Exploring Nonlinear Time Within Interactive and Adaptive Electronic Music Composition

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ABSTRACT

This practice-based research employs *Unreal Engine* game development software to compose nonlinear interactive and adaptive electronic music compositions. Nonlinearity is a focus point, and examining three distinct nonlinear standpoints provides a multi-faceted perspective and approach through philosophical principles, compositional structures, and game application. Presenting the development of a nonlinear electronic music composition framework and the subsequent affordances is key to achieving these standpoints.

The accompanying portfolio is comprised of five artefacts, two mobile applications (apps), and three desktop apps. Each of the five apps focuses on a different aspect of electronic music composition and feeds into the nonlinear electronic music composition framework. The outcome expands nonlinear music theories developed by music theorist Jonathan Kramer and explores Kramer's nonlinear categories, vertical time, moment form, modules, and gestural time. This project also reflects on the future development within this growing field.

The unique research contributions established by this project reclassify linear and nonlinear concepts of time, 'vertical time', 'moment form', 'modules', and 'gestural time' as sub-genres of nonlinear time. Within these newly established sub-genres, gestural time has been combined with manual granulation to forge a link between theory and practice and become a useable practical compositional tool, which is highlighted in practice within the artefacts. The final substantial research contribution is the Nonlinear Electronic Music Framework, which outlines the process of composing nonlinear electronic music from theoretical and practical standpoints.

Declaration

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Gloucestershire and is original except where indicated by specific reference in the text. Artificial Intelligence programming and visual effects assistance were given in *The Machines* desktop app as listed under *additional developers* on page 82. No part of the thesis has been submitted as part of any other academic award. The thesis has not been presented to any other educational institution in the United Kingdom or overseas; however, extended abstracts and practical artefacts were presented between May 2021 and June 2023, as detailed in APPENDIX A. Any views expressed in the thesis are those of the author and in no way represent those of the University.

Signed [redacted] Date 23/09/2023

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Portfolio Overview and Track List

The portfolio presents five practical artefacts, each a digital app developed for a specific purpose. Below is a list of portfolio works accompanied by a short description. Due to the nonlinear music composition techniques, *Sheets of Sound*, *Gravitational Pull*, and *The Machines* have no upper time limit. Therefore, they can be explored indefinitely, whereas *Through a Quantum Window* and *Underground* have a fixed playtime.

All the additional audio-visual supporting content listed below can be found at the following URLs. Specific links and QR codes can be found in the relevant sections.

Artefacts: <https://drive.google.com/drive/u/1/folders/1gw3_fUJkYiV97eIb_oGiwS_Cz83aIcBm>
Experiments: <https://drive.google.com/drive/u/1/folders/1m7jHkeSRNAPM87N23EZEJ3yGXKgaoIku>

Alongside this thesis and supporting audio-visual content is a physical smartphone with augmented reality apps *Sheets of Sound* and *Gravitational Pull* installed.

Sheets of Sound (2021)

A mobile augmented reality music app developed in *Unreal Engine 4*, exploring electronic music using nonlinear compositional techniques: moment form and vertical time.

UE5 Project:	
SOS_UE5.zip	
Video Demonstration:	
Sheets of Sound	2.13 mins
Audio Recordings:	
Sheets of Sound (video audio).wav	3.07 mins
Sheets of Sound alt 1.wav	4.41 mins
Sheets of Sound alt 2.wav	5.07 mins
Sheets of Sound alt 3.wav	2.12 mins

Gravitational Pull (2021)

A mobile augmented reality app developed in *Unreal Engine 4*, examining *Unreal Engine’s* built-in modular synthesis, composed using nonlinear compositional technique: moment form.

UE5 Project:	
Gravitational Pull_UE5.zip	
Video Demonstration:	
Gravitational Pull	3.41 mins
Audio Recordings:	
Gravitational Pull (video audio).wav	4.05 mins
Gravitational Pull alt 1.wav	6.10 mins
Gravitational Pull alt 2.wav	2.50 mins
Gravitational Pull alt 3.wav	1.45 mins

The Machines (2022)

A single-player interactive desktop experience developed in *Unreal Engine 5*, using nonlinear compositional techniques: vertical time, moment form, and gestural time.

Apps & UE5 Project:	
The_Machines_UE5.zip	
TheMachines_MAC.zip	
TheMachines_WINDOWS.zip	
Video Demonstration:	
The Machines	20.19 mins
Audio Recordings:	
The Machines (video audio).wav	20.32 mins
The Machines alt 1.wav	13.52 mins
The Machines alt 2.wav	15.39 mins
The Machines alt 3 (AI).wav	18.09 mins

Through a Quantum Window (2023)

An adaptive desktop app developed in *Unreal Engine 5*, using local time data to affect the outcome and nonlinear compositional techniques: modules and vertical time.

Apps & UE5 Project:	
Quantum_Window_UE5.zip	
QuantumWindow_MAC.zip	
QuantumWindow_WINDOWS.zip	
Video Demonstration:	
Through a Quantum Window	18.22 mins
Audio Recordings:	
Through a Quantum Window (video audio).wav	17.57 mins
Through a Quantum Window alt 1.wav	17.57 mins

Through a Quantum Window alt 2.wav	17.57 mins
Through a Quantum Window alt 3.wav	17.58 mins

Underground (2023)

A desktop app developed in *Unreal Engine 5* composed using nonlinear compositional technique: modules.

Apps & UE5 Project:	
Underground_UE5.zip	
Underground_MAC.zip	
Underground_WINDOWS.zip	
Video Demonstration:	
Underground	9.34 mins
Audio Recordings:	
Underground (video audio).wav	9.23 mins
Underground alt 1.wav	9.23 mins
Underground alt 2.wav	9.22 mins
Underground alt 3.wav	9.22 mins

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Finally, I have absolutely no idea where I would be without the unwavering support of my wife, Amy, whose belief, encouragement, and endurance over the last four years have been fundamental to my success; I am eternally grateful – thank you!

Notes on Terminology

Within the games industry, language barriers between artists, programmers, and producers can cause communication issues, with each discipline often using the same terminology to describe different mechanisms, factors, or ideas. The *Production Pipeline Fundamentals for Film and Games* (Green et al., 2014) offers a chart designed to highlight the differences in language within disciplines, an idea employed within this project. Green et al. determined that the chart has 'technological logic' and 'true or false' on one side and 'human emotion' and 'aesthetics' on the other (Green et al., 2014). This project straddles creative and technological disciplines, music composition and game programming, so there is slippage in terminology. A definition of potentially ambiguous terminology, which precedes its use, appears at the beginning of each chapter. Additionally, a global naming convention strategy is implemented within the practical apps, reflecting practice within the games industry.

1. INTRODUCTION

1.1 Overview and Glossary

This practice-based research explores interactive and adaptive electronic music composition, using *Unreal Engine* game development software to examine nonlinearity in music. This research consists of five nonlinear music compositions, presented as apps and recordings, several table-top experiments, and this thesis. The unique research contributions established by this project reclassify linear and nonlinear concepts of time, ‘vertical time’, ‘moment form’, ‘modules’, and ‘gestural time’ as sub-genres of nonlinear time. Within these newly established sub-genres, gestural time has been combined with manual granulation to forge a link between theory and practice and become a useable practical compositional tool, which is highlighted in practice within the artefacts. The final substantial research contribution is the Nonlinear Electronic Music Framework, which outlines the process of composing nonlinear electronic music from theoretical and practical standpoints.

This thesis contains seven chapters. Firstly, *1. INTRODUCTION* offers a rationale explaining the reasons for undertaking this research and its value. This initial chapter contextualises the research and initiates a linkage between music, nonlinearity, time, and *Unreal Engine* game development software; the chapter also details the methodological approach used within this project. The second chapter, *2. LITERATURE REVIEW* has two themes. The initial section focuses on nonlinearity within music, the second theme focuses on game application in video game music. The third chapter, *3. AN OVERVIEW OF NONLINEARITY* establishes the concept of nonlinearity and the application of nonlinearity to music. The fourth chapter, *4. THREE STRANDS OF NONLINEARITY* examines nonlinearity from philosophical, compositional, and game application standpoints. The fifth chapter, *5. A NONLINEAR ELECTRONIC MUSIC FRAMEWORK*, which, as discussed above, offers a framework for composing nonlinear electronic music. The sixth chapter, *6. PORTFOLIO COMMENTARY* comments on the experiments and practical artefacts created. The seventh chapter, *6. CONCLUSION* summarises and concludes the project. Finally, all chapters and sections presented linearly are done for ease of reading and have no intended bearing on the nonlinear theories offered.

The following terminology is established in this chapter.

Absolute time usually refers to 'clock time', used extensively in society to measure the time of day. However, a clock is a measuring device set to different times. For example, the United Kingdom annually moves between Greenwich Mean Time (GMT) and British Summer Time (BST), with GMT being one hour behind BST. In this project, absolute time is an immovable or fixed time, so it is preferred over clock time.

Electronic music was defined in 1957 by music theorist Herbert Eimert as being "based on the composition of electrically generated sounds made audible by a generator" (Eimert, 1957: 1). Although Eimert's definition is accurate for some forms of electronic music, the development of the genre requires a broader term. Robert Moog defines electronic music as "music which is made with electronic equipment" and argues that "it becomes more and more difficult to objectively consider electronic music as a distinct, bounded entity" (Moog, 1977: 855). This definition incorporates the evolution and current state of electronic music and is a more accurate reflection of the research and techniques employed in this project, preferred over Eimert's definition.

Individual time is the sense of time an individual feels in a circumstance (such as listening to music). This sense of time is subjective and dependent on the individual; that is, one individual may determine a period elapsed significantly faster or slower than another.

Player-performer is defined as a merging of multiple roles. The interactive nature of the music in this project, composed and implemented in *Unreal Engine,* allows the listener to become the performer. Due to the ludic-based nature of the applications (apps), the performer is primarily a player. The player can seamlessly move between listener, performer, and composer roles as they interact with the music system. To highlight the multiple roles the player is defined as the player-performer.

1.2 Rationale

There is a further need for research into the audio aspects of game development and some surrounding fields, such as nonlinear music in games. *An Introduction to the Participatory and Non-Linear Aspects of Video Games Audio* comments on the research conducted into sound in audio-visual media thus far determining surrounding fields have been researched thoroughly; however, “work into the sonic aspects of audio-visual media has neglected games” (Collins, 2007a: 1). Though this viewpoint is several years old, there has not been significant progress concerning nonlinear music composition. Within *Ludomusicology, Approaches to Video Game Music*, Kamp, Summers, and Sweeney argue that although there is “rapid and expansive development of video game studies [the] sub-discipline is still tackling fundamental questions concerning how video game music can be investigated” (Kamp, Summers, and Sweeney, 2016: 1). Additionally, the 2020 paper, *How Players Play Games: Observing the Influences of Game Mechanics* from Moll et al., has a similar viewpoint when discussing data-driven research and game mechanics, arguing that “despite the popularity and economical impact of games, data-driven research in game design […] is still scarce” (Moll, Frick, Rauscher, and Lux, 2020: 7). Game mechanics are essential when creating interactive and adaptive music using game development software. Research into how the player-performer interacts with game mechanics will provide valuable information when developing interactive and adaptive music.

A range of software is available for nonlinear music creation, such as *Unity* (Unity.com, n.d.) game engine, *Max* (Cycling74.com, n.d.) multimedia visual programming platform, and *Wwise* (Audiokinetic, n.d.) sound effects and music implementation middleware. However, *Unreal Engine* will predominantly be used for this project alongside *FMOD* (Fmod.com, n.d.) audio middleware. *Unreal Engine 4 (UE4)* was introduced in 2014 and was regularly updated by developers *Epic Games* until the release of *Unreal Engine 5 (UE5)* in April 2022. The development of audio capabilities became a focus of *UE4 4.15*, which unveiled a new audio engine offering several new tools and capabilities. *UE5* is versatile, with accessible source code, allowing composers to create bespoke functionality to enhance the software for specific requirements. Built-in audio capabilities include audio spatialisation, 5.1 and 7.1 surround sound, and digital signal processing (DSP) effects; additionally, there is support for an application programming interface (API). Furthermore, the new audio engine has built-in synthesis, allowing composers to develop complex audio systems offering the player-performer agency over the music outcome.

There is overlap between music production and game development, highlighted by innovations in music consumption. For example, Travis Scott performed a virtual concert in the online video game *Fortnite* in April 2020.[1] The concert yielded 12.3 million live viewers and enabled "artists and brands to reach new audiences at scale [...offering] endless, out-of-this-world creative possibilities for audience engagement and participation" (Brumby, as cited in Arrigo, 2020). There is currently rapid expansion of technologies within new realities (virtual, augmented, and mixed reality), game development, and virtual production. *Unreal Engine* is designed to enable the development of these disciplines whilst also providing a platform for experimentation within surrounding areas.

Although there is literature providing information on the use of *Unreal Engine*, most of it is focused on game implementation and acts as technical how-to guides for game development, with an expectation that the practitioner aims to create a game. As initially discussed in this rationale, more research into the emerging fields of audio in game development and nonlinear time within interactive and adaptive electronic music composition would prove beneficial. *Unreal Engine* is a useful vehicle for examining electronic nonlinear music composition and has many tools available for such an examination. As such, this software is appropriate and valid for this purpose. Finally, this project aims to fill some gaps and provide helpful information for future research.

1.3 Contextualisation

The initial research for this project focused on time and its connection to music. Humans generally think about time in relation to seconds, minutes, hours, days, months, and years, using absolute time to navigate each day and calendar time to navigate each month. Although absolute time is preferred over clock time, within *3. AN OVERVIEW OF NONLINEARITY,* an argument is made that absolute time is not a useful measurement for music and individual time should be used in its place. The connection between music and time is explored by thinking about ideas such as

[1] *Fortnite* is a free-to-play online video game created by *Unreal Engine* developers, Epic Games (fortnite.com, 2023).

distance, movement, and input. Three selected strands of nonlinear time are examined in *4.2 Philosophical Principles*, *4.3 Compositional Approach*, and *4.4 Game Application*. The focus of the practice is firmly on the latter two strands; however, a philosophical underpinning is essential to link the project to previous research and relate it to the broader world. As will be explicated in *4.3 Compositional Approach*, four nonlinear music techniques are presented in the portfolio. Vertical time focuses on extended 'now' moments, dismissing the past and rejecting the future. Moment form starts and stops but has no beginning or ending. Modules loop musical material with iteration. Finally, gestural time interrupts, reorders, and reworks the music.[2] Kramer determines gestural time as linear (Kramer, 1988); however, this project argues it is nonlinear due to the techniques employed using *Unreal Engine* and a link made to manual granulation.

The native setup of the *Unreal Engine* game development software presents scope for investigating nonlinear time and spatiality. Karen Barad's investigation on causality through their agential realism and intra-actions concepts theorises "time is not a succession of evenly spaced intervals […] and space is not a collection of pre-existing points", continuing to theorise there is no "exterior parameter called time [nor…] a container called space" (Barad, 2007: 234). There is an overlap between Barad's theory and Denis Smalley's ideas regarding time and spatiality; "we need to shift our focus of music investigation away from conceiving of music always as units in time, stretches in time, as having functions in time, to give pride of place to space and spatiality […] I think there is much more to be understood and explored in spatiality as a medium of human expression both in theory and in practice" (Smalley, 2014: 00:43:13). Building a nonlinear framework offers a link between Smalley's importance of spatiality and use of spatiality as a compositional tool. Chapter *4. A NONLINEAR ELECTRONIC MUSIC FRAMEWORK* makes strides towards this goal.

Aspects of the nonlinear electronic music composition framework are presented and developed through practical exploration within *Unreal Engine* (throughout the research, *Unreal Engine* experienced growth in development). As a result, processes developed throughout the project, and the techniques employed continuously evolved alongside the technology. Experimentation in electronic music composition is

[2] Reworking music is to create a different version without using additional material.

employed throughout, and linear electronic music composition techniques were not a point of focus when creating the finished artefacts. Instead, the music utilises nonlinear concepts such as reacting to external data sets or parameter changes through player-performer input whilst employing vertical time, moment form, modules, or gestural time.

Each portfolio artefact focuses on a different aspect of nonlinear time, combining the four nonlinear composition techniques with interactivity and adaptability. Initial experiments determined technical affordances within *Unreal Engine,* and the development of large-scale projects evolved thereafter; the five primary artefacts tie together the *4. THREE STRANDS OF NONLINEAR TIME*. The compositions are underpinned by philosophical principles and influenced by the compositional approach and game application research. This influence extends to the spatial placement of sounds within the virtual world, app titles, track names, and incorporated visuals.

This project focuses on using a game engine as a vehicle to compose nonlinear music rather than composing nonlinear music for implementation into a game. Deterding, Dixon, Khaled, and Nacke define game mechanics in non-game contexts as gamification; "based on our research, we propose a definition of 'gamification' as the use of game design elements in non-game contexts" (Deterding, Dixon, Khaled, and Nacke, 2011: 9). The use of gamification in this project is a ludic system, where the player-performer explores each app through play, intuitively learning the control mechanism(s) to navigate each experience.

Due to the nonlinear nature of the music, the playing time for some apps has no upper limit. Therefore, it is possible to play-through those apps continuously and experience a new musical pathway each time. Each play-through will have many similarities; however, repeating an exact pathway multiple times is unachievable. This phenomenon is demonstrated through testing of *The Machines* artefact, which involves six ten-minute play-throughs of *Zone 1 – Machines*; the outcomes show different routes and audio captures for each. Below is a compilation of six edited screenshots of *Zone 1 – Machines*. Each screenshot is a top-down view of the zone over ten minutes, using ray tracing to represent the route visually. The thicker lines indicate a degree of vertical and horizontal movement, either increasing or decreasing in height; the thinner lines represent horizontal movement. The screenshots are accompanied by recordings of the audio output, which are available HERE.

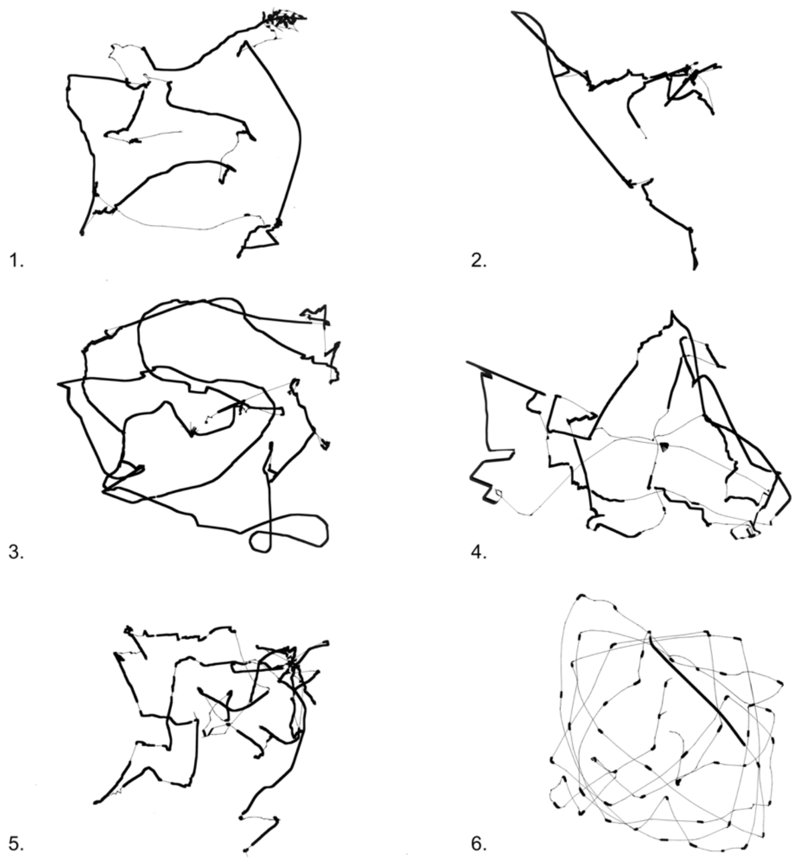

Figure 1 – Six visualised playthroughs of The Machines.

With each play-through, the sounds become interwoven differently, and the temporal space created by the music alters. Additionally, each player-performer navigates through the experience differently and becomes a functional part of the music, leaving a footprint of their musical exploration. The development process uses iteration to produce a robust outcome that feeds into the technical considerations and nonlinear compositional ideology. Although technical affordances are present, the focus is on the nonlinear musical output and creating a nonlinear electronic music composition framework. The objectives below underpin the research and provide a reference to keep progress focused.

1. Produce a portfolio of nonlinear interactive and adaptive electronic music compositions within moment form, modules, gestural and vertical time.
2. Build a ludic-based software music app for desktop computers and mobile devices.

3. Develop a system using visual scripting in *Unreal Engine* to allow player-performer agency to affect the music outcome.
4. Develop a nonlinear electronic music composition framework.

1.4 Methodology

To comprise a relevant methodology fit for this study, elements of three established methodologies have been combined, which has created a flexible, focused, iterative, and reflective model. The three methodologies are practice-based research, autoethnography, and the game development pipeline. Each of these methodologies will be briefly explained, and then an outline of how they are implemented in the project will be addressed.

Practice-based research can be defined "as an original investigation undertaken in order to gain new knowledge partly by means of practice and the outcomes of that practice" (Candy, 2006: 1). This differs from practice-led research, which is "to advance the knowledge about practice" (Candy, 2006: 1).

This project methodology is primarily based on 'practice-based research', which puts the artefacts at the forefront of the process and as the main objective, with a secondary objective focusing on the practice involved in creating the artefacts. Linda Candy's *Practice Based Research: A Guide* (Candy, 2006) offers clear insights into practice-based research, including its initial development in Australia circa 1984, with the primary idea of highlighting the value of practice. A prominent attribute of practice-based research is that a practitioner's work can only be fully understood through demonstration of the artefacts alongside the written thesis; this includes claims of originality. In other words, a complete understanding of the practitioner's work and originality can only be realised through the practical artefacts and cannot simply exist in the written thesis.

Autoethnography is a self-reflective methodology based on a qualitative research method, which "encourages experimentation and reflexivity" (Neil, 2023: 108). It provides a flexible structure to allow for a reflection of self when creating artefacts. Joanna Neil's *Digital Autoethnography* chapter in *Crafting Autoethnography* (Neil, 2023) emphasises that "autoethnographic artefacts [become…] *vehicles to reflect with*, as well as stand-alone pieces and finished products" (Neil, 2023: 118).

The game development pipeline is principally based on the ‘game development document’, an agile, iterative model where each iteration is a linear loop. This pipeline allows for the rapid development of prototypes to establish workable concepts for evaluation. K, Nevelsteen summarises that “the game design document is a well-defined set of requirements for a game design and a methodology for game development” (Nevelsteen, 2008: Abstract, para. 1).

The combined methodology used within this project stems from the underlying principles of practice-based research, which allows the artefact to be the focus whilst borrowing elements of autoethnography as a reflective lens. The project uses the iterative process of the game development pipeline to develop the artefacts, which have been produced through creative experimentation and exploration. The commentary of the artefacts is presented in written form and offers a reflection on each piece’s inspiration, idea development, and creation process. Furthermore, descriptive and discursive analysis methods are utilised to aid problem-solving and discover ‘what happened’ and ‘why’.

2. LITERATURE REVIEW

The literature review below has two themes. Firstly, the focus is on the theoretical and philosophical aspects of nonlinear music, musical temporality, and the varieties of nonlinear musical time. Secondly, the focus is on game development and the practical processes and tools. Due to the rapid evolution of the technology involved in game development, the literature review focuses on the most comprehensive, recent, and relevant texts available. Older studies quickly become less relevant in this field due to technological development and cultural context. As such, “newer research should have been built upon this older foundational work and thus should have advanced the line of work” (Savin-Baden and Major 2013: 119). Once an area of research was established, a ‘snowball technique’ was used to identify additional sources. The snowball technique entails searching relevant literature and article references or reading work by the same author, as Golding, Sharmini, and Lazarovitch (2014) recommend.

2.1 Nonlinear Music

On nonlinear music, an excellent place to start is Jonathan Kramer's 1988 book *The Time of Music* (Kramer, 1988), an inspirational point for this project and a seminal book about nonlinearity within music. Kramer tackles the subject of nonlinearity within music, which he anchors in philosophy. Kramer's approach is valuable because of the book's different perspectives regarding the subjectivity of nonlinearity in music. The initial pages offer definitions of time through authors and philosophers such as Susanne Langer, Basil de Selincourt, Errol Harris, and Thomas Clifton. The objective of the work is to investigate 'time' theoretically and aesthetically, which he deemed in 1988 "has not been recognised as an independent field of study" (Kramer, 1988: 1). Although his writing does not offer a concrete viewpoint on absolute time, he draws conclusions regarding the differences between musical and ordinary time. He agrees with Clifton's assessment of time, which is an "interaction between listener and composition", considering music to be a "series of events" that are "in flux", followed by an acceptance that "music creates many kinds of time" (Kramer, 1988: 6). Although Kramer discusses an array of musical time varieties, he focuses on "multiply-directed, gestural, moment, and vertical" (Kramer, 1988: 8).

Much of the text in *The Time of Music* focuses on Western classical music using analysis of music notation as a basis for the insights. The *Impact of Technology* chapter covers some technological impacts of that period. However, this chapter is lacking and does not consider video games or game development software, which were prevalent at the time of publication. For example, the *Commodore 64* was a home gaming console widely available in 1988 that used nonlinear composition techniques within its games (Collins, 2006). Although video games or game development was not discussed, the *Impact of Technology* chapter does offer a three-fold summary of the outcomes Kramer deemed relevant.

> It has increased their [composers] power to regulate temporal proportions; it has enabled them to compose rhythms of a complexity commensurate with the potential of their equipment; and it has opened up the compositional process to an immediacy that comes only when there is no delay between the conception and the realization of a segment of musical time.
>
> (Kramer, 1988: 79)

The book is predominantly written from the composer's perspective and does not consider the listener or player. The *Impact of Technology* chapter looks back at previous technology without embracing the cutting-edge technological advancements at the time. Although reviewer Arauco deemed a “lack of analytic tools for the study of nonlinear music” (Arauco, 1990: 155), thoroughly researching fields such as electronic and game music would have provided a comprehensive work more relevant today. The analysis of Western classical music, such as Beethoven’s *String Quartet in F Major, Opus 135*, *First Movement,* Schoenberg’s *Opus 19, No.1,* and Webern’s *Opus 29, First Movement*, provide a valuable template to expand. However, Kramer’s narrative about personal experience with time perception in a musical performance situation is more beneficial. The book is comprehensive and detailed, and although the viewpoint could have been more balanced, there is an inherent value widely acknowledged and often referred to in recent publications. Vickery (2011) picks up on themes discussed by Kramer and evaluates nonlinear musical structures, encapsulating a wide variety of music and composers, and offers a timeline of nonlinear emergence. Vickery concludes “that a structure of a musical work may be evaluated as nonlinear based on its degree of integration, contingency, compressibility and determinacy” (Vickery, 2011: 82).

Being Time: Case Studies in Musical Temporality (Glover, Gottschalk, and Harrison, 2018) utilises case studies by the authors to create a dialogue about musical temporality. Kramer’s concepts permeate throughout the book, and within the first paragraph of the introduction, the authors quote Kramer on the topic of subjective time. The book complements Kramer’s work through its narrative, based on the listener and listening experience. The authors examine chosen pieces of music using an autoethnographic methodology, which allows “each author’s narrative to emerge organically” (Glover, Gottschalk, and Harrison, 2018: 10). After the in-depth analysis of individual pieces, the conclusion uses a macro lens to offer a comparison between the pieces of music examined. They determined that within the listening sessions, each listener “experienced some kind of temporal disorientation” (Glover, Gottschalk, and Harrison, 2018: 137). Further examination into form, structure, memory, repetition, duration, speed, velocity, intensity, and subjectivity conclude the book.

In *Music & Time: Psychology, Philosophy, Practice*, authors Sergeant and Phillips (2022) offer a comparative perspective to Glover, Gottschalk, and Harrison’s ideas, which examine the perception of time through experience, memory, and contextualisation. However, unlike *Being Time: Case Studies in Musical Temporality*, Sergeant and Phillips explore multiple perspectives of listeners, performers, and composers. Much of their book examines the "judgements pertaining to the passing of time, as time so often appears to 'speed up' and 'slow down' in accordance to the context we are situated" (Sergeant and Phillips, 2022: 18). There is further investigation into the perspectives from a societal context, deemed as "perpetually evolving" (Sergeant and Phillips, 2022: 21).

A helpful chapter presents the *Listener Environment Music Interaction* (*LEMI*) model—a new framework that correlates listeners' perception of time with existing research (Sergeant & Phillips, 2022: 28). The perception of time is a complex area of research, and the authors claim the subject is in its infancy; this correlates with Kramer's viewpoint previously discussed. The *LEMI* model includes personal characteristics, environmental factors, and music stimuli. The examination of each *LEMI* model element is detailed, and insights into existing research and potential future paths offer examination from psychological, philosophical, and practice-based perspectives.

