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THE RISE OF WAVETABLE SYNTHESIS IN COMMERCIAL MUSIC AND ITS CREATIVE APPLICATIONS

Garrett Norman Scroggs
Stephen F Austin State University, garrettscroggs416@gmail.com

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By

GARRETT NORMAN SCROGGS, Bachelor of Music

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By

GARRETT NORMAN SCROGGS, Bachelor of Music

APPROVED:

James Adams, M.M., Thesis Director

Stephen Lias, Ph.D., Committee Member

Benjamin Morris, Ph.D., Committee Member

Joseph Musser, Ph.D., Committee Member

Dr. Sheryll Jerez, Ph. D.
Interim Dean of Research and Graduate Studies

ABSTRACT

Wavetable synthesis is a powerful tool for music creation that helps composers and producers develop their own unique sounds. Though wavetable synthesis has been utilized in music since the early 1980s, advancements in computer technologies in the 2000s and the subsequent releases of software synthesizers in the late 2000s and early 2010s has led to the increased presence of wavetable synthesis in commercial music. This thesis chronicles a historical overview of the use of wavetable synthesis in commercial music and demonstrates the accessibility and power that wavetable synthesis delivers in music creation. The demonstration portion of this thesis features two original compositions in the style of electronic dance music (EDM) that prominently incorporate original wavetable instruments created from recordings of two motorized vehicles, as well as an overview of the processes of their creation.

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INTRODUCTION

Wavetable synthesis is a powerful tool for music creation. To producers and music creators, wavetable synthesis offers a variety of unique sonic possibilities. Unlike some other forms of synthesis,[1] such as FM synthesis or sample-based synthesis, wavetable synthesis involves the continuous reproduction, manipulation and blending of single-cycle waveforms to produce sounds with perceived movement. It is especially suited for the creation of instruments in which their timbres slowly evolve and change over time, such as lush, atmospheric synthesizer (synth) pads. Wavetable synthesis can be used to produce many other sounds that cannot be achieved with other forms of synthesis as well.

While the first wavetable synthesizer debuted in the late 1970s,[2] technological limitations and expensive costs impeded the popularity of those synths. Alternatively, due to the to the affordability and portability of the Yamaha DX7, FM synthesis became the prevailing method of synthesis in the 1980s and was utilized in many commercially successful singles throughout the decade.

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[1] In this thesis, synthesis is defined as the production of sound through electronically-generated waveforms, such as sine waves, triangle waves, square waves, or sawtooth waves.

[2] Rory Dow, "Waldorf M," *Sound On Sound*, April 2022, https://www.soundonsound.com/reviews/waldorf-m.

Although multiple other forms of synthesis and sampling[3] were prevalent in the 1990s, and although improvements in computer technologies occurred during this time, it was not until the invention and distribution of the multicore processor in the 2000s that wavetable synthesis became one of the most used audio synthesis processes in commercial music creation today. Along the way, these computer technology advancements made it possible to easily import audio files to design and build custom wavetable sounds.

During the 2010s, wavetable software synthesizers (soft synths) like Native Instruments' Massive and Xfer Records' Serum became integral parts of the production setups of commercial electronic music hitmakers, such as Diplo, Deadmau5, Skrillex, Zedd, and Marshmello among many others. The popularity of these two soft synths helped revitalize the relevance of wavetable synthesis. Many virtual studio technology (VST) instrument manufacturers released their own soft synths that were either wavetable synths or hybrid analogue and digital synths with wavetable engines. Since 2018, Ableton, Arturia, Universal Audio, Kilohearts, and u-he have released their own soft synths with wavetable. Following this, wavetable and wavetable capable hardware synths were released by established manufacturers, like Korg, Sequential, Modal Electronics,

[3] Sampling refers to the process of isolating a short snippet of a pre-existing sound, such as a note, and using it in a different musical context.

and Waldorf, and newer companies like Ashun Sound Machines (ASM) and Groove Synthesis made names for themselves with their own wavetable synths.

Wavetable synthesis has become a prominent fixture in music, and there are no signs that it will fall out of relevance anytime soon. Over the years, there has been research involving wavetable synthesis, most notably from computer scientist Andrew Horner, whose works have been published through the *Journal of the Audio Engineering Society*.[4] Horner's research revolves around wavetable matching, a term that refers to the utilization of wavetable synthesis to simulate the sounds of acoustic instruments.[5] Additional research has been dedicated to other technical aspects of wavetable synthesis, including the impact of reducing stored wavetable data on real-time implementation.[6] Despite this existing research, there is little academic exploration into wavetable synthesis as a creative tool. Additionally, there is little research on the history of wavetable synthesis within commercial music from the early 1980s to the 2010s. In this thesis, commercial music is defined as music that is created with the intent to make a

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[4] Andrew Horner, "A Simplified Wavetable Matching Method Using Combinatorial Basis Spectra Selection," *Journal of the Audio Engineering Society* 49, no. 11 (2001): 1060-1066, http://www.aes.org/e-lib/browse.cfm?elib=10172.

[5] Andrew Horner, "Auto-Programmable FM and Wavetable Synthesizers," *Contemporary Music Review* 22, no. 3 (2003): 22, https://doi.org/10.1080/0749446032000150852.

[6] Robert Bristow-Johnson, "Wavetable Synthesis 101: A Fundamental Perspective" (paper presented at the Audio Engineering Society Convention, Los Angeles, CA, November 8-11, 1996), https://www.aes.org/e-lib/browse.cfm?elib=7379.

significant return on investment. A commercial success was initially quantified by the Recording Industry Association of America (RIAA) as 500,000 units sold (equivalent today to 75 million on-demand streams) though their standard has expanded to include multiple levels of commercial success even up to 10 million units sold (1.5 billion streams).[7]

This thesis contributes to the field of wavetable synthesis research in two ways. First, it provides an overview of the origin of wavetable synthesis, its evolution through multiple products from the late 1970s to 2023, and its use in commercial music both in its beginning stages and in the 2010s wavetable boom. Second, it demonstrates the capabilities of wavetable synthesis by providing two original compositions in the style of commercially viable electronic dance music (EDM), specifically the sub-genres of electro-house and synthwave. The creative process of these compositions, however, goes beyond how most producers utilize wavetable synthesis. While many music creators utilize the stock wavetables included within their preferred synths, I decided to create my wavetable instruments for these pieces using my own field recordings of two automobiles as sources for wavetables. While there are documented demonstrations of music creators using wavetable synthesis to mimic the sounds of vehicles, there are no prior documented demonstrations of music creators using recorded vehicle sounds exclusively as wavetable sources for every instrument within an original composition.

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[7] "Story of Gold® & Platinum®," RIAA, accessed March 25, 2023, https://www.riaa.com/gold-platinum/story/.

As wavetable synthesis continues to be frequently used in commercial music, it is important to document the evolution of this type of synthesis, along with important milestones that marked its rise to relevance. Additionally, to better understand why many producers and artists use wavetable synthesis, it is essential to demonstrate how practical and accessible it is. It is valuable to note that while the intent was to create two pieces that could serve as commercially viable works, these pieces are still largely the result of a demonstration of the power of wavetable synthesis. Thus, there may be finer details within the compositional aspects of each work that are not fully realized. In other words, the purposes of these compositions is two-fold, as they are approximately 60% representative of an experimental demonstration and about 40% representative of both creative- and practical-oriented endeavors.

CHAPTER 1: WAVETABLE SYNTHESIS IN THE TWENTIETH CENTURY

This chapter discusses the concept of wavetable synthesis, the history of its development, the products that incorporated wavetable synthesis, and its use in commercially successful records of the 1980s. It additionally covers other forms of synthesis that were more successful than wavetable synthesis from the mid to late 1980s to the 2000s. Lastly, it presents a synopsis of advancements in computer processing from the early 1970s to the mid-2000s, culminating in the invention of the multi-core processor which helped enable successful implementation of wavetable synthesis in virtual instruments.

What Is Wavetable Synthesis?

The term wavetable synthesis has often been misapplied and confused with sample-based synthesis.[8] While sample-based synthesis involves recordings of a longer duration, such as a single note from a specific instrument, wavetable synthesis only involves the use of single cycles of waveforms (see Figure 1.1) stored in data tables. This single cycle, consisting of multiple equilibrium (or zero) points, a peak point, and a

[8] Horner, "FM and Wavetable," 22.

valley point, is used by an oscillator[9] to generate a periodic waveform that creates a static sound. From there, a mechanism within the wavetable synth (that some wavetable synths refer to as the play-head) could alternate between different wavetables in real-time to create alternating textures within a single note.[10]

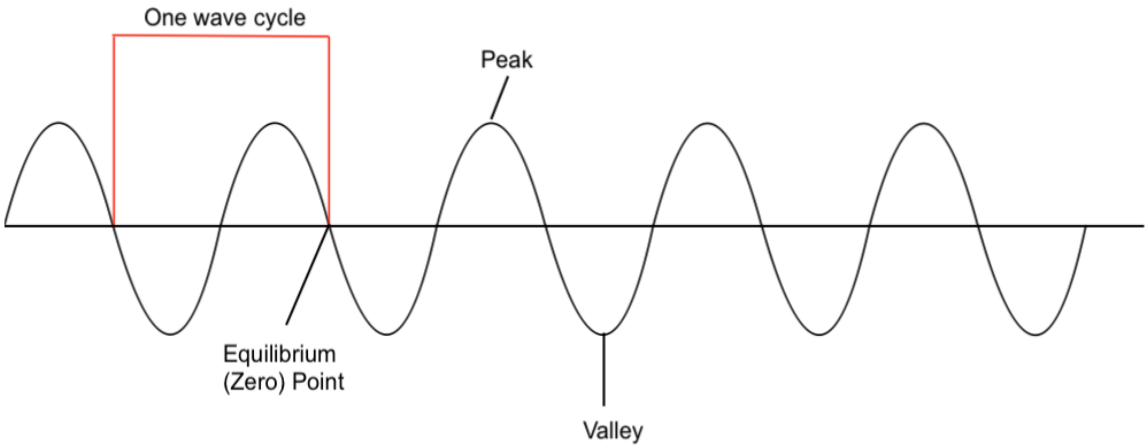

Figure 1.1: Visual representation of a sine wave showing what constitutes a cycle.

There are multiple approaches to wavetable synthesis as described by former professor and signal processing engineer Julius O. Smith III in his keynote paper to the 1991 International Computer Music Conference. The first approach, time-domain wavetable synthesis, involves the repetition of the isolated single wave cycle to achieve a more static, periodic sound. This form of simple wavetable synthesis can be traced all the

[9] An oscillator is an electronic circuit that produces an electric signal periodically, usually in the form of a sine wave, sawtooth wave, or triangle wave.

[10] Horner, "FM and Wavetable," 22.

way back to Max Matthews' computer program MUSIC.[11] The second approach, frequency-domain wavetable synthesis, features the creation of a specific desired harmonic spectrum through the interpolation of multiple different wavetables with different waveshapes. In this procedure, phasing is easily implemented for smoother transitions between the different wavetables, resulting in a more natural evolving timbre.[12]

The Origins of Wavetable Synthesis

German inventor Wolfgang Palm is often attributed with the invention of wavetable synthesis through his first wavetable synths. The initial concept of a wavetable oscillator, however, can be traced further back to the late 1950s. Max Matthews was an electrical engineer and computer music pioneer who worked at Bell Labs in the mid-1950s after studying engineering at the California Institute of Technology and the Massachusetts Institute of Technology. While working at Bell Labs, he developed a computer program for audio synthesis and composition. The original version of the program (which did not have the wavetable oscillator) was titled MUSIC I, and it was

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[11] Julius O. Smith III, "Viewpoints on the History of Digital Synthesis" (paper presented at the International Computer Music Conference, Montreal, QC, October 16-20, 1991), https://quod.lib.umich.edu/i/icmc/bbp2372.1991.001.

[12] Smith, "History of Digital Synthesis."

written in Assembler/machine code with the audio output consisting of a monophonic triangle wave tone with no control over the attack or release. The output was then stored on a magnetic tape and then converted by a digital-to-analogue converter (DAC) to present the information in an audible format. The second version of the program, MUSIC II, introduced four-voice polyphony[13] and could generate sixteen different waveform shapes.[14] This was made possible by the introduction of the wavetable oscillator,[15] which was included in future iterations of Matthews' MUSIC software as well.[16] This allowed for the first basic type of wavetable synthesis: time-domain wavetable synthesis.

Following Matthews' implementation of a wavetable oscillator, in 1977, author and computer engineer Hal Chamberlin published an article through BYTE Magazine describing the more complex technique of combining various wavetables to create a more dynamic sound. He never used the full term wavetable synthesis, but he did use the term

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[13] In the context of sound synthesis, a voice refers to a single audio signal path within a synth. Each voice is produced by one or more oscillators and travels through its own signal flow order of filters, effects, and sound amplifiers before reaching the output.

[14] C. Roads & Max Mathews, "Interview with Max Mathews," *Computer Music Journal* 4, no. 4 (Winter 1980): 15-22, https://doi.org/10.2307/3679463.

[15] Miller Puckette, "Max At Seventeen," *Computer Music Journal* 26, no. 4 (Winter 2002): 40, https://doi.org/10.1162/014892602320991356.

[16] Smith, "History of Digital Synthesis."

"wave table"[17] and presented the concept of a "pointer" (play-head) that could locate individual wave cycles stored in "…memory as a table."[18] At around the same time, composer Michael McNabb experimented with the frequency-domain wavetable synthesis in his composition *Dreamsong*,[19] which was composed at the Center for Computer Research in Music and Acoustics (CCRMA) from 1977-1978.[20] Two years later, however, German inventor and musician Wolfgang Palm properly introduced wavetable synthesis to the masses.

Wavetable Synthesis' First Hardware

In 1978, Palm had the idea for a form of digital synthesis after making his own monophonic synths, citing pitch instability as a concern for those polyphonic synths like the Oberheim Eight Voice. Using digital oscillators controlled by a microprocessor, Palm designed a wavetable system that could generate a variety of sounds from those created by sawtooth waves to resonance sweeps. As Palm explained:

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[17] Hal Chamberlin, "A Sampling of Techniques for Computer Performance of Music," *BYTE Magazine*, September 1977, 72, https://archive.org/details/byte-magazine-1977-09/mode/2up.

[18] Chamberlin, 69-70.

[19] Smith, "History of Digital Synthesis."

[20] Michael McNabb, "'Dreamsong': The Composition," *Computer Music Journal* 5, no. 4 (Winter 1982), 36, https://doi.org/10.2307/3679505.

> The idea of a wavetable system came up because I wanted not only to generate static sounds, like a sawtooth wave, but also sound sweeps, like a resonance sweep. It is best comparable to a movie film: on the film you have a lot of separate little pictures, and if you watch them in fast succession, you get the imagination of the moving picture. With wavetables it's the same: you have many single periods of sound, and when you play them one after the other, you get a dynamic sound that varies over time.[21]

That year, Palm introduced his first wavetable synth: the PPG 360A Wave Computer (see Figure 1.2). Palm quickly followed this up with the 340 Wave Computer and 380 Event Generator system, complete with a computer terminal and five-octave keyboard for playing and sequencing.[22] While producing the first line, Palm realized that the wavetable sweeps sounded harsh and grating due to the limited 8-bit technology of the time and the inability of those initial systems to alter waveforms in real time. To accommodate this, Palm decided to route the wavetable oscillators to feed into more familiar voltage-controlled filters (VCFs) for his next line of synths.[23] Though the 360A had a limited run, it was used in the production of a studio project: Tangerine Dream founding member

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[21] Wolfgang Palm, "Blast From the Past: PPG Wave," interview by Computer Music, *MusicRadar*, February 28, 2014, https://www.musicradar.com/news/tech/blast-from-the-past-ppg-wave-595219.

[22] Jonathan Miller, "Retro Family Tree," *Future Music*, Spring 2001, 88. http://www.midimanuals.com/manuals/ppg/wave_2_0/ppg_and_waldorf_history/ppgwaldorfhistory.pdf.

[23] Wolfgang Palm, "'Emulation is Boring!': Wolfgang Palm on the Past, Present and Future of Synth Design," Interview by Computer Music, *MusicRadar*, May 9, 2018, https://www.musicradar.com/news/emulation-is-boring-wolfgang-palm-on-the-past-present-and-future-of-synth-design.

Edgar Froese’s album Stuntman.

Figure 1.2: Image of the PPG 360A Wave Computer.[24]

In 1981, Palm debuted the PPG Wave 2 (see Figure 1.3), an eight-voice synth with a single oscillator.[25] While wavetable synthesis remained at the core of the Wave 2’s functionality, Palm did include a fully analogue filter and an envelope generator.[26] These

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[24] Stephen Parsick, *Black WaveComputer 360*, accessed February 4, 2023, digital image, PPG Webpages, https://ppg.synth.net/360/.

[25] Miller, “Retro Family Tree,” 88.

[26] An envelope is used to represent how a sound operates and changes in real-time. An envelope generator is a tool within a synthesizer that allows the user to shape the sound generated by adjusting various stages of it. The stages of sound generation commonly presented in envelopes include the attack, the decay, the sustain, and the release.

two components, however, were still tied to the digital oscillators, which gave the Wave 2 an advantage over other conventional synths of the time. As opposed to competing synths of the time, which generally offered six or seven waveform options to feed into the oscillator, the Wave 2 provided 30 wavetables that contained 64 waveforms each.[27] Palm released two more versions of the synth, with the Wave 2.2 debuting in 1982 and the Wave 2.3 launching in 1984. The 2.2 introduced a second oscillator per voice, allowing for the simultaneous playback of two different sounds. Users were able to pair the 2.2 with the PPG's Waveterm A music computer, which offered 8-bit sampling, advanced sequencing,[28] and the ability for more customizable wavetable creation.[29] The design of the Wave 2.3 was influenced by the arrival of Musical Instrument Digital Interface (MIDI), a new standard means of sending digital signals between different types of synths and a single master keyboard.[30] While PPG's initial communication bus containing an Expansion Voice Unit (EVU) initially offered faster data communication than MIDI, the 1984 release of the Wave 2.3 included MIDI compatibility. Alongside the Wave 2.3, PPG released the updated Waveterm B computer, which offered 16-bit

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[27] Adam Crute, "The Science of Wavetable Synthesis," *MusicTech*, August 26, 2019, https://musictech.com/guides/essential-guide/science-wavetable-synthesis/.

[28] Sequencing is the arrangement and programming of specific rhythmic patterns for notes or sounds over a specified musical period (such as eight or sixteen measures).

[29] Miller, "Retro Family Tree," 89.

[30] Craig Anderton, "What is MIDI? The Essential Guide," *Sweetwater*, June 7, 2019, https://www.sweetwater.com/insync/midi-essential-guide/.

sampling and 24-track, multitimbral sequencing through the connection of multiple EVUs.[31]

Figure 1.3: Image of the PPG Wave 2.[32]

Manufacturing around 1,000 Wave 2 synths between 1981 and 1987, the Wave 2 became the most successful product from his company. The Wave 2 found its way into the works of iconic electronic music artists like Alphaville, Tangerine Dream, Jean Michel Jarre, Tears for Fears,[33] Depeche Mode, Rush, Gary Numan and The Fixx among

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[31] Miller, "Retro Family Tree," 88.

[32] Laurent Prot, *Wave 2.0 in Laurents Studio*, accessed February 4, 2023, digital image, PPG Webpages, https://ppg.synth.net/wave20/.

[33] Bernard Vanisacker, "Iconic Manufacturer of Audio synthesizers PPG Synths Acquired by Brainworx – Alan Wilder: 'The PPG was a Sensitive, Delicate & Bloody Difficult Beast…,'" *Side-Line*, March 19, 2020, https://www.side-line.com/iconic-manufacturer-of-audio-synthesizers-ppg-synths-acquired-by-brainworx-alan-wilder-the-ppg-was-a-sensitive-delicate-bloody-difficult-beast/.

others.[34] Ex-Depeche Mode member Alan Wilder revealed that the Wave 2 was used on the group's 1982 album *A Broken Frame*.[35] He specifically noted that the album's first single "See You," which peaked at number 6 on the UK singles chart,[36] featured a variety of sounds from the Wave 2, including the bell riff and choir sounds. However, he recalled that the synth broke down on numerous occasions when they attempted to use it in live performance, eventually leading to Depeche Mode moving on from it in favor of producer Dan Miller's Synclavier.[37] In addition to Depeche Mode, Tangerine Dream heavily featured the Wave synth in their work,[38] and Palm even had working relationships with multiple members.[39] Outside of these musical acts Palm directly collaborated with, the PPG Wave found its way onto other notable artists' work as well. Singer and songwriter Stevie Nicks incorporated the PPG Wave on her 1985 single "I

[34] Wolfgang Palm, "Classic Gear: PPG Wave," *Electronic Musician*, February 2019, 34.

[35] Vanisacker, "PPG Synths Acquired by Brainworx."

[36] "Depeche Mode," Official Charts, accessed February 4, 2023, https://www.officialcharts.com/artist/20192/depeche-mode/.

[37] Vanisacker, "PPG Synths Acquired by Brainworx."

