapped to a knob on the Ars Memorium via a patch cable. Once you have found sounds you like, you click on the Save button. When you have saved all of the sounds you like, you flip the switch into Recall Mode.

In Recall Mode, the knobs can be used to make edits to the values at various states or to create new states but will not directly affect the output as they do in Edit Mode. In Recall Mode, the value of each output is the result of interpolation between all the various states you have saved within your matrix. These values are displayed on the LED indicators above the knobs, as well as on-screen when "knob plot" is selected via the menu system. In addition to the labeling of the switch and the LED indicators, one way to determine whether you are in Recall Mode is to watch the screen when you are turning the knobs. In Recall Mode, you will see a display showing the current value of each of the knobs. In Edit Mode, this information would be redundant and therefore does not appear.

One final difference is that in Recall Mode, the interpolation knob and interpolation CV input become functional. This controls how close the pointer has to be to a saved state before it begins to interpolate. In some instances, it may be important to stay as close as possible to a saved state. In others, you may want to interpolate between various points across the map all at once. All of this is possible with the interpolation knob. Turning it to the left decreases interpolation.

Menu:

In order to facilitate changes that are less likely to be accessed during regular performance use, we have implemented a simple menu system. You can use this system to save and load entire plots (collections of all the states you have saved) as well as view the state of the knobs--something that is especially valuable in Recall Mode where the knobs on the front panel will not reflect the changing output voltages. To access the menu, simply click the button to the right of the screen. From this, you can make your selection by turning the knob immediately below it and pressing the button once you have made your selection.

Saving and Loading Plots:

To save a plot, select "save plot" from the main menu. You will then see a matrix of symbols laid out in rows and columns. Select any symbol you like and click using the menu button to save. Once you do so, you will be greeted with a "Plot Saved!!" message to let you know that your information was saved. To load your plot, simply select the slot you previously saved into and click the menu button. In both cases, you can go back to the main menu by selecting the left-facing arrow in the bottom right corner.

Knob State:

As stated previously, this menu provides the user with the ability to see the state of the output jacks in Recall Mode. In an ideal world, the knobs would move in tandem with the interpolations between various states in Recall Mode, since this is not possible (in the specification of VCV and in a real eurorack module) we have provided this menu option. On the left side of the screen, the state of each of the 16 outputs is visible. The indicators on the virtual knobs show the value of that particular output. If you want to create a new state based on the state of the outputs in a particular location, this is a great way to accomplish this. To return to the main menu, simply click the menu button.

Technical Documentation

This section contains more in-depth technical information in contrast to the "quick-start" guide.

Main Function: Interpolation

In *Interpolation*, states are located in a two-dimensional interpolation space according to their (x, y) coordinates. State recall and interpolation are performed using Inverse Distance Weighting, which weights neighboring states inversely proportional to their distance from the recall position. Neighbors that are located outside a given *interpolation radius* are zeroed and do not contribute at all. *Interpolation* is the primary intended functionality of the module.

Controls

- **CV Matrix (knobs):** Program and save matrix states. In *edit* mode, values are passed directly through to the CV outputs 1-16 for audition. In *recall* mode, CV matrix values are set "silently," but can still be used to program and save interpolation states.

- **X (knob):** Interpolation `x` dimension. In *edit* mode, the `x` position is set, but does not trigger interpolation recall.
- **Y (knob):** Interpolation `y` dimension. In *edit* mode, the `y` position is set, but does not trigger interpolation recall.
- **Interpolation (knob):** This control determines the interpolation radius. A small radius considers only nearby states in interpolation, whereas a large radius considers distant states as well. States outside of the interpolation radius do not contribute at all.
- **Save (button):** Save the current CV matrix state. Adds a state to the 2d plot at the current (x, y) position using the current CV matrix values.
- **Delete (button):** Delete the most recently added state from the 2d plot. Pressing delete multiple times removes multiple states.
- **Edit/Recall (switch):** Toggle between *edit* and and *recall* modes. Edit Mode is intended for programming the 2d plot, and Recall Mode is intended for exploring the interpolation space.
- **Program (knob):** Use this knob to interface with the program menu, which allows switching between views as well as saving and recalling plots.
- **Display (button):** Select options from the program menu.

Inputs / Outputs

- **Matrix Outputs 1-16 (CV out):** Random search output. In *edit* mode, CV matrix knob values are passed directly through to output.
- **X (CV in):** Offset for `x` control. ● **Y (CV in):** Offset for `y` control.
- **Interpolation (CV in):** Offset for interpolation radius control.