Sergeant and Phillips' autoethnographic methodology offers a brief overview of Bryn Harrison's *Dead Time* (CeReNeM | Centre for Research in New Music, 2020), a piece composed for six musicians: piano, violin, flute, saxophone, percussion, and electronics. Sergeant and Philips claim the composition "raises questions for the listener regarding the degrees of sameness and difference" (Sergeant and Phillips, 2022: 71). Although this could indeed create dialogue regarding the line between sameness and repetition, no consideration about the type of difference is forthcoming. Further reflections on works overlap with *Being Time* (2018); both books discuss Morton Feldman's *Piano, Violin, Viola, Cello*, with Sergeant and Phillips directly referencing Glover, Gottschalk, and Harrison, who also investigate musical experience through a philosophical lens.

Nick Braae considers temporality in *On Popular Music and its Unruly Entanglements* (Braae, 2019), specifically the chapter *Linearity in Popular Song*. This book investigates topics including music trajectory, music flow, and music unfolding over time. Sergeant, Phillips and Braae all reference Kramer in their books when discussing the idea of 'flow'; which is presented within the context of nondirected linear time, avoiding "the implication that certain pitches become totally stable" (Kramer, 1988: 40). Braae also investigates song form in the context of linearity, whilst Sergeant and

Phillips balance out their ideas with considerations of liminal states, discontinuity, and the disruption of flow. The idea of flow permeates this thesis and is discussed from multiple viewpoints: philosophical, psychological, and musical. Gilles Deleuze examines philosophical perspectives of music temporality and the passing of time in the context of musical memory, difference, and repetition.

Further investigation considers the perception of duration, internal clocks, different types of time, and time judgements from a psychological perspective. Finally, Sergeant and Phillips compare time in everyday life to time in music while contemplating music and time within society. The conclusion offers questions, statements, and contrasting viewpoints, including the following:

> As has hopefully become apparent in the chapters in this volume, and their variety of approaches and perspectives, we conceptualise and think about time in different ways. We – the listener, composer, and/or performer – are all different. These individual differences […] mean that there can never be one representation of time during music listening.
>
> (Sergeant and Phillips, 2022: 288)

This project echoes this viewpoint. However, rather than interpreting the quote above as overwhelming and unsolvable, it is viewed as an exciting, ongoing discursive narrative that encapsulates multiple subjects, possibly leading to new research areas.

2.2 Video Game Music

> Video games have frequently been associated with newness, the present or even the future. Despite this, they have long had a close and creative relationship with history.
>
> (Cook, 2021: 343)

Throughout the initial development of the video game industry, the tools available to composers were often restrictive due to technological limitations, requiring composers to adopt creative thinking to achieve satisfactory results. The lack of channels (or voices) and instrument choice required composers to reimagine their techniques. In addition, composers were required to understand the hardware's limitations and know the operating system and programming language employed to develop the game. A comprehensive examination of available tools, implementation techniques, and requirements conducted ahead of time was helpful to ensure the development pipeline remained intact (Thomas, 2016).

Although not exclusively the case, electronic music composers often use computers to produce music, the user interfaces of which are choice-based and, as such, impose restrictions on the user (Hunt and Kirk, 2000). The implications of these restrictions are revealed in the output, meaning software choice can often define the structural parameters. For example, a sequencer-based interface with defaults set at 120 beats per minute (bpm) in 4/4, using a piano roll, will often lead the composer to output tonal music in 4/4 with a similar bpm (Mooney, 2010). The output could be due to the software's ease of use, a lack of education regarding its toolkits, or a tendency for composers to write music similar to their peers. A broad conclusion drawn from this information is that software choice impacts the output. A composer must learn alternative ways of manipulating the interface to use the software unintendedly. The result could be a departure from the above example or a realisation that alternate software would be beneficial. Often, the latter is the case, with composers opting to preserve their creative flow whilst composing electronic music (it is easy to lose creative flow when learning new and complex software). Composers' creative flow is an important aspect, which, if significantly interrupted, can result in losing an idea or changing direction.

> As we ascend the spectrum of affordance toward the higher, more difficult, extremity, we naturally begin to encounter affordances that are really rather difficult to attain with the framework [software] in question. Here, we must ask ourselves a very important question: is it worth persevering, or is there a better tool for the job?
>
> (Mooney, 2010: 151)

With consumer computers, ease of use is important due to their multiple functions and societal saturation. This factor plays a part when determining user interface design, user experience, and functionality. Furthermore, sustaining a working pipeline for composers is critical because software developers have devised methods to ensure creativity remains uninterrupted. For example, Blueprints – the node-based visual scripting language employed by *Unreal Engine* – can be viewed as a visual series of shortcuts acting like a shell to allow game developers to program without learning to use C++ (the programming language on which *Unreal Engine* is built). Torres-Ferreyros et al. determine that visual scripting is "about using the offered code to focus on the idea and not the technical details" (Torres-Ferreyros et al., 2016), a viewpoint agreed within this research. Many publications offer insights and instruction for creative software such as *Unreal Engine*. Accordingly, this section outlines the technical publications used in this project, specifically for game application. The publications offer a wealth of information and a solid foundation to work from, which an overlap in content has strengthened.

The *Game Music Handbook* (Kellman, 2020) and *Game Audio Implementation* (Stevens and Raybould, 2016) are especially useful for nonlinear composition in *Unreal Engine,* given their focus on emotional arcs, immersion, interaction, and procedural and algorithmic systems. Kellman discusses the impossibility of predicting player movement and interaction. Although video game construction guides the player's direction and tempo, the player ultimately will determine how they progress through the game. The final version of the music implemented into the game is "the combination of our composition with the player's personality and playstyle" (Kellman, 2020: xvi). Kellman also considers the composer's evolution and determines that "composers need new conceptual methodologies and technical tools" (Kellman, 2020: 4), concluding that composers should be aware of subject evolution and redefine their relationship to the field.

Game Audio Implementation (Stevens and Raybould, 2016) explicitly tackles *Unreal Engine 4*, approaching the subject from a technical aesthetic, considering areas such as core concepts, workflow, toolsets, and advanced systems. The book offers valuable information that can be extrapolated from *UE4* to *UE5*. However, the progress of software development since publication in 2016 means some information provided, although technically correct, is no longer relevant. New systems have superseded old ones and offered superior, more effective working methods. Additionally, Stevens' contribution to *The Cambridge Companion to Video Game Music* (2021) discusses agency and its impact on the interactive and adaptive music composition process.

> One of the defining features of active gameplay episodes within video games, and indeed a defining feature of interactivity itself, is that the player is granted agency; the ability to instigate actions and events of their own choosing, and crucially for music – at a time of their own choosing. Parallel, vertical or layer-based approaches to musical form within games can respond to events rapidly and continuously without impacting negatively on musical structures, since the temporal progression of the music is not interrupted.
>
> (Stevens, 2021: 87)

Chance Thomas' *Composing Music for Games* (2016) covers various topics within game composition and implementation. The initial discussion concerns scoring language and the player's expectations within a video game. "Students demonstrated a mutual understanding of the components, patterns and variants they expected to hear in music which would approximately underscore a represented game level" (Thomas, 2016: 4). Thomas discusses 'pathing', a system of music composition created to predict the player's journey through the game environment. Thomas argues "that the number and type of dramatic conditions in a game are finite and knowable. Transitions between dramatic events can likely be predicted. Thus, corresponding pathways of music scoring solutions can be mapped out in advance" (Thomas, 2016: 45,46). Thomas' view is an opposing view to that of Kellman, as discussed above, who determines that the predictability of player-performer movement is impossible to predict accurately.

Several authors have contributed to *The Cambridge Companion to Video Game Music* (2021), edited by Melanie Fritsch and Tim Summers. The authors discuss the methods employed for studying game music compared to areas such as film music, establishing that some techniques are interchangeable. However, "many such aspects of games, including their interactivity, complicate assumptions that are normally made about how we study and analyse music" (Fritsch and Summers, 2021: 131). Other chapters discuss game history, agency, communication, identity, autoethnography, phenomenology, and hermeneutics. For example, in the chapter *Game-Music-Performance: Introducing a Ludomusicological Theory and Framework* Fritsch considers "the extent to which music might be understood as a mode of gameplay" (Fritsch, 2021: 238).

Within surround sound disciplines: *Immersive Sound. The Art and Science of Binaural and Multi-Channel Audio* (Roginska and Geluso, 2018); *New Realities in Audio: A Practical Guide for VR, AR, MR and 360 Video* (Schütz, Irwin-Schütz, 2018); and *Ambisonics: A Practical 3D Audio Theory for Recording, Studio Production, Sound Reinforcement, and Virtual Reality* (Zotter and Frank, 2019) have proved beneficial reading. These publications cover the history of 3D sound, binaural audio, surround sound, ambisonics, object-based audio, immersion, wave-field synthesis, spatialisation, new realities, location-based experiences, and general practice.

Additionally, the paper *Audio Augmented Reality for Interactive Soundwalks, Sound Art and Music Delivery* (Naphtali and Rodkin, 2019) offers a framework to successfully build an audio-augmented reality experience. They acknowledge that “audio augmented reality (AAR) is not necessarily new, but the advent of the smartphone and its peripheral technologies have presented an opportunity to express and share these personal and social experiences […] in the most engaging and imaginative ways possible” (Dafna and Rodkin, 2019: 300). Investigation into musical frameworks (Hunt and Kirk, 2000) and (Mooney, 2010) have provided helpful information used to inform the practical aspects of this work and (Madigan, 2016) has provided information and ideas concerning the psychology of gamers, which has helped create the practical artefacts.

Online conferences attended throughout the project have presented innovative explorations into the latest ideas and technologies. For example, *Embracing Sound in Space: Interactive and Procedural Audio for VR* (Vik, 2021) showcased experimental audio in virtual and augmented reality. A highlight was a framework developed by host Chris Vik using *Unity* – a cross-platform game engine developed by Unity Technologies. (Unity.com, n.d.). Vik successfully manipulated a granular sampler to procedurally generate hundreds of spawn points in a virtual environment without distortion, clipping or CPU issues; this idea reflects and builds upon the concept of microtextures as discussed by Denis Smalley (Smalley, 1997; Smalley, 2014).

Further afield, the book *Ambient Play* (Hjorth and Richardson, 2020) focuses on a connection between mobile video games and the spaces they are consumed. They ask poignant questions regarding the value of mobile video games, including their relationship to the outside world. The term “Ambient Play aims to contextualize mobile games as broader practices of play” (Hjorth and Richardson, 2020: 3) and encapsulates the interwoven nature of mobile games into the broader environment. A second useful term, ‘digital wayfaring,’ links digital devices and physical space. Examples could be mobile gaming devices used while waiting for public transport or games such as *Pokémon Go*, an augmented reality app that employs a physical public outdoor space as a playable area. Finally, they determine that ‘ambient play’ contains overlap “between background, middle, and foreground” (Hjorth and Richardson, 2020:12), demonstrating how mobile gaming devices are enmeshed within our daily lives. The information regarding haptic technologies was particularly beneficial; “haptic play is about proprioception – that is, the perception of the moving body and its material sensory limits” (Hjorth and Richardson, 2020: 17). The concepts within the book have provided valuable context to inform the mobile augmented reality artefacts developed within this project.

3. AN OVERVIEW OF NONLINEARITY

3.1 Overview and Glossary

This chapter will contextualise the philosophical principles used to underpin the project. Firstly, it discusses nonlinearity from a historical perspective, establishing the development of towns and cities based on DeLanda's work (DeLanda, 2000). This idea is linked to nonlinearity in music by contemplating the perception of time. The overview concludes by discussing nonlinear techniques and tools within *Unreal Engine.*

The following terminology is established in this chapter.

Linearity and nonlinearity refer to "temporal linearity and temporal nonlinearity" (Kramer, 1988: 15). Linearity is processive and can be likened to a straight line. Linearity helps define nonlinearity. Terms such as the opposite of a straight line, not in proportion, does not progress smoothly, are used to help describe nonlinearity; nonlinearity can be thought of as a curve. If linearity is processive, nonlinearity is non-processive (Kramer, 1988). If linearity is a straight line, nonlinearity is not a straight line. Nonlinearity can be compared to a rhizome, an underground plant stem that produces vertical shoots from a horizontal growth trajectory. Deleuze and Guattari discuss the rhizome in *A Thousand Plateaus: Capitalism and Schizophrenia* (1987), comparing it to a multiplicity. This concept can be extrapolated to this project to consider nonlinearity as a multiplicity. Multiple versions of the music exist at any given time; however, the player-performer only experiences one version. Finally, Kramer defines linearity in music as characteristics "that arise from earlier events in the piece" and nonlinearity in music as characteristics "that arise from principles or tendencies governing an entire piece or section" (Kramer, 1988: 20).

Randomisation within music is similar to nonlinearity; however, the implications of nonlinearity compared to randomisation are different. In this project, randomisation is created through a game mechanic used to randomise data sets to build tools for nonlinear music creation. Randomisation is a processive unpredictability within a sequence where the relationship between one random point and another remains intact. Additionally, within *Unreal Engine* game development software, 'random in range' is a programming node that produces a random event within a specified range. Randomised events are common within game mechanics and offer the player the opportunity to have unique experiences within gameplay.

Real-world refers to being outside a simulated or virtual world environment, such as a video game or new realities experience (virtual, augmented, mixed reality).

Spatialisation is to make sound sources in a virtual environment appear from any location around a specific point; “virtual sound sources and sound reflections can be made to appear from anywhere in space around a listener” (Wenzel, Begault, Godfroy-Cooper, 2018: 5).

Spatial presence is akin to immersion and feels “like you are present in the environment generated by the computer” (Sheridan, 1992). In other words, the “emergence of presence is often determined by the allocation of attention to the virtual environment and the occlusion of the physical environment” (Wienrich, Komma, Vogt, Latoschik, 2021). In simple terms, spatial presence is “the psychological state brought on when you forget that the world you’re experiencing is created by technology” (Madigan, 2016: 61). In this thesis, spatial presence will be used in place of immersion.

Strata is the plural of *stratum* and can be defined as layers, a division, or a subset. When discussing geology, strata refer to multiple rock or soil layers. If discussing demography or statistics, strata can divide people into groups through variables such as level of education, geography, or income. However, this project uses Deleuze and Guattari’s interpretation of strata. Deleuze and Guattari depict strata as a lobster, focusing on the pair of pincers, defining it as double; “articulations that not only travel in pairs, but are in fact double” (Buchanan et al., 2004: 6). This doubling is non-processive. In music, this concept of doubling allows elements within interactive and adaptive nonlinear music to happen simultaneously, achievable through player-performer agency.

Stratification is the process by which strata are produced. Buchanan et al. divide stratification into three forms: “physiochemical, organic, anthropomorphic” (Buchanan et al., 2004: 6). These three forms represent all aspects of the world in which we live, from inorganic, chemical, and biological matter to social and physical development, human and computer systems.

Virtual “is real but not actual” (Shields, 2003). In this thesis, ‘virtual’ can be thought of as computer-generated. A ‘virtual world’ is a computer-generated world or environment.

3.2 Introducing Nonlinearity

The many facets of nonlinearity have been examined through subjects such as mathematics, philosophy, and physics. DeLanda's *A Thousand Years of Nonlinear History* (2000) focuses on philosophy and "explore[s] the possibilities of a nonlinear and non-equilibrium history" (DeLanda, 2000: 14). Chapter one of *A Thousand Years of Nonlinear History*, which focuses on energy flow within Western cities, is used as a philosophical jumping off point for this thesis, aiming to underpin nonlinearity and provide context. DeLanda describes the evolution of society between 1,000 and 2,000 AD, demonstrating the nonlinear development of towns and cities is dependent upon location and circumstance. Using Braudel's work to support his argument, DeLanda discusses how towns and cities evolved at different speeds, broadly determining that city development accelerated historical time, whilst rural development did not.[3] The difference in the evolution of these cities and rural areas established through hierarchies and meshworks can be considered nonlinear development.

The hierarchies are defined as stratified systems, whilst the meshworks are defined as "interlocking system[s] of complementary economic functions" (DeLanda, 2000: 39). DeLanda uses Deleuze and Guattari's 'abstract machines' and 'strata' metaphors from *Anti-Oedipus: Capitalism and Schizophrenia* (1983) and *A Thousand Plateaus: Capitalism and Schizophrenia* (1987) to help define the complexities of nonlinear history. The abstract machines are used to demonstrate the creation of structures, whilst strata (which within this context are extended from the geological to the societal) represent the complex layers of society. When offering an explication of meshworks, DeLanda describes an 'autocatalytic loop', a complex self-regulating system that can function without needing or excluding external factors once established. DeLanda uses a thermostat as an example of an autocatalytic loop, stating that the cause-and-effect relationship between the thermostat sensor and the effector is not linear; "in short, the causal relation does not form a straight arrow but folds back on itself, forming a closed loop" (DeLanda, 2000: 67) resulting in a maintained ambient temperature.

A broad comparison between DeLanda's nonlinear development of towns and cities and individual time perception can be made. Time mirrors the nonlinear evolution of towns and cities and does not appear to move at the same rate for everyone,

[3] Fernand Braudel was a French author and historian (Lee, 2016).

everywhere and thus can be considered nonlinear. For example, according to theoretical physicist Carlo Rovelli, “a [caesium atomic] clock placed on the floor runs a little slower than one on a table” (Rovelli, 2018: location 142). Additionally, Stephen Hawking states that if “one twin goes to live on the top of a mountain while the other stays at sea level. The first twin would age faster than the second” (Hawking, 2011: 37). Strengthening this, the theory of relativity considers everyone to have a personal measure of time: “in the theory of relativity there is no unique absolute time, but instead each individual has his own personal measure of time that depends on where he is and how he is moving” (Hawking, 2011: 37). Hans Reichenbach postulates on the philosophy of time and provides a link between the perception of time within music, and philosophy, psychology, and physics of time. Through a discussion on time structure, Reichenbach asserts that time is subjective and can flow at different rates for individuals.

> What matters is the structure of that time which controls physical events; what we wish to know is whether our emotional reaction to time is justified, whether there is time flow, objectively speaking, which makes events slide into the past and prevents them from ever returning to the present. In what sense does the future differ from the past?
>
> (Reichenbach, 1999: 18)

Hawking discusses the ‘arrows of time’, which are thermodynamic, psychological, and cosmological. Thermodynamic relates to “the direction of time in which disorder or entropy increases”; psychological relates to “the direction of time in which we feel time passes”; and cosmological relates to “the direction of time in which the universe is expanding rather than contracting” (Hawking, 2011: 119). The direction of time is helpful when discussing spatial presence whilst playing video games. Current video games can simulate location through alternate realities, and players can lose their sense of self while playing. This phenomenon is particularly prominent in realistic first-person and third-person video games such as *F1 23* (Codemasters, 2023) and *The Last of Us Part II* (Naughty Dog, 2020). If spatial presence is realised within these environments, the flux of time can become malleable, allowing a person to experience powerful moments where time appears to stretch, contract, speed up, or slow down. Within this project, this phenomenon is called a ‘now’ moment, a concept that suggests time moves flexibly, allowing the possibility of an extended present to emerge.

3.3 Nonlinearity in Music

Absolute time is a measuring device that can reference the length of a piece of music; however, when listening to music, our perception of time can shift depending on factors such as the listening environment, repeated listening, age, and interaction. Sergeant and Phillips (2022) discuss a domain shift when listening to music. Kramer (1988) discusses a time perception shift when listening and performing nonlinear music and psychologist Heyduk (1975) discusses how the predictability of a piece of music can affect perception. Video games can create temporal virtual spaces through graphics, animation, game mechanics, and audio. Electronic music can create temporal virtual spaces through sound waves emanating from loudspeakers or headphones. These temporal virtual spaces are entwined with the real-world, and factors such as structure, movement, stasis, hierarchy, order, and disorder can be created within them. Linear music presents a processive structure, whereas nonlinear music presents a non-processive structure. Interactive and adaptive music can be used to reimagine and rework nonlinear music composition, offering the possibility of constantly evolving outcomes. This evolution can affect domain, perception, and predictability and, in essence, provide time manipulation; “as listeners, we each have different capacities for perceiving, recollecting, and time-ordering sound, and different levels of acuity in the perception of temporality” (Glover, Gottschalk, and Harrison 2018: 10). Furthermore, listeners’ perceptions may shift depending on the musical material. For example, musical paths can arise, where the focus shifts between instruments, timbres or textures, and time can temporally stand still or instantaneously move forwards or backwards (Glover, Gottschalk & Harrison 2018). However, these perceptions will always appear linear from an external observer outside the listening experience. That is, someone observing the person experiencing the perception shift; this means individual time is a more helpful measurement when examining perception shifts or ‘now moments’, which will be discussed in the next section.

To conclude this section, three ideas will be summarised: ‘linear music’, ‘nonlinear music as a concept’ and ‘nonlinear music as a mechanic’.

Linear music is processive and predetermined. Playing a linear piece of music from beginning to end without interruption will gain a similar result each time.[4]

Nonlinear music as a concept can be compared to the structure of a web, offering a multiplicity of directions for the music to take. Nonlinear music can be constructed without "linear progressions and 'deep' hierarchical order; such music uses similar materials in different places to make associations across a piece. The structure could be described as a 'web', rather than a 'line'" (Snyder, 2001: 234). Within the web structure, autocatalytic loops can occur, creating independent pockets of music with no reliance or cause-and-effect on the rest of the music.

Nonlinear music as a mechanic is created within a game engine using local or global data sets, player-performer input, or artificial intelligence to create nonlinear music systems; this can be in a game or standalone music apps.

3.4 Now Moments

Nonlinear music composition techniques provide opportunities for listeners perception of time to be altered; what appear to be extended or contracted periods of time, outside of absolute time. The extended time periods are referred to as 'now moments', which are subjective and dependent on the individual listener. Sergeant and Phillips suggest that everything influences the perception of time and the "multiple and complex aspects of our environment, our biology, our culture and background, and the stimulus itself, might impact on how long or short we judge a period of time to be" (Sergeant and Phillips, 2022: 26). Exactly how long is the present considered to be? If it is considered independent "from the past and the future, the musical now seems to appear as a strip of infinite thinness, like a mathematical infinitesimal. A moment of time with no duration?" (Sergeant and Phillips, 2022: 11). For the individual, these now moments appear to extend the present thus taking longer than the absolute time measurement. As such, they appear to be significantly longer than the infinite thinness, as discussed by Sergeant and Phillips, creating a disparity between the individual having the experience and an external observer. Philosopher Susanne Langer argues that now moments are perceived differently than absolute time.

[4] However, parameters such as music predictability (Heyduk, 1975) and the listening environment could alter the listeners perception of the music, so should be taken into consideration.

> Musical duration is an image of what might be termed “lived” or “experienced” time – the passage of life that we feel as expectations become “now”, and “now” turns into unalterable fact. Such passage is measurable only in terms of sensibilities, tensions and emotions; and it has not merely a different measure, but an altogether different structure from practical or scientific time.
>
> (Langer, 1953: 109)

Researcher Marc Wittmann determines that the perception of ‘now’ falls anywhere between a few milliseconds to tens of seconds, depending on the type of moment (Webb, 2016). In *How Long is Now?* Richard Webb summarises Wittmann’s type of moment into three categories: ‘functional moments’, ‘experienced moments’, and ‘time passing’ (Webb, 2016: 238). A ‘functional moment’ is the minimal amount of time for stimuli to be processed, whereas an ‘experienced moment’ is where the brain establishes a link between stimuli. So, as a starting point, we can see that the idea of the now is dependent on the type of moment.

From a philosophical perspective, the ‘articulations within stratification’ offer a helpful parallel to nonlinear time. Deleuze and Guattari’s interpretation of the articulations of stratification is that “everything takes place in the middle […and one] articulation does not lead to the next, rather the two occur at the same time” (Buchanan et al., 2004: 7). The order in which each articulation within stratification occurs is inconsequential, and one articulation does not affect another. When compared to nonlinear music, articulations of stratification would be likened to self-contained musical segments independent from one another. One of these segments can create a ‘temporal prolonged now’ or a ‘now moment’ independent from the past or future. For the listener's individual experience, the now moment can feel like a temporal stretch or prolonging of the music at that specific point.

Sergeant and Phillips (2022) determine that the relationship between the type of moment is described as ‘states’ versus ‘processes’ and ‘moment’ versus ‘duration’. To summarise, a ‘state’ concerns how the object or event is represented at a ‘moment’ in time; a ‘process’ is how it unfolds over time or its ‘duration’ over time. The book provides four viewpoints labelled ‘thin non-extensionalism’, ‘thick non-extensionalism’, ‘thin extensionalism’, and ‘thick extensionalism’.

> The thick non-extensionalist believes that perceptual experiences are states that represent non-momentary temporal intervals […] The thin non-extensionalist believes that perceptual experiences are states that represent

> moments in time […] the thin-extensionalist believes that perceptual experiences are processes that represent moments in time, and the thick extensionalist believes that perceptual experiences are processes that represent non-momentary temporal intervals.
>
> (Sergeant & Phillips, 2022: 104)

This project takes the viewpoint of 'thick non-extensionalism', favouring states over processes, which aligns with now moments. That is, thick non-extensionalism can be described as persisting temporary time intervals. These persistent temporary intervals of time do not have a fixed duration, and the length of occurrence is determined by individual perception and function.

Within *Musical Time, The Sense of Order* (1990), Barbara Barry examines the notion of the now. She postulates how we, as listeners, are unaware of time passing when absorbed in the music. Using Husserl's *Phenomenology of Internal Time-Consciousness* (Husserl, 1964) as a foundation[5] – Barry notes that "time is never 'there' at a stretch in the way that a spatial object is there, but some part of an event in time is always on the point of arriving or has just been, with 'now' a fine point continually vanishing between the two" (Barry, 1990: 4). Barry goes on to discuss that information density and perception are linked, with more dense information perceived as more time passing, less dense information perceived as less time passing. Barry describes information density as having two extremes: 'negative density' and 'positive density'. Both densities are an "imbalance between the amount of time required for processing and the amount of time available" (Barry, 1990: 262). Negative density has less information to process within the time available, and positive density has too much. Complex compositions with no easily discernible arrangement or rules can be classified as positive density, and these complex compositions can trigger 'information overload'. Barry argues that "the complexity and irregularity of events means it is unlikely that much of what has already passed will be remembered, and without expectation of the future, the listener is confined in a continually changing present" (Barry, 1990: 263). As we will see in section *4.1 Vertical Time*, this 'continually

[5] Within the book Husserl explains the characteristics of memory and how memories are connected, describing the form of memory as "forward-and-backward-directed intentional moments, without which it [memory] cannot be" (Husserl, 1964: 139).

changing present' exists in music composed in vertical time, where the past and present are rejected for prolonged now moments.

In conclusion, it has been established that 'now' can range anywhere from a few milliseconds to several seconds, depending on the type of moment. From a philosophical standpoint, now moments can be seen through Deleuze and Guattari's 'articulations within stratification', where each articulation does not affect another, and the order is inconsequential. Sergeant and Phillips discuss 'thick non-extentionalism', which can be thought of as persisting temporary intervals of time, an idea echoed by Barry, who uses information density to determine the perception of the now, which, through complex nonlinear music, can produce a continually changing present. We shall see in *4.3.1. Sub-Genres of Nonlinearity* that different forms of nonlinear music composition can promote differing forms of now moments, dependent on the construction of the composition.

4. THREE STRANDS OF NONLINEAR TIME

4.1 Overview and Glossary

Nonlinearity needs to be considered from multiple viewpoints to provide a robust approach. As such, this chapter will discuss three topics. Firstly, *4.2 Philosophical Principles* tackles the philosophy used to underpin the project. Secondly, *4.3 Compositional Approach* discusses the compositional elements employed. Thirdly, *4.4 Game Application* reviews the technical application of music in video games, encapsulated by a succinct overview of important developments in the history of video game audio.

The *4.2 Philosophical Principles* section establishes a link between compositional structures and game application, anchoring the project within the rich history of philosophical discourse and providing context to critical thinking around the enmeshed topics this project covers. Prominent philosophical thinkers have greatly influenced this exploration into nonlinear time within interactive and adaptive music, and their influence is theoretically and practically evident. Nonlinear time and nonlinear music as concepts fall squarely within the philosophical principles and will make up a significant part of the conversation. Next, *4.3 Compositional Approach* covers the construction of nonlinear musical material reclassified as a sub-genre of nonlinear music. This is detailed by focusing on four nonlinear music techniques: vertical time, moment form, modules, and gestural time. Each of these compositional techniques is explicated within this section. Finally, *4.4 Game Application* focuses on the practicalities of nonlinear music composition prevalent in video games. This section encompasses the technical challenges and opportunities of nonlinear music composition. For example, nonlinear music composed with multiple branches to adapt to player input or gameplay mechanics. The intended application of these mechanics is for game creation; however, the scope of game creation is broad, and this project uses them for standalone nonlinear music apps developed for music exploration. The *4.4 Game Application* section is the most practical topic within this chapter. Along with an insight into the challenges faced by composers, this section covers the emergence of nonlinear music and its future development alongside technological advances. The focus is on nonlinear music composition as a mechanic, which relates to the techniques employed when using game development software introduced in *2.2 Video Game Music.*

The following terminology is established in this chapter.