[38] "On This Record the Following Stage Equipment was Used," liner notes for Christopher Franke, Edgar Froese and Johannes Schmoelling, *Poland (The Warsaw Concert)*, Tangerine Dream, recorded December 10, 1983, Jive Electro HIP 22, 194, 2 Vinyls.

[39] "Wolfgang Palm Interview," *Plugin Alliance (Blog)*, March 17, 2020, https://www.plugin-alliance.com/en/blog/blogpost/items/wolfgang-palm-interview.html.

Can't Wait,"[40] which peaked at number 16 on the Billboard Hot 100.[41] That same year, Ian Stanley of Tears for Fears clarified that the synth bass sound on their album *Songs from the Big Chair*, which included their chart-topping[42] hit "Everybody Wants to Rule the World,"[43] was created through a combination of the PPG Wave and the Yamaha DX7.[44] Norwegian synth-pop band a-ha used the Wave on their iconic single "Take On Me,"[45] which also reached number 1 on the Billboard Hot 100 in 1985.[46] Even jazz icon Miles Davis and collaborating musician Randy Hall included the PPG Wave on the

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[40] "I Can't Wait," liner notes for Rick Nowels, Stevie Nicks and Eric Pressly, *I Can't Wait (45 RPM Maxi-Single)*, Stevie Nicks, recorded 1985, Modern Records 1C K 060-20 0921 6, 1985, Vinyl.

[41] "Stevie Nicks," Billboard, accessed February 4, 2023, https://www.billboard.com/artist/stevie-nicks/.

[42] "Tears For Fears," Billboard, accessed February 4, 2023, https://www.billboard.com/artist/tears-for-fears/.

[43] Heather Johnson, "Classic Tracks: Tears for Fears' 'Everybody Wants to Rule the World,'" *Mix Online,* August 1, 2007, https://www.mixonline.com/recording/classic-tracks-tears-fears-everybody-wants-rule-world-365857.

[44] "Tears for Fears' Everybody Wants to Rule the World Synths," *Reverb Machine (blog),* September 16, 2020, https://reverbmachine.com/blog/tears-for-fears-everybody-wants-to-rule-the-world-synths/.

[45] Richard Buskin, "A-ha 'Take On Me': Classic Tracks," *Sound On Sound,* March 2011, https://www.soundonsound.com/techniques/classic-tracks-ha-take-me.

[46] "a-ha," Billboard, accessed February 9, 2023, https://www.billboard.com/artist/a-ha/.

former's song "Rubberband,"[47] the closing track from an album of the same name.[48]

While the PPG Wave 2 and its updated models brought PPG success for several years, Palm's own company only remained in business until 1987. The end of PPG was brought about by the discontinued development of the Realizer, an all-in-one recording studio machine that would have combined the tools to record and mix with those for production, sequencing, synthesis and sampling.[49] Unfortunately for Palm, the product proved to be too expensive to realistically manufacture and sell, and PPG went bankrupt before the Realizer was completed.[50] Likewise, the PPG Wave synths were expensive in comparison to other more successful synths, with costs originally starting at about $9,000 before falling to around $6,500 by the end of the product line's run.[51] In addition to high costs, PPG products had low portability, especially in comparison to the much more

[47] George Cole, "Rubberband," liner notes for Randy Hall, Attala Zane Giles and Miles Davis, *Rubberband*, Miles Davis, recorded October 1985-January 1986, Warner Records R2 599464, 2019, CD.

[48] Although the recording sessions for *Rubberband* took place in the mid 1980s, the album was not released until 2019.

[49] Vanisacker, "PPG Synths Acquired by Brainworx."

[50] Crute, "Science of Wavetable Synthesis."

[51] These prices are in 1980 dollars. The original list price of the Wave 2 would've been equivalent to a little over $23,000 in 2019 dollars.

portable, and cheaper, Yamaha DX7 synth (see Figure 1.4).[52]

Following PPG's bankruptcy, Palm joined Waldorf Electronics, and in 1989, he brought his wavetable design to the Microwave synth.[53] The Microwave was essentially a compact version Wave 2 synths, and this paved the way for a follow-up synth-line known simply as the Waldorf Wave.[54] Outside of updates to the previous releases of the Wave and Microwave, Waldorf did not release another wavetable synth until the end of the 90s with the release of the Q synth. The Q synth was presented as a DSP-driven virtual analog synth that included new wavetables (each titled ALT wave wavetables) for oscillators one and two. Just like the PPG Wave, though, hefty costs were still drawbacks on both the Waldorf Q[55] and the Waldorf Wave,[56] with the latter having the low portability of the former PPG systems.

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[52] Colm Clark, "A Sound That Changed Music: The Yamaha DX7," *Culture Sonar*, November 17, 2018, https://www.culturesonar.com/a-sound-that-changed-music-the-yamaha-dx7/.

[53] Simon Trask, "Waldorf Electronics Microwave," *Music Technology* (January 1990): 64-72, http://www.muzines.co.uk/articles/waldorf-electronics-microwave/285#.

[54] David Crombie, "Waldorf Wave," *Sound On Sound*, July 1994, 1, https://www.soundonsound.com/reviews/waldorf-wave.

[55] Gordan Reid, "Waldorf Q," *Sound On Sound*, June 2000, https://www.soundonsound.com/reviews/waldorf-q-0.

[56] Crombie, "Waldorf Wave," 2.

More Popular Forms of Synthesis

While wavetable synthesis was commercially relevant through products like the Wave, its success at the time paled in comparison to other forms of synthesis, with the most obvious being frequency modulation (FM) synthesis.[57] In FM synthesis, one simple wave form is used to modulate, or alter, the frequency of another waveform to create a more complex waveform, and that complex waveform could then be used to modulate the frequency of another waveform and so on.[58] Closely associated with FM synthesis is the Yamaha DX7, the synth that is considered by many to have defined the sound of the 1980s. While the PPG did find some commercial recordings, the Yamaha DX7 (see Figure 1.4) was used in significantly more popular hits throughout the 1980s.[59]

In addition to FM synthesis, other forms of digital and hybrid (combination of digital and analogue) synthesis remained more prevalent than wavetable throughout the 1980s. The Fairlight CMI and E-mu Emulator synths introduced sample-based synthesis

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[57] Megan Lavengood, "What Makes It Sound 80s," *Journal of Popular Music Studies* 31, no. 3 (September 2019): 73, https://doi.org/10.1525/jpms.2019.313009.

[58] Adam Crute, "Learning the Basics of FM Synthesis and How It Works," *MusicTech*, July 1, 2019, https://musictech.com/guides/essential-guide/how-fm-synthesis-works/.

[59] Lavengood, "What Makes It Sound 80s, 73-74.

Figure 1.4: Image of the Yamaha DX7.[60]

in 1979 and 1981 respectively.[61] The Fairlight is credited as the device used to “invent”[62] the idea of sampling and introduce the concept of a sequencer.[63] Sample-based synthesis was advanced through other important, and more affordable, synths like the Roland D50

[60] *Yamaha DX7*, accessed on March 1, 2023, digital image, Yamaha, https://www.yamaha.com/en/about/design/synapses/id_009.

[61] Lavengood, “What Makes It Sound 80s, 76.

[62] “Synth Nodes – Fairlight CMI The Worlds 1st DAW & Built-In Sampler,” *Iconic Underground Magazine*, August 16, 2019, https://iumag.co.uk/synth-nodes-fairlight-cmi/.

[63] “Fairlight CMI,” *Iconic Underground Magazine*.

in 1987 and the Korg M1 in 1988.[64]

Meanwhile, the Akai MPC60, released in 1988, introduced sampling and sequencing without synthesis to a large audience of up-and-coming producers in the 90s. The MPC had a small footprint and came at a much cheaper price than previously released samplers. Beyond just introducing a new medium for sampling, the MPC helped alter the way people viewed sampling as its own musical art form. The impact of the MPC was especially felt in the hip hop and electronic music communities during the 1990s, with legendary artists like Dr. Dre, Outkast and J Dilla (whose MPC is displayed in the Smithsonian Museum) making essential use of them in their musical works.[65]

Finally, another form of synthesis, called vector synthesis, also rose to prominence in the late 80s and early 90s. This method of synthesis, initially introduced by Dave Smith of Sequential Circuits, involved four different oscillators that a user could smoothly transition between via automated controllers like low frequency oscillators

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[64] Steve Howell, "Q. Can You Explain the Origins of Wavetable, S&S and Vector Synthesis?" *Sound On Sound*, February 2006, https://www.soundonsound.com/sound-advice/q-can-you-explain-origins-wavetable-ss-and-vector-synthesis.

[65] Alexander Aciman, "Meet the Unassuming Drum Machine that Changed Music Forever," *Vox*, April 16, 2018, https://www.vox.com/culture/2018/4/16/16615352/akai-mpc-music-history-impact.

(LFOs)[66] or the use of a joystick.[67]

By the late 90s, wavetable synthesis had lost its mainstream relevance thanks to these other more affordable, portable, and flexible forms of synthesis and sampling. The invention of the multicore processor in the mid-2000s, however, would be beneficial for wavetable synthesis.

Improvements In Computer Technologies

From 1971 to 2005, computer processing units (CPUs) contained a single, completely self-contained microprocessor called a core, which ran a computer program using a thread. Each thread carried out a specific task or instruction within a computer application.[68] During this time span, the implementation of superscalar processing (a method of processing in which units of instruction execution are duplicated) helped increase the power of those single cores by allowing them to operate multiple instructions simultaneously through multithreading. However, the usefulness of multithreading also

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[66] A low frequency oscillator (LFO) is a specific type of oscillator that generates a frequency that is usually below the lowest level of human hearing (20 Hertz). It is often used to modulate other parameters of a synthesizer.

[67] Howell, "Q."

[68] Martin Walker, "Multi-core Processors for Musicians," *Sound On Sound*, January 2008, https://www.soundonsound.com/sound-advice/multi-core-processors-musicians.

depended on whether a computer program was developed in a manner that lent itself to multithreading, which was not always the case.[69]

Outside of multithreading, other advancements in CPU processing power were achieved by increases in clock frequencies and data-width,[70] which impacted the speed of CPU performance. There was a limit, however, to the increases that could be made in clock frequency. Higher clock resulted in higher power consumption, which could lead to the overheating and malfunctioning of the CPU chip.[71] Thus, in 2004, Intel released the first commercial multicore processor, with AMD following later that year with their own Athlon architecture. The addition of multi-core processors made it much easier to use and operate multiple instances of virtual instrument plug-ins,[72] especially at lower buffer sizes.[73] Because of the microprocessor, the true potential of wavetable synthesis would be realized in the digital realm.

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[69] Matthew Bio, "A Brief History of the Multi-Core Desktop CPU," *TechSpot*, December 31, 2021, https://www.techspot.com/article/2363-multi-core-cpu/."

[70] Clock frequency refers to the rate in which instructions were carried out. Data-width refers to the amount of data that can be transmitted or produced in a thread at once.

[71] Bio, "Brief History of the Multi-Core."

[72] Walker, "Multi-core Processors."

[73] Buffer size refers to the amount of time it takes for a computer to process audio for listener play back.

CHAPTER 2: WAVETABLE SYNTHESIS IN THE TWENTY-FIRST CENTURY

This chapter discusses the increased prevalence of wavetable synthesis in the late 2000s and early 2010s, covering the soft synths that contributed to its popularity as well as a few that did not. Additionally, examples of hardware wavetable synths released following the popularity of the virtual wavetable instruments are mentioned. Finally, the chapter includes examples of prominent musical figures that use wavetable synthesis, as well as their commentary on the appeal of wavetable synthesis in today's music.

Wavetable Synthesis in the Digital Realm

The invention and distribution of the multi-core processor proved to be important for the development and operation of the first prominent wavetable soft synth. In 2006, virtual instrument manufacturer Native Instruments unveiled Massive.[74] The debut of this product proved to be a pivotal moment for wavetable synthesis as it became the source for a lot of recognizable drum & bass (DnB) and electronic dance music (EDM).[75] Massive was an incredibly successful product, and years later, Xfer Records' wavetable soft synth Serum would join it as another staple in many producers' creative processes.

[74] Reuben Cornell, "Massive: Past, Presets & Future," *Native Instruments (Blog)*, August 16, 2018, https://blog.native-instruments.com/massive-past-presets-future/.

[75] Future Music, "What is Wavetable Synthesis? The Ultimate Beginner's Guide," *MusicRadar*, August 9, 2021, https://www.musicradar.com/news/what-is-wavetable-synthesis.

Today, there is no shortage of options for virtual wavetable synths from established manufacturers and newer startups alike, and the popularity of wavetable synthesis in the digital domain led to a renewed interest in wavetable synthesis for hardware units.

Early Wavetable Soft Synths

Though Massive reignited widespread interest in wavetable synthesis, it was not the first digital wavetable synth. In 2000, Waldorf Electronics introduced a software emulation of the PPG Wave 2.3, titled the Wave 2.V. Longtime *Sound On Sound* writer Paul White noted that the emulation was mostly faithful to the original synth but with a few additions. There were notable omissions, however, such as the original sequencer section and some layering capabilities present on the hardware synth. The Wave 2.V still contained the original 32 PPG wavetables, and it even included the "Real PPG" option[76] that would incorporate the digital aliasing that occurred on the original PPG Wave 2.[77]

While Massive was released in 2006, two other notable wavetable soft synths were also released that same year: one by German audio equipment manufacturer

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[76] Paul White, "Waldorf PPG Wave 2.V," *Sound On Sound*, September 2000, https://www.soundonsound.com/reviews/waldorf-ppg-wave-2v.

[77] Digital aliasing refers to digital errors that contributed to the "harsh" qualities of the original synth mentioned in Chapter 1.

Terratec[78] and one by music production software company Cakewalk.[79] Terratec's product, Komplexer, was largely based on Waldorf's Micro-Q hardware synth. While the Komplexer did feature identical wavetables to that of the Micro-Q, it used resynthesis as a means of creating more seamless transitions between different wavetables. The Komplexer was intended to be part of a system with a wavetable soundcard and a MIDI keyboard controller that would allow for central processing unit (CPU) cycles to be offloaded from a user's computer to preserve processing power.[80] Meanwhile, Cakewalk's Rapture operated in a much different manner. Instead of implementing the PPG style of alternating wavetable interpolation, Rapture contained static single-cycle wavetables that were intended as a base for subtractive analogue emulation synthesis. It had what Cakewalk called the Expressive Engine that prevented digital artifacts from altering the synth's sound. In addition to the wavetables, the Rapture included six voices, and it included features like DSP for filters, modulators for generating attack, decay, sustain and release (ADSR) envelopes, step-sequencers,[81] a parametric equalizer (EQ)

[78] Alan Tubbs, "Terratec Komplexer VST," *Sound On Sound*, November 2006, https://www.soundonsound.com/reviews/terratec-komplexer-vst.

[79] Alan Tubbs, "Cakewalk Rapture," *Sound On Sound,* August 2006, https://www.soundonsound.com/reviews/cakewalk-rapture.

[80] Tubbs, "Terratec Komplexer VST."

[81] Step sequencing is a type of sequencing in which a single measure is presented on a grid and divided into beat values, which are referred to as steps. The user can program certain steps to trigger sounds or samples into a rhythmic pattern.

and other insertable effects. While each voice in the synth had its own effects, the synth included the option to route all the voices to the same chain of effects to save on CPU power, which could have been depleted if someone used all six voices at once. Rapture benefitted from the clock frequency advancements mentioned in chapter 1 as the synth's minimum system requirements recommended the use of a computer with a 1.2 (GHz) G4 processor for a Macintosh (Mac), or a 1.3 GHz processor for other personal computers (PCs), with 512 megabytes (MB).[82]

A 'Massive' Wavetable Renaissance in Commercial EDM

Though both Komplexer[83] and Rapture[84] were released to positive reviews, the success of Native Instruments' Massive is what revitalized the popularity of wavetable synthesis. Native Instruments had previously developed a variety of successful virtual instruments, and Massive was no exception.[85] Massive, pictured in Figure 2.2, was developed by product designer Mike Daliot, and his company's mission was to

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[82] Tubbs, "Cakewalk Rapture."

[83] Computer Music, "Terratec Komplexer Review," *MusicRadar*, February 14, 2008, https://www.musicradar.com/reviews/tech/terratec-komplexer-22677.

[84] Computer Music, "Cakewalk Rapture Review," *MusicRadar*, November 8, 2007, https://www.musicradar.com/reviews/tech/cakewalk-rapture-22236.

[85] Simon Price, "10 Years of Native Instruments," *Sound On Sound*, October 2006, https://www.soundonsound.com/music-business/10-years-native-instruments.

"…unlock the full spectrum of [the] possibilities"[86] of wavetable synthesis. The complex instrument featured three oscillators, a noise generator and a special modulation oscillator that could all be routed in many ways via dragging and dropping the different parameters. Each main oscillator included eighty wavetables that were sorted into four categories of wave shapes and types: Basic, Analogue/Electric, Digital/Hybrid and FX/Chords. The instrument contained a master effects section, which contained EQ, reverb, delay, chorus, flanger and tube emulation effects, and a step sequencer that could be applied to any modulation destination like the pitch oscillator. This allowed for the creation of melodic sequences that yielded similar results to that of an arpeggiator that Massive otherwise did not include. With all this complexity, Massive allowed for the use of sixteen voices by default, though the use of all sixteen voices was usually taxing on CPU power.[87] Massive's biggest selling point, however, was the quality of its sounds.

The success of Massive largely depended on the advancements in computer processing technology, including the development of the multicore processor. According to NI's product specialist Reuben Cornell, the company's goal was to create a synth that produced sounds of the best sonic quality, even if computers at that time struggled to allow the synth to operate properly.[88]

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[86] Cornell, "Massive."

[87] Simon Price, "Native Instruments Massive," *Sound On Sound*, February 2007, https://www.soundonsound.com/reviews/native-instruments-massive.

[88] Price, "Massive."

Figure 2.1: Image of the main user interface of Native Instruments' Massive.[89]

The company foresaw CPUs becoming powerful enough to support the instrument's full capabilities, so they remained focused on creating a product that would remain relevant for years after its debut. At the time of release, Massive caused many issues with the CPUs available in most consumer computers at the time, especially in its default setting.[90] To compensate for high CPU usage in its intended default mode, Native Instruments offered two other modes, High and Eco, which lessened CPU usage at the expense of the superior sound quality of the Ultra mode. Ultimately, NI recommended

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[89] *Massive*, accessed March 6, 2023, digital image, Splice, https://www.nytimes.com/2011/04/24/arts/music/max-mathews-father-of-computer-music-dies-at-84.html.

[90] Cornell, "Massive."

using a 1.4 GHz CPU at the least, though the sufficiency of that low of a GHz recommendation was debatable. In a review of the synth, Sound On Sound writer Simon Price noted that even when using either a Mac with a Dual 2.7 GHz processor or a MacBook Pro with a 2GHz Intel Core Duo processor, the CPU on both machines struggled to successful operate some basic presets using only one to six voices.[91]

Despite these technical hurdles, Massive still garnered positive reviews for having a versatile modulation system, great sound quality and a simple graphic user interface (GUI).[92] Massive proved to be popular with the EDM producer community, with many notable EDM producers incorporating the synth into their creative processes. Dubstep producer Skrillex revealed Massive to be one of his top two favorite soft synths for sound design in the early 2010s.[93] EDM producer Diplo championed Massive, incorporating it into his studio workflow. He specifically complimented the versatility of unique sound possibilities, the user-friendly GUI, the dynamic LFOs, and the ease of controlling the resulting sounds. He gave an example of the synth's versatility, commending its ability to help its user create sounds ranging from "…crazy sub-basses you would hear in drum &

[91] Price, "Massive."

[92] Team, "Native Instruments Massive Review," *MusicRadar*, December 12, 2007, https://www.musicradar.com/reviews/tech/native-instruments-massive-22644.

[93] Sunny Moore, "Skrillex on Ableton Live, Plug-ins, Production and More," Interview by Computer Music Specials, *MusicRadar*, November 3, 2011, https://www.musicradar.com/news/tech/interview-skrillex-on-ableton-live-plug-ins-production-and-more-510973.

bass tracks or hip-hop tracks to really high-end pad noises."[94] In 2018, DnB producers Drumsound & Bassline lauded praise toward the wavetable synth, similarly complimenting its intuitive GUI and the ease in which they could create "amazing"[95] sounds. They compared Massive to previous influential electronic instruments like the Linn Electronics LinnDrum, the Roland Jupiter-8, the Roland TB-303 and the Akai MPC60 sampler, noting that like these, Massive "…shaped a generation of music making […] defining DnB and the dubstep explosion all the way through the modern EDM sound of today."[96]

Massive was popular and well-received, and several other companies released similar products in unsuccessful attempts to challenge Massive's status as the standard for wavetable synthesis. In 2014, one of the most popular audio plug-in companies, Waves, released Codex, a synth that included a wavetable engine in addition to granular and subtractive synthesis.[97] Like Massive, Waves advertised their synth as having a user-

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[94] Diplo, "Diplo About Native Instruments KOMPLETE," *Native Instruments*, October 9, 2010, https://www.youtube.com/watch?v=9j7Aor_4NTE.

[95] Cornell, "Massive."

[96] Cornell, "Massive."