Alternative Function: Random Search

In *Random Search*, the module generates random matrix states and interpolates between them. The module interface is refactored to control the rate at which new states are generated and the speed of interpolation between them.

Note that the *Random Search* function does *not* use the stored matrix states but rather generates new ones on the fly. You can save states found in the *random search* function for recall in the *interpolation* function.

Controls

- **CV Matrix (knobs):** Center of random search range. Use this to offset the search range. Center is set separately for each of the 16 channels.
- **Duration (X knob):** Duration between random states, from 0 to 6 seconds.
- **Hold (Y knob):** Hold determines the interpolation speed—like portamento, set as a fraction of duration, from 0 to 100%.
- **Range (Interpolation knob):** Range of random search. This is set universally; one value controls all sixteen channels.
- **Save (button):** Save the current random state. In *random* function, states are added at a random (x, y) position. The 2d plot is shared between *interpolation* and *random* functions.
- **Delete (button):** Same as in above—delete the most recently added state.
- **Edit/Recall (switch):** Toggle between *edit* and and *recall* modes. Edit Mode is intended for programming an initial state (search center), and Recall Mode is intended for exploring the random search space around that state.
- **Program (knob):** Same as in above. ● **Display (button):** Save as in above.

Inputs / Outputs

- **Matrix Outputs 1-16 (CV out):** Interpolated output. In *edit* mode, CV matrix knob values are passed directly through to output.
- **X (CV in):** Offset for duration control.
- **Y (CV in):** Offset for hold control.
- **Interpolation (CV in):** Offset for range control.

Azathoth

Outside the ordered universe that amorphous blight of nethermost confusion which blasphemes and bubbles at the center of all infinity—the boundless daemon sultan Azathoth, whose name no lips dare speak aloud, and who gnaws hungrily in inconceivable, unlighted chambers beyond time and space amidst the muffled, maddening beating of vile drums and the thin monotonous whine of accursed flutes.

- Howard Philips Lovecraft

Monotonous whines? Check. Accursed flutes? Just possibly.

Azathoth produces chaos apprehended through the auditory sense. Unlike Nyarlathotep, there is absolutely no way this will help you make Berlin-school techno or ambient music for your succulents. There are outputs for three chaotic dimensions. It has manual control and voltage control for both the frequency and the chaotic attractor. The chaotic attractor can also be fine-tuned via an additional knob. The control input for the chaotic attractor passes through an attenuator, while the knob for setting the chaotic attractor acts as an offset.

It is possible to mix between all three chaotic dimensions (labeled X, Y, and Z) using the three attenuators above the three outputs. NOTE: these do not attenuate the signal of the individual outputs, only the mix output.

There is a *parallel/series* switch to the right of the chaotic attractor selection knob. This switches the CV modulation on the chaotic attractor between a series and parallel resistor connection. Series is the normal operating mode — the resistors simply add up, and it is equivalent to the usual behavior of CV input. The parallel mode operates similarly to a minimum function and will shut off the output unless you increase the chaos knob or input a signal. Sonically speaking, this can sound a bit like a wavefolder, or a dial-up modem, depending on the type of signals you send into the chaotic attractor CV input.

While there is a lot to understand about chaos (we strongly recommend James Gleick's book *Chaos: The Making of a New Science* as a primer on the basic concepts), the preceding information is all you need to begin using the module. While, as previously mentioned, the module is less musically flexible than any of the other modules in this set, there are other ways to use Azathoth that are less likely to annoy your neighbors: each of the chaotic attractors offers a good starting point for percussive patches. Look for the demo patches on our website for examples of this.

A Word on Chaos:

Chaotic systems are, technically speaking, deterministic — that is, not random. Given the state of a chaotic system at one moment, it is possible to compute — with full certainty — the state of the system at the next moment. This is different from random systems, in which there is, by definition, some amount of uncertainty involved. Chaos, however, is often understood colloquially to be synonymous with randomness, and the confusion comes from the odd fact that, in practice, chaotic systems can be unpredictable. This uncertainty, however, comes from factors external to the system. Chaotic systems are so sensitive to small deviations that very tiny measurement errors (even floating-point truncation errors) can cause significant divergences in output, making the system difficult to predict, practically speaking.