Actor is defined as “any object that can be placed into a [video game] level, such as a camera, static mesh, or player start location. Actors support 3D transformations such as translation, rotation, and scaling. They can be created (spawned) and destroyed through gameplay code” (Unreal Engine, n.d. a).

Adaptive audio is defined as "audio and music that reacts appropriately to - and even anticipates - gameplay” (Whitmore, 2003: 1).

Assemblage theory is defined as the “objective processes of assembly” (DeLanda, 2019: 9). A wide range of entities can be considered an assemblage, including biological and chemical organisms, atoms and molecules, species, ecosystems, and social entities (DeLanda, 2019).

Interactive audio can be defined as “sound events occurring in reaction to gameplay, which can respond to the player directly” (Collins, 2007a: 1).

Musematic can be defined as a short musical repetition, such as a riff (Nurmesjärvi, 1997).

4.2 Philosophical Principles

Within *An Overview of Nonlinearity,* a link between nonlinear philosophical history and music was examined through DeLanda's *A Thousand Years of Nonlinear History* (DeLanda, 2000). However, this project does not neatly fit into one philosophical construct, so this chapter aims to strengthen *3. AN OVERVIEW OF NONLINEARITY* and provide an anchor between the practical aspects and the theoretical concepts of the research. This is achieved by presenting a holistic view of how this project fits into the broader subject area. Philosophy informs music as music informs philosophy, and this thesis aims to link both. The philosophical principles informing this project stem from several sources, and this section discusses relevant theories postulated over the last half-century. This chapter will initially present a broad outline of philosophers and ideas influential to this project. Once established, a summary of relevant authors and topics will preface a conclusion. The philosophical principles do not refer to all text by the authors listed or, in fact, entire books. Instead, this chapter aims to use specific ideas to underpin the practice employed in this research, which is the primary focus. However, the philosophical approach is broad to reinforce the link between philosophy, music in general, and nonlinearity.

Within *A Thousand Plateaus: Capitalism and Schizophrenia* Deleuze and Guattari (1987) explore philosophical theories through six inter-linked concepts: 'stratification', 'assemblages', 'rhizome', 'plane of consistency', 'deterritorialization', and 'abstract machines' (Buchanan et al., 2004). This project considers concepts such as 'stratification', 'rhizome', 'abstract machines' from Deleuze and Guattari (1987), and 'difference', 'repetition', and 'identity' from Deleuze (2014), alongside 'causality', 'agential realism', and 'intra-actions' theorised by Karen Barad (2007). Barad's extrapolation of Bohr's theories on apparatus boundaries shows overlap between music, time, and measuring apparatus.

Holland (2013) develops Deleuze's discussion by offering tangible pathways between ideas such as repetition and music, schizophrenia, and free jazz. Buchanan et al. (2004) provide an overview of Deleuze's view on music. DeLanda (2000, 2019) offers further nonlinear historical philosophy alongside the philosophy of society, contextualising the relevance of Deleuze's theories within the last few years. Finally, Sergeant and Phillips (2022) continue the previous discourse by investigating the perception of now moments.

This overview is by no means an exhaustive study of philosophical concepts or physics, and a great deal of material is outside the scope of this research; the focus on nonlinearity should always be a consideration when reading this chapter.

4.2.1 Assemblage Theory

Another aspect of philosophy that should be considered is the concept of assemblage theory. DeLanda has expanded Deleuze and Guattari's assemblage theory – which he describes as "the main theoretical alternative to organic totalities" (DeLanda, 2019: 16).[6] DeLanda's work offers tangible examples and extrapolates the information to provide a thorough explication, using the construct of society as a basis. In *A New Philosophy of Society* (2019), DeLanda establishes that an assemblage is defined by three variables: roles, processes, and flexibility.[7] Many examples of assemblages exist, and the theory was designed to apply to "entities ranging from atoms, molecules to biological organisms, species and ecosystems" (DeLanda, 2019: 7). For example, a market can be considered an assemblage. Within a market, *roles* include organisers, traders, and customers. *Processes* exist through transactions between traders and customers. *Flexibility*, or in this case, 'flexible operation', is achieved by temporarily repurposing the space where the market is erected.

Assemblages are self-contained yet interconnected to other assemblages. An assemblage may function independently or expand to be part of a larger assemblage. For example, a market connects independent traders and producers within the surrounding area. In this project, nonlinear music can be compared to an assemblage, that is, the coming together of autocatalytic loops. Each autocatalytic loop exists independently through player-performer interaction, neither requiring nor rejecting external interaction. The autocatalytic loops constructing *The Machines* app is a

[6] 'Organic totalities' refers to the holistic examination of the subject to fully understand it.
[7] Flexible in the sense that it can "rigidify the identity of the assemblage or, on the contrary, allow the assemblage a certain latitude for more flexible operation" (DeLanda, 2019: 22).

heterogeneous collection of parts; each is flexible in location and output, and the outcome is always unique yet recognisable.

4.2.2 Rhizome

The rhizome can be used as an analogy for nonlinear time and compared in several ways. A rhizome is a stem that flows horizontally, providing a multiplicity of paths that it is possible to follow simultaneously. Much like stratification, it is possible to think of a rhizome as only having a middle, with no beginning or ending; of having unexpected connections, or unrelated objects or truths; or of a map offering tendencies, rather than a tracing, which is a reproduction. No rhizome can be a copy; similarly, no piece of linear or nonlinear music can be a copy. As explained below, individual experience will not allow this; repeated listening to a piece of linear or nonlinear music will always provide a different outcome.

When discussing linear music, Heyduk (1975) asserts that although the music played is the same, circumstance and predictability will affect the outcome. The music will be more predictable the second time through because the material has already been heard once. As such, there will be less information to process, and the listener will have more capacity to process additional information and potentially (dependent on the music's complexity) have negative information density. This impact may allow the listener to focus on parts of the music 'unheard' the first time through. Furthermore, circumstances like listener location would impact the music. For example, listening to a piece of music on a busy street using a smartphone speaker would be significantly different from listening to the same piece on a sophisticated car stereo system or in an acoustically treated recording studio. This demonstrates that predictability and circumstance affect the outcome and afford each listening an individual 'formed flexible identity' (the idea of a 'formed flexible identity' will be discussed in *4.2.5 Identities*).

The rhizome's structure reflects nonlinear music composition. The rhizome does not offer a clear path but presents simultaneous opportunities like a map. Deleuze and Guattari argue that a rhizome is in constant flux; thus, pinpointing a beginning or ending is impossible (Holland, 2013). The extrapolation of this viewpoint into nonlinear electronic music systems is present in the practical work within this project.

4.2.3 Abstract Machines

The rhizome can be used as an analogy to depict the connections of abstract machines, which can link similar or seemingly unrelated elements together. Abstract machines can be “linked to other abstract machines…because their various types are as intertwined as their operations are convergent” (Deleuze and Guattari, 1987: 514). They are not simply connected but are intertwined while remaining self-contained; however, in contrast to autocatalytic loops, they react to external input or forces. Deleuze and Guattari use a war machine as an example of an abstract machine. They argue that the ‘war machine’ can act as a rhizome “with its gaps, detours, subterranean passages, […] openings, traits, [and] holes” (Deleuze and Guattari, 1987: 415) demonstrating the complexity of the war machine is comparable to a rhizome’s complex subterranean root stem system. A fundamental affordance of an abstract machine is that the object and outcome can differ; a war machine can have music as its object. The war machine can have “specific assemblages such as building bridges or cathedrals or rendering judgements or making music or instituting science” (Deleuze and Guattari, 1987: 366). Deleuze and Guattari use a war machine as an example of “the Intra-Species Social Organisation Problem” (Holland, 2013: 115). The war machine has six variations: a ‘rhizomatic variant’, a ‘revolutionary movement variant’, the ‘war variant’, the ‘state war variant’, the ‘fascist variant’, and the ‘capital accumulation variant’ (Holland, 2013). Each variant has transformation as an object and can be likened to nonlinear music composition, which also has transformation as an object.

When discussing game development, the game machine can have a puzzle as its object, such as the puzzle video game *Portal* (Valve, 2007). In this project, the game machine can be a music machine. Abstract machines can open and close assemblages and, as such, can be considered a building block of an assemblage. An assemblage that is a local market consists of multiple abstract machines. Firstly, consider a cheese stall where a weighing machine links to a human digestive machine through food. Secondly, consider a vinyl record stall where a music playback machine connects to a human emotion machine through a music composition. Atonal music can be considered an abstract machine that reflects society or ‘global society’ from a different viewpoint. For example, Penderecki’s 1960 work *Threnody for the Victims of*

Hiroshima (Penderecki and Greenwood, 2012) could be considered an abstract machine capturing the essence of a war machine as its object.

4.2.4 Identities

A large proportion of music reflects societal narrative and is similarly structured. Rules, systems, hierarchies, tensions, resolutions, interactions, classes, differences, and repetitions are all constructs within society and music. For Eugene Holland, society can be considered linear and irreversible based on a Kantian notion of absolute time (Holland, 2013). That is, if absolute time is considered linear and irreversible, so too is society. However, DeLanda (2000) argues that the development of society is not linear, as discussed in *3.2 Introducing Nonlinearity*, which highlights DeLanda's viewpoint on the nonlinear development of towns and cities through energy flow. This nonlinear development model is reflected in nonlinear music, particularly evident in music with complex rules or atonal harmony. Furthermore, the rhizome-like construction of nonlinear music provides multiple opportunities for difference within repetition, linked inextricably to 'identities'. In this context, 'identities' represent the idea of a 'formed flexible identity'.

Identities can be thought of from multiple perspectives and are fundamental to this project. Identities can be attributed to any object and likened to markers, providing individuation between multiple objects. There are two distinct types of identities: quantitative and qualitative. Kantian philosophy falls into quantitative identities, which are examined through the unity of an object. Alternatively, qualitative identities are examined through the type of object (Sollberger, 2013). Within this project, identities are examined through a flexible model acknowledging the rhizomatic nature of identities and aligning them with a qualitative approach, reflecting the philosophical principles previously discussed and can be thought of as a map rather than a tracing.

Holland states that "the greater the degree of difference in repetition, the freer human behaviour can become – with schizophrenia designating the absolute upper limit of freedom" (Holland, 2013: 13). Holland uses an analogy of free jazz, which has general outlines and improvisation as a basis; rather than classical music, which uses specific directions and limited interpretation; or based on a map rather than a tracing. Deleuze and Guattari determine that mapping is preferable to tracing. "Tracing merely reproduces its object fixed in representation; mapping indicates its tendencies and potential for change" (Holland, 2013: 44). Flexible outlines offer a great deal of creative repetition, much like nonlinear music, whereas specific directions and rehearsal can become muscle memory like bare repetition. Using this viewpoint, repeated listening to a piece of music cannot afford a precise repetition for many reasons.

> Terry Eagleton perfectly stated the most fundamental lesson about identity when he penned the line: 'Nothing ever happens twice, precisely because it has happened once already.' In other words, a second iteration of an event is always different to a first occurrence, and changes in context, temporal or spatial, reconfigure the meanings of objects and events.
>
> (Tonelli, 2021: 327)

When listening to music, the listener will have formed expectations from an initial playthrough, regardless of any 'physical' changes, such as volume output level, playback device, or listening location. The listener will have different thoughts flowing through their head and may notice different elements. As such, the repeated act of listening is not about the repetition itself but the differences within and the identities given to each individual listening. Music artefacts contain identities; each linear recording contains the production date, composer(s), performer(s), equipment, room sound, mixing audio engineer, mastering engineer, and format imprinted on the final artefact, providing a clear and recognisable map of the process. Each nonlinear artefact presented in this project contains many properties that linear music does, alongside additional nonlinear properties. These nonlinear properties may include using internal and external data sets, player-performer input, and decision-making while playing.

Hand-thrown pottery can demonstrate identities in an object. Papmehl-Dufay's 2006 research investigates pottery and culture in Middle Neolithic Sweden. It discusses the shaping of identities through the art form, declaring, "pottery decoration has been used to communicate identity on various scales […and] that different patterns signify identities on a local or regional level" (Papmehl-Dufay, 2006: 146). Each plate thrown in a set will be individual and contain the identities of the plate as an object alongside the potter's identities. Inflexions of the potter's personality will be imprinted on the plate, providing a map of the process involved. It is possible to describe each of these examples through stratification. That is, the identities of each of them could be considered an assemblage of meanings and histories.

Stratification, assemblages, rhizomes, and abstract machines all contain identities. Each now moment will have a unique identity linked to the individual experiencing it; each assemblage or machine will contain a unique identity constructed from the elements within, and each rhizome will grow uniquely through the ground; the final form will be dependent on climate, soil density, and nutrition. However, identity is a consequence of difference and repetition, which are the markers of each identity. Without difference and repetition, no individual identity can occur, meaning the objects cannot exist as separate entities. Deleuze describes identity: "all identities are only simulated, produced as an optical 'effect' by the more profound game of difference and repetition" (Deleuze, 2014: 17).

Barad (2007) conceptualised their 'agential realist' framework, which postulates the differences between 'interaction' and 'intra-action'. The framework argues that "agencies are only distinct in a relational, not an absolute sense […and that] they don't exist as individual elements" (Barad, 2007: 57). This means the relationship is an essential part of, and is paramount to, its existence. The framework was created to rethink the fundamental concepts such as "matter, discourse, causality, agency, power, identity, embodiment, objectivity, space, and time" (Barad, 2007: 26). Within the framework, Barad devotes a chapter to apparatus boundaries, which discusses an issue when using measuring apparatus within an experiment; a topic which has implications for this research. "Apparatus are not passive observing instruments, on the contrary, they are productive of (and part of) phenomena" (Barad, 2007: 143). Barad demonstrates this problem using the Stern-Gerlach experiment in space quantization, which was successful in part due to Otto Stern's sulfuric breath from his cigar becoming a fundamental part of the experiment. "Stern's sulfuric breath [turned] the faint, nearly invisible, silver traces into jet black silver sulfide traces" (Barad, 2007: 165). This experiment demonstrates that there is no clear place where the measuring equipment stops and the experiment begins, a phenomenon which is also true for nonlinear music composition.

For this project, Barad's theory indicates overlap between the choice and limitations of the software used, equipment available, and the researcher's skill and focus. Additional variables, such as player-performer input, complicate the matter; however, rather than seeing this as a flaw or weakness, the project is constructed to embrace the unpredictability, deeming the unpredictability as an inevitability of nonlinearity within electronic music.

Barad draws parallels to Michael Frayn's 1998 play *Copenhagen* (A narrative based on the reasons physicist Werner Heisenberg went to Copenhagen in 1941); this project draws parallels to the uncertainty principle. In this respect, nonlinearity within electronic music can have no definitive outcome, and neither can this project. There is a commonality in nonlinearity, unpredictability, and the Uncertainty Principle: they are flexible and cannot be predicted. As such, multiple repetitions of this project will produce different outcomes. Outlining general principles is possible, but the details would remain uncertain and impossible to recreate. However, the 'subjectivity of outcome' is prevalent in nonlinear music and video games and must be considered in both mediums.

4.2.5 Summary

This section outlines 'assemblage theory', 'rhizome', 'abstract machines' and 'identities' and has demonstrated common threads and linkage between each. One common thread throughout the section is the general theme of flexibility. Although it would be possible to examine each of these subjects in depth, this would be outside the scope of this research. Instead, the purpose is to present a foundation, contextualising the philosophical discourse within the compositional approach and practical application. This foundation will be used in the next section to discuss the four genres of nonlinear time researched within this project: vertical time, moment form, modules, and gestural time.

4.3 Compositional Approach

4.3.1 Sub-Genres of Nonlinearity

Most musical structures contain aspects of linear and nonlinear time. Kramer states that "linearity and nonlinearity are the two fundamental means by which music structures time and by which time structures music. Nonlinearity is not merely the absence of linearity but is itself a structural force" (Kramer, 1988: 20). Kramer's work discusses several types of linear and nonlinear time, such as "gestural time, vertical time, multiply-directed time, moment time, absolute or ordinary time, clock time, directed linear time, nondirected linear time, nonlinear time, Stravinsky's psychological and ontological time, Langer's virtual time, [and] Epstein's chronometric and integral time" (Kramer, 1988: 9). It is possible to split the several types of time into 'sub-genres' of nonlinear time and 'categories of time'. Whereas all fall within the categories of time, the compositional approaches discussed here are determined to be routed in the sub-genres of nonlinear time. Creating nonlinearity within music is possible through augmentation, diminution, reordering, reworking, directional change, an undefined point of origin, or randomisation.

Linearity is processive, and like causality, a happening of an event directly influences a later event. As a non-processive property, nonlinearity uses non-sequential principles that do not rely on a single direction of movement; thus, nonlinear time can seemingly progress in several different directions without previous events impacting later events. This ties back to *3.3 Nonlinearity in Music,* where Snyder discusses connections between phrases, sections or parts of a piece as being 'web-like'. The rhizome analogy, having random lateral shoots, also fits the description. From a practical standpoint, the 'web-like' structure can be created using randomisation, input, and algorithms. It is possible to apply these concepts and tools to more common compositional approaches, which can create a linear piece of music that essentially 'sounds nonlinear', implying that linear music is an aesthetic and not actual. Music analysts have retrospectively applied nonlinear music composition techniques to a body of composers from Western classical to electronic and acousmatic music, analysing recordings and music notation. As considered below, analysis of compositions from Xenakis, Stockhausen, Stravinsky, Riley, Satie, and Ikeda offers insights into the construction of nonlinear music. Whilst nonlinearity has been a cornerstone of the investigation, broader topics such as temporality and granulated time are examined below (Vikery, 2011; Glover Gottschalk and Harrison, 2018).

Four sub-genres of nonlinear musical time construct the compositional approaches within this project. First, vertical time stems from the notion that the past and future are absent or rejected, leaving only an extended present. Second, moment form can be considered sections or pieces of music that start and stop but do not begin or end. Third, modules are like iterative loops or patterns. Finally, within gestural time, the temporal space created by a piece of music can be interrupted and reordered (Kramer, 1988). There is an overlap between these forms of nonlinear time discussed in this chapter, along with extensions and opposites. It is possible to compose a piece of music that falls within multiple genres of nonlinear time. For example, a vertical composition could be split into sections that use iterative loops as a construction technique, thus straddling vertical time and modules.

4.3.1 Vertical Time

Vertical time is the most extreme form of nonlinear music composition and comprises some or all the following attributes. It is a form of music that can be described as harmonically static and uses a fixed sound palette that does not evolve. Phrases, cadences, tension and release, beginnings, and endings are not prevalent in the construction of vertical time. Kramer uses examples from Iannis Xenakis, Larry Austin, and Terry Riley to highlight the affordances of vertical time. “Xenakis’ Bohor I (1962) […] lacks internal phrase differentiation […] Austin’s Caritas (1969) does contain subtle changes […] but the changes are not articulated by cadences […] Riley’s A Rainbow in Curved Air (1969) […has phrases, but they] refuse to form a hierarchy and are therefore heard to some extent as arbitrary” (Kramer, 1988: 55). In *Being Time: Case Studies in Musical Temporality*, authors, Glover, Gottschalk, and Harrison examine a variety of music to observe nonlinear characteristics. Of particular interest is Ryoji Ikeda’s +/- (Ikeda, 1996), which resembles minimal techno without the kick drum. A repetitive clicking seems to encircle the listener, distorting time perception, allowing subtleties within the rhythmic palette and changes in timbre to become a focus. The composition uses a static sound palette and lacks phrasing or significant development, and as a result, it can be considered a composition in vertical time.

Techno music, particularly sub-genres under the umbrella of techno, has many compositions that fit into the vertical time category. When discussing techno, Dyndahl states, “instead of using functional principles of linear propulsion or tension and relaxation, the techno sound creates a state of trance-inducing, hypnotic suggestion” (Dyndahl, 2005: 98). Dyndahl describes vertical time as having components that are “present from the beginning, and [are] gradually discovered or experienced by the listener” (Dyndahl, 2005: 96). This is the case with *Out of Tune,* from techno producer Shifted, a piece of music that uses a minimal sound palette and has no melodic development throughout. Although subtle changes exist, they are formed of blended layers that fade out instead of resolving. In *From Pac-Man to Pop Music*, Kaae determines that “‘techno’ dance music seems to have much in common with the 1950s avant-garde when it comes to time” (Kaae, 2011: 81).

Sheets of Sound is a piece composed for this project and is categorised within vertical time. It is harmonically static and created from a fixed sound palette determined at the beginning of the music. There is no development of the music through the addition of instrumentation, no use of phrase building or song form, and the music starts and stops yet does not have a beginning or ending. Furthermore, the music has no internal or external dependencies, and no “event depends on any other” (Kramer, 1988: 55).

The culmination of qualities and structures outlined above can produce an extended present or a now moment, which, as we have seen in *4.2.1 Now Moments*, is a moment of time perceived for a prolonged period. Within the now moment in vertical time, the future and past become absent, and the flux of time appears to slow. Eventually, the now moment becomes the entire existence of the music, rejecting the future and past. It is possible to liken the listening experience to a meditation, where attention becomes narrowed, and musical intricacies often overlooked become a central focus. Eventually, temporal contrasts are formed by latching onto specific sounds, using them as a root or a path with no clear direction. Many offshoots and multiple dead ends occur, reflecting the structure of a rhizome.

Listener attention forms the depth of contrasts; subtleties are only evident with a certain amount of focus or time spent with a piece of vertical time. This is evident through Erik Satie’s *Vexations*, a solo piano composition that uses an 18-note theme repeated 840 times. The piece transitions back and forth between a single melodic line and a harmonised version. The music may appear without movement or progression to the casual listener; however, contrasts develop, and hierarchies form through focus and prolonged listening. Furthermore, the hierarchies can fluctuate when listened to multiple times. Snyder (2001) determines that re-living the experience in one's head between each listening can influence the perception of the music. Arauco (1990) determines that hierarchies and contrasts within vertical time are subjective and based on individual listening behaviour. As such, it is futile to presuppose exact conditions to achieve them. However, creating hierarchies and contrasts is possible through musical factors such as frequency/pitch, melodic or rhythmic content, panning, and timbre of the sound source. External factors within the listening environment include playback system, venue, number and relationship within the listening party members, and activity level.

There are commonalities between vertical time and the music associated with rave culture. When analysing transformative mechanisms within rave culture, Newson et al. discuss a loss of ego and identities, an experience they identify through "the popular expression 'I lost myself in the music'" (Newson et al., 2021: 7). This loss of identities is also prevalent in video games where players become spatially present in the experience. It occurs when players "stop paying attention to the technology between [them] and the virtual world of the game […] Deindividuation is a mental state where people's identity fades into the background of their thoughts so much that they become much more susceptible to cues from the environment and people around them" (Madigan, 2016: 14,95).[8] The loss of identities on the dancefloor and when playing video games is possible through the 'state of flow', a state balanced between frustration and boredom. The state of flow theory was developed by psychologist Mihaly Csikszentmihalyi (1975) and is a fundamental strategy in the game development pipeline.

> In *flow*, an activity balances a person between challenge and ability, frustration and boredom, to produce an experience of achievement and happiness. This concept is very interesting for game designers because

[8] This links back to Barbara Barry's interpretation of now moments where the listener gets absorbed in the now.

> this balance between challenge and ability is exactly what we are trying to achieve with gameplay.
>
> (Fullerton, 2014: 99)

A form of flow is evident in interactive, nonlinear music apps such as the *Panoramical* video game (Ramallo and Kanaga, 2015), where the player-performer is offered agency over predetermined parameters affecting the music output. The aim is to navigate through the music experience and achieve the state of flow where possible. Within this unique music environment, now moments can occur through contrasts and hierarchies, individualised to each player-performer by their actions. However, where one person experiences contrasts and hierarchies, another may not. Where one person perceives a now moment, another does not perceive a change, and a third perceives a diminution of the present. Glover et al. argue that now moments are "neither entirely linear nor proportional" (Glover, Gottschalk, and Harrison, 2018: 12,14), the extent of which is dependent on the individual.

There is overlap between the state of flow and Barad's measuring apparatus theory, which Glover, Gottschalk, and Harrison highlight when they discuss the effects a change in the listening environment makes on the perception of the music. When discussing Ikeda's (1996) composition, Richard Glover compares his perception of listening on headphones and speakers, explaining, "one major variable which impacts upon one's own temporal sense is the mode of listening" (Glover, Gottschalk, and Harrison, 2018: 122). This theory highlights how the apparatus and listening environment can affect individual perception of the music and adds weight to the flexibility of now moments, which, as discussed in *4.2.1 Now Moments,* have a length dependent on function. Furthermore, multiple listening by the same person may not yield the same results due to the identities formed. For example, experiencing a now moment on the first listen may not be replicated on the second. This raises the question about the most appropriate tool for measuring the individual listening experience and encapsulating this individuality. As seen in *3.2 Introducing Nonlinearity* and *3.3 Nonlinearity in Music*, the appropriate tool should be individual time rather than absolute time. Individual time as a measurement will reflect the flexibility of now moments and would be more beneficial than using absolute time, which does not consider the formed flexible identity of the music.

4.3.2 Moment Form

Moment form[9] – stems from ‘open mobile form’, a compositional technique developed in the 1950s by composers such as Earle Brown, Karlheinz Stockhausen, and Pierre Boulez. Open form was created to “describe a musical form where the sequence of elements or sections of a notated work is indeterminate or left up to the performer” (Kocher, 2016: 3). Welsh (1994) summarises pieces composed with an ‘open-structure’ can be classified as ‘mobiles’.[10] For example, Stockhausen’s *Klavierstück XI* (1955) for solo piano uses open mobile form. The piece is divided into 19 fragments presented to the performer on an oversized score that can be played in any random order within the performance; each fragment can be considered a moment. Stockhausen’s *Momente* (1965) develops this idea of moment form for an ensemble, using a score that can be rearranged for each concert with notation inserts that attach to the main score and vary in position and duration (Elheran, 1965).

Moment form can be considered sections or pieces of music that start and stop but do not begin or end. Each moment has qualities of an extended now moment, avoiding harmonic functionality and climaxes, and as such, the order of each moment is irrelevant to the listening experience. Moment form is not harmonically static, although structural cadences are never employed; as such, the music feels disjointed from a linear perspective. Instead, motifs, harmonic continuity, and rhythmic repetition can be employed throughout, which helps the cohesion of the music. Unlike vertical time, moment form can recall past moments and present expectations of upcoming moments. However, as Kramer (1978) discusses, the beginning and ending of the music can be compared to starting a piece of music mid-way through and stopping it before the end, which is why it starts and stops rather than begins and ends.

[9] In *Time of Music* (1988), Kramer uses moment time; this thesis prefers moment form over moment time.
[10] Welsh includes selected works by Earle Brown, Karlheinz Stockhausen, and Pierre Boulez, such as “*Twenty-Five Pages* (1953), *Available Forms I and II* (1961-62), *Modules I and II* (1967), and *Tracking Pierrot* (1992) by Earle Brown, *Klavierstuck XI* (1957) by Karlheinz Stockhausen, *Piano Sonata No. 3* (1956-57) and *Structures, Livre II* (1956-61) by Pierre Boulez” (Welsh, 1994: 256).

Stravinsky's *Symphonies of Wind Instruments* (1920) has melodic, harmonic, and rhythmic themes, which are repeated within the work and echoed in the combination of instrumentation and voicings. Throughout the piece, these themes develop; however, no ending is achievable. Listening to the moments in any order would achieve the same outcome. As such, it can be retrospectively analysed as being in moment form or having a moment form aesthetic. In a paper analysing *Symphonies of Wind Instruments*, Alexander Rehding considers viewpoints from music theorists Edward T. Cone, Christopher Hasty, and Jonathan Kramer. Cone pioneered the idea of discontinuity with the composition and "reads the *Symphonies* as based on 'stratification', 'interlock' and 'synthesis'" (Rehding, 1998: 39). However, Cone also states that although discontinuity exists, the influence of the music is evident even between moments. Hasty "makes a very convincing attempt at showing functional connections" (Rehding, 1998: 39) between moments, strengthening Cone's idea of music influence throughout. Finally, in *Time of Music* (1988), Kramer thoroughly analyses *Symphonies of Wind Instruments* and concludes that it "is not purely in moment time but can be heard in terms of voice leading ('linearity') as well as non-linearity" (Rehding, 1998: 41).

Moment form is conceptual as well as practical. The lack of recollection and expectation in vertical time are compositional tools within moment form. These tools offer more potential for melodic, harmonic, and rhythmic development, tools more relevant for popular song than the fixed sound palette and stasis of vertical time. Although moment form can straddle different styles of music, some are more structurally suited. Nick Collins discusses moment form in relation to algorithmic music. He argues that moment form demonstrates the ability to "abruptly jump between composed sections but [is] unable to demonstrate much real dramatic direction" (Collins, 2009: 103). In *Gravitational Pull* (a piece composed for this project), the player-performer can physically jump between sections by moving a smartphone back and forth, and as such, is a useful example of moment form. The structure of this piece will be examined in *5.3 Gravitational Pull*.