[97] Matt Vanacoro, "Review: Waves Codex," *Ask Audio*, October 28, 2014, https://ask.audio/articles/review-waves-codex.

friendly GUI and additional processing effects like chorus, delay, reverb, and distortion.[98] This synth, however, did introduce features not found in Massive, such as a dedicated arpeggiator and the ability for a user to import their own wavetables.[99] While Codex was praised for having "sonic diversity and quality"[100] for its price point (listed at $200 upon release), it was criticized for not offering anything truly innovative.[101] Ultimately, Codex did not reach the level of popularity that Massive obtained. However, another wavetable soft synth released that same year did just that.

Wavetable's "Dream Synthesizer"

In 2014, audio plug-in manufacturer Xfer Records released their landmark synth, Serum, pictured in Figure 2.3.[102] Xfer Records was originally a record label founded by electronic musicians Joel Zimmerman (better known by his stage name Deadmau5) and

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[98] "Waves Release Codex Wavetable Synth," *Sound On Sound*, July 10, 2014, https://www.soundonsound.com/news/waves-release-codex-wavetable-synth.

[99] "Codex," *Sound On Sound*.

[100] Vanacoro, "Waves Codex."

[101] Computer Music, "Waves Codex Review," *MusicRadar*, January 12, 2015, https://www.musicradar.com/reviews/tech/waves-codex-613355.

[102] Ben Rogerson, "Xfer Records Releases Serum, the 'Dream' Plugin Synth," *MusicRadar*, September 22, 2014, https://www.musicradar.com/news/tech/xfer-records-releases-serum-the-dream-plugin-synth-607401.

Steve Duda.[103] Steve Duda was a sample programmer, sound designer and audio engineer[104] who worked for Nine Inch Nails during the creation of their album *The Fragile*.[105] After collaborating with F Expansion to create their acoustic drum plug-in BFD, Duda decided to become a software programmer and create his own plug-ins.[106]

Figure 2.2: Image of the main GUI of Xfer Records' Serum.

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[103] I Love Music Academy, "Partners in Education! Xfer Record's & I Love Music Academy," *I Love Music*, June 17, 2017, https://ilovemusic.in/blog/partners-in-education-xfer-records-i-love-music-academy/.

[104] "Steve Duda: Berklee Online Interview Series with Loudon Stearns and Erin Barra," interview by Loudon Stearns and Erin Barra, *Berklee Online*, August 25, 2020, https://www.youtube.com/watch?v=pyI0-ve7vaU.

[105] Charlie Clouser and Karél Psota, "LA Creatives: Charlie Clouser and Karél Psota Discuss Sampling + Sound Design," *Orchestra Tools*, April 24, 2020, https://www.youtube.com/watch?v=or7QMpGR2jQ.

[106] "Steve Duda," *Berklee Online*.

According to Xfer Records' website, Serum was created to be a "dream synthesizer."[107] The product description on Xfer's website elaborated on this intention, stating that:

> The dream synthesizer did not seem to exist: a wavetable synthesizer with a truly high-quality sound, visual and creative workflow-oriented interface to make creating and altering sounds fun instead of tedious, and the ability to 'go deep' when desired - to create / import / edit / morph wavetables, and manipulate these on playback in real-time.[108]

In an interview, Steve Duda emphasized that the GUI design for Serum was a large motivator for the creation of the synth due to his frustrations with that of Massive. He recalled:

> Using Massive in the context of having clients sitting behind you was […] sort of stressful and not very pleasant of an experience because […] you really couldn't see things. You couldn't see times on the envelope. You couldn't see […] where your LFOs [were] playing back. There was so much lack of visual feedback that it made [using Massive] frustrating.[109]

The GUI proved to be a significant factor in the positive reception Serum garnered from music publications like *Sound On Sound* and *MusicRadar*.[110] Functionally, the virtual

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[107] "Serum," *Xfer Records*, accessed February 14, 2023, https://xferrecords.com/products/serum.

[108] "Serum," *Xfer Records*.

[109] "Steve Duda on Serum's Success & Parallels Between Music and Programming (The EDM Prodcast #157)," interview by Aden Russell, *EDMProd*, August 22, 2021, https://www.youtube.com/watch?v=7aThBnLJ6WI.

instrument consisted of four sound sources: two wavetable oscillators, a sub-oscillator (an oscillator that generates a sound an octave below the played pitch), and a noise generator.

Serum shared a few similarities with Massive. It contained wavetable presets sorted into categories, with Serum's examples being Analog, Digital, Spectral, User and Vowel. Serum featured an easy drag and drop system, where envelopes and LFOs alike could easily be routed to automate various controls of any of the four sound sources or ten processing effects modules.[111] Serum was also like Massive in that it could be a bit CPU heavy and that it did not include a true arpeggiator.[112]

A key differentiating feature that separated Serum from Massive, though, was the option to import audio. It featured an advanced wavetable editor window where wavetables could be constructed from imported audio, waveforms drawn in manually or the application of mathematical formulas. Serum included methods of interpolating (a method of creating smoother transitions between wavetables by artificially adding in more table frames) through a variety of options like Crossfading or Spectral Morphing.[113]

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[110] Computer Music, "Xfer Records Serum Review," *MusicRadar*, January 9, 2015, https://www.musicradar.com/reviews/tech/xfer-records-serum-613138.

[111] The term module refers to different components of a synthesizer, such as oscillators, filters, or, in this case, effects that are combined to produce sounds. For hardware synths, modules were connected, or "patched" together by cables, switches, or panels.

[112] Nagle, "Serum."

[113] Nagle, "Serum."

In addition to garnering praise from music gear publications, notable commercial EDM producers quickly implemented Serum into their workflow as many had done with Massive. Notable users of Serum include Zedd, David Guetta, Marshmello, Deadmau5, and Mike Shinoda of Linkin Park.[114] Zedd mentioned Serum as one of his favorite soft synths, specifically praising it for its ability to create any sound one could desire.[115] Meanwhile, David Guetta declared Serum as "…probably the most standard synth today"[116] in a behind-the-scenes video for the creation of his future rave remix of "Titanium."

The success of Serum was aided by popular music creation and collaboration platform Splice in 2016. After Serum had initially risen to the number 2 position on Splice's Top Plugins chart, it became the first plug-in to be offered by Splice in a "Rent-to-Own" purchasing plan. This plan offered users the normal $189.00 retail price in installments of $9.99 per month, while still allowing users access to the full version of

[114] As documented from public interviews, articles, commentary and livestream videos from DJ Mag, Splice, and YouTube among others.

[115] Zedd, "Zedd: Music Production Feedback & Tips (& Why You Shouldn't be Avicii) [Twitch]," *Sol State*, July 15, 2020, https://www.youtube.com/watch?v=fqHvrBY-UiU.

[116] "David Guetta Makes a Future Rave 'Titanium' Edit From Scratch," *DJ Mag*, September 16, 2021, https://www.youtube.com/watch?v=awRcImBSmT0.

Serum and complete ownership of their product license following the final payment.[117] Steve Duda revealed that Splice reached out to him after the company noticed the large quantity of users' digital audio workstation (DAW) sessions utilizing Serum in their database. Duda agreed to offer his product in this "Rent-to-Own" plan as a more affordable alternative after considering the amount of potential revenue lost due to rampant piracy of the product. The "Rent-to-Own" offer on Serum brought in more revenue for Xfer Records than anticipated, and the more affordable alternative yielded an increase in users of the product.[118] Wavetable synthesis had thus reached a new level of accessibility with the lower price point.

Wavetable Soft Synth Explosion

Following the successes of Massive and Serum, other manufacturers started releasing their own digital synths featuring wavetable synthesis. In 2015, Spectrasonics introduced a wavetable engine and their own collection of over 400 wavetables in the second version of their powerful instrument Omnisphere.[119] In 2018, music software company Ableton released their aptly titled Wavetable, integrating it within their DAW

[117] Reuben Raman, "Serum Plugin Now Available Rent-to-Own," *Splice (Blog)*, August 3, 2016, https://splice.com/blog/introducing-serum-plugin-rent-to-own/.

[118] Duda, "Serum's Success."

[119] Paul Nagle, "Spectrasonics Omnisphere 2," *Sound On Sound*, August 2015, https://www.soundonsound.com/reviews/spectrasonics-omnisphere-2.

Ableton Live.[120] That same year, virtual instrument manufacturer Arturia released Pigments, deviating from their usual concentration on creating software emulations of classic hardware synths.[121]

Figure 2.3: Image of the main GUI of Arturia's Pigments 4.[122]

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[120] Len Sasso, "Wavetable: Ableton's New Synth," *Sound On Sound*, May 2018, https://www.soundonsound.com/techniques/wavetable-abletons-new-synth.

[121] Computer Music, "Arturia Pigments Review," *MusicRadar*, March 4, 2019, https://www.musicradar.com/reviews/arturia-pigments-3.

[122] *Pigments 4 - User Interface (Main)*, accessed March 6, 2023, digital image, Plugin Boutique, https://www.pluginboutique.com/product/1-Instruments/4-Synth/5018-Pigments-3.

Pigments particularly received praise for combining its powerful wavetable engine and complex design with an intuitive GUI[123] and an easily understood modulation system.[124] Following the introductions and successes of these products, Native Instruments redesigned and updated Massive, which they titled Massive X, in 2019. While this "sequel"[125] product was noted as being completely new and different, its original method of sound generation via wavetable oscillators with wavetable presets remained the same as the original.[126] In 2022, one of the most popular companies in the pro audio industry, Universal Audio, released their Opal Morphing Synthesizer. This hybrid synth featured three oscillators that could function in wavetable or analog mode, and it contained 91 wavetables organized by categories that included Digital, Synth, Complex, Vocal/Vowel and Instrument.[127] That December, Arturia presented Pigments 4, their most recently

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[123] Rory Dow, "Arturia Pigments," Sound On Sound, May 2019, https://www.soundonsound.com/reviews/arturia-pigments.

[124] Computer Music, "Pigments Review."

[125] Simon Sherbourne, "Native Instruments Massive X," *Sound On Sound*, November 2019, https://www.soundonsound.com/reviews/native-instruments-massive-x.

[126] Sherbourne, "Massive X."

[127] Alex Holmes, "Universal Audio Opal Morphing Synthesizer Review: Analogue Meets Wavetable in UA's New Flagship Soft Synth," *MusicTech*, May 18, 2022, https://musictech.com/reviews/software-instruments/universal-audio-opal-morphing-synthesizer-review/.

updated version of Pigments featuring new wavetables and a new ring modulation[128] feature for its wavetable engine.[129] Like these larger entities, other less popular virtual instrument manufacturers, such as Kilohearts[130] and u-he,[131] released their own comparable products in this timeframe.

Wavetable Synthesis in Recent Hardware

Following the increased popularity wavetable soft synths, more manufacturers started releasing hardware synths that used wavetable synthesis. In late 2019, Chinese synth manufacturer Ashun Sound Machines (ASM) announced the Hydrasynth synth as their first product. Within this synth, two of the oscillators could switch to WaveScan mode, which would allow a user to generate sounds created from movements between 8

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[128] Ring modulation is the process in which two audio signals are multiplied by each other a new output signal. One signal, the carrier, is usually a simpler waveform while the other, the carrier, is a more complex one. The resulting signal produces both the sum and difference of the frequencies in the original signals.

[129] Rob Puricelli, "Review: Arturia Pigments 4 Polychrome Synth," *Gearnews*, December 13, 2022, https://www.gearnews.com/review-arturia-pigments-4-polychrome-synth/.

[130] Computer Music, "Kilohearts Phase Plant Review," *MusicRadar*, August 18, 2019, https://www.musicradar.com/reviews/kilohearts-phase-plant.

[131] Simon Arblaster, "u-he's Hive 2 Synth is Here and it Promises to be Supercharged, Sleeker and more Streamlined," *MusicRadar*, May 29, 2019, https://www.musicradar.com/news/u-he-hive-2-is-here-and-it-promises-to-be-supercharged-sleeker-and-more-streamlined.

wavetables.[132] In January 2020, Sequential announced their hybrid synth, the Pro 3, at the National Association of Music Merchants (NAMM) Show.[133] It featured two VCOs and one wavetable oscillator, with the wavetable oscillator containing 32 wavetables with sixteen waves each.[134]

Figure 2.4: Image of the Sequential Pro 3.[135]

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[132] Paul Nagle, "ASM Hydrasynth," *Sound On Sound*, May 2020, https://www.soundonsound.com/reviews/asm-hydrasynth.

[133] "NAMM 2020 — Sequential Pro 3," *Sound On Sound*, January 1, 2020, https://www.soundonsound.com/news/namm-2020-sequential-pro-3.

[134] Peter Kirn, "Sequential's Pro 3 is a New Synth, While the Others Clone – So How Does it Stack Up?" *CDM*, January 5, 2020, https://cdm.link/2020/01/sequential-pro-3/.

[135] *Sequential Pro 3 Multi-Filter Mono Synth*, accessed March 6, 2023, digital image, Sweetwater, https://www.sweetwater.com/store/detail/Pro3--sequential-pro-3-multi-filter-mono-synth.

That same year, Modal Electronics released the Argon 8X, an eight-voice polyphonic synth with 24 wavetable banks, wavetable modification, dual oscillator engines, a built-in arpeggiator with automation, a sequencer and three envelope generators among other features.[136] *Sound On Sound* writer Simon Sherbourne noted specifically noted that the sound engine shared a similar structure to products like Serum, Massive, and Hydrasynth.[137] The following year, Korg released Modwave, which featured two oscillators that could alternate between Wavetable, Dual-Wavetable and Sample modes.[138] The synth was capable of producing up to 32 voices and included over 200 wavetables, organized categorically, with the ability to manipulate them.[139] Near the end of 2021, Waldorf announced the release of the Waldorf M, a desktop synth inspired by the original Microwave capable of 8 voices.[140] Unlike the original Microwave, the synth's 2 wavetable oscillators could each load a different wavetable, and the M included 96 wavetables with the option to add 30.[141] In 2022, budding instrument startup Groove

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[136] Simon Sherbourne, "Modal Electronics Argon 8X," *Sound On Sound*, June 2020, https://www.soundonsound.com/reviews/modal-electronics-argon-8x.

[137] Sherbourne, "Argon 8X."

[138] Rory Dow, "Korg Modwave," *Sound On Sound*, September 2021, https://www.soundonsound.com/reviews/korg-modwave.

[139] Dow, "Modwave."

[140] Dow, "Waldorf M."

Synthesis announced their first product: a wavetable hardware synth that was inspired by the PPG Wave. This instrument, called the 3rd Wave, included 32 PPG-inspired wavetables, an analogue low-pass filter,[142] 4 ADSR envelopes, 4 LFOs, and a tool allowing users to import audio for custom wavetable creation.[143] The 3rd Wave (pictured in Figure 2.5) was presented at the 2022 NAMM Show, and it earned Groove Synthesis a Best in Show award in the "Companies to Watch" category.[144]

Figure 2.5: Image of Groove Synthesis' 3rd Wave.[145]

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[141] Peter Kirn, "Waldorf are Back to the Future with M Wavetable Synth," *CDM*, September 14, 2021, https://cdm.link/2021/09/waldorf-are-back-to-the-future-with-m-wavetable-synth/.

[142] A low-pass filter is a sound frequency filter that attenuates or removes harmonic content that occurs at frequencies above a determined cut-off frequency while leaving the lower frequencies unaffected. A high-pass filter attenuates frequencies below the cut-off frequency while leaving the higher frequencies unaffected.

[143] "3rd Wave Advanced Wavetable Synth," Groove Synthesis, accessed January 25, 2023, https://www.groovesynthesis.com/3rdwave/.

[144] "'Best in Show' at The 2022 NAMM Show," NAMM, accessed January 25, 2023, https://www.namm.org/nammu/industry/best-show-2022-namm-show.

The Appeal of Wavetable Synthesis in the 2020s

To producers and music creators in the 2020s, one of the most appealing aspects of wavetable synthesis is the variety of unique soundscapes that can be created with it. As previously stated, producers like Zedd and Diplo echoed these sentiments about their wavetable soft synths of choice. Additionally, in February of 2021, electronic musician and music technology writer Adam Douglas penned an article for online music gear retailer Reverb, titled "Harnessing the Power of Hardware Wavetable Synthesis." In this article, he reached out to prominent YouTube musicians and synth experts Andrew Huang and BoBeats, as well as Director of Product Development at ASM Glenn Darcey, to give further insight into the appeal of wavetable synthesis. Darcey noted the wide array of sonic possibilities that wavetable synthesis offers in a lengthy answer:

> Synthesizers that use wavetables offer a wider array of sonic options than does a synthesizer that only has two or three different waveforms. A traditional analog synth might only have four waveforms that you then take harmonics away from using filters. Most wavetable synths have the traditional saw, square, triangle, [and] sine waves that synths have had since the 60s, because those are great, iconic sounds but they also then have the ability to go beyond those sounds by having waves that have more complex harmonic structures. You can also do more tonal shaping at the oscillator level than you can on a traditional four-wave synth. It allows you to create sounds that have a wider range and opens the door to new creative options.[146]

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[145] 3rd Wave, accessed March 6, 2023, digital image, Groove Synthesis, https://www.groovesynthesis.com/3rdwave/.

[146] Adam Douglas, "Harnessing the Power of Hardware Wavetable Synthesis," *Reverb*, February 4, 2021, https://reverb.com/news/harnessing-the-power-of-hardware-wavetable-synthesis.

BoBeats agreed, noting that with wavetable synthesis, he was able to "…more quickly get away from the standard waveforms like saw (and) square and move into uncharted territory quicker."[147] Both Huang and Douglas argued that the sonic versatility of wavetable synthesis minimized the amount of additional processing necessary for sound shaping. Hunag stated, "…Because there are an infinite variety of possible waves, and combinations that can be morphed between, [wavetable synthesis] makes for a really flexible and dynamic way to shape timbre without resorting to the usual filters and EQ."[148] Additionally, Huang also echoed Darcey's sentiment concerning wavetable synthesis' abilities to produce sounds with evolving textures while stating the following:

> I'll use a wavetable synth for anything where I want that tonal movement within a sound. Bass, chords, leads, sound effects. These sounds can find a place in many types of productions, from drone to dubstep to IDM to pop.

Ultimately, wavetable synthesis appeals to music creators who want to have an extensive sonic palette at their disposal, whether they are after sounds with more complex textures or sounds in which timbres evolve over time.

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147 Douglas, "Hardware Wavetable Synthesis."

148 Douglas, "Hardware Wavetable Synthesis."

CHAPTER 3: REVVING IN THE NIGHT

Chapter 3 focuses on the first of my compositions, “Revving in the Night,” describing the creative process for this piece from the beginning reference song and car sound selections through the creation of the sounds of a few select instruments. This chapter mentions the recording of one vehicle: a 2012 Chevrolet (Chevy) Equinox. I used the recordings obtained from this vehicle as wavetable sources on every instrument in the composition. It should be noted that the specific method of wavetable synthesis utilized by Serum is that of frequency-domain synthesis. Like most modern wavetable synths, Serum offers the ability to play through and interpolate between collections of different wavetables. Most instruments in this piece, including the first two mentioned in this chapter, span the length of many wavetables of differing wave cycles.

Electronic Dance Music

I began the process of creating “Revving in the Night” by considering a commercially viable musical work under the umbrella of electronic dance music (EDM) to use as a reference work. Though EDM is a musical genre itself,[149] it also serves as umbrella term for an array of different musical subgenres, like drum & bass, house,

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[149] Richard James Burgess, *The History of Music Production* (Oxford: Oxford University Press, 2014), 115.

trance, and trip hop, produced with computers and electronic instruments for the purpose of dancing.[150] Thus, my goal was to produce a piece within a sub-genre of EDM.

The Reference Work

The reference work for "Revving in the Night" was "Blinding Lights" by The Weeknd. Aside from this song being a personal favorite, I chose it for its musical style and commercial success. At the time of this writing, "Blinding Lights" is ranked number one on Billboard's Greatest of All Time Hot 100 Songs chart, which is calculated by a songs' all-time performance on Billboard Hot 100 chart.[151] Hot 100 chart placements stem from a combination of physical sales, digital sales, online streaming, and radio airplay.[152] Thus, in terms of overall chart performance, "Blinding Lights" is the most commercially successful song of all time. In terms of digital sales and equivalent

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[150] Kembrew McLeod, "Genres, Subgenres, Sub-Subgenres and More: Musical and Social Differentiation Within Electronic/Dance Music Communities," *Journal of Popular Music Studies* 13, no. 1 (2001): 60, https://doi.org/10.1111/j.1533-1598.2001.tb00013.x.

[151] "Greatest of All Time Hot 100 Songs," *Billboard*, accessed February 15, 2023, https://www.billboard.com/charts/greatest-hot-100-singles/.

[152] "Billboard Charts Legend," *Billboard*, accessed February 15, 2023, https://www.billboard.com/billboard-charts-legend/.

streaming units, “Blinding Lights” was the best-selling digital single of 2020,[153] and in 2023, it remains the most-streamed song of all time on popular music streaming service Spotify.[154]

Musically, the song has been classified as a synth-pop[155] and synthwave[156] song, both of which fit under the umbrella of EDM. One big difference between “Blinding Lights” and “Revving in the Night,” though, is the lack of vocals in the latter. “Revving in the Night” is strictly instrumental, which is common in synthwave music. Although I produced my piece in a manner that allows space for vocals, the main melody of the piece uses the first instrument discussed in this chapter because I wanted to emphasize the wavetable instruments themselves.