While chaos is interesting from a technical and philosophical perspective, you may be curious what the musical consequences of chaos are and why you might reach for a computationally expensive chaotic oscillator instead of a random source. Let's look at a few musically relevant properties of chaos:

1. Sensitive dependence on chaotic attractor shape. The shape of the chaotic oscillator is very sensitive to small changes (that's why we include a fine-tune knob), so it can be seemingly unpredictable when modulated or just too sensitive to control effectively. There's a lot of fun in those "edges of chaos" between chaotic attractors.

2. Most of the patterns produced by the chaotic oscillator are more structured (more periodic) than random signals. So, it's not necessarily a source of randomness but more like a source of continued variation on a theme. You get these wonky loops, but the loops are a little bit different each time through.

I/O:

Knobs:

- **Attractor:** Chaotic attractor, or waveform shape. This knob controls a variable resistance in the circuit model. Adjusting it brings the oscillator through a family of double and single scroll attractors, including chaotic waveforms as well as sinusoidal, periodic, and quasi-periodic patterns.
- **Attractor Fine:** Fine-tune adjustment to the chaotic attractor.
- **Frequency:** Oscillator frequency. Note, frequency values are *approximate* because the resonant frequency of the oscillator is dependent on the current attractor as well!
- **X Mix:** X mix level.
- **Y Mix:** Y mix level.

- **Z Mix:** Z mix level.
- **Attractor CV Attenuverter:** Attractor CV input attenuverter.
- **Frequency CV Attenuator:** Frequency CV input attenuator.

Inputs/Outputs:

- **Attractor (CV in):** Attractor CV input.
- **Frequency (CV in):** Frequency CV input.
- **X Output:** Oscillator output.
- **Y Output:** First derivative of oscillator output.
- **Z Output:** Second derivative of oscillator output.
- **Mix Output:** Mixed signal output.

Right-click options

- **Actions** (Reset Initial Conditions): Reset oscillator signals to initial starting values. Use this to reset the oscillator (if it blows up) without clearing your parameters (as a full "Initialize" would do).
- **CPU Load (**Low, Medium, High, Very High): These values determine the numerical solver accuracy (time step). Higher accuracy solutions require a greater CPU load. Higher accuracy tends to sound "smoother," as the oscillator stays closer to the true signal orbit
- **Solver** (Euler, Rk2, Rk4): Selects between different numerical solver algorithms. Euler requires the lowest CPU load and Rk4 the highest. Each solver has slightly different noise profiles. Due to the particular nonlinearities of this oscillator, increasing the accuracy ("CPU Load") is generally better (more accurate) than using a more computationally expensive solver.

A few notes from DK

- The "Attractor" knob adjusts a variable resistance in the circuit model, which affects the oscillator waveform pattern.
- Transitions between attractor patterns can be extremely sensitive and difficult to control, which is why we have a fine-tune knob.
- The oscillator attractor (waveform pattern) exhibits hysteresis — the waveform pattern is dependent not just on the current "attractor" value, but also on the previous oscillator state. You might find when using the oscillator that it doesn't always return to the same attractor when you set the knob to the same value. This is why.
- The ability to change oscillator frequency is unique to the digital model.
- Chaotic systems are often visualized in phase-space, which plots the system variables against one another rather than through time. The first and second

derivative outputs are given so that the oscillator phase portrait can be plotted on a scope. They also have distinct spectral profiles.

Nyarlathotep

Nyarlathotep . . . the crawling chaos . . . I am the last . . . I will tell the audient void. . . .

- Howard Philips Lovecraft

Nyarlathotep is a multidimensional ~~being~~ chaotic low-frequency oscillator (LFO). It is produced by the same formless chaos that created Azathoth, but moves at rates imperceptible to humans (it is perhaps more dangerous because of this). The frequency of its semi-periodic oscillations can be manually controlled via the frequency knob. It has manual control and voltage-control for both the frequency and the chaotic attractor. The chaotic attractor can also be fine-tuned via an additional knob. The control input for the chaotic attractor passes through an attenuator, while the knob for setting the chaotic attractor acts as an offset.

Three chaotic dimensions are available via the X, Y, and Z outputs. A user-defined mix of all three is available via the mix output. NOTE: the X,Y and Z attenuates do not attenuate the signal of the individual outputs, only the mix output.

While there is a lot to understand about chaos (we strongly recommend James Gleick's book *Chaos: The Making of a New Science* as a primer on the basic concepts), the preceding information is all you need to begin using the module. You may be familiar with LFOs or random voltage sources from traditional subtractive synthesizers. The outputs of Nyarlathotep are not always periodic or aperiodic. Some are quasi-periodic and offer (usually small) variations on patterns or shapes. We encourage you to experiment with Nyarlathotep. Although it is capable of producing chaos, this does not necessarily imply the aesthetic qualities typically associated with the colloquial use of the word "chaos" (i.e., messiness, noisiness, a lack of order). We have made use of it in traditionally melodic patches to emulate the drift of analog oscillators, to name one example.