4.3.3 Modules

Modules are nonlinear loops or patterns; each is complete and independent and can be placed anywhere in the linear order of the composition. As such, each module can be considered an autocatalytic loop. Modules are intricately connected to create a large-scale piece of music. “Large-scale connections exist throughout the expanse of the music, which provoke “deeper hierarchical meanings than local connections” (Paynter, 2015: 51), an idea that can be likened to the interconnected functionality of assemblages. Complex threads can be woven through the modules: harmonic, melodic, rhythmic voicings, or note clusters. These elements can have commonalities, although their identities remain independent. Modules are like iterative loops or patterns, often complex and intricately entwined. Paynter (2015) discusses connections between patterns and compares the process to asymmetric patterns of Turkish rugs. Although these complex patterns look symmetrical on the surface, they are imperfect, giving a greater sense of depth. Patterns have “comparable structural importance” (Paynter, 2015: 49), and although the patterns are superficially accurate, an asymmetry exists throughout.

Modules was conceptualised and developed by avant-garde composer Morton Feldman. Feldman was inspired by author Leo Tolstoy’s process when writing *War and Peace*. Tolstoy would write nonlinear sentences, which he cut into ‘noodles’ to be rearranged on a table, an approach adopted by William S Burroughs when writing *Naked Lunch* (Feldman, in Paynter 2015: 55).[11] Feldman thought of modules “as a compositional raw material” (Paynter, 2015: 54), which helped him reimagine his method of composing music and build a compositional framework. He was interested in pattern variations, which is evident in *Spring of Chosroes* (1977), which “evoked the patterns and colours of Turkish carpets” (Paynter, 2015: 47). He was moving in the opposite direction to his peers “Boulez and Stockhausen, whose process has tended toward elaboration and systematization of method” (Feldman, 1985: 2). The modules have subtle differences and, at first glance, can seem to be replications; however, they are reiterations, and with deeper listening, these reiterations will reveal themselves. This idea can be likened to the differences between a tracing and a map, the latter offering greater flexibility than the former and with it revealing creative repetition. Feldman describes these reiterations as ‘extensions’ rather than developments; extensions must not alter the module's identity, which is already complete.

[11] Earle Brown’s *Modules I and II,* should be considered ‘open form’ (which became moment form), and not be confused with Morton Feldman’s Modules composition technique.

Modules do not adhere to structures like many other nonlinear compositional formats. Feldman rejected serialism “to avoid the clichés of the International School of present day avant-garde” (O’Hara, as cited in Feldman, 1985: 2). Familiar cadences and accents are absent, and there is a lesser sense of formal structure. Hierarchy exists, but the onus is on the listener to uncover them. When contemplating Feldman’s work, journalist Tom Service wrote, “my sense of time had been altered, so intently focused was I on the way the music changed from note to note and chord to chord. It created a living, breathing network of relationships that extended across its length” (Service, 2012). The relationships are intricately entwined, much like any transport network or weather system. Although independent, changing one module will affect another, as the wind will affect the direction of the rain, or a broken-down vehicle will impact the traffic flow.

To summarise the differences between modules and moment form, modules have connections from one to the next through iteration and intricate development; altering a module will impact another. Within moment form, moments do not share connections; altering one moment will not impact another. Although a single module could become a moment, multiple iterated modules could not become multiple moments due to their connections.

4.3.4 Gestural Time and Manual Granulation

Gestural time is not strictly a compositional technique; however, this section explores how the philosophy of gestural time can be applied to ‘manual granulation’ to forge a link between theory and practice. Within gestural time, the continuity of a composition can be interrupted and reordered, affecting the temporal space created by a piece of music. “Events appear in an order in gestural time that is different from their order in ordinary [absolute] time” (Kramer, 1988: 6). A temporal space in music delineates how the music exists within time, often concerning the direction of time as we know it (past, present, and future). Kramer considers that gestural time is a reordering “but not a destruction” (Kramer, 1988: 169) and thus is, in fact, linear. However, although it is agreed that ‘reordering’ is a more appropriate term than ‘destruction’, the explanation below aims to demonstrate how manual granulation can be harnessed to create a piece of nonlinear music in gestural time. Kramer claims that his “purpose is not so much to make definitive statements as to invite readers to take on the challenge of listening to music in new ways" (Kramer, 1988: 8).

'Musical gesture' is fundamental to gestural time and should be considered holistically. For example, musical gesture can present a new section, a dynamic shift, or a harmonic change within gestural time. Although these gestures can be composed of individual note shifts or cadences, the outcome affects the entire piece. Kramer determines there can become a conflict between gesture and function if the musical gesture does not adhere to structural expectations. He provides detailed examples of gestural time in *Time of Music*, using Haydn, Berlioz, and Beethoven.[12] In *Haydn's String Quartet in Bb*, "the composer places so many closing formulas […] one after another that we do not quite believe in the finality" (Kramer, 1988: 140). Another example, Berlioz's *Le Corsaire Overture*, is considered to have two beginnings. The first beginning seems to be quickly forgotten due to the speed at which it disappears, and as such, it is up to the listener to determine the structure of the opening of the piece. Thomas Clifton determines the reordering "is not an independent process but a relation between a person and an experienced event" (Clifton, as cited in Kramer, 1988: 6).

Manual granulation derives from granular synthesis, which "involves generating thousands of very short sonic grains to form larger acoustic events" (Roads, 1988: 11). Manual granulation requires the sound to be broken into "its component parts and to use scripting or other implementation techniques to describe an algorithmic method of playback" (Paul, 2011: 137). Granulation usually contains grain sizes of anywhere between 1 to 100 milliseconds in length; however, manual granulation can include larger grain sizes, which could be viewed "as 'units' of granulation" (Paul, 2011: 137). By breaking the music down into its 'component parts', it is possible to slice sounds into grains vertically or horizontally. This idea will be covered in more detail in the *4.3.4 Method*; however, the general process is conducted when exporting audio from a digital audio workstation (DAW). Capturing a vertical slice means exporting all instruments within a given timeframe, for example, the timeframe of a beat or a bar. Alternatively, capturing a horizontal slice is to export the entire track length, capturing single instruments or instrument collections, such as a strings section. The grains

[12] Chapters 5 and 6 in Time of Music (1988) analyse Beethoven's *String Quartet in F Major, Opus 135, First Movement.*

(which are not required to be equal in length) are reordered on playback to produce a 'masked' version of the original composition where song form, melody, and harmony become unrecognisable.

Manual granulation can diminish the player-performer's recognition of the original music and alter the perception of time. Through the reordering and masking of the music, temporal entanglements can form between silence and sound. The sound can affect the duration of the silence and vice-versa (Glover, Gottschalk, and Harrison, 2018). "As listeners, we each have different capacities for perceiving, recollecting, and time-ordering sound, and different levels of acuity in the perception of temporality" (Glover, Gottschalk, and Harrison, 2018: 9). Glover, Gottschalk, and Harrison argue that the "act of listening to music is a powerful scenario for bringing temporal awareness sharply into definition" (Glover, Gottschalk, and Harrison, 2018: 7).

In this project, an example of gestural time through manual granulation is *Stomach* in *The Machines,* which divides and repeats a musical phrase through player-performer movement[13]. This method reorders the music sections into grains and produces multiple beginnings, cadences and endings or multiple beginnings and no endings. The ending could become the beginning and produce a conflict between gesture and function, ultimately affecting the structural integrity of the music.

4.4 Game Application

Within modern society[14] – technological development is accelerating, which in turn is affecting the pace of life (Rosa 2003). This development is discussed in *A Thousand Years of Nonlinear History* (Delanda, 2000), which highlights that evolution is nonlinear; "technology won't be viewed as evolving in a straight line" (Delanda, 2000: 73). There is a growing linkage between music, gaming, film, and television, through areas such as virtual production and audio-visual performances. For example, The Royal Shakespeare Company's *Dream* is an interpretation of *A Midsummer Night's Dream* that aired in 2021. The production uses motion capture and *Unreal Engine* to

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[13] An audio recording of *Stomach* is located here:
<https://drive.google.com/file/d/1Zd8j_ILd_fy_Uu2eWxcrZl69ppNbhd3O/view?usp=share_link>

[14] "As historians like Reinhart Koselleck have persuasively argued, the general sense of a "speed-up" has accompanied modern society at least since the middle of the eighteenth century" (Rosa, 2003).

present an interactive virtual performance demonstrating the potential evolution of the technology (Royal Shakespeare Company, n.d).

This technological innovation is a trend reflected in music composition and is particularly prominent in electronic music composition, previously demonstrated in *1.2 Rationale* using Travis Scott's music performance in the video game *Fortnite* as an example. Acknowledging this trend is significant in providing consumers (now often regarded as 'producer-consumers') with effective and engaging content to consume, augment, and develop. The acceleration and expansion of technology are increasingly penetrating all areas of our lives through smartphones, laptops, and tablets. The expansion will advance through technology such as augmented reality, which is currently being developed for navigation, training, and education purposes. Throughout this expansion, the audience and technology will evolve and understanding both will become ever more beneficial and essential (Collins, Tessler, and Kapralos, 2014).

This section is not a comprehensive overview of the emergence of video games, game audio, and game development; instead, the aim is to provide examples of the challenges faced by the industry whilst outlining technological innovation. The purpose is to demonstrate the speed at which the technology and sector have evolved and examine how the hardware and software have developed, detailing the presence of nonlinearity within the field. Examining the development of video games allows for a more comprehensive understanding of nonlinearity in music alongside nonlinear techniques and strategies for audio development.

4.4.1 A Brief Timeline

The technological evolution of video games was determined by hardware, software, and the ingenuity of game developers. The acceleration depended upon circumstance, location, and developer focus, which was predominately concerned with visual gameplay and game mechanics; game audio was not developed at the same pace. For example, the *Magnavox: Odyssey*, a gaming console released in 1972, could not output sound. However, sufficient progress was made in developing audio capabilities and systems, and by 1983, the *Nintendo Famicom* was equipped with five voices (KyuSik, GyuBeom, and TaeYong, 2007). The technology within the *Famicom* used subtractive synthesis chips called programmable sound generators "that offered little control over timbre and were usually restricted to square waveforms, with limited possibility for manipulation" (Collins, 2007 b: 213). Low-level machine instruction, such as *Assembly Language*, was required to implement the audio into systems such as the *Commodore 64* home gaming console. For this reason, many audio programmers simultaneously worked on multiple aspects of game development and were not audio specialists or music composers. Collins claims this combination "helped to create the unique aesthetic of early games audio" (Collins, 2007 b: 215).

Within this time, the challenge for composers was to create music capable of supporting gameplay to "effectively express the genre characteristics and enhance the game experience" (KyuSik, GyuBeom, and TaeYong, 2007). The illusion of creating a full soundtrack became essential to negate the technical limitations of the audio systems in the early gaming consoles. This concept was achieved by dynamically reassigning the voices to change between waveforms multiple times in quick succession. For example, the music for *Commando* (1985) on the *Commodore 64* fully utilised the three available voices by doubling up the function of each. A single voice is programmed to use a square wave to play a bassline with an interwoven noise generator to create a snare drum.

Looping became popular around 1984, when "techno and hip-hop were beginning to see mainstream exposure" (Collins, 2007 b: 218). The car racing video game *Outrun* (1987) by *Sega*[15] – utilised looping successfully through the techno-inspired soundtrack composed by Hiroshi Kawaguchi (a programmer turned composer). The video game was developed for the *Japanese Master System: Sega*, one of the first home gaming consoles to utilise sampling. A selection of alternate soundtracks can be chosen in-game upon race start, using an FM-style car radio user interface. In this context, the looping aesthetic solved the limited memory issue whilst providing agency and variation for the player. This interactable system paved the way for nonlinear music functionality and demonstrates the increase in nonlinearity within game music.

By 1994, streaming music was supported, offering more complex audio systems, affording more agency to the player-performer, and allowing the composers to create interactive and adaptive nonlinear music for games. Furthermore, the technological advancements provided up to 24 channels with a 44.1 kHz sample rate. This evolution

[15] OutRun Video Game. (AL82 Retrogaming Longplays, 2015)

“gave video game music the equal footing with other popular music it had lacked” (KyuSik, GyuBeom, and TaeYong, 2007: 3). As will be demonstrated in the next section, the release of *Unreal Engine* game development software has offered game audio designers and music composers greater freedom to explore nonlinearity in music, which is where this research is focused.

4.4.2 Techniques and Tools

Shifting the focus to techniques and tools within the creation of nonlinear music, using *Unreal Engine 5* (*UE5*) game development software as a compositional tool can expand the linear approach and link nonlinear music as a mechanic with nonlinear music as a concept. This linkage exists through the native set-up of *UE5*, which supports the creation of nonlinear properties. The emulation of real-world properties is prevalent in the virtual worlds of game environments. Within game development, environment creation and narrative are vital components that inform game creation's visual and aural aspects. The player-performer has agency over many properties, including physics, scale, location, distance, speed, repetition, navigation, interaction, and spatialisation, all native to the software. Schütze and Irwin-Schütze consolidate these properties into three categories: time domain, frequency domain, and spatial domain.

> [Within Time Domain] events transpire at different intervals during each playthrough and users can unlock narrative elements in a nonlinear order […Within Frequency Domain] events that can be repeated might happen only once or they might happen once every 2 seconds […Within Spatial Domain] events and objects move in multiple directions, and […] users have freedom to move through 3D space, at any distance.
>
> (Schütze and Irwin-Schütze, 2018: location 488)

Audio spatialisation can create the sensation of sound emanating from sources surrounding the listener, as is possible within the real-world (Schütze and Irwin-Schütze, 2018). A player-performer in a spatialised virtual environment will hear the sounds in all directions on all X, Y, and Z axes, as would be heard outside a virtual environment. Headphones are recommended for player-performers to take advantage of audio spatialisation; “ambisonic, binaural, and spherical surround [sound] can certainly be delivered through loudspeaker systems, but this is not likely to be the optimal delivery format” (Schütze and Irwin-Schütze, 2018: location 636). Headphones always allow the player-performer to be in the optimal place for spatialised playback because they are “at a fixed distance to the listener’s ears at all times” (Schütze and Irwin-Schütze, 2018: location 655).

The combination of spatiality, interactivity, and adaptability adds a compositional opportunity not afforded to linear music composition. This combination offers the chance to begin, move, or end anywhere along the X, Y, and Z axes, resulting in the possibility of composing a piece of music that can start from any position, move in any direction, augment, diminish, reorder, or rework elements. In this situation, music elements can be located anywhere around the listener, allowing them to navigate to or from at will. These elements contain properties that can be manipulated in real-time, which can be synchronous or asynchronous or move between both; they can also affect each other sonically. The outcome offers a spatial environment that can adapt to player-performer input and afford them agency over the music outcome.

The virtual environment within *UE5* offers a multitude of opportunities for exploration. Creating musical concepts that would be challenging, intangible, implausible, or impossible outside of the virtual game environment is achievable. If desired, these virtual game environments provide the possibility to defy physics and ignore gravity. It is possible to place audio components on a vertical plane, hundreds of meters apart, or to appear randomly as the player-performer performs an action. All this is achievable through player-performer interaction, game mechanics, and artificial intelligence, and as the software evolves, the possibilities keep expanding. Composing music using *UE5* as a music production tool allows the possibility of rethinking the linear approach and synthesising a new way of conceptualising and producing interactive and adaptive electronic music.

Unreal Engine was initially designed and built by programmer and founder Tim Sweeney to develop a game idea by a colleague, which was written in *Assembly Language* (Lightbown, 2018). Sweeney developed *Unreal Editor,* and the first game, *Unreal,* was released in 1998 (Lee, Doran, and Misra, 2016). *Unreal Engine 5*, the version predominantly used in this project, was released in April 2022. It has a highly sophisticated audio mixer offering digital signal processing and procedural synthesis. The system, built using C++ programming language, has a beneficial API capable of communicating with external software, such as *Ableton Live* DAW. The audio mixer “has added next-generation audio rendering features that provide unprecedented control and flexibility to audio designers working on real-time experiences" (Unreal Engine, 2022).

Dynamic audio, comprising tools such as spatialisation, attenuation, occlusion, filtering, and concurrency, are all native to *Unreal Engine*, providing a sophisticated system capable of recreating 'real-world' sound placement and environmental factors that affect them. Dynamic audio systems "can provide an immersive experience because virtual sound sources and sound reflections can be made to appear from anywhere in space around a listener" (Roginska and Geluso, 2018: 5). Within *Unreal Engine,* this creates the opportunity to construct sophisticated interactive and adaptive spatially present nonlinear audio environments. However, although *Unreal Engine 5* offers an enhanced toolkit, the focus is on game application. As a result, some more common tools for audio production are missing or challenging to use. Furthermore, the user interface is not visually comparable to most DAWs, so many composers face a steep learning curve when initially using the software. Although the complex nature of the toolkit and software requires audio designers to consider a different approach, it does afford greater freedom to explore nonlinearity in music.

4.4.3 Linearity vs. Nonlinearity

There are significant differences between linear and nonlinear music composition. A linear music recording offers the composer comprehensive control over the composition, potentially determining the exact circumstances concerning music playback. Providing the playback is uninterrupted, linear music composition should technically always produce the same result; however, as has been discussed in *3. THREE STRANDS OF NONLINEAR TIME*, there will be subjectivities dependent on factors such as the playback system, repeated listening, and listening space. The modification of linear electronic music has been evident since the birth of house music in the early 1980s. Through the "combination of disco with drum machines and reel-to-reel tape edits" (Eshun, 2000: 73), DJs have been looping, reordering, and remixing music, creating 'new' pieces that could be considered nonlinear. Also, as we have seen, this nonlinear trait is evident in-game audio through games such as *Outrun* (1987). There is further overlap between specific sub-genres of European techno music and nonlinearity. Musicologists Blokhus and Molde argue, "techno har ingen lineær retning [techno has no linear direction]" (Blokhus and Molde, as cited in Collins, 2008: 81), an idea discussed previously within the *3.3.1 Vertical Time* section.

Within game music, nonlinear composition techniques and mechanics effectively engage the player-performer while providing real-time aural feedback to enhance gameplay. Player-performer input is a critical consideration and can significantly impact the requirements of music playback. Ultimately, player-performer movement is unpredictable, so calculating time spent on tasks, such as doubling back or revisiting an area, is impossible; "realistically, there is no way to predict how each player will navigate the game. This means the final form and shape of [the] music can only be partially predetermined" (Kellman, 2020: 19). This unpredictability challenges the composer to write multiple paths to allow for player-performer agency over the outcome. Additionally, it affords the player-performer agency over the music regardless of the objective. For example, the objective of the practical artefacts in this project is to affect the music. *Outrun* (1987) discussed in *3.4.1 A Brief Timeline* does not have music development or manipulation as a primary objective; however, the player-performer is still afforded agency over the music outcome. Finally, dynamic audio encapsulates nonlinearity within video games through interactivity and adaptive elements. As such, these elements should be considered throughout the entire process of nonlinear music composition.

4.4.4 Implementation

The user interface of most DAWs is divided into individual tracks, each dedicated to a specific instrument or set of instruments. Often, DAW layouts present 'time' running from left to right with 'tracks' or 'channels' running from top to bottom. Exporting the entire composition, specific vertical or horizontal sections, or individual instruments is possible. This flexible export process is beneficial within game audio, allowing for more significant music manipulation in the game engine. For example, a synth loop can be triggered if a player loiters in a specific area. In a different scenario, a single guitar melody can play when there is no danger, with the full band kicking in when an adversary appears. Additionally, music can guide the players' morals, accelerate decision-making, provide feedback, and steer the player along a specific path, helping to determine the game's flow. Furthermore, the music must be dynamic and emotive when necessary and signify intensity levels, which can be complex. There are many approaches to structuring game music, for example, “The Secret of Monkey Island, where the score modulates effortlessly from song to song […or] Uurnog Unlimited, where music algorithms evolve alongside player choices” (Kellman, 2020: 7).

The function of the music can be complex and raise composition and implementation challenges from the outset. For instance, creating harmonically dense adaptive music that reacts to gameplay presents a problem. How will the music resolve when the situation changes? If the music immediately responds to a player moving from danger to safety, at what point will the music change? Would it be the next beat, the end of the bar, or the end of the phrase? What happens if the player moves between areas in quick succession? How does the music react in that scenario? Karen Collins’ (2006) article *Loops and Bloops: Music of the Commodore 64 Games* approaches this complexity by outlining distinctions between loop sizes: microloops, mesoloops and macroloops. This approach offers a useful nonlinear music composition method encapsulating loops within loops. Collins describes this method, “a two-note bassline may provide a (musematic) microloop which repeats twice in a two-bar (discursive) mesoloop, which is then part of a longer eight-bar macroloop” (Collins, 2006: 4). Thinking in this level of detail when composing nonlinear music for games, or nonlinear music apps provide a flexible and adaptable model, addressing some of the complex implementation issues faced with the unpredictability of player-performer agency.

Additionally, the gaming device or platform needs consideration. A dedicated desktop gaming machine, such as a PC, PlayStation, or Xbox, will require different techniques than a casual gaming device, such as a smartphone. This is true from an auditory perspective and the player-performer's playing style and consumption habits. The importance of audio in games is dependent on the type of game and device used. Recent advancements in this area are prominent in mobile gaming, specifically through new realities (virtual, augmented, and mixed). Mobile gaming has added to the complexities of game development, significantly affecting audio development. The examination of mobile gaming and techniques involved in translating game development to less powerful machines[16] – highlights a comparison to the initial issues game developers had in the 1970s to 1990s when the technology was in its infancy (as discussed in *3.4.1 Brief Timeline*). Innovative thinking is required to develop

[16] Such as PlayStation to a smartphone. An example is *Minecraft*, which has versions on PC, PlayStation, Xbox, and smartphone (Minecraft.net, n.d).

systems capable of supporting the vision of game developers whilst also balancing the integration of mobile gaming within our daily lives.

4.4.5 Summary

Nonlinear music in games and game-like apps is multifaceted, requiring examination from multiple angles. The advancement of technology within computer games and game development software is moving at such a pace that there is constant scope to conduct further research into the field. Game development is expanding and will continue in the foreseeable future.[17] *Unreal Engine 5* is crucial for exploring interactive and adaptive nonlinear music composition opportunities. With the speed of technological growth and a focus on audio development, further research into this evolving area will help provide insights into future trends of nonlinear music composition. Furthermore, music composition methods will evolve alongside technological development, so insights and framework(s) will be fundamental in explicating the process.

[17] "The global video game market was valued at USD 195.65 billion in 2021 and is expected to expand at a compound annual growth rate (CAGR) of 12.9% from 2022 to 2030" (Grand View Research, 2022).

5. A NONLINEAR ELECTRONIC MUSIC FRAMEWORK

5.1 Overview

> A framework for music is any entity, construct, system, or paradigm that contributes in some way to the composition or performance of music. A framework is a tool, in essence, but one which can be physical or conceptual. An affordance is something that a framework allows one to do […] Because a framework can be used in many different ways, and for different purposes, every framework has a number of different affordances that it offers to its users.
>
> (Mooney, 2010: 146)

This chapter is informed by the practice-based research conducted for this project, offering a rationale, contextualisation, and ethical principles. A system is developed to explicate the interactive and adaptive electronic music composition process, which examines theory through philosophical principles, game application, and compositional approach. The development and implementation method used in this project is discussed, along with potential limitations. This chapter does not provide case studies or analysis of game audio. Instead, it reveals several affordances of *Unreal Engine* as a music composition tool. The framework is designed to be a standalone document used by music practitioners interested in developing a toolkit for composing interactive and adaptive electronic music.

Mooney's 2010 paper *Frameworks & Affordances: Understanding the Tools of Music-Making* has helpful information on physical and conceptual systems, considering "the physical tools of music-making and the conceptual systems as essentially the same thing" (Mooney, 2010: 144). Within *5.5 Framework Method*, physical tools and conceptual systems are developed to demonstrate the methods employed in this project to create interactive and adaptive electronic music compositions.

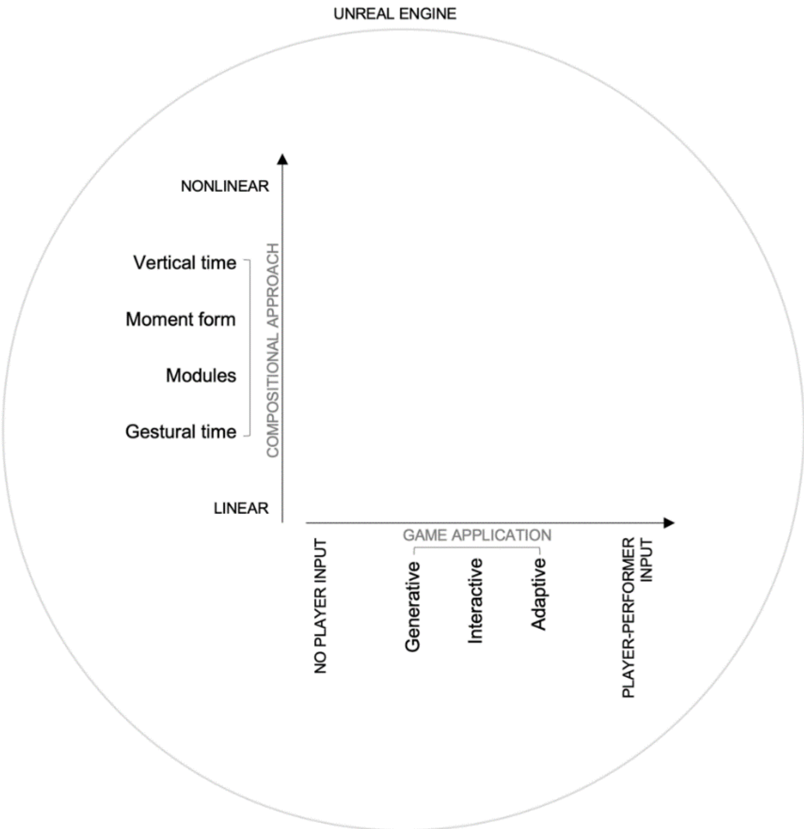

Figure 2 –Nonlinear Electronic Music Composition Framework.

Figure 2 offers a visual representation and summary of the practical framework, depicting an outline for composing nonlinear electronic music and showing a sliding scale of linearity to nonlinearity. The Y-axis represents the *Compositional Approach* and sub-genres of nonlinearity, with *gestural time* being the least nonlinear and *vertical time* being the most nonlinear. The X-axis represents a sliding scale of nonlinearity in *Game Application,* with *no player input* being linear and *player-performer-input* being nonlinear. When composing interactive and adaptive nonlinear electronic music, composers should use both axes to select the *Compositional Approach* and *Game Application*, using the research presented in this thesis to underpin the choices. The axes are encircled by *Unreal Engine*, the platform used to conduct this research. The illustration is intentionally circular to represent the non-processive nature of nonlinearity and demonstrate the overlap between elements.

In *Figure 2*, the highest degree of nonlinearity on the *Compositional Approach* (Y-axis) can also be acknowledged as the most subjective. This subjectivity is evident in the nonlinear compositional technique vertical time, with now moments and hierarchies dependent on individual perception, and each contains a formed flexible identity. Furthermore, there is subjectivity in the presentation order of sub-genres. It could be reasoned that gestural time is more nonlinear than modules. However, it is more helpful to focus on the elements within the framework rather than degrees of subjectivity. As such, the subjectivity is acknowledged, as is the potential of future researchers refining the framework presented.

The purpose of *Figure 2* is to offer an illustration to complement the framework developed. As Mooney (2010) has described, a framework is a tool that contributes to music composition, which the theoretical and practical work within the research has aimed to accomplish. Analysing music with a nonlinear lens can help demonstrate a development timeline to see how the nonlinear compositional techniques evolved and predict future trends.

5.2 Compositional and Theoretical Approach

Now that the framework concept has been introduced, an overview of the compositional approach and theory, examined through philosophical principles, is relevant. This section draws on the *4. THREE STRANDS OF NONLINEAR TIME* chapter, where each concept is comprehensively addressed.

A focus on nonlinearity through the four sub-genres of nonlinear time (vertical time, moment form, modules, and gestural time) can be utilised as a compositional approach. Each of the four sub-genres has unique characteristics that can be employed, a succinct overview of which is presented here. Vertical time has a static sound palette, which does not develop throughout the composition. Moment Form has sections of music that start and stop but do not begin or end. Modules is comprised of iterative loops. Gestural Time is combined with manual granulation to create grains of the composition that can be interrupted and reordered.

The philosophy behind the four sub-genres helps to provide a linkage between theory and practice. The concept of the rhizome is a useful analogy for nonlinear time. Deleuze and Guattari discuss the rhizome in depth in *A Thousand Plateaus: Capitalism and Schizophrenia* (1987). They deem a rhizome only has a middle and no beginning or ending, much like nonlinear time in music. A rhizome is a subterranean plant stem that grows shoots horizontally. The growth of shoots can be thought of as a multiplicity of possible paths which can be followed simultaneously. This idea is inextricably linked to nonlinearity within music. The static sound palette of vertical time provides the possibility of listeners experiencing 'now moments', which appear to be extended periods of time but do not correlate to the absolute time measurement. These now moments depend on the individual and offer the possibility of multiple interpretations due to their subjective nature. Additionally, the rhizome analogy correlates to moment form, which has no beginning or ending.