[153] “The Weeknd Wins 2020’s IFPI Global Digital Single Award for Blinding Lights,” *IFPI*, March 19, 2021, https://www.ifpi.org/the-weeknd-wins-2020s-ifpi-global-digital-single-award-for-blinding-lights/.

[154] Barnaby Lane, “These Are the 25 Most Streamed Spotify Songs of All Time,” *Insider.com*, February 4, 2023, https://www.insider.com/most-streamed-spotify-songs-of-all-time.

[155] Heran Mamo, “The Greatest Hit: The New No. 1 Song of All Time,’” *Billboard*, November 23, 2021, https://www.billboard.com/music/features/the-weeknd-blinding-lights-billboard-cover-story-2021-interview-1235001282/.

[156] Derrick Rossignol, “The Weeknd Goes Full Synthwave on the Yearning New Single ‘Blinding Lights,’” *Uproxx*, November 29, 2019, https://uproxx.com/music/the-weeknd-blinding-lights/.

Recording the Equinox

Naturally, the process of “Revving in the Night” began with considerations of specific vehicle sounds should be recorded. First, I brainstormed and charted out a list of desired vehicle sounds. In the original chart, pictured in Table 1, I loosely sorted the sounds into three sonic categories: Short Attack - Short Duration, Short/Medium Attack - Medium Duration and Slow Attack - Long Duration.

Next, I conducted online research to acquire general knowledge of techniques used for recording different vehicle sounds to inform my recording process. Sources included multiple video demonstrations from microphone manufacturer RØDE[157] (one was a collaboration with Ric Viers,[158] author of the book *The Sound Effects Bible: How to Create and Record Hollywood Style Sound Effects*), one from Swedish post-production company Pole Positions Productions,[159] and one from professional sound effects engineer Alex Knickerbocker.[160]

[157] Ryan Burke, “RØDE Racing - Pro Microphone Setup,” *RØDE,* November 13, 2017, https://www.youtube.com/watch?v=4kB458Q9Y9M.

[158] Rick Viers, “RØDE University - Location Sound Effects Recording,” *RØDE*, November 7, 2011, https://www.youtube.com/watch?v=Eb_7SHmMy_E.

[159] “Ultimate Guide to Vehicle Sound Design & Recording,” *Aftertouch Audio*, November 8, 2021, https://www.youtube.com/watch?v=hlkaX13NmO0.

[160] Alex Knickerbocker, “Recording Cars for Hollywood Films, How The Pros Do It,” *Alex Knickerbocker*, March 11, 2019, https://www.youtube.com/watch?v=wkpGMiG7rxU.

Table 3: A rough catalogue of proposed Equinox sounds to record.

Vehicle Sound Types					
Short Attack - Short Duration		Short/Medium Attack - Medium Duration		Slow Attack - Long Duration	
Sound	Location	Sound	Location	Sound	Location
Opening Car Door	Outside Car	Single Car Alarm	Outside Car	Tires rotating	Outside car - pointed to road
Opening Car Door	Inside Car	Multiple Alarms	Outside Car	Tires rotating	Mic inside wheel well
Opening back car door	Inside Car	Switching to reverse	Inside car	Side mirror movements	Outside car
Opening back car door	Outside Car	Front Windshield Wipers	Inside Car	Exhaust muffler	Outside car
Popping Trunk	Outside Car	Front Windshield Wipers	Outside Car	Exhaust muffler	Inside muffler
Popping Trunk	Under hood	Back Windshield wipers	Inside Car	Seat movement adjustme	Inside car
Car Horn - Short	Outside Car - Close	Back Windshield wipers	Outside Car	Rolling Windows Up	Outside Car
Car Horn - Short	Outside Car - Far	Car Horn - Long	Outside Car - Close	Engine revving	Under hood - in airbox
Seatbelt click	Inside Car	Car Horn - Long	Outside Car - Far	Engine revving	Outside Car
Car Beep (Lights)	Inside Car	Horn honking	Under hood	Engine revving	Inside Car
		Engine rattling	Inside Car	Engine running	Under hood
		Engine rattling	Under hood	Engine running	Outside car
				Loud A/C	Inside Car
				Rolling Windows Up	Inside Car
				Side mirror movements	Outside Car
				Car radio static	Inside car

After determining the sounds I wanted and how to best capture them, I considered which vehicles might work best. One of the vehicles I chose was my 2012 Chevrolet (Chevy) Equinox, with multiple factors informing this decision. The first factor was ease of access. Furthermore, the Equinox produced a few specific sounds I wanted, one of which was an unusual rattling noise the engine often made.

To record sounds from the Equinox, a friend assisted by performing the actions that would generate the required sounds. The equipment for this field recording session included a TASCAM DR-40X portable recording device and a Shure SM-57 microphone (mic). While capturing the sounds inside the vehicle, I used the mics included on the DR-40X. While attempting to record the sounds outside the vehicle, however, the built-in mics picked up an overabundance of wind noise, causing the signal to distort. To combat this, I connected the SM-57 into one of the external mic inputs on the recording device. This alleviated the issue of capturing excess wind noise, so I captured the rest of the sounds outside the vehicle with the SM-57. While capturing these recordings, I reorganized the original chart (see Table 2), taking note of the recording locations (inside or outside the car), the recording devices and mics used, the distance and position of the mics from the sound source, the attack type of the sound (fast or slow), and the general recording duration (long or short).

Table 4: Catalogue of the recordings captured from the Equinox.

Equinox Sound Recordings					
Sound	Location	Microphone Type	Microphone Position	Attack Type	Duration Type
Closing Car Door	Inside Car	TASCAM DR-40X Built-in	2-3 inches from connection of door and frame	Fast	Short
Closing Car Door	Outside Car	TASCAM DR-40X with SM-57	2-3 inches from connection of door and frame	Fast	Short
Opening Car Door	Inside Car	TASCAM DR-40X Built-in	2-3 inches from connection of door and frame	Fast	Short
Opening Car Door	Outside Car	TASCAM DR-40X with SM-57	2-3 inches from intersection of door and frame	Fast	Short
Opening Trunk	Inside Car	TASCAM DR-40X Built-in	2-3 inches from connection of door and frame	Fast	Short
Opening Trunk	Outside Car	TASCAM DR-40X with SM-57	2-3 inches from connection of door and frame	Fast	Short
Closing Trunk	Inside Car	TASCAM DR-40X Built-in	2-3 inches from connection of door and frame	Fast	Short
Closing Trunk	Outside Car	TASCAM DR-40X with SM-57	2-3 inches from connection of door and frame	Fast	Short
Popping Hood	Outside Car	TASCAM DR-40X with SM-57	2-3 inches the center of the hood connection	Fast	Short
Car Horn (Short)	Outside Car	TASCAM DR-40X with SM-57	3 feet from the center of the front of the car	Fast	Short
Car Horn (Short)	Outside Car	TASCAM DR-40X with SM-57	25 feet from the center of the front of the car	Fast	Short
Car Horn (Long)	Outside Car	TASCAM DR-40X with SM-57	3 feet from the center of the front of the car	Fast	Long
Car Horn (Long)	Outside Car	TASCAM DR-40X with SM-57	25 feet from the center of the front of the car	Fast	Long
Car Alarm	Outside Car	TASCAM DR-40X with SM-57	3 feet from the center of the front of the car	Fast	Long
Car Alarm	Outside Car	TASCAM DR-40X with SM-57	25 feet from the center of the front of the car	Fast	Long
Car Beep (Lights)	Inside Car	TASCAM DR-40X Built-in	2-3 inches from the driver's side dash speaker	Fast	Short
Seatbelt Click	Inside Car	TASCAM DR-40X Built-in	2-3 inches from seatbelt clicker	Fast	Short
Seatbelt Movement	Inside Car	TASCAM DR-40X Built-in	3-4 inches from path of seatbelt	Slow	Short
Seat Adjustments (Distance)	Inside Car	TASCAM DR-40X Built-in	Standing up outside the car, 2-3 inches intersection of bottom and back	Slow	Long
Seat Adjustments (Angle)	Inside Car	TASCAM DR-40X Built-in	Standing up outside the car, 2-3 inches intersection of bottom and back	Slow	Long
Seat Adjustments (Back Expansion)	Inside Car	TASCAM DR-40X Built-in	Standing up outside the car, 2-3 inches intersection of bottom and back	Slow	Long
Front Windshield Wipers	Inside Car	TASCAM DR-40X Built-in	2-3 inches from center of windshield	Slow	Long
Front Windshield Wipers	Outside Car	TASCAM DR-40X with SM-57	7 inches from at center of windshield	Slow	Long
Back Windshield Wipers	Inside Car	TASCAM DR-40X Built-in	2-3 inches from center of windshield	Slow	Long
Back Windshield Wipers	Outside Car	TASCAM DR-40X with SM-57	2-3 inches from center of windshield	Slow	Long
Vehicle Moving (10 MPH)	Outside Car	TASCAM DR-40X with SM-57	4-5 inches from tires driving by, 2-3 off the ground	Slow	Long
Vehicle Moving (10 MPH)	Outside Car	TASCAM DR-40X with SM-57	4-5 inches from tires driving by, 2-3 off the ground	Slow	Long
Side Mirror Movements (Up)	Outside Car	TASCAM DR-40X with SM-57	2-3 inches from the mirror	Slow	Long
Side Mirror Movements (Left)	Outside Car	TASCAM DR-40X with SM-57	2-3 inches from the mirror	Slow	Long
Rolling Windows Up	Inside Car	TASCAM DR-40X Built-in	2-3 inches from intersection of the window bottom and frame	Slow	Long
Rolling Windows Up	Outside Car	TASCAM DR-40X with SM-57	2-3 inches from intersection of the window bottom and frame	Slow	Long
Rolling Windows Down	Inside Car	TASCAM DR-40X Built-in	2-3 inches from intersection of the window bottom and frame	Slow	Long
Rolling Windows Down	Outside Car	TASCAM DR-40X with SM-57	2-3 inches from intersection of the window bottom and frame	Slow	Long
Engine Revving	Outside Car (Open Hood)	TASCAM DR-40X with SM-57	2-3 inches from the engine	Slow	Long
Engine Revving	Outside Car	TASCAM DR-40X with SM-57	2 feet from the center of the front of the car	Slow	Long
Engine Revving	Inside Car	TASCAM DR-40X Built-in	2-3 inches from the center of the bottom of the windshield	Slow	Long
Engine Revving	Outside Exhaust Pipe	TASCAM DR-40X with SM-57	2 inches from the exhaust pipe, perpendicular	Slow	Long
Engine Rattling	Outside Car (Open Hood)	TASCAM DR-40X with SM-57	3 inches from engine	Fast	Long
Car Running	Outside Exhaust Pipe	TASCAM DR-40X with SM-57	2 inches from the exhaust pipe, perpendicular	Slow	Long
Loud A/C	Inside Car	TASCAM DR-40X Built-in	3-4 inches from the vent, perpendicular	Slow	Long
Car Radio Static (Dash Speaker)	Inside car	TASCAM DR-40X Built-in	2-3 inches from the driver's side dash speaker	Fast	Long
Car Radio Static (Door Speaker)	Inside Car	TASCAM DR-40X Built-in	2-3 inches from the driver's side door speaker	Fast	Long

Editing and Processing My Recordings

After completing the Equinox session, I imported the recordings from the DR-40X onto my laptop. I then selected most viable recordings and imported them into a Logic Pro session. Each recording had similar processing on different channels in the Mixer view of Logic Pro (see Figure 3.1). The first effect on each audio channel (track) was iZotope’s RX 10 Spectral De-Noise plug-in (see Figure 3.2). To use this plug-in, I looped a section of pure noise in each clip before clicking the ‘Learn’ button to allow the algorithm to isolate the unwanted noise and remove it from the recording.

Figure 3.1: Image of the Mixer view for the processing session in Logic Pro.

Figure 3.2: Image of the GUI for RX 10 Spectral De-Noise.

I trimmed each individual clip to a desirable length in the Editor window (see Figure 3.3), adding small fade-ins and fade-outs to the beginning and end of each clip to eliminate abrupt noise pops. I then added Logic Pro's Gain plug-in on each channel, using it to increase or decrease the volume of each sound until its signal reached an optimal level. The last effect in each processing chain was a Logic Pro graphic EQ. For most of the channels, I only added low- and high-pass filters to remove unnecessary frequency content. A few of the sounds called for a slight, broad boost in the upper midrange of their frequency spectrums. These three plug-ins formed the processing chain for every sound recorded from the Equinox. I then re-exported each sound for wavetable manipulation.

Figure 3.3: Image of the Editor window for the processing session in Logic Pro.

Preparing My Composer Session

For the main composition session, I created 30 Software Instrument tracks though only used 18, and I loaded each one with an instance of Xfer Records' Serum soft synth. Since my goal was to create a song in a similar vein to that of a successful hit song, I imported a stereo audio file of "Blinding Lights" into an audio track to use for structuring and mix referencing. After this, I set the session tempo to 171 beats per minute (BPM) to match that of "Blinding Lights." I then used markers to indicate starting points for each section in the song, such as the introduction, verses, pre-choruses, choruses, and the bridge. While doing this, I took an artistic liberty to slightly deviate my piece's structure from that of the reference. In "Blinding Lights," the first verse is twice as long as the second verse, with the former being 16 measures and the latter being 8 measures. I wanted "Revving in the Night," however, to have verses of equal measure length, so I removed half of the first verse of the "Blinding Lights" file to place the markers more accurately.

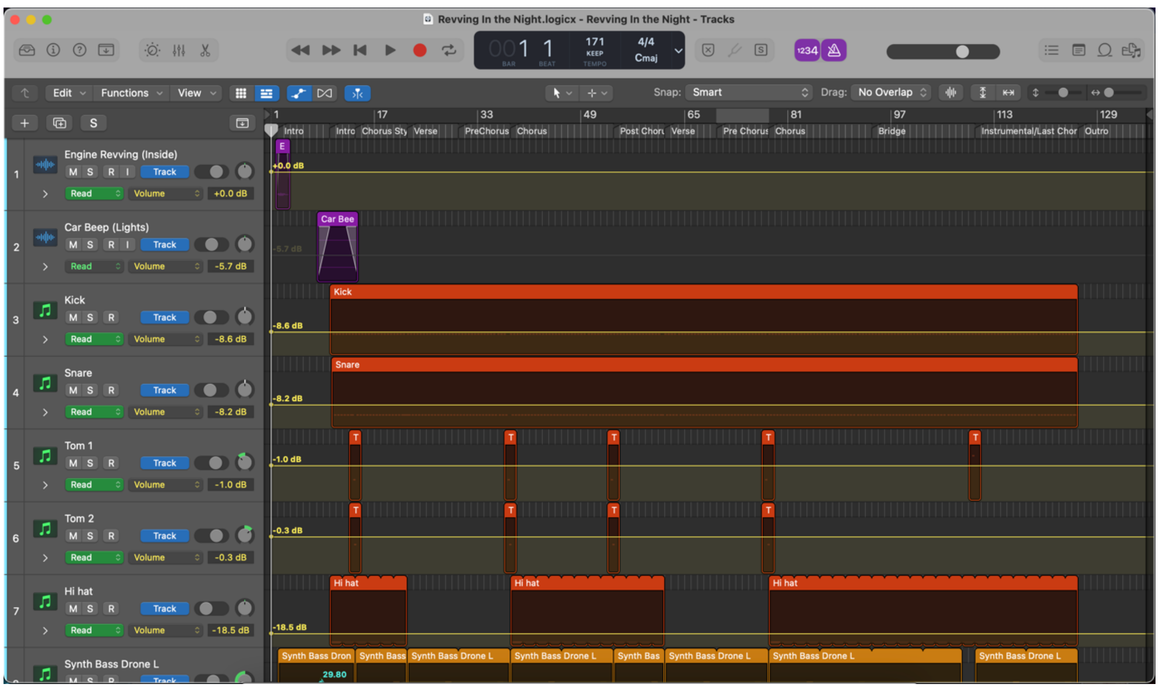

Figure 3.4: Image of the Editor window in the "Revving in the Night" session.

Pictured below (see Table 3) is a chart that identifies the recordings I transformed into wavetables for this piece, the instruments I created with those wavetables, and the additional Sub and Noise oscillators that I layered within Serum on each track. This thesis does not detail the creation of every wavetable instrument, but it does cover my creation of three important instruments: the 'Main Synth Melody,' the 'Synth Bass Drone' that emulates the sound of an engine revving at the beginning, and the 'Kick.' In addition to the wavetable instruments, I placed two original audio recording clips, the 'Car Beep (Lights)' and the inside 'Engine Revving,' at the beginning of the piece as transitions into their corresponding synth sounds.

Table 3: Catalogue of the recordings used for their corresponding wavetable instruments.

"Revving in the Night" Wavetable Instrument Components				
Recording(s)	Instrument(s)	Layered With Sub Oscillator - Wave Type	Layered With Noise - Preset	Vehicle
Seatbelt Click	Kick	Yes - Sine	Yes - XF_Kck_Atk15	Equinox
Seatbelt Movement	Kick	Yes - Sine	Yes - XF_Kck_Atk15	Equinox
Closing Trunk (Outside)	Snare	Yes - Sine	Yes - SH1 Noise	Equinox
Closing Car Door (Inside)	Toms (1 & 2)	No	Yes - icon_tom fl	Equinox
Opening Car Door (Inside)	Toms (1 & 2)	No	Yes - icon_tom fl	Equinox
Seat Adjustments (Distance)	Hi Hat	No	Yes - AC Hum 1	Equinox
Engine Revving (Inside)	Synth Bass Drone	Yes - Sawtooth	Yes - ARP White	Equinox
Car Radio Static (Door Speaker)	Synth Bass Stabs	Yes - Pulse	Yes - J 60	Equinox
Car Alarm (Far)	Beginning Melodic Synth	Yes - Sawtooth	Yes - ARP White	Equinox
Car Beep (Lights)	Main Synth Melody	Yes - Sawtooth	Yes - ARP White	Equinox
Rolling Windows Up	Synth Pad	Yes - Pulse	Yes - J 60	Equinox
Car Horn Long (3 ft. distance)	Synth Pad 2	Yes - Sawtooth	No	Equinox
Radio Static (Dash Speaker)	Synth Pad 3	Yes - Sine	Yes - J 60	Equinox
Side Mirror Adjustments (Up)	Synth String Layer	Yes - Square	Yes - AC Hum 1	Equinox
Car Horn Short (3 ft. distance)	Arpegiatted Synth	Yes - Sine	No	Equinox
Engine Revving (Exhaust Pipe)	Riser/Fall	No	Yes - AC Hum 2	Equinox

Main Synth Melody

The melodic synth line that appears during the introduction and the post-chorus sections of "Blinding Lights" is one of the most memorable elements of the song, so I produced the 'Main Synth Melody' (MSM) instrument in a similar sonic fashion to add that element of memorability to my piece. I created the wavetable instrument for this melody with the audio sample ‘Car Beep (Lights),’ which was a recording of the alarm meant to remind the driver to switch the headlight gear back to automatic before turning the car off. The sound of the alarm had a simple, consistently pitched sound that I thought would produce a clean, fairly well-articulated sound suitable for a keyboard riff. I placed the original recording of the alarm at the beginning of the piece, using used volume fades on the clip and volume automation on the ‘MSM’ track to create a transition from the recording into the wavetable instrument. This was a creative decision to showcase the transformation of the original car alarm into the ‘MSM.’

To begin creating the ‘MSM’ instrument, I imported the ‘Car Beep’ recording into Oscillator A on the front panel of Serum through the ‘Dynamic Pitch Zero Snap’ setting (see Figure 3.5). This process separated the waveform of the recording into 256 wavetables that each began and ended at an equilibrium (or zero) point. I assigned low frequency oscillator (LFO) 1 to automatically control the positioning of the wavetable play head (see Figure 3.6). I completed this procedure by clicking on the LFO 1 knob and moving the parameter over to the wavetable position (WT Pos) knob under Oscillator A. I changed the mode of LFO 1 to the ‘Envelope’ mode (see Figure 3.8), which causes the LFO to only cycle through the wavetables once when a note is triggered, before altering the shape of LFO 1.

Figure 3.5: Image of the audio import options, including the ‘Dynamic Pitch Zero-Snap’ setting, in the Oscillator window.

Figure 3.6a: Image of the selection of LFO.

Figure 3.6b: Image of LFO 1 being assigned to control the wavetable position knob of Oscillator A.

In their default settings, each LFO's shape is a triangle that is displayed on an x-y axis (see Figure 3.7). Serum, however, offers the ability to use points to shape the LFO, so I altered the shape to make the play-head move across all the wavetables in a slightly exponential manner that produced a desirable sonic result. The shaping of the LFOs for this instrument (as well as most of the instruments) involved some experimentation with shape adjusting to achieve the sound that I wanted. To form the new shape, I moved the original center point at the top of the triangle to the left side of the y axis and then the new center point of the descending linear slope downward to make an exponential shape (see Figure 3.8).

Figure 3.7: Image of the default shape of each LFO in Serum.