I/O:

Knobs:

- **Attractor:** Chaotic attractor, or waveform shape. This knob controls a variable resistance in the circuit model. Adjusting it brings the oscillator through a family of double and single scroll attractors, including chaotic waveforms as well as sinusoidal, periodic, and quasi-periodic patterns.
- **Attractor Fine:** Fine-tune adjustment to chaotic attractor.

- **Frequency:** Oscillator frequency. Note, frequency values are *approximate* because the resonant frequency of the oscillator is dependent on the current attractor as well!
- **X Mix:** X mix level.
- **Y Mix:** Y mix level.
- **Z Mix:** Z mix level.
- **Attractor CV Attenuverter:** Attractor CV input attenuverter.
- **Frequency CV Attenuator:** Frequency CV input attenuator.

Inputs/Outputs:

- **Attractor (CV in):** Attractor CV input.
- **Frequency (CV in):** Frequency CV input.
- **X Output:** Oscillator output.
- **Y Output:** First derivative of oscillator output.
- **Z Output:** Second derivative of oscillator output.
- **Mix Output:** Mixed signal output.

Right-click options

- **Actions** (Reset Initial Conditions): Reset oscillator signals to initial starting values. Use this to reset the oscillator (if it blows up) without clearing your parameters (as a full "Initialize" would do).
- **CPU Load (**Low, Medium, High, Very High): These values determine the numerical solver accuracy (time step). Higher accuracy solutions require a greater CPU load. Higher accuracy tends to sound "smoother," as the oscillator stays closer to the true signal orbit
- **Solver** (Euler, Rk2, Rk4): Selects between different numerical solver algorithms. Euler requires the lowest CPU load and Rk4 the highest. Each solver has slightly different noise profiles. Due to the particular nonlinearities of this oscillator, increasing the accuracy ("CPU Load") is generally better (more accurate) than using a more computationally expensive solver.

A few notes from dk

- The "Attractor" knob adjusts a variable resistance in the circuit model, which affects the oscillator waveform pattern.
- Transitions between attractor patterns can be extremely sensitive and difficult to control, which is why we have a fine-tune knob.
- The oscillator attractor (waveform pattern) exhibits hysteresis — the waveform pattern is dependent not just on the current "attractor" value, but

also on the previous oscillator state. You might find when using the oscillator that it doesn't always return to the same attractor when you set the knob to the same value. This is why.

- The ability to change oscillator frequency is unique to the digital model.
- Chaotic systems are often visualized in phase-space, which plots the system variables against one another rather than through time. The first and second derivative outputs are given so that the oscillator phase portrait can be plotted on a scope. They also have distinct spectral profiles.

Hastur

Hastur is a simulated vactrol. It is truly modular in that it allows you direct access to a basic electronic component to do what you wish. Want to turn your vanilla VCA/VCF into a lowpass gate? Just send a trigger/impulse response into the input. Need a weird waveshaper with analog modeling capabilities? Praise Hastur. This circuit is almost exactly the same as the vactrol simulation in Yog-Sothoth, but rather than emulating a specific use case, you can make like Aleister Crowley and "do what thou wilt."

I/O:

In receives any gate, trigger or impulse response, audio or control signal.

Out is the signal that has been processed by the vactrol.

The *Attack* and *Decay* CV inputs control the respective parameters. The curve of these slopes has been modeled on the characteristics of real vactrols.

Knobs:

Level attenuates the input level.

Drive saturates the output signal.

Hysteresis is a lagging force that slowly returns the voltage output to a higher voltage. The *Hysteresis* knob controls how long this process takes.

Depth controls the maximum voltage the output will return to.

Attack controls the time it takes for the resulting signal to reach its peak. Due to the unique properties of photocells the vactrols take longer to decay than they do reach peak voltage.

Decay controls the time it takes for the resulting signal to fall to its lowest point.

A Word on Vactrols:

Vactrols are an early implementation of voltage control, also known as optocouplers. They consist of a photo-resistor and a light source, typically an LED, so that when you send voltage into the LED and increase the brightness, you control how much voltage can pass through the photo-resistor.