Further philosophical concepts, such as 'abstract machines', allow seemingly unrelated elements to be linked. These abstract machines are self-contained whilst still being connected. This idea relates well to nonlinearity in music, which affords the same idea and is useful when composing nonlinear music. A looped musical element could interact and affect another musical element whilst remaining self-contained. Lastly, 'identities' are linked to any object and provide individuation for each. Every piece of music contains multiple identities, dependent on circumstance, as do rhizome and abstract machines. The idea of multiple identities is expanded when contemplating interactive and adaptive music, which allows for multiple versions to be played. The theoretical underpinning discussed aims to provide a conceptual basis for composing interactive and adaptive nonlinear electronic music. The sub-genres of nonlinear time each provide characteristics that can be employed to achieve this aim.

5.3 Unreal Engine as a Music-Making Tool

Unreal Engine is expansive software, and to detail the affordances of each aspect is outside this project's scope; this section will focus on the MetaSounds audio system and its integration into Blueprints. Blueprints are a visual scripting system utilising "reusable code with libraries […and] object orientated programming […] The engine has specialized libraries for game development" (Torres-Ferreyros et al., 2016).

The primary use of *Unreal Engine* is for game development, and although functionality exists for audio implementation, it is not widely regarded as a music-making tool; up until the *Game Developers Conference (GDC) 2017* (Unreal Engine, 2017), the audio system was a more limited aspect of the architecture. Before introducing the Quartz subsystem in *UE4* 4.26 in December 2020, synchronising audio required complex visual scripting or third-party software such as *Wwise* or *FMOD*.[18] With the release of *UE5* in April 2022, a significant upgrade to the audio system became available. MetaSounds is a "high-performance audio system that provides audio designers with complete control over a Digital Signal Processing (DSP) graph for the generation of sound sources" (Unreal Engine, n.d. b). MetaSounds affords the composer a versatile graphical interface that can be manipulated through a mouse and qwerty keyboard via drop-down menus and visual scripting. Some of the functionality and logic of *Unreal Engine's* Blueprint system are available in MetaSounds with the addition of audio-specific systems such as an array of generators (additive synth, LFO, noise, saw, sine, square, triangle, wavetable oscillator), audio effects (delays and filters) and dynamic elements (compressors and limiters). It is possible to construct specific inputs to allow Blueprints to communicate with MetaSounds to create interactivity and adaptability, incorporate gameplay elements and allow player-performer agency over the outcome.

When composing electronic music, using MetaSounds is substantially different from a DAW. For example, the default view of *Logic X* DAW presents the composer with a linear interface set up at 120bpm, in 4/4, with a grid depicting bars and beats and a key signature of C major. Furthermore, there is a selection of software instrument presets alongside native MIDI functionality. Alternatively, MetaSounds presents the composer with a blank canvas and a mono output. The native pitch measurement is frequency, which replaces tempered tuning, and time measurement is seconds, which replaces beats per minute. Similarly to Blueprints, the visual scripting in MetaSounds (*Figure 3* below) flows from left to right with inputs on the left and outputs on the right.

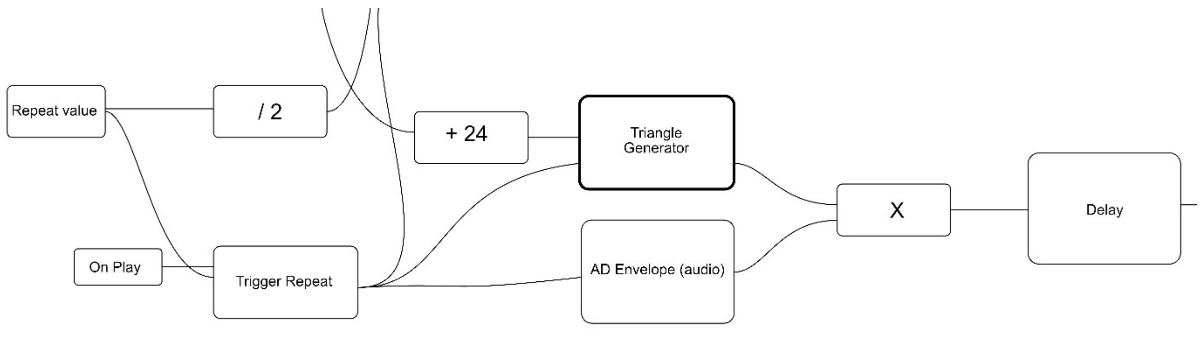

Figure 3 - The triangle generator in the illustration below was created first, with the surrounding functionality developed afterwards.

[18] *Wwise (*Audiokinetic, n.d.) and *FMOD* (Fmod.com, n.d.) are audio middleware designed to implement sound effects and music into game engines such as *Unreal Engine* and *Unity*.

Although, at the outset, this is a linear interface, the creation of the scripting does not often develop in that order. Incorporating MetaSounds into Blueprints expands the possibilities for creating complex music systems. Spatialisation is native to *Unreal Engine,* which allows the composer to use parameters including distance, location, and rotation as musical devices. Gameplay parameters such as health, damage systems or task completion can be employed to affect the music and offer the player-performer agency over the outcome. Additionally, artificial intelligence (AI) or non-player characters (NPC) can be created to amend, expand, or disrupt the outcome. It is also possible to utilise external data sets such as local time or weather information internally or through an API. With these systems, data sonification can become a musical device to enhance a composer's toolkit.

The above systems allow the creation of generative, interactive, and adaptive music, which includes player-performer input within its architecture. Randomisation and data sets are valuable tools to be utilised in the pursuit of nonlinear electronic music composition, and the breadth of the ideas alongside technological advances afford composers a wealth of choices with which to experiment. As systems develop and technology advances, so do the possibilities. Denis Smalley's viewpoint, which argues that music investigation should focus on spatiality rather than clock time as a basis for developing music, could be expanded to focus on nonlinearity. This exploration can incorporate spatiality, adaptability, player-performer agency, and artificial intelligence, all of which are accessible through *Unreal Engine* game development software.

Unreal Engine can be a collaborative platform to create music systems through version control platforms such as *GitHub* or *Perforce*.[19] *Unreal Engine's* source code is available and can be rebuilt from the ground up with amendments or additions to the core functionality, affording composers the potential to build bespoke audio systems. The flexibility of the software allows composers to explore new possibilities within electronic music.

[19] Github is an "AI-powered developer platform to build, scale, and deliver secure software" (Github.com, n.d.). "Perforce Software is a leading provider of development and DevOps solutions (Russell, 2021).

5.4 Limitations

Due to the many processes coinciding, *Unreal Engine* provides command-line tools to aid developers with visual output. This visualisation is essential with complex audio systems, which can often confuse which sounds are playing and why; problem-solving is an integral part of music composition using *Unreal Engine*. When composing interactive and adaptive music using *Unreal Engine*, the outcome requires rigorous testing through player-performer or data-related input, which can be time-consuming. Specific simulated testing scenarios, which can be generalised to help comprehend the whole composition, are necessary to avoid this time-consuming process. For example, when using external data sets from the local weather service, such as daily temperature in Celsius, simulating a range of temperatures (rather than waiting for the temperature to change) will significantly help speed up the composition process. Due to the potential complexity of audio system development, multiple simulations may be required to gain an accurate understanding of the outcome. Further limitations in the form of high system specifications, large disk space requirements, lack of common tools (such as native MIDI setup and VST plug-ins) and a steep learning curve should also be considered.

Linearity and nonlinearity are evident in most forms of music (Kramer, 1988). However, due to the complexities of the systems, interactive and adaptive nonlinear electronic music composition can be challenging to understand. Furthermore, the unpredictability of player-performer input makes the composer's task extremely difficult, and as such, consideration for all eventualities is ideal; however, this is unfeasible with complex audio systems due to the countless possible paths available, speed of movement and mechanics involved in the composition.

5.5 Framework Method

This agile and flexible method is conceived through the practice-based research conducted to create the five artefacts in this project. The method was developed through creative experimentation and exploration; however, it is underpinned by the game development pipeline, which broadly consists of *pre-production*, *production*, and *post-production*. Each cycle through the game development pipeline is an agile iteration, covering the three 'method stages'. *Figure 4* below comprises three overlapping circles representing the stages, the centre of which symbolises the outcome. Although the forthcoming process description is linear, there is interplay between stages, and moving fluidly back and forth between each stage is possible.

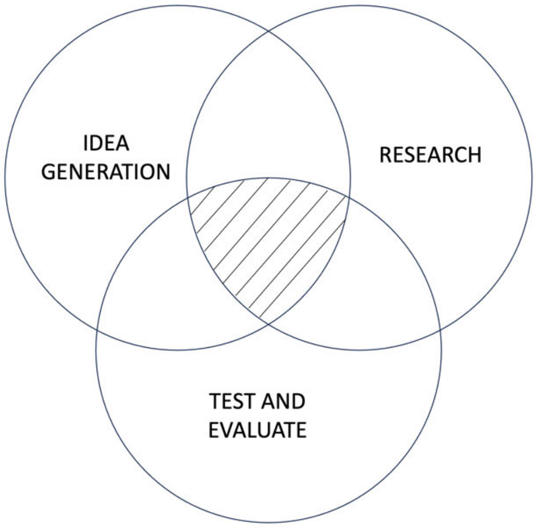

Figure 4 - Method Stages

Idea Generation

A beneficial way to start the composition process is through rapid creative, iterative experimentation. The iterative development approach can be used to create a concept template, which can later be duplicated, adapted, or augmented. Once the concept is decided upon, several options should be considered. The appropriate platform, such as a desktop machine or a mobile device, is needed. Secondly, the desired format should be chosen, such as 2D, 3D, virtual, augmented, or mixed reality. Thirdly, consideration should be paid to how the player-performer will navigate the experience. Finally, what type of controller would be used: a mouse and keyboard, game controller, body movement, or bespoke device? Answering these questions is beneficial to help focus the piece.

By the end of the development process, each idea should be fully fleshed out and implemented into the game engine as a prototype. Some pieces might initially be conceptualised in *Unreal Engine*, while others are created in a DAW. Developing ideas in a DAW allows access to plug-ins and software instruments unavailable in *Unreal Engine*, which expands the choice of instrument and effects palettes. However, the output of a DAW is a .wav file, which has limitations when implemented into *Unreal*

Engine compared to the generators in *UE5's* MetaSounds (which can efficiently respond to parameter changes such as pitch or tempo shifts). Furthermore, trying to envisage the interactive aspects of concepts conceived in a DAW might prove problematic and often lead to re-evaluating or redeveloping the idea.

Research

Research into existing practice helps contextualise and solidify ideas and aids in identifying strong and weak options. The research should span technical methods to understand possibilities and offer insights into potential gaps and areas for development whilst also providing knowledge of the advances and limitations of the game engine. Conducting research at the project's beginning and cyclically after each piece's completion is integral to keeping up to date with software developments while ensuring the ideas do not stray from the initial concept. A comparison of the initial concept to the current state is required to evaluate if they complement or match. Technical, functional, and stylistic considerations are needed to determine the project's suitability.

Testing

All systems should be thoroughly tested to assess the interactive elements' functionality. Within *UE5's* MetaSounds*,* a simulate button allows an easy method of testing interactivity. If the music was composed in a DAW, there may be disparities between *Unreal Engine* and the DAW that require tweaking to remedy any differences, which, overall, can be accomplished through gain staging. Furthermore, re-evaluating the flow of the music composition once interactive and adaptive elements are implemented will also be required.

If controlling MetaSounds in Blueprints, the controllable composition parameters should be mapped with the interactable game mechanics through iteration and testing. Although this aspect of the process is technically focused, a great deal of creativity is involved in this step, which will affect the composition. Some parameters can be mapped to allow the player-performer agency, and others can be mapped to generative or randomised systems. This phase involves significant problem-solving and should be conducted using a step-by-step approach, testing at each stage. Dedicated testing systems should be created to simulate interactivity, which, although initially time-consuming to set up, will prove to be time-efficient and help keep the focus on the main objective.

Difficulties may arise when trying to achieve an effective final mix, which lies with the inability to listen to all music states; as such, trying to master music with over a million different states can present difficulties. Specific tools are available to accomplish these tasks, which will prove beneficial. For example, a sound concurrency asset within a voice management system in *Unreal Engine* is available to address such a problem. This system allows a threshold to be set to limit the number of sounds played. When reaching the threshold, rules govern the program's actions to deal with the sound asset, such as ‘stop farthest, then oldest’. The sound concurrency asset can be assigned to individual or multiple sounds simultaneously.

Technical Considerations

Consideration regarding the music export process from a DAW will be required, informed by the transitions needed in *Unreal Engine* between notes, sections, or stems. Several transition types are regularly used in game audio implementation: immediate, through a crossfade, at the end of one section, at the end of a measure, at two or four bars, or on a specific beat. If and how the music loops is also a consideration, alongside tempo or time signature changes. There are two implementation methods: transitional forms and parallel forms. Transitional forms require exporting the audio as a vertical slice, and parallel forms require exporting the audio horizontally.

When exporting from a DAW, all instruments within designated time constraints are exported to create a vertical slice of the composition. For example, a 69-bar composition that requires exporting a vertical slice on each beat equates to 276 vertical slices needed to achieve the desired interactivity once implemented (see *Figure 5* below).

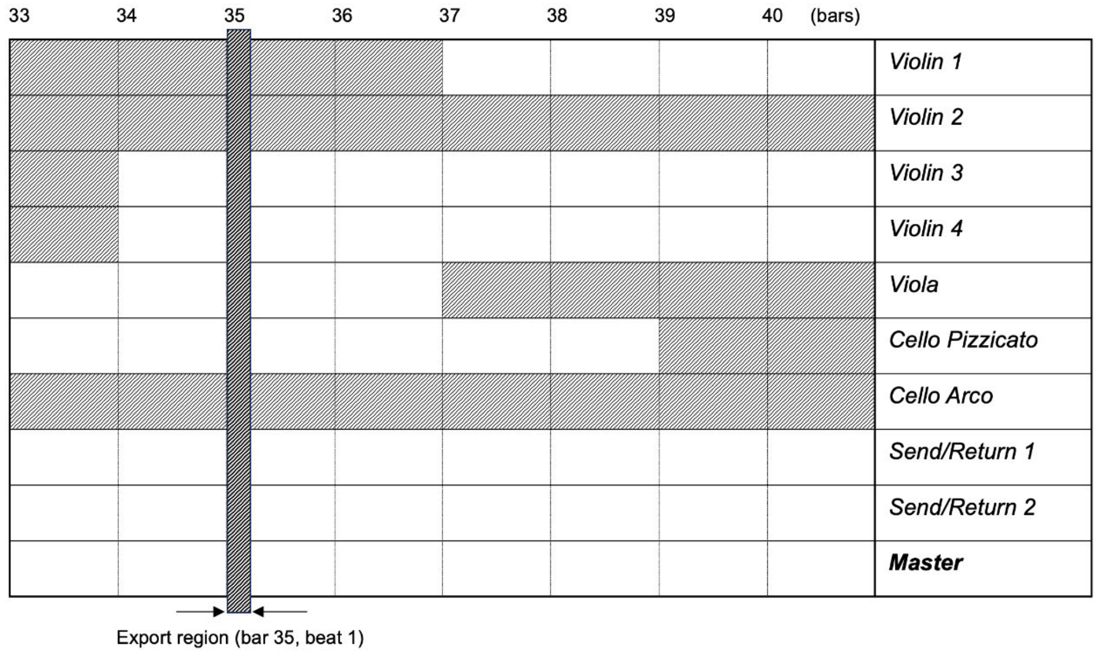

Figure 5 - Illustration of a vertical slice of Stomach from The Machines. Bar 35, beat 1 is set up for export. All instruments will be exported; active tracks are Violin 1, Violin 2, and Cello Arco.

Attention should be paid to the beginning and ending of each slice to ensure no pops or clicks are audible. This is accomplished by setting the amplitude to zero crossing at the beginning and end of the slice. However, due to the interactive and adaptive nature of the music systems, some clicks or pops might still be audible, which can be solved through the method chosen to transition between audio segments.

The overall amplitude levels should be set proportionally and appropriately between -1db and -16db LUFS. Ensuring appropriate amplitude levels is an important step, and as such, time should be spent implementing small samples into the engine for testing to achieve the best result. Tweaking amplitude levels is required to balance the parts once implemented; however, if substantial amplitude changes are required, the samples should be disregarded, and the process should start again.

Horizontal and vertical export require the same level of attention; however, the horizontal export method involves exporting individual notes, tracks or stems. Figure 6 below demonstrates one bar of a cello being exported.

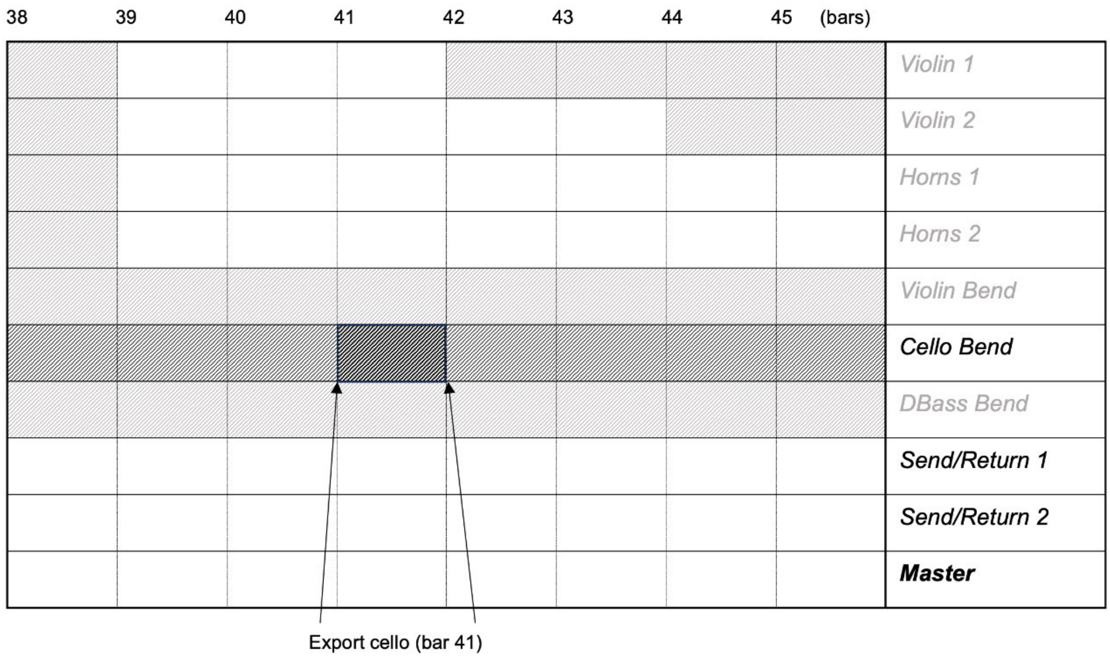

Figure 6 – Illustration of a horizontal slice of a composition. Cello Bend, bar 41, is set up for export.

Lastly, suitably naming files is essential due to the numerous samples required. Abbreviations should be used throughout the pieces to provide detail to the samples without causing issues with the filename and file path exceeding the operating system's limit. The abbreviations referenced descriptors such as instrument, technique, note range, and function. For example, *BViolin_E4*, when unpacked, is ‘bend, violin, note E4’.

The method above details an overarching approach which can be used when composing interactive and adaptive electronic music. The system presented above was developed using the game development pipeline through iterative creative experimentation and exploration. Although the outcome for each composition will differ, the process should be followed for each to ensure the best result.

6. PORTFOLIO COMMENTARY

6.1 Overview and Glossary

The portfolio commentary provides an opportunity to contextualise the compositions from the initial idea development to the completed final artefact. The process and learning of the research have evolved throughout, even at the time of writing, and the work presented is created without a predetermined idea of the outcome. The composition process uses the affordances of *Unreal Engine,* such as a shift from key signatures, time signatures, and scales—towards input, randomisation, automation, and mapping data sets. This technical approach has shifted the focus from outcome to process, and as such, the outcome has primarily been left 'as is' rather than reworked to fit within a particular aesthetic.

Morton Feldman discusses the 'controls' composers adhere to and determines they are "nothing more than accepted practice." He argues that "music is still based on just a few technical models. As soon as you leave them, you are in an area of music not recognisable" (Feldman, 1985: 7). The music presented is nonlinear, lacking crescendos, decrescendos, and resolution, which changes the expectation afforded from linear music and, with it, alters the listening experience. The interactive and adaptive elements keep the music fresh, and although the music is recognisable, the individual elements differ with each listen. This process elevates the listener to become a player-performer and reworks the composer as a curator.

The methodology discussed in the *1. INTRODUCTION* is fundamental to the processes used throughout the creation of the artefacts. The principles of practice-based research have allowed the creation of the experiments and artefacts to be the focus. Whilst the experiments have gone through the iterative process enough to allow a presentable version, they are not refined like the artefacts. However, after development, all experiments and artefacts presented have been reflected upon in an autoethnographic approach to help understand the processes involved when composing interactive and adaptive electronic music.

Although gameplay terminology is used when describing the technical processes of the final music compositions, the apps produced are not intended to be games; there are no objectives, rewards, punishments or intended routes for the player. Instead, the apps are classified as ‘sandbox play apps’ with a single focus: exploring sound. The principles are based on a ludic system, which is “fundamentally time-based and [has] temporal structure[s]” (Lindley, 2004: 183). This ludic system is where participants experience the music through play. Clausen connects gameplay, player movement, and playing a musical instrument, postulating that by “moving an avatar through an adventure […] one might say we are playing a certain sort of instrument” (Clausen, 2017: 453).

The following terminology is established in this chapter.

Event tick is based on frame rate. Frame rate is how many frames are called per second. Event tick is an event which is called on each frame. For example, if the frame rate is 60 frames per second (fps), event tick will be called 60 times per second. However, if the frame rate is reduced to 30 fps, event tick will only be called 30 times per second.

Sintbox is an amalgamation of ‘sound interaction box’ and is used when referring to the technical aspect of the implementation process.

6.2 Experimentation

Experimentation within this project has been crucial to exploring ideas, methods, and techniques. The experimentation was an early part of the process and informed the final artefacts technically. However, due to the purpose of undertaking the experiments, the completion of one experiment did not necessarily creatively inform the idea for the next. The initial experiments did not specifically look at nonlinearity. Instead, they solved technical problems such as how to synchronise instruments or musical phrases, trigger sounds through specific actions, or repurpose game parameters such as the use of ‘event tick’ to manipulate sounds. Realising creative musical ideas in *Unreal Engine* requires a substantial amount of problem-solving. The most beneficial way of achieving the necessary skills to complete this was to focus on problem-solving before concentrating on the creative process. The experiments are developed to do just that using the agile, iterative model of the game development pipeline methodology.

Unreal Engine is updated regularly, and since the ‘new audio engine’ was announced in 2017, a focus on audio development within the software by *Epic Games* has been ongoing (Unreal Engine, 2017). As a result, many of the initial experiments conducted in this project solved problems that have since been rectified through *Unreal Engine’s* software updates, rendering them redundant. However, the selected notable experiments included are still valid for this project. The table below is a summary of the experiments, showing the purpose of each.

App	Purpose
Objects & Triggers	To study the effects on electronic music composition output when considering in-game distance rather than rhythmic values or beats per minute.
Interactive Kick	To develop a music system using *UE4* and *FMOD* to research the effects of player-performer agency over rhythmic music output.
Rhythm Shift	
Ambient Chord	To develop a music system using *UE4* and *FMOD* to research the effects of player-performer agency over harmonic music output.
Bouncing Ball – Free Jazz	To create a generative music composition using in-game physics (gravity) as a tool to trigger the samples.
Where the Sun Remains	To research the use of *Unreal Engine’s* Quartz music system to synchronise audio and develop a method for player-performer agency using pre-determined music samples.

6.2.1 Objects & Triggers

UE4 | 4.26.2 | 2019 ***Access Link***

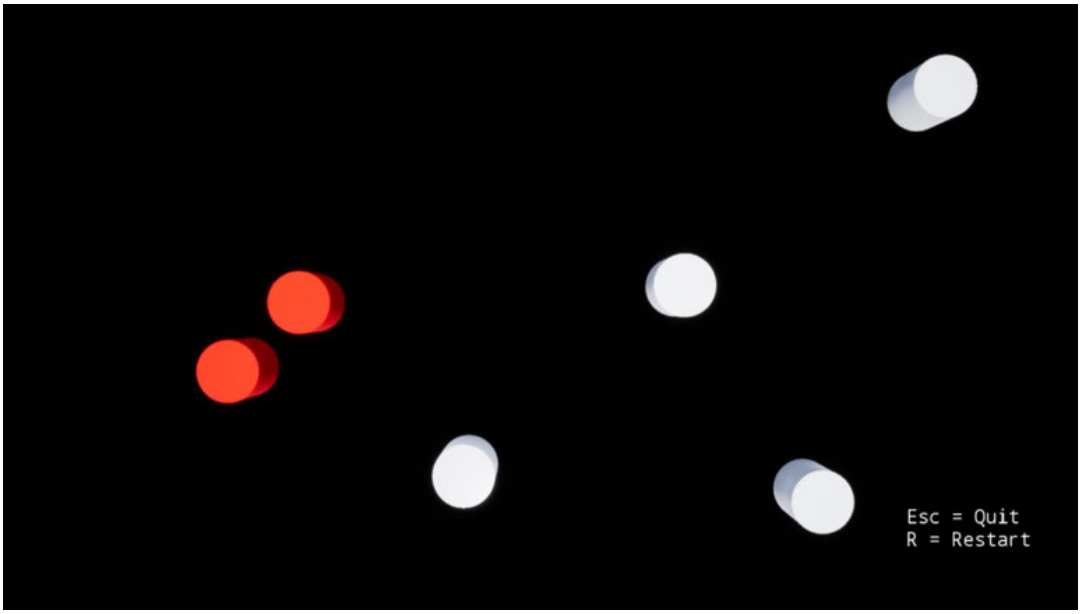

Figure 7 - Screenshot from Objects & Triggers. The red objects are active (playing audio), and the white ones are inactive (silent).

The idea behind *Objects & Triggers* is to envisage an alternative way of creating music. Rather than music notation on a score or .wav files in a DAW, *Objects & Triggers* uses the distance between two points as a parameter to trigger musical instruments. Each object is programmed to move between two points (A and B) in a straight line. The distance between the points and the speed of movement affects when and how the sounds are triggered. For example, the slower the movement speed, the more time will elapse between notes; the faster the speed, the less time will elapse. Creating a top-down environment in this manner has allowed for a different approach, starting point, and outcome. The techniques employed use object movement to trigger sounds instead of thinking about beats per minute (BPM), time signature, harmony, or loop length.

Additionally, changing the visual aesthetic away from a linear (left to right) user interface used in a DAW has impacted the decisions made. As discussed in the *2. LITERATURE REVIEW*, Hunt and Kirk (2000) determine that choice-based user interfaces can impact the output through visual aesthetics, software limitations, and ease of use. For *Objects and Triggers*, the movement mechanic was the primary focus and was created before the audio was implemented, negating some more ‘obvious’ choice-based decisions. Although the final audio output was carefully considered, the movement mechanic established the length, spatialisation, and interaction between sounds, placing it as a fundamental compositional tool. *Objects & Triggers* is an example of a piece that would have turned out differently if created in a DAW.

6.2.2 Interactive Kick, Rhythm Shift & Ambient Chord

UE4 | 4.26.2 | 2020 ***Access Link***

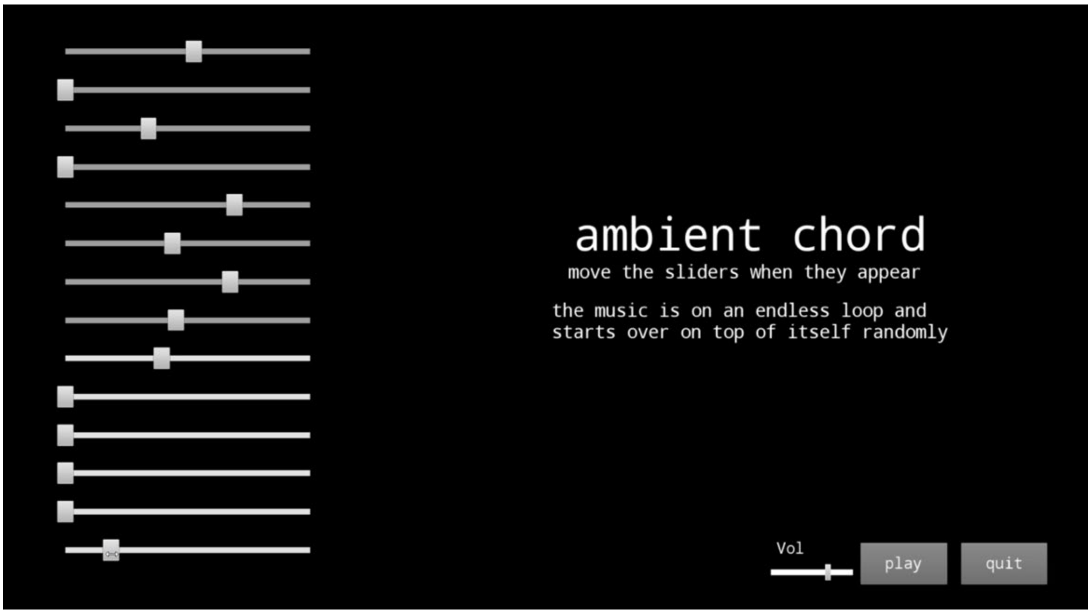

Figure 8 - The user interface for Ambient Chord. The top eight volume sliders control persistent arco violin and viola pitches; the bottom six volume sliders control persistent arco bass pitches.