Figure 3.8: Image of the shape and settings for LFO 1.

After reshaping LFO 1, I deleted all but some simple sine waves contained in wavetables 24 through 74 (see Figure 3.9) and then normalized each wavetable individually (see Figure 3.10). Then I inserted crossfades between the wavetables to bring out the brighter frequencies.

Figure 3.9: Image of the Add/Remove menu in the Table Edit window.

Figure 3.10: Image of the ‘Process’ menu in the Table Edit window.

I adjusted the fine-tuning value to -6 cents under the ‘FIN’ section in Oscillator A (see Figure 3.6b). Finally, I changed the playback mode of the LFO to ‘Trigger’ in the ‘Rate’ section. I left the ‘Rate’ knob in its default mode, which is synced to the project’s BPM. I did, however, adjust it to 1/8, which allowed for the LFO to completely cycle through all the wavetables every eighth note (see Figure 3.8), as opposed to the default quarter note (see Figures 3.5 and 3.6).

I imported the same recording into Oscillator B through the same ‘Dynamic Pitch Zero-Snap’ option. For this oscillator, I kept wavetables 12 through 256. As with the wavetables in Oscillator A, I added crossfades to the wavetables, normalized them separately, and added another set of crossfades between those new tables to eliminate unwanted popping noises. I assigned LFO 2 to control the wavetable play-head of Oscillator B, which I modified into an ascending exponential slope with a shorter peak point. I set the rate of this LFO to 1/32 while shaping the sound from that oscillator. Otherwise, I left the remaining settings LFO 2 settings the same as those for LFO 1. I then changed the fine tune value to 7 cents.

In addition to the two main wavetable oscillators, I used the Noise and Sub oscillators to layer the sound. For this synth, I used the Sub oscillator to generate a sawtooth wave tuned up an octave to add a quicker attack (Figure 3.11). In the Noise oscillator, I chose the “ARP White” preset to generate white noise for adding a subtle character to the tone. To ensure that the noise only lasted for the length of each note played, I enabled the one-shot mode by checking the box next to the right arrow symbol in the Noise section (see Figure 3.12). I layered both oscillators sparingly, with the output of the Sub oscillator at 13% and the output of the Noise oscillator at 5%.

Figure 3.11: Image of the Sub Oscillator in Serum.

I then adjusted the parameters of ADSR Envelope 1 to achieve a staccato sound for the melody. This sound only used Envelope 1. I increased the attack time from 0 to 5 milliseconds for a quick, but not immediate, attack for the overall sound. The other ADSR parameters included:

- a decay time to 968 milliseconds (ms)
- a sustain level to -12 decibels (dB)
- a release time to 277 ms.

Finally, I made some further adjustments in the Filter section (see Figure 3.13) to remove unnecessary low frequency content and add more heft to the sound. In the Filter section, I applied a high-pass filter with a 12 dB per octave slope using the “High 12” setting and enabled all the oscillators to be affected by this filter. I set the ‘Filter Resonance’ knob to 10% to add a slight boost to the peak of the filter to bring out the attack of that frequency. I adjusted ‘Drive’ knob to 14 % to add a slight bit of harmonic saturation to the sound and changed the ‘Fat’ knob to 100% to add a perceived sonic weight.

Figure 3.12: Picture of the Noise oscillator in Serum.

Figure 3.13: Image of the Filter section in Serum as used for the 'Main Synth Melody.'

Finally, I enabled multiple effects modules in the FX (effects) section, shown in Figure 3.14, including distortion, chorus, EQ, reverb (reverberation), and delay. The distortion added subtle harmonic saturation and the chorus effected added a sense of stereo widening to the sound. For the EQ, I applied a high-pass filter to remove frequency content from 10 kilohertz (kHz) and above. Finally, I inserted reverb and delay effects to place the synth in a larger sonic space. On the reverb unit, I applied the 'Hall'[161] setting with 4.7 s delay time before mixing in 46% of the affected signal. These effects all helped add the final polish to this synth to make it sonically comparable to the main melodic synth line in "Blinding Lights."

Figure 3.14: Image of the Distortion, Chorus, EQ and Reverb in the FX Section.

Synth Bass Drone

Another common musical element of synthwave that is exemplified in "Blinding Lights" is the deep synth bass drone, so that was an element of special importance in "Revving in the Night." In "Revving in the Night," however, this synth bass briefly imitates the sound of its original wavetable recording: the revving of the Equinox engine

[161] The 'Hall' setting in the reverb unit is a setting with a long decay of up to multiple seconds. This setting is meant to emulate the sound of reverberation in a concert hall.

recorded from inside the vehicle. It is worth noting that there were three tracks that used this virtual instrument, with one placed in the center of the stereo image while the other two were panned towards the left and right of the sound space. However, aside from each track triggering an imitation of the engine revving at different times, each instance of the instrument was created in the same manner.

For this instrument, I used the recording, captured from inside the vehicle, of the Equinox engine revving. I imported it into Serum's Oscillator A through the 'Constant Frame Size (Pitch Average)' setting. Through this setting, the cycle length of every wavetable is determined by the pitch of the noise in the recording (or at least what Serum determines to be the pitch). From there, I edited the wavetables in Oscillator A by:

- selecting wavetables 180 through 213 and deleting the rest.
- creating new wavetables with waveform shapes formed to ensure smooth sonic transitions between the already existing wavetables (see Figure 3.15).
- inserting crossfades between these 256 wavetables to further ensure smooth transitions between them.

In the LFO section, I assigned LFO 1 to control the positioning of the wavetable play-head in Oscillator A, but the shape of this one was much different than those used for the melodic synth (see Figure 3.16).

Figure 3.15: Image of the Morph menu in the Table Edit window.

I inverted the default triangle shape and positioned the middle point in the center of the x-y axis, causing the play-head to only cycle from wavetables 256 through 129 and back. After this gave me a desirable sound, I made further adjustments to LFO 1's settings by:

- switching the LFO into 'Envelope' mode.
- setting the 'Rate' knob to cycle through once every 8 measures (bars) with the 8 bar setting.

Finally, I shifted the pitch within Oscillator A down by an octave by setting the Oct amount to -1 (see Figure 3.16) to add low frequency content.

Figure 3.16: Image of the Serum settings for the Synth Bass Drone.

In this case, Oscillator B served as the crux of the more audible evolving bass sound. I produced this sound by:

- importing the same recording through the same setting as Oscillator A.
- auditioning and selecting 28 individual, unconnected wavetables that shared sonic similarities through waveforms that resembled saw waves before removing the rest.
- inserting transitional wavetables to smooth out the sound.

- assigning LFO 2 to control the wavetable position play-head.
- setting the rate of LFO 2 to cycle through once every 4 bars.
- shaping LFO 2 by raising both the left and right points to about halfway between the middle and the top of the y axis (see Figure 3.17).

LFO 2's shape limited the number of total wavetables used, with the play-head traveling from wavetables 256 through 179 and back. The sound, however, was as I wanted.

Figure 3.17: Image of the shape of LFO 2 in the Synth Bass Drone.

I layered wavetable oscillators with the Sub and Noise oscillators. To add a grittier texture to the bass, I used a sawtooth wave from the Sub Oscillator in the same octave range. However, I wanted this portion of the sound to appear to rise in volume, so I automated the output of this oscillator to be controlled by Envelope 2 (see Figure 3.18). This ADSR envelope featured:

- a slow attack time of 1.2 seconds (s).
- a decay rate of 1.4 s.
- a sustain percentage of 88.32%.[162]
- a release of 1.18 s.

Figure 3.18: Image of Envelope 2 in the Synth Bass Drone, which is routed to the output of the Sub oscillator.

Meanwhile, to add an analogue-like character to the sound, I utilized the Noise oscillator. I selected the “CymMicBleed” (Cymbal Microphone Bleed) noise preset and enabled one-shot mode so the noise would only occur with every note played.

I wanted this instrument to have a droning quality, so I set configured the ADSR controls of Envelope 1 (see Figure 3.16) to have:

- a quick attack of 40 ms.
- a longer decay time of 2.44 s.
- a release time of 1.07 s.

The next thing I wanted to do was to control the high frequency content in the sound by slowly introducing more of it over the course of each note played. To do this, I navigated to the Filter section (see Figure 3.16) and applied a low-pass filter with a 12 dB per octave slope to all 4 oscillators. I assigned LFO 3 to control the frequency cutoff of this filter (see Figure 3.19) configured LFO 3 by:

- changing the shape to retain the general triangle shape, but with a lowered center point on the y axis and raised the left and right end points sitting just below the center of the x axis.
- enabling ‘Envelope’ mode for this LFO.
- setting the rate of the LFO cycle to 4 bars.

[162] For Envelope 1, the amount of sustain is represented by volume in decibel value. For the remaining envelopes, the sustain time is represented by a percentage value.

This gradually increased the high frequencies of the sound over the course of each note, further contributing to the evolving nature of the ‘Synth Bass Drone.’

Figure 3.19: Image of LFO 3 in the Synth Bass Drone.

Finally, I used several effects from the FX section, (see Figure 3.20) including:

- a phaser mixed in at 16% to add signal phasing for interesting sonic effect.
- a chorus to add some stereo width.
- a reverb to place the sound in a large perceived space.

Figure 3.20: Image of the FX section with the Phaser, Chorus and Reverb effects.

While the synth bass drone sound itself was complete, three tracks used this instrument in the piece, with one used as a center channel and the others panned to the left and right. Both the left and right channels featured automation to the Coarse pitch[163] (abbreviated as CRS in Figure 3.16) sections of Oscillators A & B. I selected automation parameter for Oscillator A's Coarse pitch on each instrument track in Logic Pro (see Figure 3.21) and drew in automation for an increase followed by a decrease in number values. Then, I completed the same process with the automation parameter for Oscillator B's Coarse pitch on each track, drawing in similar increases and decrease in values. This automation of Coarse pitch resulted in the brief imitations of an engine revving within the

[163] The Coarse pitch sections of Serum are useful for automating the continuous transposition of a sound's pitch without the sound arriving at specific notes between automation points.

synth bass drone tracks, and it is this imitation that alludes to the title of the piece: "Revving in the Night."

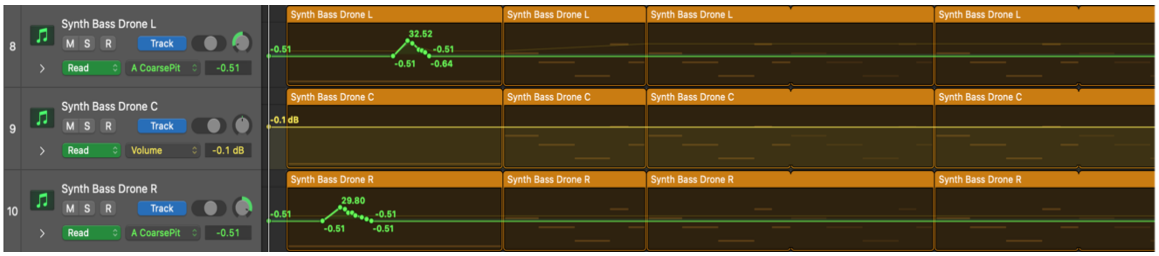

Figure 3.21: Image of the Coarse pitch automation for the left and right 'Synth Bass Drone' channels.

Kick

The last wavetable instrument that is discussed in this chapter is the kick drum. As stated above in Figure 6, I used two recordings were to create the wavetables for this instrument: the 'Seatbelt Click' and the 'Seatbelt Movement.' The process for creating the 'Kick,' however, did not begin with the wavetable oscillators. Instead, I first adjusted the settings in Envelope 1. Since this was instrument was emulating a kick drum, I set the Envelope with:

- a quick attack of 0.3 ms.
- a quick hold time of 0.5 ms.
- a decay time of 106 ms.
- a release time of 233 ms.

The decay and the release time, though quick, were both significantly longer than the attack and hold times to mimic the natural decay of sound that occurs after a real kick drum hit.

After adjusting Envelope 1, I began to create the sound of Oscillator A, hoping to produce the bulk of the kick's lower midrange frequencies. To do this, I produced the sound of Oscillator A by:

- normalizing the wavetables.
- isolating wavetables 54 through 254 and deleting the first 53 wavetables.
- inserting morphing wavetables, bringing the total number of wavetables up to 254.
- inserting crossfades to ensure a smoother transition between wavetables.

Next, I altered the shape of LFO 1 shape from its default triangle shape into a descending exponential slope with a smaller peak ending at the center of the x axis (see Figure 3.22). I then additionally configured LFO 1 by:

- enabling 'Envelope' mode for LFO 1.
- setting the rate at 1/2 so one LFO cycle would occur over the length of a half note beat.

I experimented with changing the starting position of the wavetable position knob in Oscillator A until I found the most desirable point of attack for the sound (wavetable 56). Lastly, to achieve the emulation of a kick drum's low midrange, I pitched Oscillator A down one octave.

Figure 3.22: Image of the shape of LFO 1 in the kick drum.

For Oscillator B, I wanted another layer of midrange sound with a different sonic character than that of Oscillator A. I created the sound of Oscillator B by:

- importing the ‘Seatbelt Movement’ recording into Oscillator B through the ‘Dynamic Pitch Follow’ setting.
- eliminating wavetables with barely any waveform shapes, electing to keep 117 through 254.
- Adding crossfades were added between the remaining 138 wavetables.
- assigning LFO 2 to control the wavetable position knob in Oscillator B
- altering the shape of LFO 2 until I achieved the sound I wanted, forming an ascending exponential slope (see Figure 3.23).

- setting the rate to span one LFO cycle per eighth note.

Figure 3.23: Image of the shape LFO 2 in the kick drum.

From there, I used the Sub and Noise oscillators to add low and high frequency content respectively. From the Sub oscillator, I added a pitched-down sine wave to add low frequency punch. To add high frequency content for the transient of the kick drum, I used the Noise oscillator in one-shot mode. The preset labelled “XF_KickAtk_15” served as a sonically ideal choice for the desired transient attack. It is worth noting that while the Sub and Noise oscillators contributed greatly to the low and high frequency content respectively, the overall tone of the kick drum was still heavily shaped by the two wavetable oscillators.

I then routed the oscillators through the Filter section, where a 12 dB per octave low-pass filter was applied (see Figure 3.24). I also increased the 'Drive' and 'Fat' knobs to 100% to add more punch to the kick. To simulate the dissipating of high transient frequencies after a quick attack, I assigned an LFO to control the filter frequency cutoff. LFO 3 (pictured in Figure 3.24) automated the frequency cutoff to alternate from 2 kilohertz (kHz) to 168 Hz to decrease the amount of high frequency content throughout the short duration of the kick drum. Finally, to accentuate the attacks of the high midrange and low frequency content, I inserted an EQ from the FX section with 4 dB increase of about 2300 Hz a 3 dB boost at 53 Hz.

Figure 3.24: Image of the kick drum settings in Serum, including the displays of LFO 3 and the Filter section.

Summary

Every instrument in “Revving in the Night” was created through wavetable synthesis, with all the wavetables coming from recordings of sounds generated by the 2012 Chevy Equinox. Using the wavetable instrument Serum, these recordings were manipulated into a variety of different sounds appropriate for the synth-pop and synthwave genres. Also, I included two of the audio recordings in close proximity of the wavetable instruments created from them, calling attention to the transformations of those specific sounds.

CHAPTER 4: IF IT'S BROKE (DON'T FIX IT)

This chapter focuses on the creation of "If It's Broke (Don't Fix It)." I discuss the creative process of this piece from the beginning reference work and vehicle sound selections to the creation of three specific wavetable instruments. The three instruments covered are 'Arp 2.1,' 'Drop Synth,' and 'Engine Drone.' While the last chapter detailed the recording of the 2012 Chevrolet Equinox, this one discusses the recording of the second vehicle, a 2022 Toyota RAV4. While most of the wavetable instruments in "If It's Broke (Don't Fix It)" were created with recordings of various sounds from the RAV4, however, a couple of them utilized the sound recordings from the Equinox. As with the previous piece, a majority of the instruments in "If It's Broke (Don't Fix It) are created via the repeated play through and interpolation of many different wavetables with different wave cycles. For most of the instruments, the separated wave cycles remained in the same order as they initially were in the recording. However, one of the instruments, the 'Drop Synth,' was created using similarly shaped individual wave cycles that were not initially in that order. The rest of the instruments in this piece, as well as most of the instruments in "Revving In the Night," retained the initial order of the wavetables generated upon import (aside from the addition of transitionary wavetables added via morphing).

The Reference Work

The reference work for “If It's Broke (Don’t Fix It)” was “Lunar” by producers David Guetta and Afrojack. This piece, like “Blinding Lights,” was chosen as a reference for its commercial success and its musical style. “Lunar” is an electro-house[164] composition that differs in musical style from “Blinding Lights” while still falling within the EDM umbrella.[165] Though “Lunar” did not achieve a level of commercial success comparable to that of “Blinding Lights,” it found success on the UK Dance Singles Chart, reaching a peak position of 22.[166]

Recording the RAV4

The second vehicle I recorded was a Toyota RAV4 that produced a vastly different collection of sounds than the Equinox. The unusual electronic sounds and quieter hybrid engine made for interesting wavetable recordings. Because I was recording outside, I used a Shure SM-58 to filter out the unwanted ambient wind noise and ran it rhough a Focusrite Scarlett 18i20 interface. I recorded the audio from the Scarlett straight into Logic Pro (see Figure 4.1). Instead of gathering a bunch of shorter recordings for

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[164] “Lunar (Original Mix),” Beatport, accessed February 21, 2023, https://www.beatport.com/track/lunar-original-mix/2447111.

[165] McLeod, “Genres, Subgenres, Sub-Subgenres and More.”

[166] “Official Dance Singles Chart Top 40: 21 August 2011 - 27 August 2011,” Official Charts, accessed February 21, 2023, https://www.officialcharts.com/charts/dance-singles-chart/20110821/104/.

each individual sound, I obtained five longer, continuous recordings with several different sounds captured in each of them. In addition to using my Scarlett and SM-58 setup, I used the built-in microphone on an iPhone 12 Pro Max for four different continuous recordings to capture higher frequencies that the SM-58 would not.

I edited and processed these recordings in a similar manner to the Equinox recordings. (see Figures 4.2 and 4.3). However, they were quiet and required multiple levels of gain processing to bring them up to a workable level. Additionally, the recordings required noise reduction and simple EQ filters to remove unwanted noise and unnecessary low and high frequency content. After processing, I exported the recordings for wavetable manipulation and produced a catalogue of them (see Table 4).

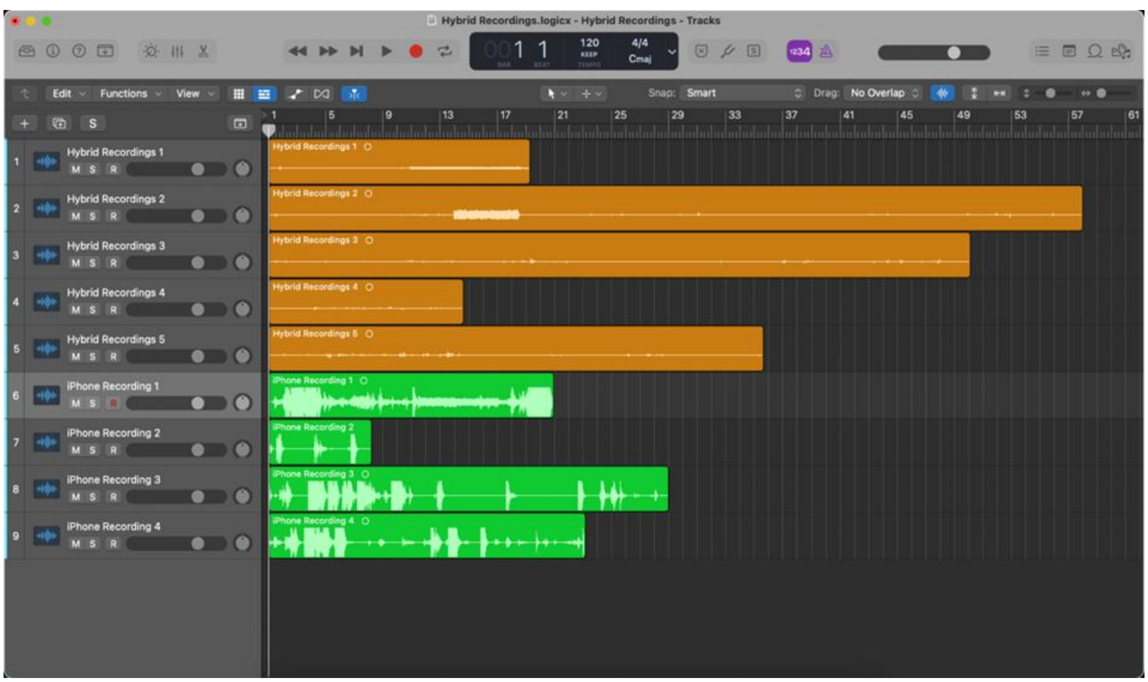

Figure 4.1: Image of the Editor window of the Logic Pro session containing the unedited RAV4 recordings.