Some early synthesizers, most notably those made by Don Buchla, used vactrols, and this gave them some characteristic properties, most notably their ability to convert a trigger to an envelope that was great for percussive and plucked string sounds. The reason this happens is that photocells don't change resistance immediately as the light hits them, there is a lag, and the attack is shorter than the decay, which is very similar to how most sounds occur in the real world.

Shoggoth

Formless protoplasm able to mock and reflect all forms and organs and processes - viscous agglutinations of bubbling cells - rubbery fifteen-foot spheroids infinitely plastic and ductile - slaves of suggestion, builders of cities - more and more sullen, more and more intelligent, more and more amphibious, more and more imitative! Great God! What madness made even those blasphemous Old Ones willing to use and carve such things?

- Howard Philips Lovecraft

Shoggoth is an amorphous mass that assumes the shape of the task at hand. It can operate as a filter, slew rate limiter, low-frequency oscillator, audio-rate oscillator, logic gate, gate to trigger converter, sample rate limiter, random voltage generator, envelope generator, and many other uses. Given the patch-programmable nature of the device, it is best to describe each feature rather than describing what it does since it can do many things. The fish rots from the head down, so let's begin with the top of the module:

Cycle

With cycle enabled, the module functions as an oscillator. It can run up to audio rate. Next to the cycle button, there is a gate input. When the gate is high, the module will oscillate. When it is low, the module will stop oscillating. This can be useful for timed bursts of triggers/gates or as a hard gate for chiptune-esque sounds when running at audio rate. Keep in mind that the gate input always overrides the manual button.

Rise, Fall, and Volt Per Octave

From here on out, the functionality will change depending on what mode you are in and what you have patched in the module. In **cycle mode**, **rise** and **fall** control the shape of the waveform and also the rate of oscillation. Think of it this way: **rise** controls how long it takes the waveform to reach its peak; **fall** controls how long it takes the voltage to recede from that peak. If you reduce the time it takes to reach its peak, the faster it will oscillate. The same is true for the time it takes to fall from the peak. The frequency of the oscillator will always equal the time it takes to **rise** plus the time it takes to **fall**. The **volt-per octave knob** covers 10 octaves, meaning that the total **rise** and **fall** time will be increased or decreased by a total of ten octaves depending on the position of the knob. Because the primary use of the module occurs at control (aka sub-audio) rates, the lower octaves are prioritized; therefore, any control voltage entering the V/Octave input is offset by -5 volts within the module. This may seem odd, but it allows for more precise control of the low frequencies on the module itself.

If sending an external signal into the module, Shoggoth will now act as a slew limiter. This means that **rise** and **fall** now control the rate at which voltage changes. For example, if you sent in a sequence of alternatively rising and falling notes and set the **rise** and **fall** knobs to the positions indicated in the image below, the rising notes would slowly glissando before immediately falling to the next note.

Since each of these can be externally controlled via the input to the right of the knob, it is possible to create continually modulating waveshapes or to sequence glissando on a per-note basis.

Logarithmic to Exponential Control

This control sets the curve of the oscillator/slew. To the extreme left, the oscillator will rise more slowly as it approaches its peak (aka a **logarithmic** curve). In the center position, it will rise and fall linearly. To the extreme right, the oscillator will rise fast as it approaches its peak (aka an **exponential** curve). When the symmetry switch is switched up into the **ON** position, as it is in the figure below, the **logarithmic** and **exponential** curves will be applied to the **rise** and **fall** equally. If it is not engaged, the **fall** time will be exponential when the **rise** time is set to a **logarithmic** curve and will be **logarithmic** when the rise time is set to **exponential**.

Sample and Hold, Trigger In, Signal In

As with the previous sections, the function of these inputs depends on whether or not cycle mode is engaged. If **cycle** mode is enabled, sending a gate into the sample and hold input will “hold” the instantaneous voltage of the oscillator as long as the gate is high. This produces “staircase” waveforms where a continuous voltage is broken up into a series of discrete steps.

If you sample at a higher rate than your oscillator, the S/H process will not be audible, but if it is lower than the rate of the oscillator, you will hear aliasing. While it is not within the scope of this manual to explain the Nyquist-Shannon sampling theorem, the gist is that by sampling at a lower rate than twice the highest harmonic of the original waveform, you will introduce “aliases”--additional audible waveforms. These sounds are characteristic of many early synthesizers and samplers (samplers especially). When **cycle** is disengaged, the waveform entering the signal input will be sampled.

When **cycle** is engaged, The **trigger input** will reset the **rise** and **fall** cycle (this is referred to as "sync" on most audio-rate oscillators). When **cycle** is disengaged, a trigger into this input starts
a single instance of the rise and fall process.