The intention of *Interactive Kick*, *Rhythm Shift* and *Ambient Chord* was to create interactive audio experiences the listener has agency over. All three pieces were created using *FMOD Studio* middleware and *UE4* and offer a simple interface for user interaction. *Interactive Kick* contains five sliders that control three delays, a pitch control, and a master volume. *Rhythm Shift* contains three sliders affecting accent (velocity) and two delays. *Ambient Chord* (pictured above) contains 14 sliders, each affecting a single string instrument note, making up a C Major scale. The top eight sliders adjust the violin and viola volumes; the bottom six adjust the cello and double bass volumes. When the sliders are changed, they offer instant feedback to the player-performer. Each slider affects, alters, or disrupts the output rhythmically or harmonically. The player-performer decides how liberally to use the effects and whether to 'set and forget' or constantly adjust them as the music progresses. The significant difference between *Ambient Chord* and the other two apps is the element of harmony; it has traded rhythmic intricacies for harmonic content.

Composing these three pieces in *FMOD Studio* helped gain an understanding of the unfamiliar software and determine if it could be helpful as a compositional tool for nonlinear music composition. The software is designed as “an end-to-end solution for adding expressive adaptive audio to games” (Fmod, n.d). As such, it should be an ideal solution for composing interactive and adaptive electronic music. However, the interface is much like a DAW, so as a practitioner trying to explore nonlinear music, the interface feels awkwardly like it is geared to develop linear music. Although the experiments were deemed successful both functionally and artistically, the process of composing them through this system felt somewhat inefficient. Moving back and forth between two different platforms disrupted the compositional flow, and it did not feel robust relying on two pieces of software rather than one. The three experiments concluded that a focus on *Unreal Engine* would follow, and no further investigation into *Fmod* would be conducted. Previously, working exclusively with *Unreal Engine’s* user interface in the initial experiments has led to a different way of thinking about composing nonlinear music as the design feels more comfortably geared towards experimentation and exploration in this area.

6.2.3 Bouncing Ball – Free Jazz *UE4* Experiment

UE4 | 4.26.2 | 2020 ***Access Link***

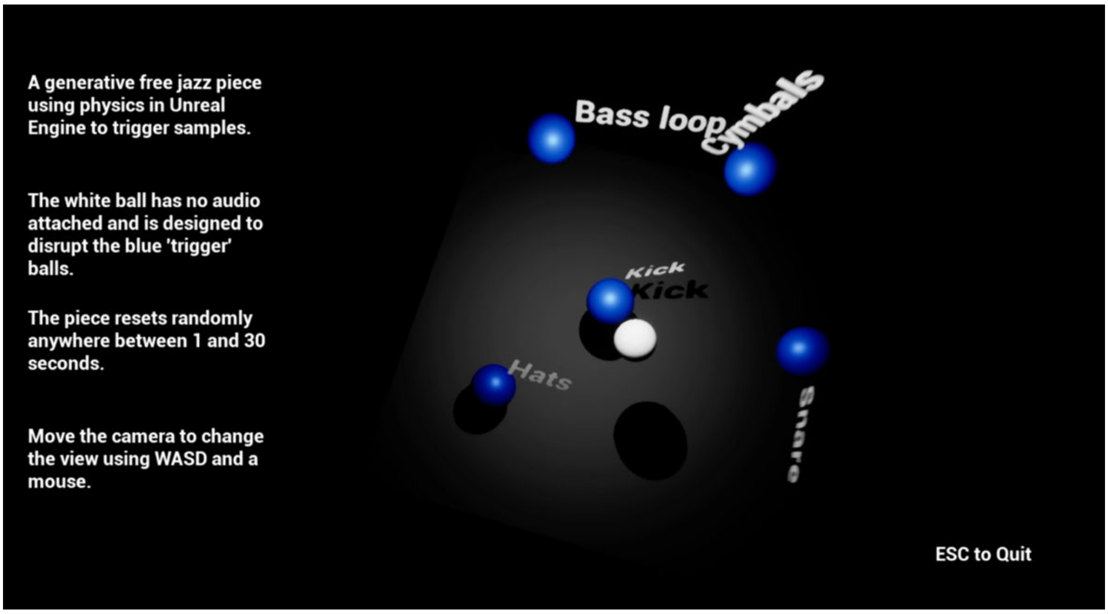

Figure 9 - A screenshot from Bouncing Ball – Free Jazz. When each blue trigger ball hits the floor, an assigned sample is played from a range of randomised samples.

Bouncing Ball is a generative free jazz piece using physics in *UE4* to trigger instrumental jazz audio samples. The spheres are dropped from a designated height and a sample is triggered when they hit the ground. This idea operates without a fixed form; the only given is the initial release of the balls when the piece begins. The music resets randomly between 1 and 30 seconds without pause (other than the time it takes for the balls to fall to the ground after reset). Within predetermined constraints, the white ball is designed to bounce at a random trajectory and disrupt the blue 'trigger' balls; a random sample is selected when the blue trigger balls collide with the virtual floor. Overall, the blue trigger balls operate identically to each other; however, some contain one-shots, and some contain a series of notes, which can lead to overlapping sounds, building up layers of music. The piece has no recognisable key signature or time signature; the intention was to build a generative piece of music without a fixed form.

The unpredictability of the music, particularly from the rhythmic aspect, can make it challenging to listen. However, like a live free-jazz performance, there can be sparks of interest and cohesion. However, although the trigger timings are randomised-in-a-range, there is no actual element of improvisation. As a result, the experience significantly differs when listening rather than simultaneously watching and listening. Without visuals to guide the listener, the music becomes less predictable. There is no second point of focus, and only the chaotic sonic experience to capture attention. The idea is an iteration of a previous early experiment which operated in the same manner. However, instead of jazz samples, the initial experiment had four spheres, each of them containing one music box note.

6.2.4 Where the Sun Remains

UE4 | 4.26.2 | 2021 ***Access Link***

Figure 10 - A screenshot from Where the Sun Remains. Each floating sphere contains a sample that can be triggered through player-performer interaction.

Where the Sun Remains is more comprehensive than the previously discussed initial experiments and focuses on the *Quartz* music system, a synchronised clock system accessible from any Blueprint in *UE4*. This system allows the quantisation of samples with settings of 1 bar, 1/2, 1/4, 1/8, 1/16, and 1/32 (equivalent to the default frames per second). *Quartz* works with .wav files or *Sound Cues* and combines them effectively to provide a robust music foundation. Player-performer movement beneath the floating-coloured spheres will trigger various actions. For example, triggering the blue spheres will play a series of randomised piano notes and retriggering them will change their pitch. Each instrument has a different quantization point ranging from 1/16 to one bar. Multiplication was used to achieve a sample triggered on an offbeat. For example, the hi-hats are quantized to 1/4 note with a multiplication of 1.5, resulting in a trigger point of 1/8 offbeat. This system has been used extensively with the above-mentioned piano notes.

Due to player-performer input triggering specific notes or microloops, rather than mesoloops and macroloops, the player-performer has comprehensive control over the music outcome. For instance, a player-performer can trigger melodic elements on one occasion and rhythmic elements on the next. Subsequently, some trigger points are designed to affect the entirety of the piece. For example, when triggering the sphere containing *BP_Strings*, it will play a string passage and simultaneously fade down all other audio playing. Additionally, triggering the sphere *BP_WriteableAudio* will sample the generative drums and play them back, repeating the recording in time with the music.

6.3 Artefacts

6.3.1 Sheets of Sound

Development date	Dec 2020 – Aug 2021
Unreal Engine version	4.26.2 (updated to 5.1.1)
Compositional technique(s)	Vertical time, moment form
Link(s)	***Access Link***

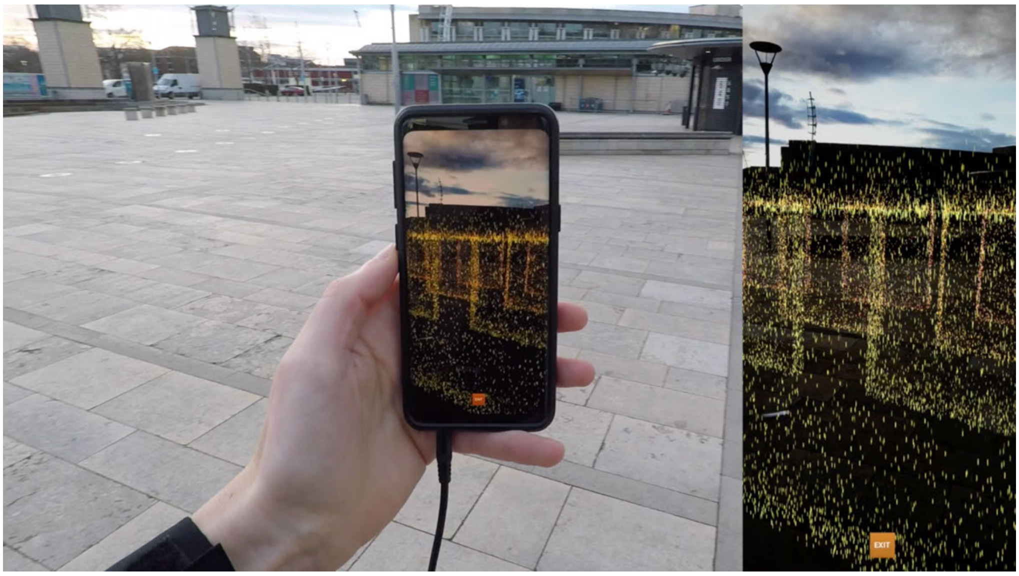

Figure 11 – Sheets of Sound augmented reality visuals overlayed in a public space. The right-hand side shows a screen recording of the visuals as seen on the smartphone in the centre of the image.

The inspiration for *Sheets of Sound* (*SoS*) is from a term attributed to the saxophonist John Coltrane, whose dense harmonic improvisations felt like a wall of sound emanating from his saxophone.[20] According to Ratliff (2011), this was around the time of the beginning of Coltrane's trance music (1958 onwards), evident on *Russian Lullaby* from his *Soultrane* LP on Prestige, from approximately the 60-second mark (Coltrane, 1958). Although *Russian Lullaby* is stylistically different from *SoS*, the denseness of the music is evident in both compositions.

The initial idea for *SoS* was a musical maze through which the player-performer would navigate. However, it was decided that navigating a maze and simultaneously

[20] "The critic Ira Gilter…in the liner notes to Coltrane's 1958 Soultrane LP on Prestige, had called this kind of playing 'sheets of sound'" (Ratliff, 2011).

exploring sound added an unnecessary complication. Instead, the player-performer would be allowed free reign to explore the sounds however they wished. The grid system (consisting of atonal autocatalytic sound sources) was a useful starting place for creating an artefact. The relatively simple system could easily be envisioned and worked favourably in the given timeframe. The augmented reality system had previously been investigated, and the implementation of sound sources was similar to the system used when creating ambient and environment sound assets for video games. The two primary considerations were the scale of the app, which required optimisation to allow for smooth and clear playback of the sounds, and the unknown of developing for a mobile device. The construction of the artefact ‘led the practice’; that is, the artefact was not developed in a strict manner. Rather practical, creative exploration was established as the primary method, which fits into the practice-based research methodology presented in *1. INTRODUCTION.*

SoS is composed with a static sound palette and falls within the vertical time compositional technique. Using a series of Ambient Sound Actors, *SoS* explores vertical time through tonal discontinuities. Each sound consists of a predetermined loop that does not develop throughout. The music starts with app activation and stops when the player-performer decides it should. There is no beginning or ending of the music; no specified route the player-performer should take. As a result, there is no song structure as such. It becomes up to the player-performer to decide how they experience the composition. Although primarily in vertical time, *SoS* also falls within the moment form compositional technique. Using Stockhausen’s work *Momente* as a reference, it is possible to reorder each moment in *SoS* in any configuration; the order of moments is arbitrary. However, *Momente* has clear gaps between moments, whereas *SoS* does not. The intention of *SoS* was to create a spatially present experience, and periodic silence might break the player-performer's sense of spatial presence, an important aspect of this interactive experience.

SoS is an augmented reality app designed for a smartphone. The player-performer uses a smartphone to activate or ‘conduct’ the sounds; the only additional equipment required is a set of Bluetooth headphones used as a listening device. On activation, the app anchors the smartphone's location locally, which becomes the starting point. The app uses the smartphone camera to overlay augmented reality visuals and location-specific sounds onto a real-world setting (see *Figure 11* above). The player-performer should look through the smartphone to see the visuals while exploring the app. The app offers the player-performer an experience in which they must physically move around to interact with the sounds. Spatialisation is enabled in the app, meaning movement in any direction or orientation will affect the headphone playback, much in the same way as would be the case outside of the virtual environment. Sounds located to the left of the smartphone will be heard in the left headphone, right in the right, and rotating on the spot will switch them.

Effective transitions between the sounds are achievable with careful control by the player-performer. As shown in *Figure 12* below, the sounds are laid out in an 8X8 grid, spaced apart by 200uu (*Unreal* units) on the Y-axis and 300uu on the X-axis in the virtual world. One uu is equivalent to one meter, and when including the attenuation falloff distance, the floor space required for *SoS* is 20 x 29 meters. The idea for the grid layout developed when experimenting with the concept of a musical maze. *Figure 13* below shows particle sheets as visuals, which create a tangible space for the player-performer to explore, offering corridors or hallways of sound and a clear boundary.

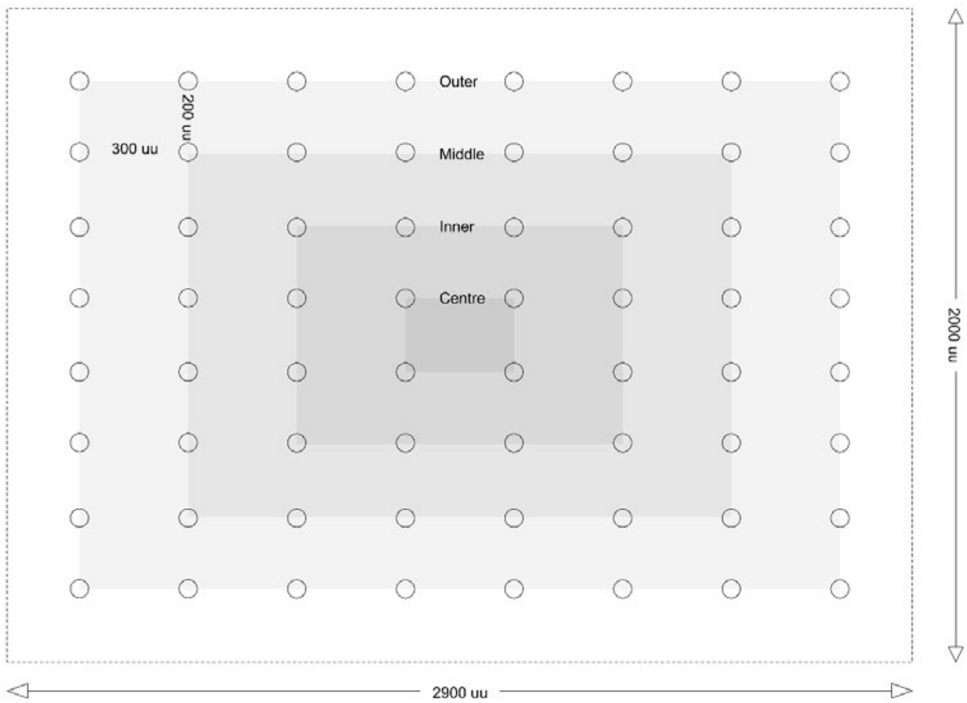

Figure 12 - Orthographic grid layout illustration of Sheets of Sound (the circles represent sound sources).

The sound palette consists of 64 individual .wav files created in *Ableton Live* and rendered as loops ranging between 1 and 64 seconds in length. The loops were created with software instruments within *Ableton* and electronic hardware instruments such as the *MFB Tanzbär* drum machine, *Arturia Microbrute*, *Korg Volca Bass*, and *Korg Volca Keys* synthesisers. Although there is built-in software synthesis availability in *Unreal Engine 4.26*, this was not used for this composition. Instead, the hardware listed above was chosen to create the sound palette. The audio loops are mesoloops or macroloops, ranging from around 1.4 seconds to 32 seconds. The loops have a visceral quality; they are musically dense, without daylight or space to pause. They were recorded and edited over a week and treated as 64 individual loops, each mixed and mastered before implementation into *Unreal Engine*. While composing, tempo, time signature, key signature, rhythm, or harmony were not considerations; instead, the intention was to explore the output created when the loops overlap and how player-performer movement and agency affect the outcome.

Four rings divide the 8x8 grid: outer, middle, inner, and centre; each ring houses randomly spawned loops. The outer ring contains 28 loops, the middle ring contains 20 loops, the inner ring contains 12 loops, and the centre ring contains four loops. The loops are categorised using a sliding scale with dissonance on one end and consonance on the other. The outer ring has the most dissonant loops assigned; the centre ring has the most consonant loops assigned. There are coloured sheets of particles accompanying each sound as a visual aid and reference point to the sound's location (see *Figure 13* below). They are colour-coordinated with the 'type' of sound; red represents the most dissonant, green represents the most consonant, and in between are orange and yellow. Each loop is cued to start on 'event begin play' (as soon as the app starts) and set to overlap at different points each time. However, if out of range from the player-performer, they will not play, restarting when the player-performer is again in listening range.

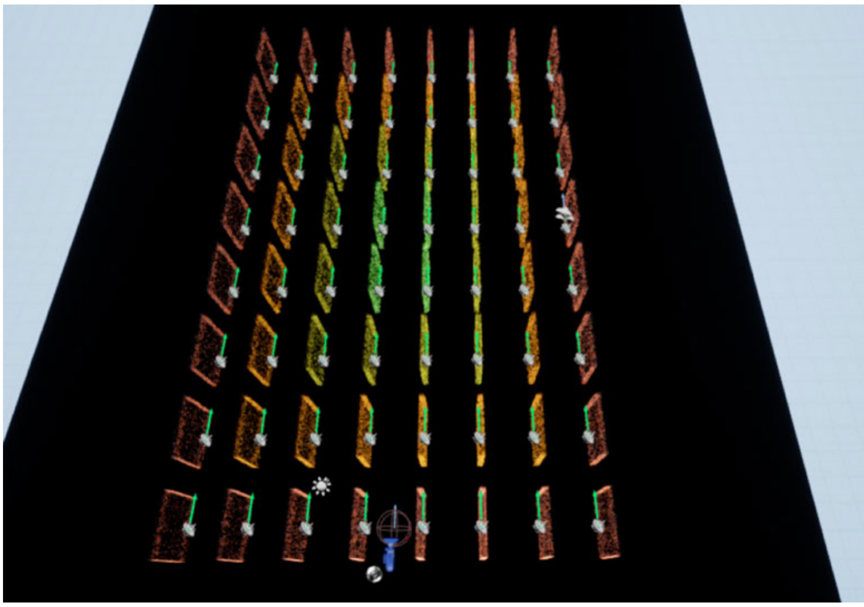

Figure 13 – SoS top-down grid layout view within Unreal Engine.

There are identities created with each experience; however, each recording is recognisable as a version of *SoS* due to the sound palette. There is a great deal of power and energy in *SoS*, and interesting poly-rhythmic and textural static phrases emerge. Significant differences exist between using the app and listening to the audio playback afterwards, partly attributed to being either a player-performer (in control of the experience) or a listener (experiencing a previous performance). When listening to audio playback, it is possible to latch on to the detail within the sound palette and interactions between loops. Whilst using the app, the music feels more exciting and unexpected. It is possible to latch onto multiple sounds simultaneously whilst exploring the composition through breadcrumbs, that is, hearing and navigating towards sounds of interest.

SoS is static and does not have internal phrase development or beginnings and endings. The harmonic content has a formed flexible identity, augmented through overlapping loops in close proximity. Sound spatialisation determines that the music does not pass by linearly. It is possible to experience each sound from any angle or distance within the attenuation curve and for as long as the player-performer wishes. The player-performer can acknowledge and act upon the hierarchies achieved through smartphone movement. These factors reflect the structure of a rhizome and allow the player-performer to experience music in vertical time and achieve now moments where possible.

In previous works, the compositional process for linear music stemmed from a rigid idea and a fixed form. The composition process for *SoS* allowed exploration and experimentation to lead the development, which helped the piece evolve through iteration whilst elevating nonlinearity to the forefront of the compositional process. This process provided a flexible template, which helped establish the initial basis of the *Nonlinear Electronic Music Framework*, which was developed through the remainder of the forthcoming pieces.

6.3.2 Gravitational Pull

Development date	Jan 2021 – Aug 2021
Unreal Engine version	4.26 (updated to 5.1.1)
Compositional technique(s)	Moment form
Link(s)	***Access Link***

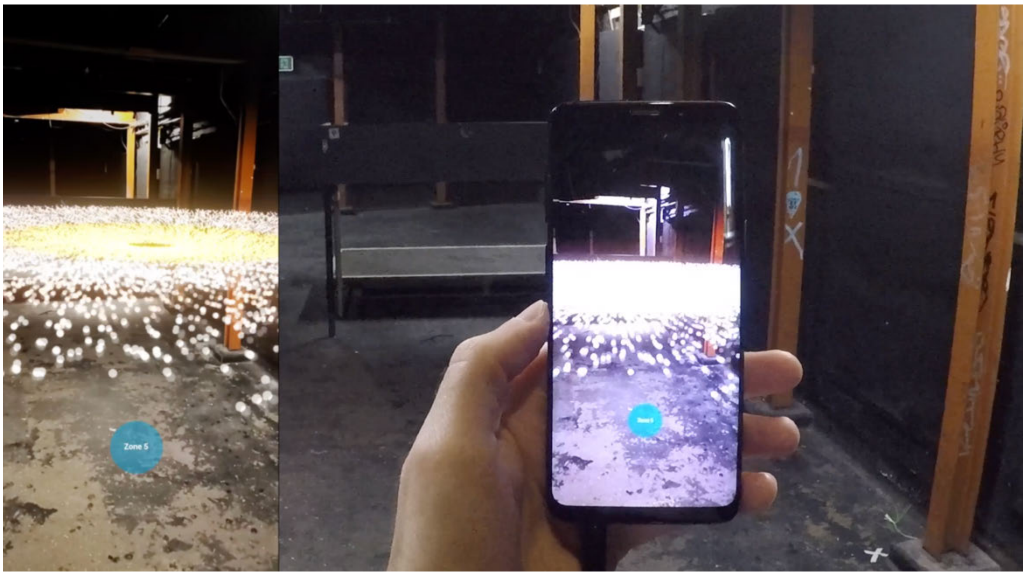

Figure 14 - Screenshot from Gravitational Pull. The left-hand side shows a screen recording of the visuals as seen on the smartphone in the centre of the screen.

Gravitational Pull is comprised of synthesised music using nonlinear compositional technique moment form. The time elapsed between each moment depends on the distance the player-performer is to the centre. It is an augmented reality app that uses a smartphone in the same manner as *SoS*. *Gravitational Pull* is based on a central spherical focal point, which, on approach, speeds up the tempo and changes the harmony, melody, and a multitude of effects. The app runs indefinitely, meaning the player-performer can experience as many moments as they wish. If exploring each music aspect, they will eventually be drawn to the composition's central point through a spinning particle effect.

Gravitational Pull utilised the iterative nature of the game development pipeline but was primarily developed through a discarded attempt to create a concept called '*Point Music*'. *Point Music* is essentially the next step of *SoS,* which turns the horizontal plane into a vertical plane. The concept is a series of vertical points created in augmented reality, each point being a note or series of notes triggered as the player-performer moves the smartphone through the points. The idea was for the player-performer to create melodies with this technique; eventually, the scope would be scaled out to include different instrumentation and functionality. The initial placement of the smartphone established the starting position. However, triggering the points became problematic due to their precise location, resulting in an unreliable hit-and-miss scenario, alongside the position unintentionally shifting whilst in use. Eventually, the idea was repurposed to replace the grid with a single point, which became the centre of *Gravitational Pull.*

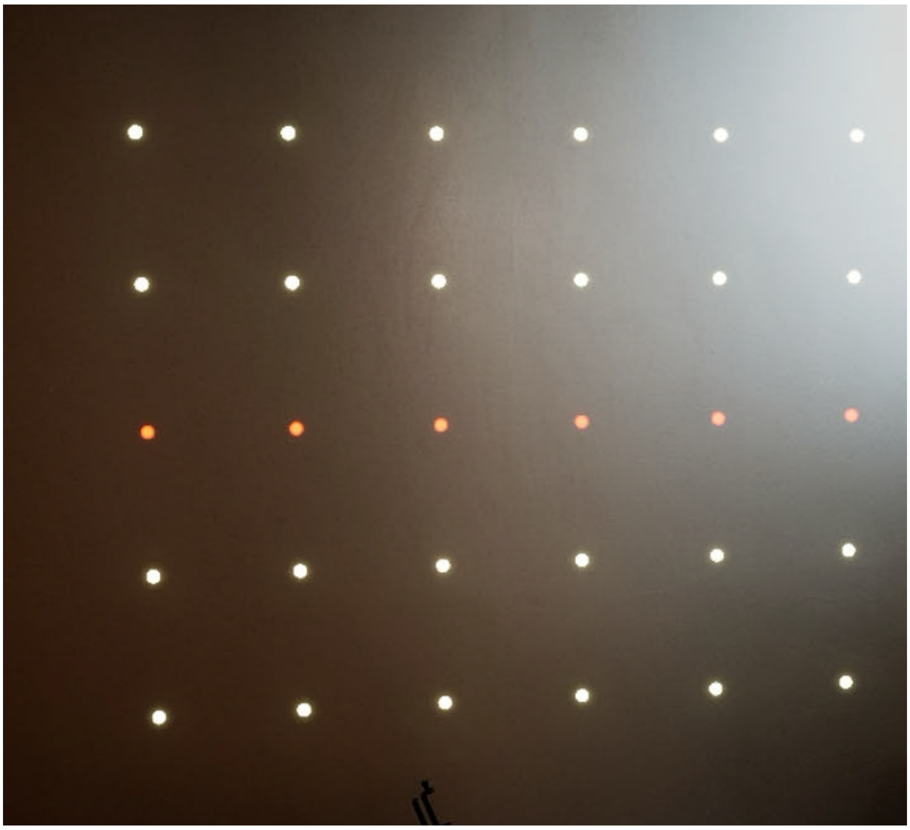

Figure 15 - Point Music visualisation

Instead of a vertical grid, a single sphere was enlarged and horizontal rings ‘zones’ were established around the sphere. The playable area is split into 13 invisible zones, with zone 0 in the centre and zone 12 furthest out; each zone offers a parameter change such as melodic or harmonic adjustment, a shift in ADSR (attack, decay, sustain, release) parameters, or a change or addition of effects. If the player-performer is physically located in a zone when triggered, the related parameter changes outlined above will activate. Aside from parameter changes, each zone contains a time delay responsible for the time elapsed between moments occurring. For example, if the player-performer triggers zone 7, parameter changes related to zone 7 will take effect, with a time delay between 7-7.9 seconds applied. If the player-performer moves to zone 3, parameter changes related to zone 3 will take effect, with a time delay between 3 and 3.9 seconds applied.

As the player-performer navigates further from the central swirl, the gap between moments increases, which is achieved by utilising the Blueprint node ‘In Range’ float variable attached to the camera position. The intention is to see how the player-performer reacts to extended gaps between moments and if the extended gaps between moments disrupt the music. The physical distance between each zone is short enough to step through, so there is the possibility of traversing multiple zones quickly. For example, the player-performer could move from zone 5 to zone 3, missing zone 4, or from zone 9 to zone 1, missing all zones in-between. On app activation, the player-performer begins each experience in zone 7 and is free to move around the space in any order or direction. There is no specified duration; it is up to the player-performer to determine the piece's length, structure, and movement. Additionally, any effects will be applied to the current and ensuing zones and will continue to be active until updated when the player-performer triggers another zone. However, although the effects remain active, the music in each zone will fade out, and once there is no audible sound, the effects will no longer be heard.