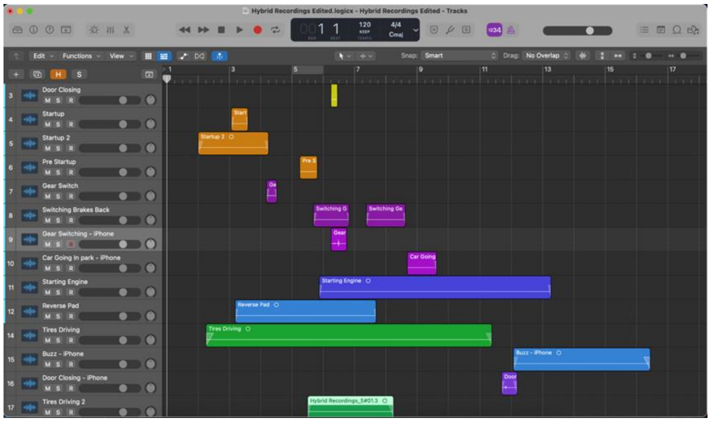

Figure 4.2: Image of the Editor window in the Logic Pro session containing the edited and processed RAV4 recordings.

Figure 4.3: Image of the Mixer window in the RAV4 editing session.

Figure 4.4: Image of the RX Spectral De-Noise plug-in after removing the noise from the recording of the RAV4's parking brake sound.

Table 4: Catalogue of the recordings captured from the RAV4.

RAV4 Sound Recordings					
Sound	Location	Microphone Type	Microphone Position	Attack Type	Duration Type
Starting Up Alert	Inside Car - Door Open	Focusrite Scarlett with SM-57	5-6 inches from and pointed to center of driver's side dashboard	Short	Fast
Pre-Start Up Alert	Inside Car - Door Open	Focusrite Scarlett with SM-57	5-6 inches from and pointed to center of driver's side dashboard	Long	Fast
Gear Switch	Inside Car	Focusrite Scarlett with SM-57	2-3 feet from the center of the front of the car	Short	Slow
Gear Switch	Inside Car	iPhone 12 Pro Max	3-4 inches from gear stick	Long	Slow
Engine running at start	Outside Car	Focusrite Scarlett with SM-57	2-3 feet from the center of the front of the car	Long	Slow
Engine running at start	Outside Car	iPhone 12 Pro Max	1 foot underneath front of the car, laying by the front driver's side tire	Long	Slow
In Reverse Noise	Outside Car	Focusrite Scarlett with SM-57	2-3 feet from the center of the front of the car	Long	Slow
Out of Park Brake Alert	Outside Car	Focusrite Scarlett with SM-57	2-3 inches under the back of the car	Short	Slow
Out of Park Brake Alert	Outside Car	iPhone 12 Pro Max	1 foot underneath back of the car	Short	Slow
Into Park Brake Alert	Outside Car	Focusrite Scarlett with SM-57	2-3 inches under the back of the car	Short	Fast
Into Park Brake Alert	Outside Car	iPhone 12 Pro Max	1 foot underneath back of the car	Short	Fast
Tires On Gravel	Outside Car	Focusrite Scarlett with SM-57	Pointed towards tire, 1 foot off the ground and 1 foot from tire	Long	Slow
Door Closing	Outside Car	Focusrite Scarlett with SM-57	2-3 feet from the center of the front of the car	Short	Fast
Door Closing	Outside Car	iPhone 12 Pro Max	1 foot from the door on the driver's side	Short	Fast
Screech	Outside Car	iPhone 12 Pro Max	6 inches underneath back of the car	Short	Slow
RAV4 Engine Hum	Outside Car	iPhone 12 Pro Max	2-3 feet from the center of the front of the car	Short	Slow

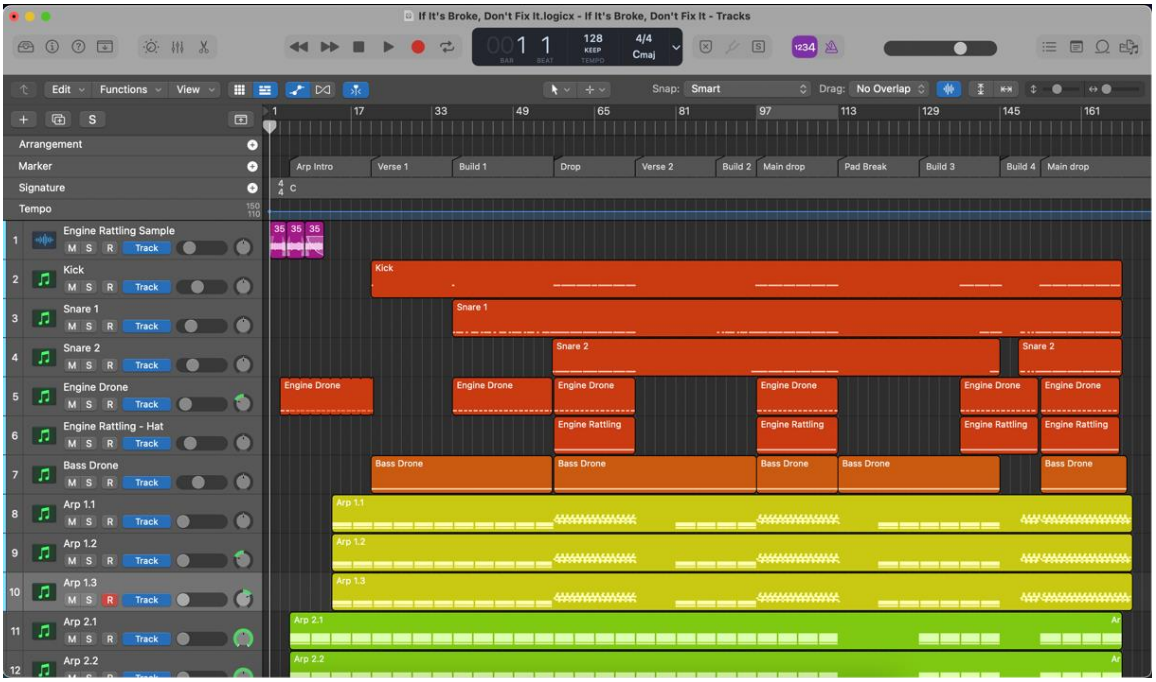

Figure 4.5: Image of the Editor view in the Logic Pro session for "If It's Broke (Don't Fix It)" showing the markers for each section of the piece.

Table 5: Catalogue of the recordings used for their corresponding wavetable instruments.

"If It's Broke (Don't Fix It)" Wavetable Instrument Components				
Recording(s)	Instrument	Layered With Sub Oscillator - Wave Type	Layered With Noise - Preset	Vehicle
Door Closing (iPhone)	Kick	Yes - Sine	Yes - XF_Kck_Atk_14	RAV4
Gear Switch	Snare 1	No	No	RAV4
Gear Switch	Snare 2	Yes - Sine	Yes - BrightWhite	RAV4
Engine Rattling	Engine Drone	No	Yes - AC hum1	Equinox
Engine Rattling	Hi Hat	No	Yes - AC hum1	Equinox
Pre-Start-Up	Arp 1.1	Yes - Square	No	RAV4
Pre-Start-Up	Arp 1.2	Yes - Saw	No	RAV4
Out of Park Alert (iPhone)	Arp 1.3	No	No	RAV4
Screech	Arp 2.1	No	No	RAV4
Seat Adjustments (Distance)	Arp 2.2	No	No	Equinox
Starting Up Alert	Drop Synth	No	No	RAV4
Starting Up Alert	Drop Synth.2	Yes - Saw	Yes - Organ Noise	RAV4
Into Park Brake Alert	Noise Transition 1	No	Yes - AC hum1	RAV4
Out of Park Brake Altert	Noise Transition 1	No	Yes - AC hum1	RAV4
Out of Park Brake Alert (iPhone)	Noise Transition 2	No	Yes - Organ Noise	RAV4
In Reverse Alert	Bass Drone	No	No	RAV4
RAV Engine Hum (iPhone)	Pad	Yes - Saw	Yes - Air Can 1	RAV4
RAV Engine Hum (iPhone)	Glitch Pad	No	No	RAV4
Tires On Gravel	Glitch Pad 2	Yes - Saw	No	RAV4

Like in Chapter 3, Chapter 4 only discusses the creation of three essential wavetable instruments in “If It's Broke (Don’t Fix It),” but a complete list of the vehicle recordings used can be seen in Table 5. The original recording of the engine rattling is also placed at the beginning of the piece to lead into the ‘Engine Drone’ instrument.

Arp 2.1

‘Arp 2.1’ is the main layer of the arpeggiated synth melody that remains the most constant throughout the composition. The reference work, “Lunar,” included a similar arpeggio that contained the first melodic material within that piece, and this instrument serves that same purpose for my composition. As shown in Table 5, I created this wavetable instrument using the ‘Screech’ recording (a recording of the tires that accidentally produced a shrill, high-pitched sound) in both wavetable oscillators.[167] Unlike the wavetable instruments discussed in Chapter 3, the timbre of this wavetable instrument gradually changes through parameter automation in the main ADSR envelope. My goal was to create a clean instrument for the arpeggiated sequence that would sound desirable artificially placed in a large perceived space. I started constructing the sound in the Oscillator A section to create a sound with less high frequency content. I produced the sound in Oscillator A by:

[167] The sound of the Screech recording was not intentionally obtained, but it was nevertheless a useful source for wavetable manipulation.

- importing the recording was imported into Oscillator A (see Figure 4.6).
- isolating wavetables 109 through 254 before deleting the first 108 that emitted barely audible signals and contained no visual amplitudes.
- transforming the shapes of the wave cycles in the remaining tables through the ‘Spectral (Zero All Phases)’ setting.
- I added transitional waveforms to create new set of 256 wavetables.
- assigning LFO (low frequency oscillator) 1 to control the wavetable position play-head (see Figure 4.7).
- changing the shape of LFO 1 from the default triangle shape to that of an upward linear slope (see Figure 4.8) to ensure a liner playthrough of wavetables 1 to 256, create the desired sound of the instrument.
- adjusting the ‘Rate’ knob of Envelope 1 to the ‘Bar’ setting, resulting in one LFO cycle per measure to ensure all the wavetables are played through in each measure.
- adding crossfades between wavetables (see Figure 4.9) to ensure a smoother sound.
- routing the signal of Oscillator A through the Filter section (see Figure 4.10) and applying a low-pass filter with a 24 dB (decibels) per octave slope, a cutoff frequency of 4819 hertz (Hz), and a ‘Fat’ knob adjustment to 100% to fill out the sound.

Figure 4.6: Image of the Screech recording being imported into Serum through the ‘Normal (Dynamic Pitch Follow)’ setting in Oscillator A.

Figure 4.7a: Image of the selection of LFO 1 in the Oscillator window.

Figure 4.7b: Image of LFO 1 being assigned to control the wavetable position knob of Oscillator A in the Oscillator window.

Figure 4.8: Image of the LFO 1 section.

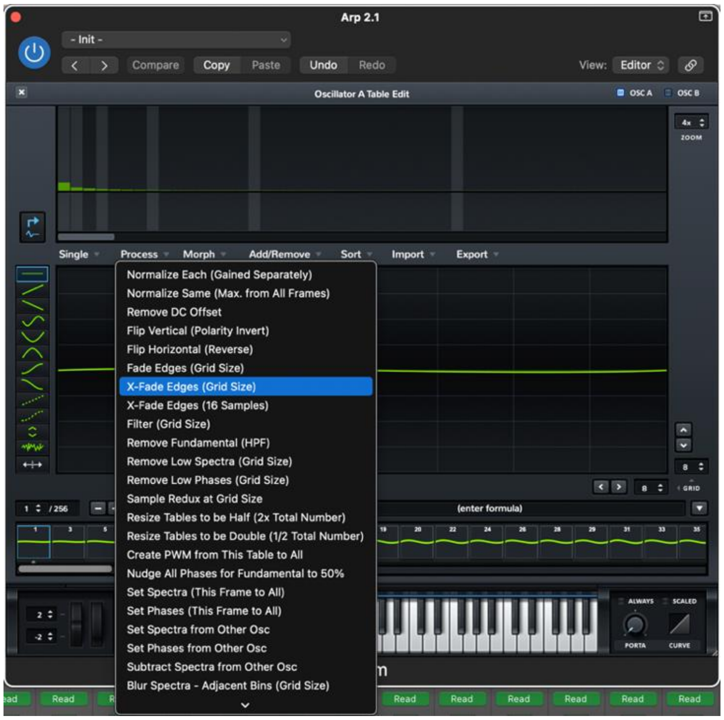

Figure 4.9: Image of the ‘X-Fade Edges (Grid Size)’ option selected in the Processing menu within the Table Edit window.

Figure 4.10: Image of the Filter section in Serum for Arp 2.1.

Once I was done creating the desired sound of Oscillator A, I moved on to Oscillator B. I aimed to create a sound like that of Oscillator A but with more high frequency content to add a layer of perceived brightness. I created the sound of Oscillator B by:

- importing the ‘Screech’ recording into Oscillator B through the same settings.
- isolating wavetables 109-254.
- assigning Envelope 2 to the wavetable position play-head.
- configuring the shape of Envelope 2 through experimentation with an attack time of 703 milliseconds (ms), a decay time of 1.39 seconds (s), a sustain percentage of 63.71 percent, and a release time to 943 ms (see Figure 4.11).

This altered shape resulted in the play-head position only alternating between fifteen wavetables in a cycle. After adjusting the starting position of the wavetable play-head to wavetable 62, however, the desired sound for Oscillator B was realized.

Figure 4.11: Image of the shape of Envelope 2.

As shown in Table 5, I only used the wavetable oscillators for the creation of this instrument. As previously stated, however, I automated the shape of Envelope 1 to change over time to create a timbral evolution from measures (mm.) 23 through 33. The initial settings for Envelope 1 (see Figure 4.12a) included:

- a quick attack time of 1.8 ms.
- a decay time of 847 ms.
- a sustain volume of -23.5 dB.
- a release time of 305 ms.

While most of the parameters for Envelope 1 remained the same throughout the length of the composition, I gradually increased the decay time to 20.9 s (see Figure 4.12b) over the course of measures 23 to 33 (see Figure 4.13).

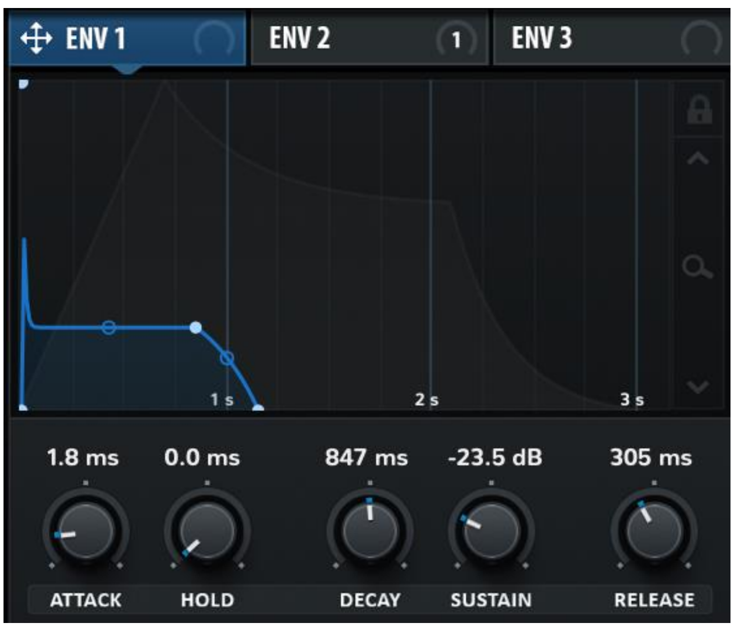

Figure 4.12a: Image of the first shape of Envelope 1.

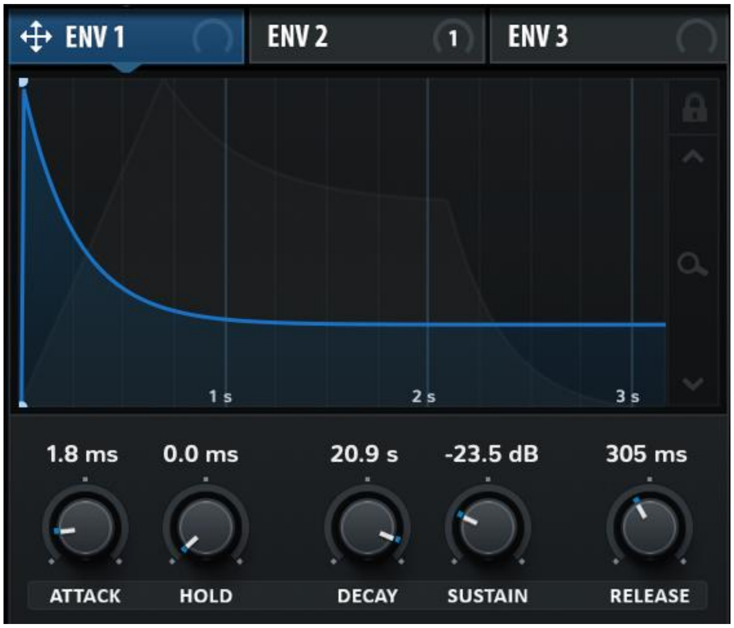

Figure 4.12b: Image of the second shape of Envelope 1.

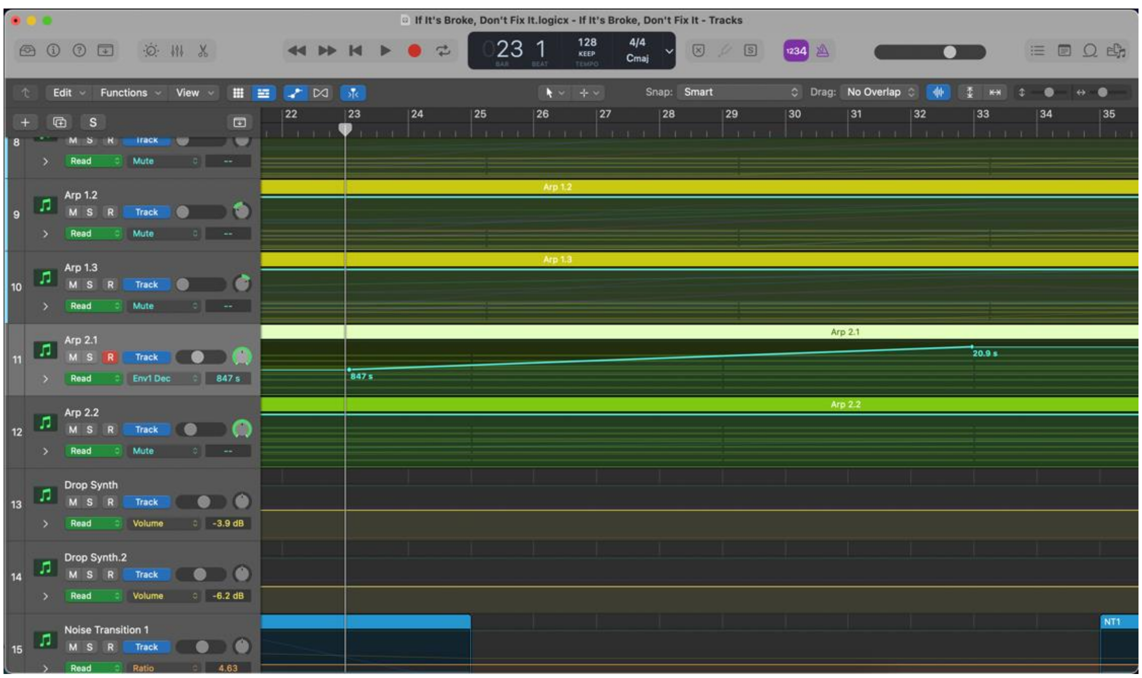

Figure 4.13: Image of the automation for the decay time of Envelope 1 in the Editor window of Logic Pro.

The gradual increase in decay time transformed the timbre from a staccato articulation with separated notes to a legato sound with increased connectivity between individual notes.

Once I finalized the core sound of ‘Arp 2.1’ in the Oscillator section of Serum, (see Figure 4.14), I added three effects modules in the FX section (see Figure 4.15):

- a reverb unit with the ‘Hall’ setting and a decay time of 12 s, mixed with the unaffected dry signal at 45% place the sound in a large space.
- a delay with 43% delay feedback, mixed with the dry signal at 40%.
- an EQ with a high-pass filter to remove unnecessary low frequency content from 275 Hz and below.

These effects added the polish necessary to make the sound suitable for an atmospheric arpeggio capable of introducing and adding cohesion to the composition.

Figure 4.14: Image of the Oscillator view in Serum showing the final settings for Arp 2.1.

Figure 4.15: Image of the FX section in Serum for Arp 2.1.

The Drop Synth

The Drop Synth serves as the centerpiece of the drop[168] sections of the composition, though it additionally appears within the second verse and builds two, three, and four. For this instrument, I wanted a more up-front, aggressive lead sound to be the driving force of the various drop and build sections. I imported 'Starting Up Alert' recording into both wavetable oscillators. For Oscillator A specifically, I wanted to shape the main portion of the sound with a quick attack. I began by importing the audio clip through the 'FFT512' option. Unlike the previously mentioned import modes, the 'FFT512' setting (as well as the other 'FFT' settings) divides the audio into sections of time, analyzes the frequency spectrum of the waveform, and organizes the spectral information into new wavetables. Basically, this setting does more than merely divide the waveforms from the original audio into wavetables.