The **signal input** is bypassed when **cycle** is engaged. When **cycle** is disengaged, the signal processing described in the preceding sections will occur to whatever signal is received in this input.

End of Rise, End of Cycle, Signal Out

All things move toward their end, but like a multicursal labyrinth (or the human digestive system), there are multiple ways out of Shoggoth. **End of Rise** outputs a gate from the time the voltage has completed its rise to the time the voltage falls back to zero. **End of Fall** outputs a gate from the time the voltage has completed its fall until it rises to its peak voltage. Since these outputs effectively provide two clock pulses per clock cycle, Shoggoth can be used as a clock multiplier. Multiple Shoggoths can be chained together for additional multiplications.

Finally, signal out is your original signal, chopped and slewed. You may or may not recognize it.

Yog-Sothoth

Yog-Sothoth knows the gate. Yog-Sothoth is the gate. Yog-Sothoth is the key and guardian of the gate. Past, present, future, all are one in Yog-Sothoth…

– Howard Philips Lovecraft

Yog-Sothoth is an emulation of the low pass gates from early modular synthesizers such as the Buchla 100 series. The design incorporates a simulation of a vactrol—an early method for voltage control still valued for "organic" envelope shapes it produces—and models of the signal flow of a discrete, Sallen-Key filter. It also incorporates a voltage-controlled amplifier (**VCA**) that can be used in conjunction with the filter.

When modeling an analog design, it is necessary to isolate which elements are aesthetically relevant. This is not always apparent from simply looking at a schematic or even by punching in values into circuit modeling software. Often, the important aspects of an analog design can only be understood through the extended use of these systems. We have extensive experience using the San Francisco Tape Music Center prototype Buchla system at Mills College and have incorporated some of our favorite aspects of the design into the Madness suite. With Yog-Sothoth, we incorporated the mild post-filter saturation that is characteristic of early analog filters and made sure that saturation/drive circuits produced the same harmonics in self-oscillation as these early designs.

I/O:

Yog-Sothoth has six inputs and one output. **Audio In** is where you send the signal you want to process, and **Out** is where the fully processed signal comes out.

The rest of the available inputs are for control voltage, although it is also possible to send in an audio-rate signal to frequency modulate the filter or to amplitude modulate the incoming signal via the **VCA**. **VCA CV** and **VCF CV** are both linear inputs and have individual attenuators, as well as a master attenuator for all CV inputs. **Exp In** bends linear input voltages along an exponential curve before sending the signal to both the VCF and the VCA.

The **VCF CV** input will take a trigger, gate, or any sufficiently short transient and turn it into an envelope. Mastering the use of this input will allow you to create truly unique sounds with envelopes, not unlike those found in plucked acoustic

instruments. You will hear this sound on Morton Subotnik's *Silver Apples of the Moon* and Suzanne Cianni's early recordings (among many others). This section uses a simulated vactrol to produce its envelopes. For more on vactrols, see below.
In addition to these standard controls, Yog-Sothoth also allows for voltage control of the resonance and overdrive of the filter. By externally controlling these inputs, vastly different timbres can be obtained.

Knobs

Yog-Sothoth has eight knobs that the user may adjust in real-time: **Filter Frequency**, **Resonance**, **Drive**, **VCA offset**, **Vactrol Envelope Response**, as well as attenuators for the **VCA**, **VCF**, and **Exp** CV inputs.

Low-pass filters remove high frequencies, so the **Filter Frequency** knob sets the highest frequency that will pass through the filter when the input to the various CV inputs is 0 volts. You can also think of it as a frequency offset to the various CV ins. Similarly, **VCA** offset controls how much of the input signal is attenuated before the signal passes through the output--assuming that the CV coming into the **VCA** In is 0 volts.

Resonance controls how much the output of the filter is fed back into itself, creating resonant peaks as the filter frequency is swept and producing wild self-oscillations depending on the amount of resonance and the amplitude of the input signal.

Drive is an addition to the standard LPG design that allows for even greater sound-sculpting capabilities. Typically the amount of overdrive or **Drive** is determined by the amplitude of the input signal. We have decoupled these controls in order to let the user determine the exact amount of drive that they want at differing amplitude levels. Since both the amplitude and the drive affect the resonance/feedback, this gives you even more room to experiment.

Finally, **Vactrol Envelope** is a unique digital feature that allows the user to control the shape of the vactrol response. The further the knob is turned clockwise, the shorter the envelope response is.

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