Gravitational Pull is composed in moment form highlighted by the 13 zones (each containing a moment of parameter adjustments acting as musical devices). Moment form is established through the ability of the player-performer to traverse through zones and play them in any order without affecting the music outcome. Each moment has the potential to present the expectation of upcoming moments, which can fall at a seemingly arbitrary time, depending on player-performer movement. The anticipation of the moments becomes as much a part of the music as the spaces between them. Each zone creates a moment void of harmonic functionality and structural cadences when triggered. There are differences between zones, either melodic, harmonic, or using audio effects. The melodic and harmonic elements are activated when the player-performer triggers a zone. The melody and harmony utilise a sine wave to produce a pure tone around D#Maj11, within the note range G#0 to D#7. There is no melodic or harmonic development as such; instead, inversions of D#Maj11 are offered throughout the composition.

Zone 0 (at the centre of the app) is the most active and intense. It does not climax; instead, it offers a sustained moment of dense music that encapsulates the player-performer spatially, that is, surrounding the player-performer with sound. The moments' frequency (or time delay) lessens as the player-performer moves away from the centre. As a result, space appears between moments, and the intensity dims. Motifs appear in the composition, which, alongside the underlying drone, helps *Gravitational Pull* feel cohesive. The random-in-a-range node acts like an improvisatory device, offering multiple versions of the motifs. The music starts and stops through player-performer interaction but does not offer a beginning or ending. There is no finale, outro, coda, or any musical device depicting the end of the music; the ending is when the player-performer presses stop on the app, which, if not stopped, will allow the music to continue until the smartphone battery runs out of power.

The composition uses *UE4's* built-in Modular Synthesis system, Ambient Sound Actors, and Sound Cues. The Ambient Sound Actors and Sound Cues are populated with .wav files set to loop indefinitely. Varying effects using randomised settings alter and enhance the melodic and harmonic content, the application of which unfolds onto approaching material. *Figure 16* below, depicts the underlying drone loop that uses a similar car acceleration technique in video games to achieve the rising pitch as the player-performer approaches the central zone. This works by decreasing the interval between activation, which increases the playback rate. This technique adds to the intensity of the music and aims to demonstrate to the performer-player the effect their movement has on the music. The visuals reflect a link between the player-performer movement and the music, demonstrated through particle effects and user interface elements. The central swirling visual particle effect offers a focal point upon app start. Without this, it would be challenging for the player-performer to understand where to move, particularly when the first musical moment has finished. A heads-up display is visible on zone activation to show the player-performer which zone they are in currently. There are intentionally no outer visual boundaries, making it possible for the player-performer to navigate outside of audible range.

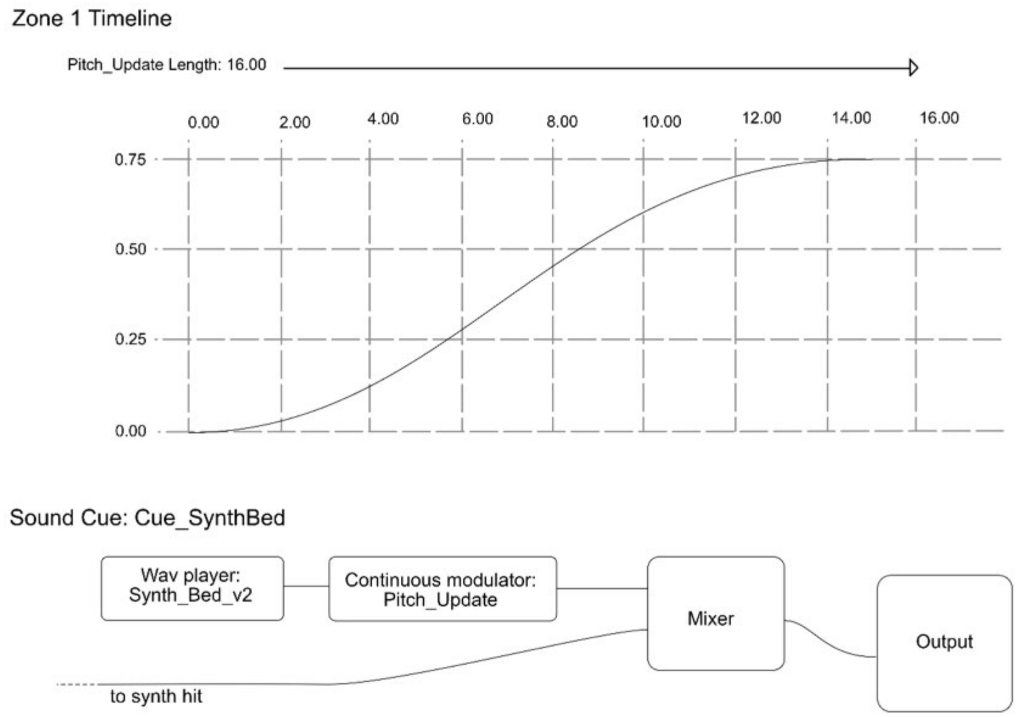

Figure 16 - Gravitational Pull Timeline Affecting Sound Cue Pitch.

It was a challenging piece of music to compose due to the complexity of the music system. *Gravitational Pull* was developed in *UE4* before the release of *UE5,* and as such, the systems for music implementation into *Unreal Engine* required more scripting. The Modular Synthesis system is relatively rudimentary compared to MetaSounds. Subsequently, there were limitations and complications when implementing ideas into an augmented reality system. Furthermore, as with *SoS*, intermittent clicking and popping appears to be due to the limitations of the smartphone. Experiencing *Gravitational Pull* as a stereo linear audio-only experience (i.e., as a listener) is less effective than experiencing the app as a player-performer. *Gravitational Pull* is most effective as an interactive app where the player-performer has control of the music structure by conducting the music. Efficient use of the musical material hides a complexity to the programming, which is not reflected in the outcome. However, as with *SoS*, *Gravitational Pull's* sound palette and approach create a recognisable interactive nonlinear electronic music composition.

Sheets of Sound and *Gravitational Pull* were useful learning experiences and demonstrated the smartphone capabilities' limitations. *Gravitational Pull* was incredibly challenging to develop using UE4 4.26 synthesis capabilities, and the outcome did not represent the development time involved. There were difficulties with several processes due to the complexity of the system. *Gravitation Pull* was completed shortly before the beta release of *UE5*, which boasted a new audio engine design based on modular synthesis principles. The advertised specifications required to use *UE5* made it clear that to explore the full potential of the new audio system, mobile applications would be restrictive, and as we shall see in the following example, using a desktop device would allow unrestricted access to the new audio system, MetaSounds.

6.3.3 The Machines

Development date	Sep 2021 – Sep 2022
Unreal Engine version	(started) 4.26.2 – (completed) 5.1.1
Compositional techniques	Moment form, modules, gestural time
Additional developers	Jay Broderick – visuals, Ben Russell – AI programming

Link(s)	***Access Link***

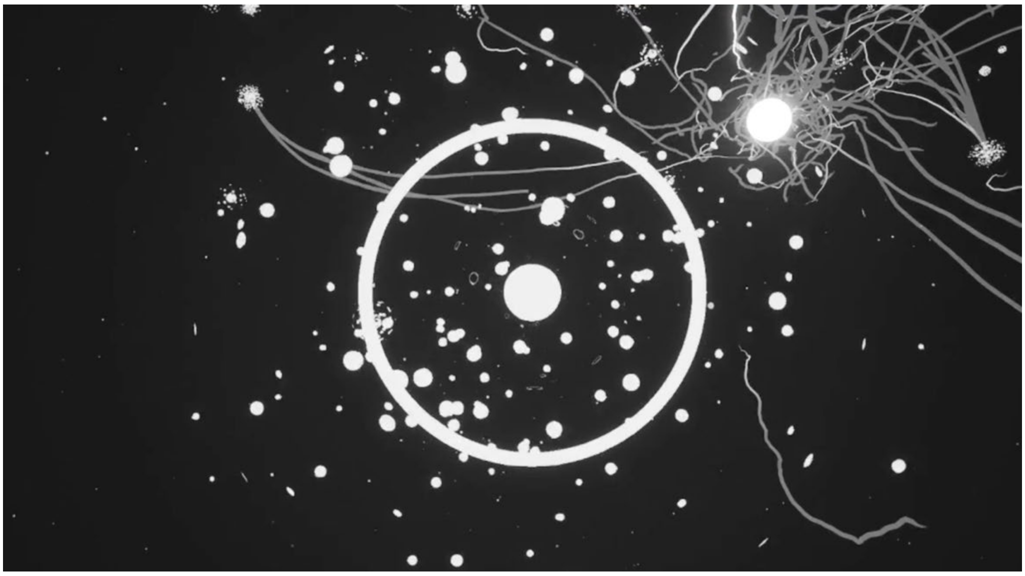

Figure 17 - Screenshot of The Machines, Zone 1 - Machines.

The next app developed to completion was *The Machines*. The initial aim was to create a mobile, geo-located app to be used outside as a 'walking music tour'. The inspiration came from Naphtali and Rodkin (2019) through their interactive soundwalks. However, as had been discovered with the previous two apps (*SoS* and *Gravitational Pull)*, there was an imbalance between the exploration of *Unreal Engine's* audio engine and the operating capabilities of the available *Samsung G9* smartphones. As such, it was decided to pivot and develop for desktop computer to take advantage of the increased processing power. This decision was taken relatively early in the production process, which allowed time to reconfigure and rebuild the app.

It became evident early in the development cycle that the complex systems involved in achieving the desired outcome would require help from a specialist programmer, and it was deemed beneficial to spend time developing the audio system rather than grappling with the intricacies of creating the pick-up or AI systems. As such, a programmer was employed to complete these systems, paid for by the Epic MegaGrant award received in November 2021.

This was the largest and most complex app to date, which stretched knowledge. Due to the newness of *UE5* and MetaSounds, there were minimal resources to help assist development. As such, the iterative development model from the game development pipeline methodology was implemented to support the trial-and-error approach required. Alongside this, the learning from the previous two pieces was utilised to continue the practice-led approach. Having established the foundations of the *Nonlinear Electronic Music Framework* over the last two pieces allowed for a more thorough exploration of nonlinearity in electronic music.

Creative experimentation and exploration were at the heart of this app development, and multiple times, the creative intention and result differed significantly. This was due to the purposefully vague creative intention devised to enhance the experimentation and exploration within MetaSounds. However, unknown systems, functions, and parameters in MetaSounds presented challenges and often required strategic thinking, research, and additional learning to find acceptable solutions.

The overarching concept for *The Machines* takes inspiration from philosophers Gilles Deleuze, Felix Guattari. Concepts such as the rhizome and abstract machines were instrumental in visualising the interactions between sounds and how the player-performer interacts and navigates through the app. Further sound and visual inspiration came from the video game *Inside* (Playdead, 2016), released in 2016 by game development company and publisher, Playdead. *Inside*, composer and sound designer Martin Andersen created dense chords of suspended sound, which complemented the sluggishness of the character's movement. Both were designed with fear, anticipation, and intrigue in mind. *Inside* specifically inspired the middle zone *In Between* in *The Machines* from an auditory and movement perspective.[21] Each zone has a different inspiration point and set of mechanics. An overview of the concept is presented below, after which each zone is discussed individually.

[21] 'Zone' is used instead of 'level' due to the association of the term level within video games. Levels are associated with objectives and increasing difficulty throughout gameplay, neither of which is appropriate in this instance.

The Machines[22] – is a single-player interactive desktop experience demonstrating electronic music and audio programming techniques within *UE5*. The compositional techniques employed in this app are modules, gestural time, and moment form; elements of vertical time are evident but not explicitly employed as a compositional technique. The project started on *UE4* 4.26.2; however, at the beginning of the process, *UE5* Early Access became available. Therefore, upgrading the project was prioritised to take advantage of the newly available audio tools. The focus was on nonlinearity and was designed primarily as an audio experience. The player-performer explores three distinct zones, each focused on one aspect of sound design and electronic music composition. Due to the nonlinear approach to the music, each zone has no set time limit and no set route or objective outside of musical exploration. However, the intended player-performer engagement of each zone is approximately seven to ten minutes, delivering 21 to 30 minutes of music when thoroughly visiting all zones (this is based on the speed of AI movement without player-performer participation).[23] It is possible to move between zones by traversing through a portal, which appears after the player-performer visits a designated percentage of sintboxes.

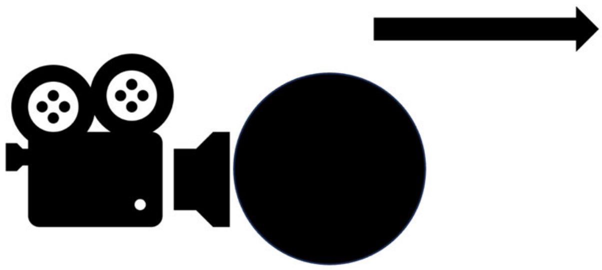

Figure 18 - Screenshot depicting the player pawn (consisting of a camera, sphere, and arrow, all hidden within the experience when played).

The player-performer moves an invisible pawn and has basic controls consisting of movement and a pickup functionality for use in the initial zone (see Figure 18 above). Interaction between the player-performer and sintbox is achieved by moving inside the centre of the sound source, which will trigger the sound (see Figure 19 below).

[22] For clarity, the entire project is called *The Machines* and the first zone is *Machines.*
[23] To visit all sounds in the first zone *Machines* can take up to 60 minutes dependent on route.

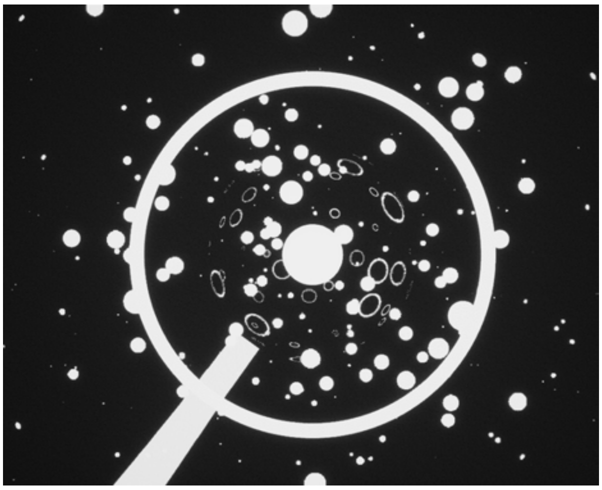

Figure 19 - Screenshot demonstrating visual interaction with a sintbox. The ring is visible when the player interacts with the sintbox, like the trail, in the bottom left of the image.

This interaction initiates several processes, which differ between zones. For example, the sintbox will activate the sound source, effects, and visual trails in the first and second zones while incrementing one portal key.[24] In addition, the visual particles will increase, and the sintbox will react visually to the audio output. At the centre of each sintbox, particles flicker around a nucleus, offering the player-performer a visual guide to the sintboxes location. In addition, a ring appears on interaction, along with interaction trails, which develop in the direction of the upcoming location of the portal to the next zone (see Figure 20 below).

Figure 20 - Screenshot of The Machines with the portal (bottom left) and interaction trails.

Zone 1 – *Machines*

Conceptually, *Machines* was inspired by *Stockhausen: Gaze Through the Stars*. A 2018 album by Riccaiarda Belgiojoso – keyboard, piano; Mario Mariotti – trumpet;

[24] Multiple keys are required to pass through the portal to the next zone.

Walter Prati – electronic cello, which reinterprets selected works of Stockhausen (Belgiojoso et al., 2018). Most compositions on *Stockhausen: Gaze Through the Stars* are under two minutes long. *Machines* uses a similar aesthetic, constructed of a complex system of short modules which the player-performer conducts to create a more extensive interwoven work. The zone focuses on experimental electronic music harnessing MetaSounds built-in audio synthesis functionality in *UE5*. All sound modules use MetaSounds; no external synthesis or audio files are used. The sintboxes have a pickup functionality, which allows movement by the player-performer in any direction. Each sintbox contains a unique MetaSound, which, when triggered, plays through an audible loop; the MetaSounds have interactable inputs set up to allow the player-performer to manipulate the sintbox in various ways; this could be a change in pitch, bpm or crossfade between sound generators.

Machines contains an 8X8 grid, creating 64 sounds spawned randomly within the area.[25] The sintboxes are spawned between 100 and 10,000 on the X-axis, equating to 1 and 100 metres. By default, *UE5* has spatialised sound; the spatialisation works on all X, Y, and Z axes. This system allows the player-performer to explore the zone, independently activating and manipulating each sintbox. The zone starts with no audible sounds, and the music development depends on the player-performer's actions. The sound attenuation of the sintboxes is set with an inner radius of 3,000 and a falloff distance of 30,000, allowing the output of the sintboxes to overlap (see Figure 21 below). To manage the number of concurrent audible sounds, voice management and global concurrency are limited to 16 voices, with a resolution rule of ‘stop farthest then oldest’.

[25] Machines grid layout

- 35,000 X 35,000 grid
- Range 0 to 35,000
- Divided into 64 cells (8X8)
- Spawned on the X-axis randomly between 100 and 10,000.

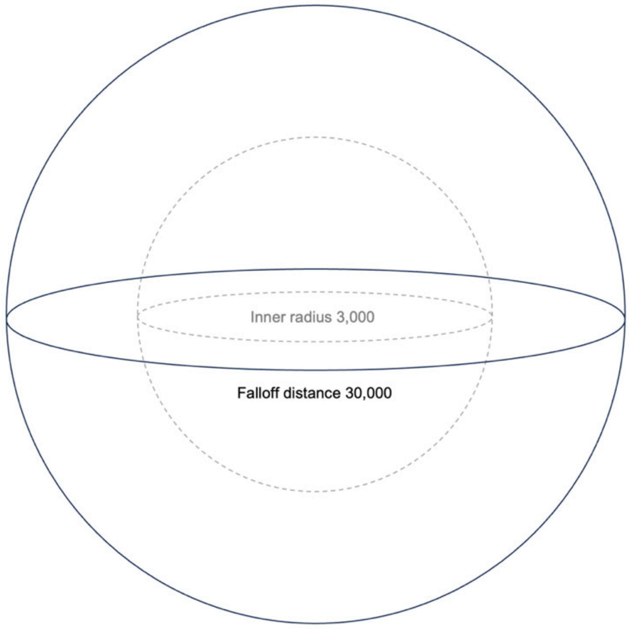

Figure 21 - Screenshot demonstrating the attenuation settings of the Zone 1 – Machines.

Machines uses 64 individual nonlinear modules with large-scale connections (an idea discussed in *4.3.3 Modules*). "Large-scale connections, especially those that involve two or more connective elements, have deeper hierarchical meanings than local connections" (Paynter, 2015: 51). For example, each module uses an interactive, iterative loop connected through tempo, pitch, timbre, and location. All modules can be relocated anywhere in the zone through player-performer interaction. The relocation of a module can affect tempo, pitch, timbre, effects, and gain, dependent on the available inputs created for the specific module. For example, the sintbox of module *Cuboid* allows six interaction points (see *Figure 22* below). The pitch of the module can be changed, along with the addition of sine, triangle and saw generators. These elements fade in through player-performer interaction (modulation occurs through a sine offset and saw LFO). On the other hand, the sintbox of module *Phalanges* (see *Figure 23* below) only has one interaction point, pitch change, achieved through movement on the Z-axis, which is initially set through the spawn location, after which it can be affected through the pickup functionality.

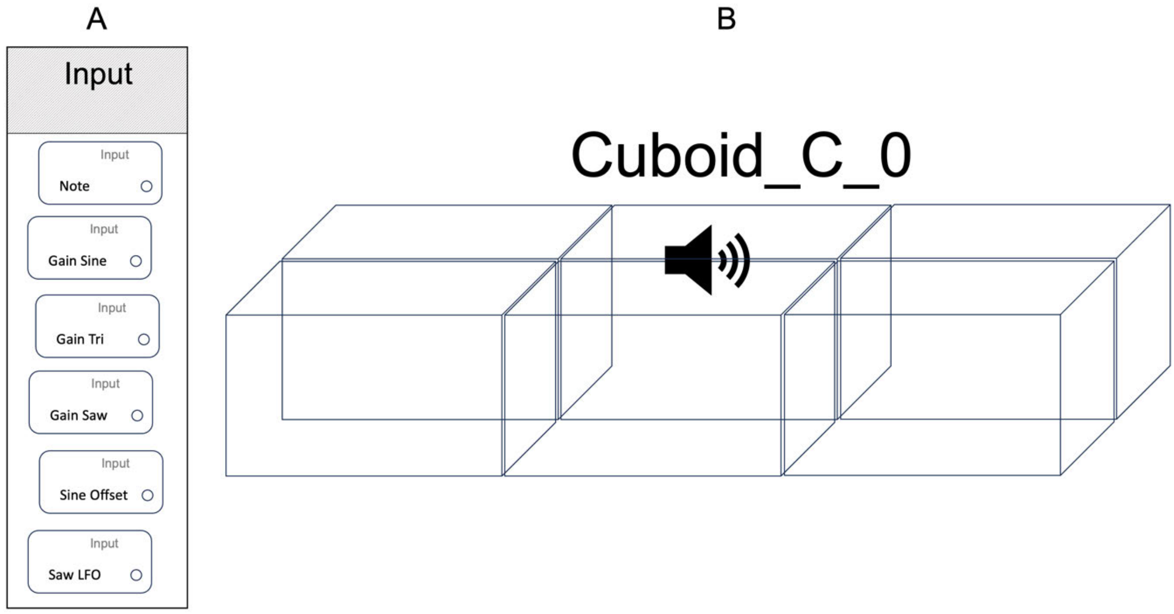

Figure 22 - Screenshots demonstrating (A) MS_Cuboid MetaSound interactable inputs visible in Blueprints and (B) the collision boxes of MS_Cuboid. Each collision box is interactable by the player-performer.

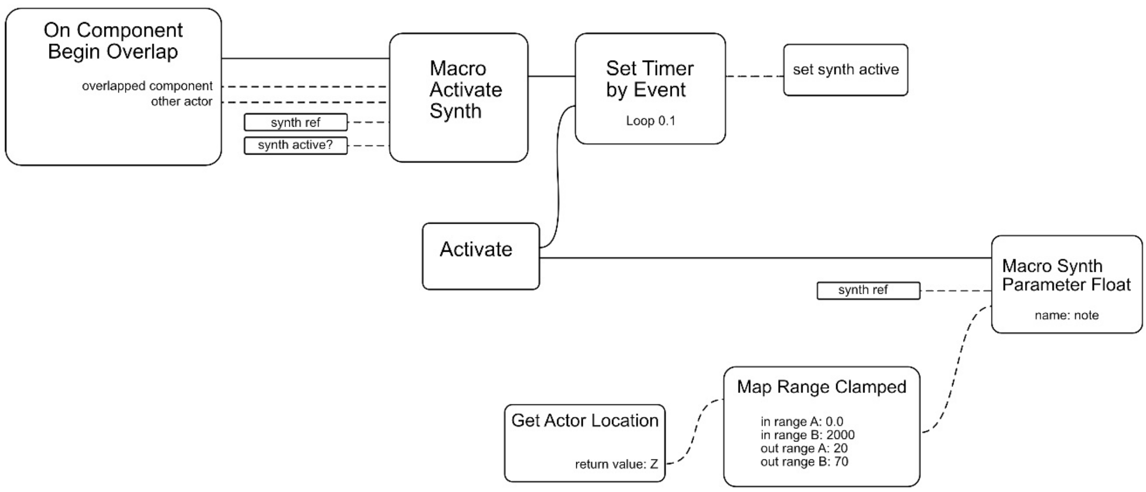

Figure 23 - Illustration of pitch change in the MS_Phalanges sintbox within the Blueprint script.

The iterative development approach for each module comprised creating a foundation, a duplication, an adaption, or augmentation. Once the duplication was created, it was either adapted or augmented to achieve a ‘new’ piece of music. The modules are not time-synched, so elements can overlap to create complex rhythmic patterns and harmonic textures. Location plays a prominent role in the piece's outcome, and player-performer or module movement can connect or disconnect modules. Placing modules on top of one another creates an illusion of a single complex module and can have multi-textural or polyrhythmic properties. It is possible to create a ‘chain’ of sintboxes using this technique, building a dense music palette with large-scale connections.

Zone 2 – *In Between*

This zone focuses on the implementation of pre-composed software synthesis. There are 41 single .wav files, 22 seconds long, combined in *UE5* to create 25 randomly spawned chords. Orbiting sounds accompany the chords randomised-in-a-range, which trigger the chords when moving through their path. The timbre of the chords progresses over time through the introduction of a bit crusher, which gradually diminishes the bit depth. This zone does not offer the ability to pick up and move the sintboxes; rather, movement within the level is limited to player-performer movement and the orbiting sounds. To further reflect this calmness, the player-performer pawn speed is slower than in zones 1 and 3.

In Between is multidirectional music designed to be listened to forwards and backwards. The order of events is irrelevant to the temporal space created by the music. The music has implied verticality due to the static chords (both harmonically and spatially), which do not develop over time; once spawned, the chords cannot be moved or altered. Additionally, the static chords spawned randomly within a grid are void of a beginning or ending. There is no correct, incorrect, proposed, or fixed route the player-performer should take. As such, *In Between* can be considered a composition in moment form, with an implied verticality. Chords can be listened to without interruption for as long as the player-performer wishes, producing a prolonged present; however, the player-performer can establish moments dependent on movement.

In Between is inspired by the stillness and feeling of Abul Mogard’s 2018 album *Above All Dream*s (Mogard, 2018), an album which somehow feels like the movement of clouds, where each cloud is a deep, rich harmonic texture colliding with the next. The overlapping textures create altered states, providing an enriched harmonic palette. *In Between* is sonically different from the music created in *Machines*. The idea was developed by composing all 25 chords in *Ableton* and implementing them in *UE5* to randomly spawn to produce areas of harmony and dissonance dependent on their spawn point. Each chord uses the same software synth sample, slowly fading in and out.[26] Fading in is incorporated into the .wav file, whilst fading out is achieved through the attenuation settings, activated by the player-performer moving away from the chord location. The five orbiting sounds move through the chords, adding rhythmic and harmonic layers. They spawn on independent orbits varying in size within the bounds of the zone. Their arbitrary interaction with the chords speaks to the lack of expectation in the music. The idea for implementation was to create a sense of spatial presence for the player-performer, with each chord tone positioned around the central sintbox (see Figure 24 below).

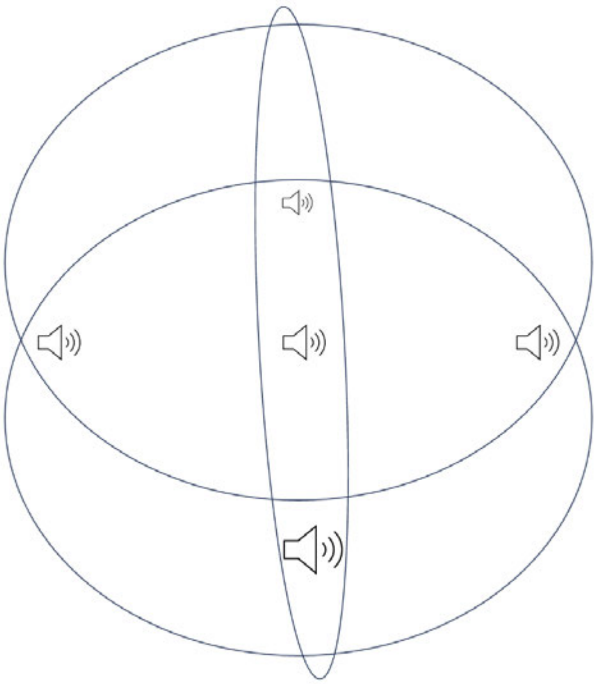

Figure 24 - Illustration of a five-note chord positioned around the central sintbox. Each speaker icon shows the position of a chord tone. The root note is placed centrally, with the chord tones rising anticlockwise around the perimeter.

Zone 3 – *Rhizome*

This zone focuses on implementing contemporary orchestral music composed in *Ableton*. The work examines the crossover between acoustic and electronic music. There are 15 pieces using a combination of orchestral instrumentation and electronic elements loosely based on contemporary classical music techniques. The dense dissonant movement and "subtle shifts of tone colour" (Schwarm, 2020) from Ligeti's *Atmosphères* (Ligeti, 2012) – original release 1961 – inspires *Rhizome.* Utilising this richer harmonic content was beneficial to help gain an understanding of the

[26] *Ethereal Earth.* (Native Instruments, 2022).

practicalities of composing in a nonlinear format. Much of this process was trial and error and required visualising how the musical parts would work within *UE5* and how player-performer interaction would affect the music. The zone relies heavily on audio samples developed in *Ableton* and implemented into MetaSounds, using 1,300 wav samples throughout the 15 pieces. The tempo of each piece is local; that is, there is no master clock keeping all the music synchronised. The result finds that the music overlaps and melds together, creating unusual transitions between each piece.