Once the wavetables were created, I finished producing the sound for Oscillator A by:

- isolating 23 unconnected wavetables with similar perceived sonic characteristics and deleting the rest.
- inserting transitional wavetables to smoothen out the sound.
- assigning LFO 1 to control the wavetable position play-head.

[168] In EDM, the drop is the section of a piece that features an abrupt contrast in the rhythm, melody, or bass line. This section can be thought of as a loose equivalent to a chorus in pop music.

- changing the shape of LFO 1 to a downward linear slope spanning across the entire x & y axes to use wavetables 1 through 23 on longer notes.
- adjusting the 'Rate' knob of LFO 1 to the 1/8 setting to trigger an LFO cycle every eighth note (I did, however, automate this parameter within Logic Pro to change the rate from 1/8 to 1/16 during the end of builds two and four to increase the clarity of the sixteenth notes).
- lowering the pitch of the signal two octaves (see Figure 4.16) to place the sound in the octave range I desired for the 'Drop Synth' while retaining the sonic characteristics I had achieved with Oscillator A.

Figure 4.16: Image of Oscillators A & B of the 'Drop Synth,' both of which are pitched down two octaves.

The resulting sound of the signal served as the main texture, so I aimed to create a sonic layer with a bit more subtlety Oscillator B. I wanted this oscillator to produce a sound with a slightly slower attack and more timbral change in the decay on longer notes. I achieved this by:

- importing the 'Starting Up Alert' recording through the 'Constant Frame Size (Pitch Avg.)' setting.
- transforming the wavetables through the 'Spectral (Zero All Phases)' option.
- narrowing the range of usable wavetables to 119-174 to achieve a more consistent timbre.
- assigning LFO 2 to control Oscillator B's wavetable position play-head.
- altering the shape of LFO 2 to an upward linear slope.
- setting the 'Rate' knob was set to a static, non-automated one Bar setting (one LFO cycle per measure).
- setting LFO 2 to 'Trigger' mode (see Figure 4.17) to restart the LFO cycle at the beginning of every note instead of having it repeat all the way through at a constant rate.

These settings resulted in the play-head only cycling through five wavetables during longer notes. However, I achieved a desired lead sound for Oscillator B after setting the play-head to start on wavetable 15 and cycle through to 20. As with Oscillator A, I pitched Oscillator B's signal two octaves down.

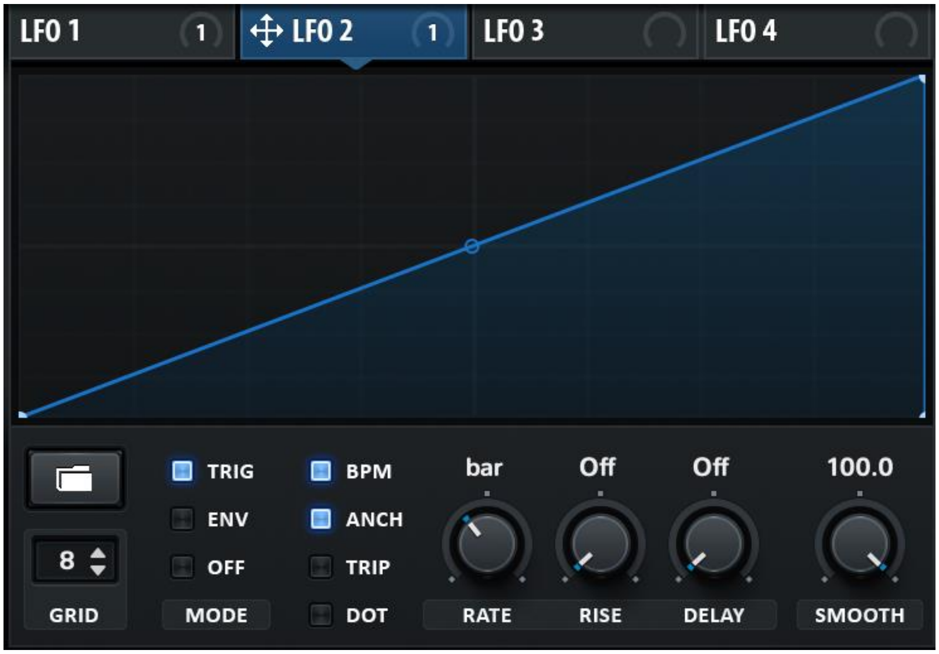

Figure 4.17: Image of the shape and settings of LFO 2.

I routed both oscillators through the Filter section (see Figure 4.18). In the Filter section, I:

- applied a low-pass filter with an 18 dB per octave slope to remove undesired higher frequencies from 3234 Hz and above.
- set the ‘Drive’ knob to 55% to add volume and slight distortion to the sound.
- set the ‘Fat’ knob to 100% to add a perceived sonic heft to it.

Finally, I inserted two effects from the FX section (see Figure 4.19):

- a distortion unit to add slightly harsher harmonics to the sound, emphasizing the decay of the sound from Oscillator B.
- a compressor to further control the loudness range of the instrument.

The result of this was an aggressive, driving lead synth sound perfect for being the centerpiece of the composition's drop sections.

Figure 4.18: Image of the Filter section of Serum for the 'Drop Synth.'

Figure 4.19: Image of the FX section in Serum for the 'Drop Section.'

The Engine Drone

The final instrument discussed in this chapter is the Engine Drone. This wavetable instrument served as both an imitation of an operating vehicle engine and as a steady rhythmic element akin to an electronic hi hat. This was one of the simplest instruments to make, but it serves as a throughline to the composition that ties the work to the title. The title of the work "If It's Broke (Don't Fix It)" is a brash reference to the loud rattling caused by the Equinox engine. The instrument, however, imitates a functioning engine but with a consistent tempo of 128 beats per minute (BPM). For this instrument, I only used one wavetable oscillator, creating the 'Engine Drone' by:

- importing the 'Engine Rattling' recording into Oscillator A through the 'Constant Frame Size (Pitch Avg.)' setting.
- isolating the wavetables I deemed the most sonically useful (wavetables 149-256).
- adding crossfades to assure smooth transitions between the wavetables.
- Assigning LFO 1 to control the wavetable position knob of the oscillator A.
- changing the shape of LFO to a descending linear slope to cycle through wavetables in a linear manner.
- setting the 'Rate' knob was set to 1/16 to set the rhythm of the sound.

To add high frequency content suitable for a hi hat sound, I layered the signal of Oscillator A with that of the Noise oscillator. For the noise oscillator, I wanted a type of noise that could combine with the signal of oscillator A to emulate an engine running. I chose the "AC hum1" preset and assigned the output level from the Noise oscillator to be automated by LFO 2, which had a shape of the descending exponential slope to create a slight sound decay (see Figure 4.20). At this point, though, I still was not satisfied with the clarity of the attack, so I adjusted Oscillator A's wavetable position knob to only alternate from wavetables 14 through 28 to increase its intelligibility.

Figure 4.20: Image of the shape of LFO 2.

I also configured Envelope 1 with the following settings:

- an immediate 0.0 ms attack time.
- a 'Hold' time of 1.99 s to maintain a consistent volume.
- a decay time at 0.0 ms for an immediate cutoff of the sound.
- a release of 330 ms to mimic a natural fading of a sound after it stops.

Meanwhile, I routed the signal from Oscillator A through the Filter section. The Filter section featured a low-pass filter to remove frequency content from 600 Hz and above, and the ‘Drive’ knob was increased to 40% to add volume with a tiny bit of distortion to the signal. Finally, in the FX section, I inserted an EQ with a high-pass filter with the cutoff frequency at 333 Hz to remove unnecessary low end frequency content. Those last filters helped create a wavetable instrument that both mimicked the sound of a running car engine and served the rhythmic function of a hi hat.

Summary

As with the last piece, I created every instrument in this composition using wavetable synthesis in Serum. Most of the wavetable sources for these instruments were the recordings containing sounds from the 2022 Toyota RAV4. Two of the instruments, however, used recordings from the 2012 Equinox, one of which influenced the piece’s title. Like “Revving in the Night,” “If It's Broke (Don’t Fix It)” included an Equinox recording at the beginning of the piece and a transition to its corresponding virtual instrument to emphasize the association of the two. “If It’s Broke (Don’t Fix It)” once again demonstrates the power and practicality of wavetable synthesis through the manipulation of various vehicle recordings into an array of virtual instrument textures.

CONCLUSION

This thesis highlights the accessibility, creative flexibility, and commercial influence of wavetable synthesis through both a historical overview of it and a documentation of its role in two original compositions. Wavetable synthesis remains a heavily utilized tool in commercial music today. It is a powerful tool for music creation that can offer an array of both new and familiar sounds for composers.

Chapters 1 & 2 contain a historical overview of wavetable synthesis to highlight its use in and influence on commercial music. While researching the history of wavetable synthesis, I expanded my knowledge on the developments of not only wavetable synthesis but other forms of synthesis as well. I additionally gained a greater appreciation for how wavetable synthesis uniquely operates compared to other types of synthesis. Some surprising realizations emerged throughout the researching process. While gathering information, I was surprised to learn of the hit records and prominent artists that used the PPG Wave. Compared to other classic hardware synths, like the Fairlight CMI and the Yamaha DX7, or the recent wavetable software synths, like Massive and Serum, I had little knowledge of the PPG Wave's existence before beginning my research on wavetable synthesis. It is much more apparent to me now, however, how important the PPG Wave was for the foundation of wavetable synthesis. I do hope, however, that this portion of my thesis also brings a greater awareness to the contribution of Max Matthews' development of the first wavetable oscillator.

Chapters 3 and 4 showcase the power of wavetable synthesis through the transformation of vehicle recordings into virtual instruments practical for commercially viable EDM compositions. Through the creation of these pieces, I discovered just how valuable a wavetable soft synth like Serum could be for music creation. Most producers tend to only take advantage of the wavetables already included within Serum, but my creative process showcases a greater potential of the synth by utilizing its ability to transform original recordings into unique wavetables with distinct waveform shapes. I gained a better understanding of how certain waveform shapes work best for specific sounds, and I acquired more experience in creating my own sounds from custom wavetables. The process of learning to use Serum and all its features through experimentation has equipped me with a powerful tool for creating my own music in the future.

While wavetable synthesis has been both the subject of technological research and brief historical summaries, this thesis presents academic exploration into its historical and creative use in modern commercially viable music. As more wavetable synths continue to be released, however, and as previously released ones are continually updated, the continued prominence of wavetable synthesis will continue warrant additional scholarly study. Innovations in music technologies continue to occur frequently and rapidly within the professional audio industry. This thesis, as a result, may not be able to address the latest innovations or milestones of wavetable synthesis within the next few years. For now, however, this thesis presents an additional resource for other researchers and composers looking to further explore and engage the topic of wavetable synthesis.

BIBLIOGRAPHY

Aciman, Alexander. “Meet the Unassuming Drum Machine that Changed Music Forever,” *Vox*, April 16, 2018, https://www.vox.com/culture/2018/4/16/16615352/akai-mpc-music-history-impact.

“a-ha.” Billboard. Accessed February 9, 2023. https://www.billboard.com/artist/a-ha/.

Anderton, Craig. “What is MIDI? The Essential Guide.” *Sweetwater*, June 7, 2019. https://www.sweetwater.com/insync/midi-essential-guide/.

Arblaster, Simon. “u-he’s Hive 2 Synth is Here and It Promises to be Supercharged, Sleeker and more Streamlined.” *MusicRadar*, May 29, 2019. https://www.musicradar.com/news/u-he-hive-2-is-here-and-it-promises-to-be-supercharged-sleeker-and-more-streamlined.

“‘Best in Show’ at The 2022 NAMM Show.” NAMM. Accessed January 25, 2023. https://www.namm.org/nammu/industry/best-show-2022-namm-show.

“Billboard Charts Legend.” *Billboard*. Accessed February 15, 2023. https://www.billboard.com/billboard-charts-legend/.

Bio, Matthew. “A Brief History of the Multi-Core Desktop CPU.” *TechSpot*, December 31, 2021. https://www.techspot.com/article/2363-multi-core-cpu/.

“A Brief History of EDM.” *The Los Angeles Film School*, August 5, 2017. https://www.lafilm.edu/blog/brief-history-edm/.

Bristow-Johnson, Robert. “Wavetable Synthesis 101: A Fundamental Perspective.” Paper presented at the Audio Engineering Society Convention, Los Angeles, CA, November 8-11, 1996. https://www.aes.org/e-lib/browse.cfm?elib=7379.

Burgess, Richard James. *The History of Music Production*. Oxford: Oxford University Press, 2014.

Burke, Ryan. “RØDE Racing - Pro Microphone Setup.” *RØDE*, November 13, 2017. https://www.youtube.com/watch?v=4kB458Q9Y9M.

Buskin, Richard. "A-ha 'Take On Me.'" *Sound On Sound*, March 2011. https://www.soundonsound.com/techniques/classic-tracks-ha-take-me.

Chamberlin, Hal. "A Sampling of Techniques for Computer Performance of Music." *BYTE Magazine*, September 1977. https://archive.org/details/byte-magazine-1977-09/mode/2up.

Clark, Colm. "A Sound That Changed Music: The Yamaha DX7." *Culture Sonar*, November 17, 2018. https://www.culturesonar.com/a-sound-that-changed-music-the-yamaha-dx7/.

Clouser, Charlie and Karél Psota. "LA Creatives: Charlie Clouser and Karél Psota Discuss Sampling + Sound Design." *Orchestra Tools*, April 24, 2020. https://www.youtube.com/watch?v=or7QMpGR2jQ.

Cole, George. "Rubberband." Liner Notes for Hall, Randy, Attala Zane Giles and Miles Davis. *Rubberband*. Miles Davis. Recorded October 1985-January 1986. Warner Records R2 599464, 2019, CD.

Coover, Bob. "Groove Synthesis: 'The 3rd Wave is Our Imagination of What Would've Happened if PPG Had Stayed in Business.'" Interview by Matt Mullen. *MusicRadar*, July 8, 2022. https://www.musicradar.com/news/groove-synthesis-3rd-wave-interview.

Computer Music. "Arturia Pigments Review." *MusicRadar*, March 4, 2019. https://www.musicradar.com/reviews/arturia-pigments.

_________. "Cakewalk Rapture Review." *MusicRadar*, November 8, 2007. https://www.musicradar.com/reviews/tech/cakewalk-rapture-22236.

_________. "How to Use Ableton Live 10's Wavetable Synth." *MusicRadar*, May 18, 2018. https://www.musicradar.com/how-to/how-to-use-ableton-live-10s-wavetable-synth.

_________. "Kilohearts Phase Plant Review." *MusicRadar*, August 18, 2019. https://www.musicradar.com/reviews/kilohearts-phase-plant.

_________. "Terratec Komplexer Review." *MusicRadar*, February 14, 2008. https://www.musicradar.com/reviews/tech/terratec-komplexer-22677.

_________. “Waves Codex Review.” *MusicRadar*, January 12, 2015. https://www.musicradar.com/reviews/tech/waves-codex-613355.

_________. “Wolfgang Palm PPG WaveMapper 2 Review.” *MusicRadar*, March 13, 2015. https://www.musicradar.com/reviews/tech/wolfgang-palm-ppg-wavemapper-2-617550.

_________. “Xfer Records Serum Review.” *MusicRadar*, January 9, 2015. https://www.musicradar.com/reviews/tech/xfer-records-serum-613138.

Cornell, Reuben. “Massive: Past, Presets & Future.” *Native Instruments (Blog)*, August 16, 2018. https://blog.native-instruments.com/massive-past-presets-future/.

Cram, Preston. “What Is Synthwave?” *ElectroZombines*, June 24, 2021. https://electrozombies.com/magazine/article/what-is-synthwave/.

Crombie, David. “Waldorf Wave.” *Sound On Sound*, July 1994. https://www.soundonsound.com/reviews/waldorf-wave.

Crute, Adam. “Learning the Basics of FM Synthesis and How It Works.” *MusicTech*, July 1, 2019. https://musictech.com/guides/essential-guide/how-fm-synthesis-works/.

_________. “The Science of Wavetable Synthesis.” *MusicTech*, August 26, 2019. https://musictech.com/guides/essential-guide/science-wavetable-synthesis/.

Deadmau5, “Deadmau5 Live Stream July 31, 2014 [7/31/2014],” *YouTube*, July 31, 2014. https://www.youtube.com/watch?v=8EMhjocxlpQ.

“Depeche Mode.” Official Charts. Accessed February 4, 2023. https://www.officialcharts.com/artist/20192/depeche-mode/.

Diplo. “Diplo about Native Instruments KOMPLETE.” *Native Instruments*, October 9, 2010. https://www.youtube.com/watch?v=9j7Aor_4NTE.

Dow, Rory. “Arturia Pigments.” *Sound On Sound*, May 2019. https://www.soundonsound.com/reviews/arturia-pigments.

_________. “Korg Modwave.” *Sound On Sound*, September 2021. https://www.soundonsound.com/reviews/korg-modwave.

_________. “Waldorf M.” *Sound On Sound*, April 2022. https://www.soundonsound.com/reviews/waldorf-m.

Douglas, Adam. “Harnessing the Power of Hardware Wavetable Synthesis.” *Reverb*, February 4, 2021. https://reverb.com/news/harnessing-the-power-of-hardware-wavetable-synthesis.

_________. “Klevgrand Tomofon Review: Turning the Tables on Wavetable Synthesis.” *MusicTech*, December 13, 2022. https://musictech.com/reviews/klevgrand-tomofon-wavetable-synthesizer/.

Duda, Steve. “Steve Duda: Berklee Online Interview Series with Loudon Stearns and Erin Barra.” Interview by Loudon Stearns and Erin Barra. *Berklee Online*, August 25, 2020, https://www.youtube.com/watch?v=pyI0-ve7vaU.

_________. “Steve Duda on Serum’s Success & Parallels Between Music and Programming (The EDM Prodcast #157).” Interview by Aden Russell. *EDMProd*, August 22, 2021. https://www.youtube.com/watch?v=7aThBnLJ6WI.

Eisele, Andrew. “Understanding the History and Operation of Wavetable Synthesis.” *B&H*, October 21, 2018. https://www.bhphotovideo.com/explora/pro-audio/tips-and-solutions/understanding-history-and-operation-wavetable-synthesis.

Future Music. “What is Wavetable Synthesis? The Ultimate Beginner's Guide.” *MusicRadar*, August 9, 2021. https://www.musicradar.com/news/what-is-wavetable-synthesis.

“Greatest of All Time Hot 100 Songs.” *Billboard*. Accessed February 15, 2023. https://www.billboard.com/charts/greatest-hot-100-singles/.

Guetta, David. “David Guetta Makes a Future Rave ‘Titanium’ Edit From Scratch.” *DJ Mag*, September 16, 2021. https://www.youtube.com/watch?v=awRcImBSmT0.

_________. “How to Make Remixes & Mash-ups, With David Guetta.” *DJ Mag*, July 1, 2021, https://www.youtube.com/watch?v=kUoI5Vv8Bu8.

Holmes, Alex. “Universal Audio Opal Morphing Synthesizer Feview: Analogue Meets Wavetable in UA’s New Flagship Soft Synth.” *MusicTech*, May 18, 2022. https://musictech.com/reviews/software-instruments/universal-audio-opal-morphing-synthesizer-review/.

Horner, Andrew. “Auto-Programmable FM and Wavetable Synthesizers.” *Contemporary Music Review* 22, no. 3 (2003): 21-29. https://doi.org/10.1080/0749446032000150852.

_________. “A Simplified Wavetable Matching Method Using Combinatorial Basis Spectra Selection.” *Journal of the Audio Engineering Society* 49, no. 11 (2001): 1060-1066, http://www.aes.org/e-lib/browse.cfm?elib=10172.

Howell, Steve. “Q. Can You Explain the Origins of Wavetable, S&S and Vector Synthesis?” *Sound On Sound*, February 2006. https://www.soundonsound.com/sound-advice/q-can-you-explain-origins-wavetable-ss-and-vector-synthesis.

“I Can’t Wait.” Liner Notes for Nowels, Rick, Stevie Knicks and Eric Pressly. *I Can’t Wait (45 RPM Maxi-Single)*. Steve Knicks. Recorded 1985. Modern Records 1C K 060-20 0921 6, 1985. Vinyl.

“Partners in Education! Xfer Record’s & I Love Music Academy.” *I Love Music*, June 17, 2017. https://ilovemusic.in/blog/partners-in-education-xfer-records-i-love-music-academy/.

Johnson, Heather. “Classic Tracks: Tears for Fears’ ‘Everybody Wants to Rule the World.’” *Mix Online*, August 1, 2007. https://www.mixonline.com/recording/classic-tracks-tears-fears-everybody-wants-rule-world-365857.

Kirn, Peter. “Sequential’s Pro 3 is a New Synth, While the Others Clone – So How Does It Stack Up?” *CDM*, January 5, 2020. https://cdm.link/2020/01/sequential-pro-3/.

_________. “Waldorf are Back to the Future with M Wavetable Synth.” *CDM*, September 14, 2021. https://cdm.link/2021/09/waldorf-are-back-to-the-future-with-m-wavetable-synth/.

Knickerbocker, Alex. “Recording Cars for Hollywood Films, How The Pros Do It.” *Alex Knickerbocker*, March 11, 2019. https://www.youtube.com/watch?v=wkpGMiG7rxU.

Lane, Barnaby. “These Are the 25 Most Streamed Spotify Songs of All Time.” *Insider.com*, February 4, 2023. https://www.insider.com/most-streamed-spotify-songs-of-all-time.

Lavengood, Megan. “What Makes It Sound 80s.” *Journal of Popular Music Studies* 31, no. 3 (September 2019): 73-94. https://doi.org/10.1525/jpms.2019.313009.

Leete, Norm. “Fairlight CMI [Retrozone].” *Sound On Sound*, April 1999. https://www.soundonsound.com/reviews/fairlight-cmi-retrozone.

“Lunar (Original Mix).” Beatport. Accessed February 21, 2023. https://www.beatport.com/track/lunar-original-mix/2447111.

Mamo, Heran. “The Greatest Hit: The New No. 1 Song of All Time.’” *Billboard*. November 23, 2021. https://www.billboard.com/music/features/the-weeknd-blinding-lights-billboard-cover-story-2021-interview-1235001282/.

Marshmello. “Marshmello - Alone (Stems).” *Splice*. Accessed September 6, 2020. https://splice.com/marshmello/alone-contest.

McLeod, Kembrew. “Genres, Subgenres, Sub-Subgenres and More: Musical and Social Differentiation Within Electronic/Dance Music Communities.” *Journal of Popular Music Studies* 13, no. 1 (2001): 59-75. https://doi.org/10.1111/j.1533-1598.2001.tb00013.x.

McNabb, Michael. “‘Dreamsong’: The Composition.” *Computer Music Journal* 5, no. 4 (Winter 1982): 36-53. https://doi.org/10.2307/3679505.

Miller, Jonathan. “Retro Family Tree.” *Future Music*, Spring 2001. http://www.midimanuals.com/manuals/ppg/wave_2_0/ppg_and_waldorf_history/ppgwaldorfhistory.pdf.

Moore, Sunny. “Skrillex on Ableton Live, Plug-ins, Production and More.” Interview by Computer Music Specials. *MusicRadar*, November 3, 2011. https://www.musicradar.com/news/tech/interview-skrillex-on-ableton-live-plug-ins-production-and-more-510973.

Nagle, Paul. “ASM Hydrasynth,” *Sound On Sound*, May 2020. https://www.soundonsound.com/reviews/asm-hydrasynth.

_________. “Spectrasonics Omnisphere 2.” *Sound On Sound*, August 2015. https://www.soundonsound.com/reviews/spectrasonics-omnisphere-2.

_________. “Xfer Records Serum.” *Sound On Sound*, July 2015. https://www.soundonsound.com/reviews/xfer-records-serum.

"NAMM 2020 — Sequential Pro 3." *Sound On Sound*, January 1, 2020. https://www.soundonsound.com/news/namm-2020-sequential-pro-3.

"Official Dance Singles Chart Top 40: 21 August 2011 - 27 August 2011." Official Charts. Accessed February 21, 2023. https://www.officialcharts.com/charts/dance-singles-chart/20110821/104/.

"On This Record the Following Stage Equipment was Used." Liner Notes for Christopher Franke, Edgar Froese and Johannes Schmoelling. *Poland (The Warsaw Concert)*. Tangerine Dream. Recorded December 10, 1983. Jive Electro HIP 22, 194, 2 Vinyls.

Palm, Wolfgang. "Blast From the Past: PPG Wave." Interview by Computer Music. *MusicRadar*. February 28, 2014. https://www.musicradar.com/news/tech/blast-from-the-past-ppg-wave-595219.

_________. "Classic Gear: PPG Wave." *Electronic Musician*, February 2019.

_________. "'Emulation is Boring!': Wolfgang Palm on the Past, Present and Future of Synth Design." Interview by Computer Music. *MusicRadar*, May 9, 2018. https://www.musicradar.com/news/emulation-is-boring-wolfgang-palm-on-the-past-present-and-future-of-synth-design.

_________. "Wolfgang Palm Interview." *Plugin Alliance (Blog)*, March 17, 2020. https://www.plugin-alliance.com/en/blog/blogpost/items/wolfgang-palm-interview.html.

"PPG Wave 2.3 & Waveterm B." *Sound On Sound*, December 1996. https://www.soundonsound.com/reviews/ppg-wave-23-waveterm-b.

Price, Simon. "10 Years of Native Instruments." *Sound On Sound*, October 2006. https://www.soundonsound.com/music-business/10-years-native-instruments.

_________. "Native Instruments Massive." *Sound On Sound*, February 2007. https://www.soundonsound.com/reviews/native-instruments-massive.

Puckette, Miller. "Max At Seventeen" *Computer Music Journal* 26, no. 4 (Winter 2002): 31-43. https://doi.org/10.1162/014892602320991356.

Puricelli, Rob. "Review: Arturia Pigments 4 Polychrome Synth." *Gearnews*, December

13, 2022. https://www.gearnews.com/review-arturia-pigments-4-polychrome-synth/.

Raman, Reuben. “Serum Plugin Now Available Rent-to-Own.” *Splice (Blog)*, August 3, 2016. https://splice.com/blog/introducing-serum-plugin-rent-to-own/.

Reid, Gordan. “Waldorf Q.” *Sound On Sound*, June 2000. https://www.soundonsound.com/reviews/waldorf-q-0.

“RIAA and GR&F Certification Audit Requirements: RIAA Digital Single Award,” RIAA. Accessed April 24. https://www.riaa.com/wp-content/uploads/2016/02/DIGITAL-SINGLE-AWARD-RIAA-AND-GRF-CERTIFICATION-AUDIT-REQUIREMENTS.pdf

Roads, C. & Max Mathews. “Interview with Max Mathews.” *Computer Music Journal* 4, no. 4 (Winter 1980): 15-22. https://doi.org/10.2307/3679463.

Rogerson, Ben. “Xfer Records Releases Serum, the ‘Dream’ Plugin Synth.” *MusicRadar*, September 22, 2014. https://www.musicradar.com/news/tech/xfer-records-releases-serum-the-dream-plugin-synth-607401.

Rossignol, Derrick. “The Weeknd Goes Full Synthwave on the Yearning New Single ‘Blinding Lights.’” *Uproxx*, November 29, 2019. https://uproxx.com/music/the-weeknd-blinding-lights/.

Sasso, Len. “Wavetable: Ableton’s New Synth.” *Sound On Sound*, May 2018. https://www.soundonsound.com/techniques/wavetable-abletons-new-synth.

“Serum.” *Xfer Records*. Accessed February 14, 2023. https://xferrecords.com/products/serum.

Sherbourne, Simon. “Modal Electronics Argon 8X.” *Sound On Sound*, June 2020. https://www.soundonsound.com/reviews/modal-electronics-argon-8x.

_________. “Native Instruments Massive X.” *Sound On Sound*, November 2019. https://www.soundonsound.com/reviews/native-instruments-massive-x.

Shinoda, Mike. “8.24.20 – I’m Back!” *Shinoda* Livestreams, August 24, 2020. https://www.youtube.com/watch?v=X9137ojBpg8.

Smith III, Julius O. “Viewpoints on the History of Digital Synthesis.” Paper presented at the International Computer Music Conference, Montreal, QC, October 16-20, 1991. https://quod.lib.umich.edu/i/icmc/bbp2372.1991.001.

"Stevie Nicks." Billboard. Accessed February 4, 2023. https://www.billboard.com/artist/stevie-nicks/.

"Story of Gold® & Platinum®." RIAA. Accessed March 25, 2023. https://www.riaa.com/gold-platinum/story/.

"Synth Nodes – Fairlight CMI The Worlds 1st DAW & Built-In Sampler." *Iconic Underground Magazine (Blog)*, August 16, 2019. https://iumag.co.uk/synth-nodes-fairlight-cmi/.

Team. "Native Instruments Massive Review." *MusicRadar*, December 12, 2007. https://www.musicradar.com/reviews/tech/native-instruments-massive-22644.

"Tears For Fears." Billboard. Accessed February 4, 2023. https://www.billboard.com/artist/tears-for-fears/.

"Tears for Fears' Everybody Wants to Rule the World Synths." *Reverb Machine (blog)*, September 16, 2020. https://reverbmachine.com/blog/tears-for-fears-everybody-wants-to-rule-the-world-synths/.

Trask, Simon. "Waldorf Electronics Microwave." *Music Technology* (January 1990): 64-72, http://www.muzines.co.uk/articles/waldorf-electronics-microwave/285#.

Tubbs, Alan. "Cakewalk Rapture." *Sound On Sound*, August 2006. https://www.soundonsound.com/reviews/cakewalk-rapture.

_________. "Terratec Komplexer VST" *Sound On Sound*, November 2006. https://www.soundonsound.com/reviews/terratec-komplexer-vst.

Twells, John. "The 14 Most Important Synths in Electronic Music History – and the Musicians Who Use Them." *FactMag*, September 15, 2016. https://www.factmag.com/2016/09/15/14-most-important-synths/.

"Ultimate Guide to Vehicle Sound Design & Recording." *Aftertouch Audio*, November 8, 2021. https://www.youtube.com/watch?v=hlkaX13NmO0.

Vanacoro, Matt. "Review: Waves Codex." *Ask Audio*, October 28, 2014. https://ask.audio/articles/review-waves-codex.

Vanisacker, Bernard. “Iconic Manufacturer of Audio synthesizers PPG Synths Acquired by Brainworx – Alan Wilder: ‘The PPG was a Sensitive, Delicate & Bloody Difficult Beast…’” *Side-Line*, March 19, 2020. https://www.side-line.com/iconic-manufacturer-of-audio-synthesizers-ppg-synths-acquired-by-brainworx-alan-wilder-the-ppg-was-a-sensitive-delicate-bloody-difficult-beast/.

Viers, Rick. “RØDE University - Location Sound Effects Recording.” *RØDE*, November 7, 2011. https://www.youtube.com/watch?v=Eb_7SHmMy_E.

Vincent, Robin. “Wolfgang Palm Retires, Hands PPG to Brainworx and Plugin Alliance.” *Gearnews*, March 19, 2020. https://www.gearnews.com/wolfgang-palm-retires-hands-ppg-to-brainworx-and-plugin-alliance/.

Walker, Martin. “Multi-core Processors For Musicians.” *Sound On Sound*, January 2008, https://www.soundonsound.com/sound-advice/multi-core-processors-musicians.

“Waves Release Codex Wavetable Synth.” *Sound On Sound*, July 10, 2014. https://www.soundonsound.com/news/waves-release-codex-wavetable-synth.

“The Weeknd Wins 2020’s IFPI Global Digital Single Award for Blinding Lights.” *IFPI*, March 19, 2021. https://www.ifpi.org/the-weeknd-wins-2020s-ifpi-global-digital-single-award-for-blinding-lights/.

White, Paul. “Waldorf PPG Wave 2.V.” *Sound On Sound*, September 2000. https://www.soundonsound.com/reviews/waldorf-ppg-wave-2v.

Willings, Sam. “Vital Is a New Free Wavetable Synth With Unique Spectral Warping.” *MusicTech*, November 25, 2020. https://musictech.com/news/matt-tytel-vital-free-synth/.

Wilson, Scott. “NI Releases Massive X, Successor to its Popular Massive Synth.” *Fact Magazine*, June 27, 2019. https://www.factmag.com/2019/06/27/native-instruments-massive-x-released/.

Zedd. “Zedd: Music Production Feedback & Tips (& Why You Shouldn’t be Avicii) [Twitch].” *Sol State*, July 15, 2020. https://www.youtube.com/watch?v=fqHvrBY-UiU.

GLOSSARY

ADSR – Acronym for Attack, Decay, Sustain and Release.

ADSR envelope – A tool used to visually represent how a sound operates and changes in real-time through the attack, decay, sustain, and release.

Amplitude – The distance between an equilibrium point and a peak or valley point in a sound wave or electrical signal.

Arpeggio – A sequence of individually played and repeated musical notes that form a chord.

Arpeggiator – A tool that is included in many synthesizers that automatically generates an arpeggio from a played chord.

Attack – The amount of time it takes a sound or signal source to reach its peak level potential whether that be electrical signal or sound pressure level.

Automation – A programmable adjustment of specific parameters within a plug-in, virtual instrument, or DAW assigned to occur at specific times.

BPM – Acronym for beats per minute. This is a measurement of the tempo.

Buffer size - The number of samples it takes for a computer to process audio for listener play back. This affects playback latency.

Cents – A unit of measurement for musical intervals. Within an octave, there are 12 semitones, and there are 100 cents in each semitone.

Chorus – An audio effect caused by the layering of a sound signal with multiple duplicates of itself slightly delayed at different times.

Coarse pitch – An unspecified measurement of musical intervals larger than cents. In a wavetable synthesizer, a coarse pitch adjustment knob is useful for automating continuous transposition of a sound’s pitch through larger intervals.

Comb filtering – Frequency filtering (attenuation or amplification) created by layering a duplicated audio signal on top of itself.

Commercial music – A broad term that is applied to music composed in a style or genre that is often commercially successful and appeals to a large audience of people. Commercially successful was initially defined by the Recording Industry Association of America as selling 500,000 copies.

Compressor – A tool that is used to decrease the dynamic range of an audio signal.

Crossfade – A form of interpolating that creates a smooth transition between two different waveforms or audio signals.

Cutoff frequency – The frequency that acts as a starting point of attenuation for filtering effects, such as a low-pass or high-pass filter.

Cycle – A small segment of a waveform that contains one peak and one valley. The segment usually begins and ends at the equilibrium (or zero) point of the waveform, additionally containing at least a third equilibrium point between the peak and valley.

Digital audio workstation (DAW) – A software program in which users can compose, produce, edit, mix, or master music in.

Decibel – A logarithmic measurement unit of sound pressure, usually in terms of acoustic or electrical power. In this measurement system, an increase of 3 decibels equates to twice the perceived sound volume.

Decay – The time it takes for a sound to fall from its peak signal to the sustained portion of a sound.

Delay – An effect tool that duplicates and postpones the start time of an audio signal to create an artificial echo.

Digital aliasing – A term for an unintended alteration in sound signal that results from errors in conversion from an analog signal to a digital signal.

Distortion – A form of audio processing that alters the frequency spectrum of a signal through the addition of harmonics. The additional harmonics are a result of an increased audio signal level, or gain.

Drop – The point of a musical work that features an abrupt contrast in the rhythm, melody, or bass line. This usually begins the busiest and/or loudest section of the piece, often featuring a louder kick drum. This is prevalent in electronic dance music.

Dynamic range – This is the difference between the lowest amplitude and the highest amplitude of a waveform. In practical terms, this equates to the difference between the quietest and loudest levels of an audio signal, and it is measured in decibels.

Envelope generator - A tool within a synthesizer that allows the user to shape the sound generated by adjusting various stages of it. The stages of sound generation commonly presented in envelopes include the attack, the decay, the sustain, and the release.

Equalizer (EQ) – A tool used to alter the frequency content of an audio signal through level attenuation or amplification of specific frequency ranges.

Electro-house – A subgenre of electronic dance music that is generally defined by a large presence of low frequency content and a BPM of 128.

Electronic dance music (EDM) – A broad style of electronic music that is perceived as danceable. It encompasses many different subgenres, such as drum & bass, house, or trance, and is generally composed for performances at music festivals and clubs.

Feedback – The process in which a percentage of an already-delayed audio signal is sent through processing again to create additional echoes.

Filter – A tool used to attenuate frequency content in an audio signal.

Fine-tuning – The adjustment of pitch in cents.

Flanger – An effect tool used to alter a sound through comb filtering caused by the duplication and slight postponing of an audio signal. Unlike a delay effect, the amount of time that a signal is postponed gradually changes, which causes the filtering effect.

Frequency modulation (FM) synthesis – A form of synthesis in which one simple wave form is used to modulate, or alter, the frequency of another waveform to create a new, often more complex waveform.

Frequency – The number of times a signal or sound wave oscillates within a unit of time measured in Hertz (oscillations per second).

Frequency-domain wavetable synthesis – A form of wavetable synthesis in which a specific desired harmonic spectrum is created through the interpolation of multiple wavetables. In this procedure, phasing is easily implemented for smoother transitions between the different wavetables.

Fundamental frequency – The lowest frequency in an audio signal.

Gain – The amplification of an audio signal level.

Harmonic – A frequency in an audio signal that is a multiple of a fundamental frequency.

High-pass filter – A filter that is used to attenuate or remove frequencies below a determined cut-off frequency while the higher frequencies remain unaffected.

Hertz (Hz) – The standard unit of frequency measurement equivalent to cycles per second.

Interpolation – A method of determining or predicting unknown data values between two data points and replacing missing values with approximated new ones. In the context of wavetable synthesis, interpolation is used to create smoother transitions between wavetables.

Latency – The amount of time (in milliseconds) it takes for a computer playback system to receive, process, and send an audio signal to its output.

Low frequency oscillator (LFO) – A specific oscillator that generates a frequency that is usually below the lowest level of human hearing (20 Hertz). It is often used to modulate other parameters of a synthesizer.

Low-pass filter - A filter that is used to attenuate or remove harmonic content that occurs at frequencies above a determined cut-off frequency while the lower frequencies remain unaffected.

Modular – An adjective for something that relates to modules.

Module – A component of a synthesizer, such as an oscillator or a filter. Different components are combined to generate sounds.

Modulation – The process in which the waveform of one sound wave, called the carrier signal, is altered by another sound wave, called the modulation signal.

Oscillator - An electronic circuit that produces an electric audio signal periodically. The electronic signal usually has a simple waveform such as a sine wave, sawtooth wave, or triangle wave.

Periodic waveform – A waveform whose shape is regularly repeated.

Phaser – An effect that is used to alter frequencies within an audio signal by layering the original with a duplicated version that has undergone filtering.

Plug-in – An outside component of software that adds new features to an existing software program. In audio production, a plug-in is added within a digital audio workstation, and it usually contains an audio processing effect or a virtual instrument.

Release – The amount of time for sound to reach silence from its sustain level.

Reverb – Short for reverberation. Reverb is an audio effect that simulates the continued resonance of a sound in a spatial environment.

Ring modulation - The process in which two audio signals are multiplied by each other a new output signal. One signal, the carrier, is usually a simpler waveform while the other, the carrier, is a more complex one. The resulting signal produces both the sum and difference of the frequencies in the original signals.

Sample-based synthesis – A form of synthesis that uses sound recordings as sources for soundwave generation (also known as sampling synthesis).

Sampling – The process of isolating a snippet of a pre-existing sound recording and using it in a different musical context.

Synthesis – The production of sound through electronically-generated waveforms, such as sine waves, triangle waves, square waves, or sawtooth waves.

Sequencing - The arrangement and programming of specific rhythmic patterns for notes or sounds over a specified musical period.

Shaping – The process of altering a sound by changing the shape of a waveform or modifying an audio signal’s frequency content.

Spectral morphing – A form of interpolation that involves the analyzing, reorganizing, and blending of frequency content into transitional waveforms or wavetables.

Step sequencing - A type of sequencing in which a single measure or limited number of measures are presented on a grid and divided into beat values called steps. The user can program certain steps to trigger sounds or samples into a rhythmic pattern.

Sustain – The consistent level of sound throughout its duration. In the context of synthesis, it is the amount of time that a note is played or triggered.

Synth-pop – A subgenre of both electronic dance music and pop music. It is characterized by the use of electronic synthesizers within a typical pop song musical structure.

Synthwave – A subgenre of electronic and electronic dance music that's characterized by the use of synthesizer timbres that evoke the sounds of 1980s electronic music, video game music, and film scores within modern musical contexts.

Tempo – The speed at which a musical work is performed, usually measured in beats per minute (BPM).

Timbre – The perceived sound quality or texture of a sound or tone.

Time-domain wavetable synthesis – A form of wavetable synthesis in which a single wave cycle is stored in a wavetable that is periodically reproduced to create a sound.

Tube emulation – An effect that simulates the sound of vacuum tube pre-amplifiers and amplifiers.

Vector synthesis – A form of synthesis in which four oscillators are presented in quadrants. The sounds of these oscillators can be combined or morphed between using a joystick.

Virtual instrument – A software plug-in that is used for sound creation in software. A virtual instrument can be an emulation of a real instrument or something completely different.

Voice – A single audio signal path generated in a synthesizer. Each voice is produced by one or more oscillators and travels through its own signal flow order of filters, effects, and sound amplifiers before reaching the output.

Waveform – The shape of a sound or signal wave.

VITA

After completing his work at James Earl Rudder High School in Bryan, Texas in 2016, Garrett Scroggs entered Stephen F. Austin State University in Nacogdoches, Texas. During the summer of 2019, he interned at a recording studio, BCS Recording, in Bryan, Texas. He received the degree of Bachelor of Music from Stephen F. Austin State University in May of 2020. In August of 2021, he entered the Graduate School of Stephen F. Austin State University and received the degree of Master of Music in May of 2023.

Permanent Address: 5533 Emily Dr.
Bryan, TX 77807

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