As with *In Betwee*n, *Rhizome* does not allow the player-performer to pick up the sintboxes. Although the sintbox remains the central focus point, an additional surrounding ring system contains eight compositional layers. For example, the eight rings from the music *Lungs* (from outer to inner) contains a synth pad, strings, crotales, woodwind, low horns, low strings, a concert drum, and a synthesizer. *Kidneys* (from outer to inner) contains a harp, a violin, a synthesizer, a bass, bpm, stereo delay feedback level, whole note divisions, and panning. The player-performer cannot reach the sintbox without passing through the rings; however, the sintbox must be activated to spawn the portal and allow access to the next zone. A larger portal activation radius has been added to reflect the more extensive surrounding ring system. *Rhizome* focuses on the game application of nonlinearity and was the most challenging zone to compose, involving the most complex compositional techniques. In addition, player-performer interaction was prioritised.

Although *The Machines* may seem like a candidate for virtual reality, there are barriers to the project design that would make the application difficult. The main issues faced are the size of the area used and the verticality of the project. *The Machines* would require an area of 800 square meters of physical space, so teleportation would be required to mitigate the distance. However, the requirement of teleportation would break the music flow and alter the interactions between sintboxes, ultimately changing the player-performer's perception of the music and the outcome. Scaling down the project would still require significant space, so it would not be feasible. In addition, the project uses verticality to adjust sintbox parameters, actioned by player-performer agency. This function would be limited to the player-performer's reach and thus would affect the amount of parameter adjustment possible.

The scale and complexity of The Machines accelerated knowledge through experimentation and exploration. The development curve was substantial due to the different techniques employed in each zone. This process effectively became the starting point of a transition from a composer making linear music for games to being a composer making nonlinear music. The focus shifted from working in macro loops to working in micro loops, which offers more flexibility. The processes include predominantly thinking verticality (splicing vertical micro loops for implementation into the engine) rather than thinking horizontally (splicing macro loops in the same manner as linear music composition). Adopting this process allows for significantly more manipulation of the micro loops, offering the potential for more complex patterns and allowing the material to be utilised more effectively. This was a substantial shift in thinking and led to more experimentation and more unknowns. Often, the outcome was significantly different when transferring the micro loops from the DAW to MetaSounds. Whilst composing in the DAW, a great deal of imagination was required to envisage the outcome in MetaSounds; however, the implementation methods did not always align with the envisaged idea. As such, the implementation method became an important part of the creative practice to the extent that ‘different’ or ‘new’ pieces were born out of the difficult, complex, or misaligned implementation method. This important part of the creative practice was not foreseen yet became an important tool in creating nonlinear music within this project.

6.3.4 Through a Quantum Window

Development date	Nov 2022 – Aug 2023
Unreal Engine version	5.1.1
Compositional technique(s)	Modules, vertical time
Link(s)	***Access Link***

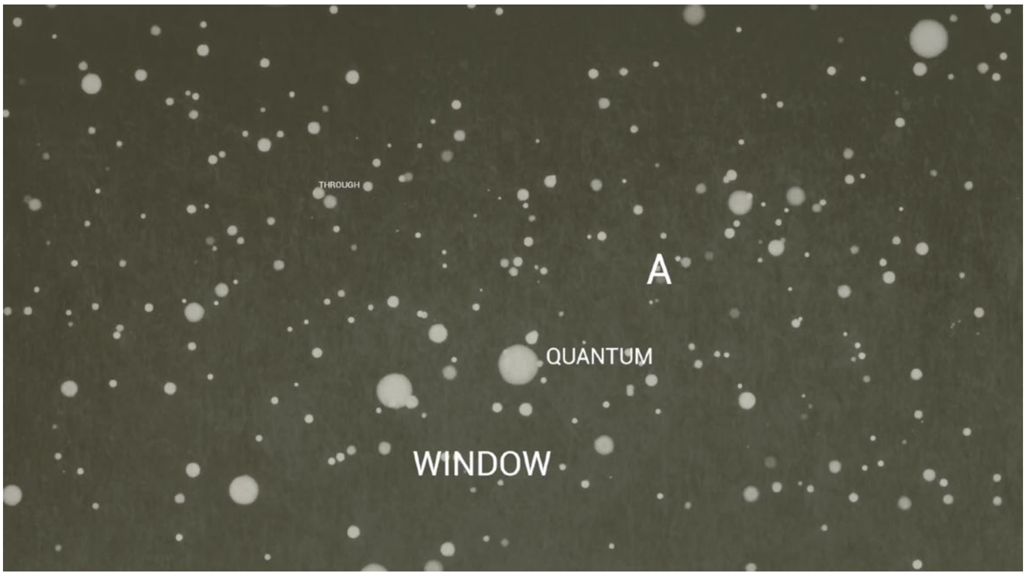

Figure 25 - Screenshot from Through a Quantum Window user interface.

Whilst completing *The Machines*, *Through a Quantum Window* was conceptualised as an adaptive extended play (EP) music app that uses local time and date data (GMT) to adjust parameters and affect the outcome. The EP is designed for desktop and mobile devices and intended for playback on a stereo speaker system. The EP is a continuous piece of music, divided into four music compositions, the names and themes loosely based on ideas from quantum mechanics: *Ether*, *Expansion*, *Contraction*, and *Collapse*. *In addition, a Brief History of Time: From the Big Bang to Black Holes* (Hawking, 2011) and *Meeting the Universe Halfway* (Barad, 2007) helped generate thematic ideas and offer points of inspiration. Musically, *Through a Quantum Window* is inspired by the generative system Brian Eno developed in his 1978 *Music for Airports* (Eno, 1979).

Although this EP primarily focuses on the development and implementation process of adaptive music, the nonlinear compositional techniques modules and vertical time are employed in the first piece, *Ether*. Spatialisation and player-performer input were unrequired due to the chosen playback system (A stereo pair of speakers or stereo headphones). The previous compositions did not fully utilise adaptability and, as such, *Through a Quantum Window* uses adaptability as a focal point in favour of interactivity. Therefore, the role of the player-performer is redundant, and rather than being actively involved with the composition, they become the listener. In this regard, the EP automatically plays when initiated, and no interaction from the listener is required. The purpose was to produce an adaptive EP that required no input from the listener and offered different versions with each play, similar to a jazz quartet's improvised musical performances.

Unlike *SoS*, *Gravitational Pull*, or *The Machines*, *Through a Quantum Window* has an established playback time of 18 minutes. The EP contains one uninterrupted stream of music split into four tracks. Within the established playback time, the tracks adjust the start and stop time within a designated range; additionally, the elements of each track vary in length according to specific parameters, such as the time of day or date the playback occurs. As a result, the elements have a cyclical pattern, often harmonically and rhythmically independent but not synched. The element variation can affect the structure and shift the importance of certain aspects or focal points, ultimately affecting the perception of the composition. Although several similar techniques were employed, this was a significantly different composition process from previous pieces.

Each idea for the EP was developed in MetaSounds and started with sound generators, such as sine, saw, or triangle waves. Initially, the focus was on sculpting the generators using envelopes and effects to develop useable ideas. Once the initial idea generation was complete, the focus moved to tweaking the idea and playing it back in *UE5* to see if the result would be usable. This process was slow and repetitive and had to be conducted in real-time to help understand the potential outcomes the adaptive elements would achieve. The multiple factors involved, and the time taken (due to the complexity of creation and implementation) meant ideas would become distorted or lost. However, through the process, useable ideas developed, or accidental breakthroughs occurred that could not be foreseen; breakthroughs became the focus of the piece, ultimately defining the outcome of the EP. For example, *Figure 26* below, shows the noise generator Blueprint used to create the bubbling waves sound in *Contraction*. The Blueprint illustrates the noise generator parsed through multiple timelines and parameter controls to affect the output. This level of control was achievable through step-by-step experimentation. Once achieved, the idea established the theme of the piece, becoming an anchor for the other elements and defining the overall structure.

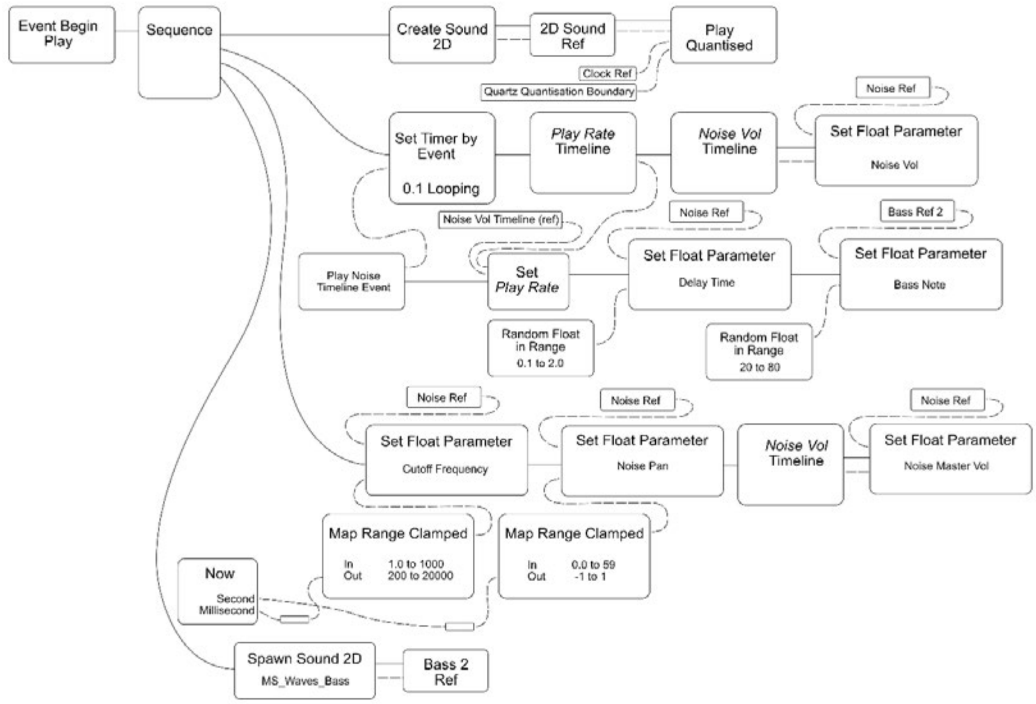

Figure 26 - Illustration of Noise Generator Blueprint in UE5

The composition process adopted step-by-step experimentation throughout. *Ether* takes advantage of convolution reverb, which achieves a thick, ethereal pad sound from a seemingly unremarkable sine wave generator. The impulse response was created from a pre-existing snare drum sample already implemented into the *UE5* project, initially for a different purpose. The composition started from an arpeggio drenched in convolution reverb, which rises and falls randomised-in-a-range; the result is a slowly evolving ethereal chord pattern that underlies the composition. Dan Carr (2019) analyses Brian Eno's *Music for Airports* (Eno, 1979) and discusses the processes used to create the album. Of particular interest was the timbre changes created in track *1/1*, which was achieved by slowing down the recordings. A deviation of this idea was implemented into *Ether* through a bitcrusher distortion effect that doubled in speed with each cycle. The bitcrusher was placed on Ether's output channel, resulting in the audio being down-sampled as the sample rate and bit depth were reduced.

The second piece, *Expansion,* slowly blends into the remnants of *Ether* and immediately introduces a beat-driven, iterative melodic loop, which uses the modules nonlinear compositional technique. Additionally, as demonstrated in *Figure 27* below, the melody count is amended five times within the piece, achieved through internal and external data sets. As with Ether, this idea is also derived from *Music for Airports* (Eno, 1979)*,* this time the inspiration point is the seven different length loops found in track *2/1*.

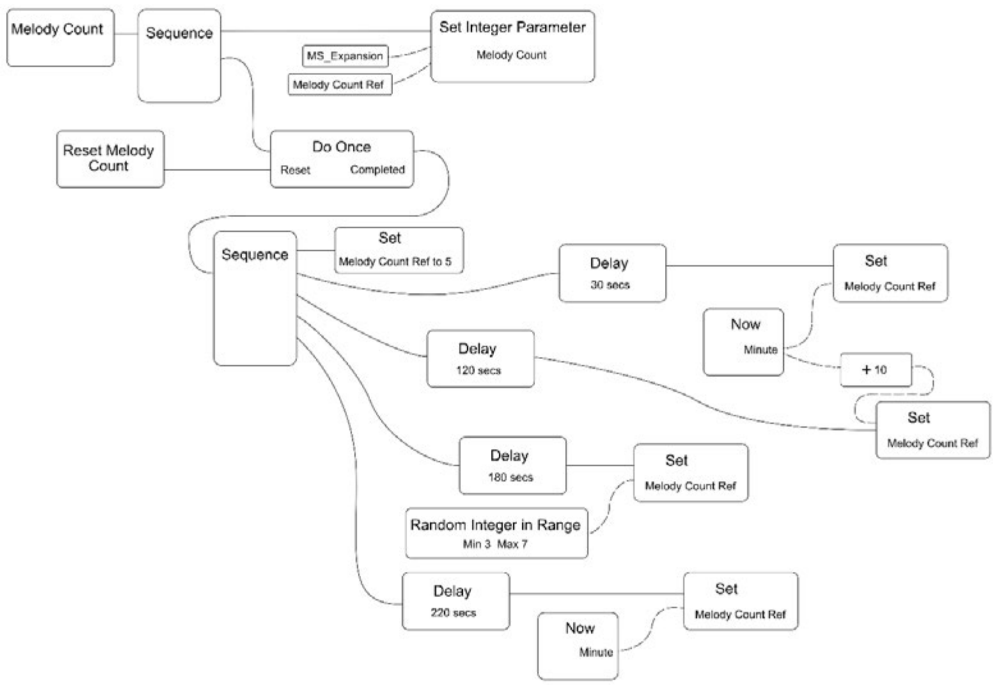

Figure 27 – Illustration of 'Expansion' Melody Count Blueprint in UE5

The third piece, *Contraction,* utilises multiple layers to create a bubbling effect emerging underneath the exit of *Expansion*. The sound palette is developed throughout *Contraction* by adjusting the beat, achieved using a beat multiplier, and delay flooded and reset multiple times, pausing between each reset. As *Contraction* fades out, the fourth piece, *Collapse,* fades in. A noise generator is initially heard, creating a wave-like effect, giving way to a slow, repeated melody. This melody is interrupted by sudden tempo changes, which eventually destroy the continuity of the piece. This destruction is increased using a bitcrusher placed on the main output, which is the same technique used on *Ether*. The sample rate and bit depth are gradually lowered, eventually destroying all audible frequencies, and collapsing the music.

Through a Quantum Window consists of many elements interwoven throughout. Several parameters and parts were changed during the composition process to see how they might fit together. Although an overarching idea was evident from the outset of the composition, no concepts were solidified beforehand, allowing experimentation to be the focus. The result is an iterative piece of music employing sub-genres of nonlinear time, modules, and vertical time. The EP adapts to the time and date played, offering the listener a unique experience with each playthrough. *Through a Quantum Window* has complex systems in place designed to deliver the required adaptability. Although *The Machines* was a more extensive piece, there were several unique problems that required solving in *Through a Quantum Window*, which proved challenging.

Working directly within MetaSounds and Blueprints was a slow process and highlighted the difficulties when creating complex musical systems. Realising and evaluating ideas could be a time-consuming process. For example, applying long impulse response reverb to a set of notes created in MetaSounds takes significant time to start and stop. As such, multiple testing systems were developed to allow testing to be as streamlined as possible. However, this process 'became' the composition process in *Through a Quantum Window.* Multiple ideas were trialled, tested, and developed, and many were eventually discarded or superseded with evolved ideas. This piece was composed slowly, with significant time spent considering alternate possibilities, resulting in an experimental EP that delivers a seamless, adaptive, nonlinear electronic music experience. The processes involved in developing *Through a Quantum Window* were different from the previous pieces, which all used .wav files created in a DAW to some extent. The sole development in MetaSounds involved more complex thinking, and the outcome was less predictable. This piece bolstered the exploration and experimentation process, and although the focus of the piece is adaptability, it also enhanced the technical considerations given to the *Nonlinear Electronic Music Framework*.

6.3.5 Underground

Development date	Dec 2022 – Jan 2023
Unreal Engine version	5.1.1
Compositional techniques	Modules
Link(s)	***Access Link***

Figure 28 - Screenshot from Underground.

Underground was inspired by *Form and Process in Morton Feldman's Spring of Chosroes* (Paynter, 2015), in which Paynter analyses the relationship between Feldman's music and "a legendary garden carpet created for the sixth-century Sassanian king Chosroes I (r. 531-79)" (Paynter, 2015: 48). Paynter discusses asymmetries and determines that there is an established hierarchy within the design, which he concludes is to make the music "'sound good'" (Paynter, 2015: 50). Paynter also establishes pitch class and rhythm as the "most important aspects of a pattern's identity" (Paynter, 2015: 50). *Underground* was a logical progression from *Through a Quantum Window* and focused on the idea of modules as patterns and creating a map to provide a set of rules to determine creative practice, deciding to use the *London Underground* map as a template. Whilst *Through a Quantum Window* is an exploration of adaptability, *Underground* is an exploration of the sub-genre of nonlinear time, Modules.

Each module is based on a single indefinite sine wave and is an independent loop that can start or stop without affecting the other modules in the piece. There are 13 modules; six are randomly selected simultaneously and overlap when playing. Each module roughly traces the path of a London Underground tube line (based on the tube map rather than geographical distance) and uses the verticality of the map to dictate the pitch of each sound wave generator. *Figure 29* below, shows the *Bakerloo Line* Timeline alongside the pan movement between speakers. The length of the specific train line dictates the length of each module. The number of stations for each line is used to create the rhythmic aspects of that module; a decrease in amplitude to 0db LUFS represents each station. The amount of time a module spends in each station is proportionate to the length of the module, divided by the number of stations. The pre-established *London Underground* zones were used to divide up the map (Transport for London, n.d.). The X-axis has nine zones, each representing 60 seconds, creating a maximum module length of 540 seconds. The Y-axis has six zones, each representing 10 MIDI values, ranging from 10-70 (notes Bb-1 – Bb4). Underlying the modules is a continuous fluttering idle sound alongside a five-part arpeggiated chord, which sparsely interjects a flurry of notes to break the idle flow.

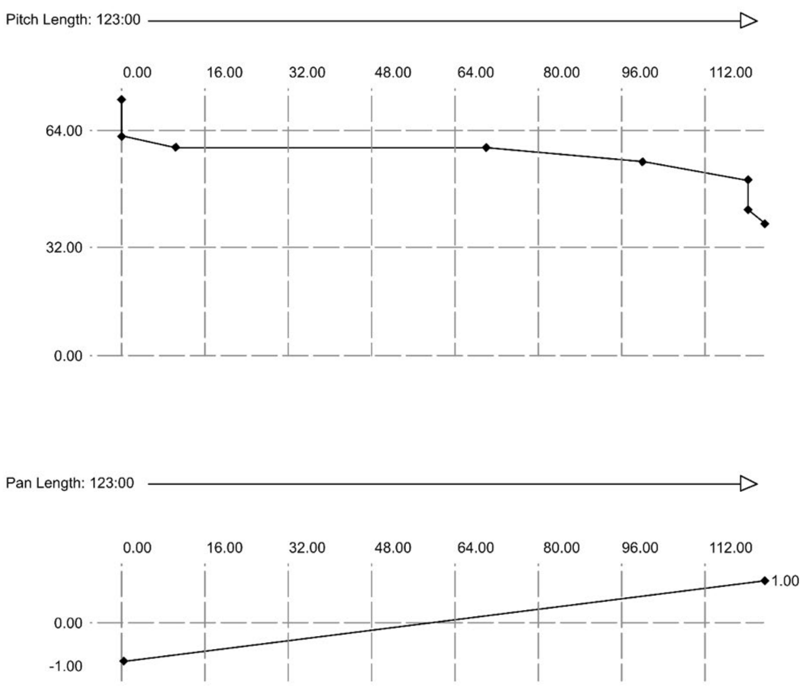

Figure 29 – Illustration of 'Bakerloo Line' pitch and pan Timelines in UE5

As shown in *Figure 30* below, the modules use a Blueprint timeline to change pitch and add the required rhythmic silences representing the stations. The ‘play rate’, or speed of the timeline, is randomised-in-a-range between 0.5 – 20 (0.5 is equivalent to half the timeline speed, or 20 is equivalent to increasing it by 20 times). Additionally, the module uses a second parameter adjustment in the timeline to pan from one speaker to the other. This adjustment affects the outcome significantly and produces a jittering sound through the rhythmic silences, which interweaves through the other modules.

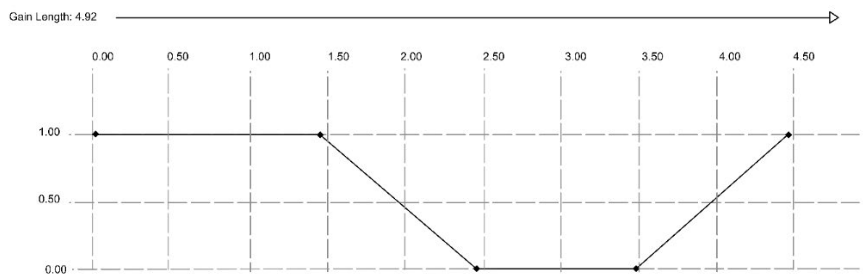

Figure 30 - Illustration of 'Bakerloo Line' station Timeline in UE5

A significant amount of artistic interpretation and judgement is employed throughout to create a ‘balanced’ composition, much in the same way “Feldman used the timbral qualities that ‘make the piano sound good’ to derive his choice[s]” (Paynter, 2015: 50) in *Spring of Chosroes*. In *Underground*, the map was established roughly by eye. In addition, several modules' pitch boundaries were moved to ‘balance’ the composition. Initially, all 13 modules played simultaneously; however, the result felt crowded, and the piece lost its definition. To combat this, they were divided into six groups, allowing a maximum of six modules to be audible at any time.

Underground is an app for desktop or mobile devices, and the playback design is for a stereo speaker system or stereo headphones. In this case, the player-performer becomes the listener, so there are no interactive elements. Instead, the music adapts to data such as the ‘play rate’ (which determines the speed of the timeline playback) and a delay (affecting module activation). Once a module has completed its cycle, the actor containing the information is destroyed, and a new actor is spawned. *Figure 31* below, shows three screenshots of the Outliner information (which contains all the actors currently in use within the project). Outliner 1 shows two active modules

(*Bakerloo* and *Hammersmith & City*), and Outliners 2 and 3 show three active modules. It is also possible to see the number of times a module has been played, determined by the number affixed after its name. For example, *BP_Hammersmith_City0* is updated to *BP_Hammersmith_City1* in Outliner 3, which means it has been activated twice.

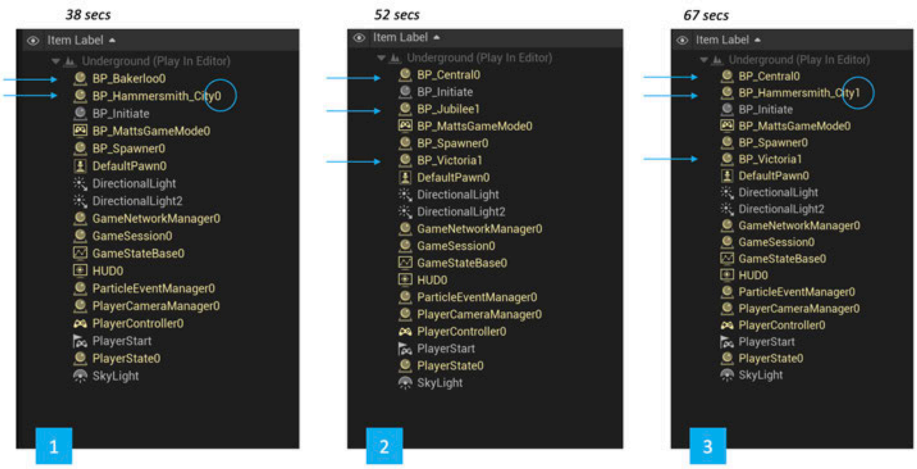

Figure 31 - Underground Outliner information

The iteration of the modules in *Underground* is comparable to the differences found in the repeated patterns of hand-woven carpets. In *Underground,* the timeline play rate affects the module's speed and length (in seconds) and the time it takes to pan from one speaker to the other. Both affect the rhythm of the module and, thus, the outcome. These differences create a piece of music woven together similarly to a hand-woven carpet. Although recognisable, each copy of the carpet will be imprecise; each playback of *Underground*, although recognisable, will present a different version.

Underground was the last artefact to be created and the quickest. Conceptually and technically, the piece was relatively straightforward. However, this ease of creation was informed by the four previous artefacts discussed and the many experiments conducted. It was possible to visualise the outcome practically and technically, allowing the workflow to be rapid and with relatively few issues. This was partly due to the learning of the previous pieces and the fuller development of the *Nonlinear Electronic Music Framework*.

6.4 Summary

Significant theoretical and practical development has been conducted in this project. This was due to the methodology employed, which allowed the artefacts to be the focus whilst being developed under the iterative system of the games development pipeline. Reflecting on each experiment or artefact has allowed learning from one piece to inform the next through the simple system of discovering what happened and why. This was undertaken in this manner to allow for creative exploration and experimentation within *Unreal Engine*, through investigation into the sub-genres of nonlinear time.

Regarding the experiments, although not explicitly focused on nonlinearity, each experiment presented has helped develop an understanding of nonlinear techniques and implementation strategies. This initial practical work was accomplished alongside theoretical learning and proved beneficial for creating the final artefacts. Furthermore, reflecting on each piece, when completed, contributed significantly to this aim.

Creating the artefacts has helped develop an understanding of the sub-genres of nonlinear time and how to compose within these sub-genres from a technical perspective. This has directly led to the construction of the *5. NONLINEAR ELECTRONIC MUSIC FRAMEWORK*, which itself is a record of how to compose nonlinear electronic music theoretically and practically.

7. CONCLUSION

This chapter demonstrates how each research objective has been answered through a project summary. This summary concludes by articulating how a nonlinear electronic music composition framework in *Unreal Engine* can be derived from the research presented in this thesis. This thesis explores nonlinear time within interactive and adaptive electronic music composition, using *Unreal Engine* game development software as an experimental platform to conduct the research. Four research objectives were established in the thesis, from which conclusions were drawn, which will now be clarified and discussed.

1. Produce a portfolio of nonlinear interactive and adaptive electronic music compositions within moment form, modules, gestural and vertical time.

A portfolio of five interactive and adaptive pieces was produced to explore the four sub-genres of nonlinear time evidenced as artefacts and through the *6. PORTFOLIO COMMENTARY*. Vertical time was employed in *Sheets of Sound* and *Through a Quantum Window*. Moment form was employed in *Gravitational Pull*, *The Machines*, and *Sheets of Sound*. Modules was employed in *The Machines*, *Through a Quantum Window* and *Underground*. Gestural time was employed in *The Machines*. Furthermore, each artefact contained either interactive or adaptive elements or both. Within this development process, the concept of gestural time was applied to the practical process of manual granulation. This technique was employed in the *Rhizome* zone in *The Machines* to create a piece of music that can be reordered so significantly that the music creates a conflict between gesture and function and has the potential to alter the listener's perception of time.

The creation of the portfolio has demonstrated the complexities and challenges faced when writing music within the four sub-genres of musical time. There are many strands to consider, and a distinction between theory and practice has been challenging to address, which has come to light in the process. *The Time of Music* (Kramer, 1988) has attempted to link theory and practice, and the *4.3 Compositional Approach* has expanded Kramer’s ideas towards electronic music.

2. Build a ludic-based software music app for desktop computers and mobile devices.

The five portfolio pieces discussed above are ludic-based software music apps created for both mobile and desktop devices. These are ‘sandbox play apps’ focused on nonlinear electronic music, which allow the player-performer to explore and experience nonlinear electronic music through play. Appropriate interaction systems were created for each app, such as smartphone movement for augmented reality apps *Sheets of Sound* and *Gravitational Pull*. Additionally, technical affordances, which varied depending on the device, were examined. For example, smartphone apps were well suited to augmented reality; however, they struggled with complex, large-scale systems, even when optimised.

3. Develop a system using visual scripting in *Unreal Engine* to allow player-performer agency to affect the music outcome.

The visual scripting system developed to allow player-performer agency over the music outcome is evident in the artefacts, *5. A NONLINEAR ELECTRONIC MUSIC FRAMEWORK* and *6. PORTFOLIO COMMENTARY*. Several experiments and apps allowed player-performer agency over the outcome, including the augmented reality mobile apps *Sheets of Sound* and *Gravitational Pull*. Both apps allowed the player-performer to affect the music by moving the smartphone in any direction. *The Machines* desktop app allowed the player-performer to use a keyboard and mouse or a game controller to move within each zone. *Zone 1 – Machines* allows the player-performer agency to pick up and move the sintboxes, activating them and changing parameters. In *Zone 2 – In Between* and *Zone 3 – Rhizome*, the player-performer can only interact with the sintboxes through movement. The option to pick up the sintboxes was not implemented due to the stylistic approach employed within the zones. However, all levels afford the player-performer agency to affect the music outcome. The visual scripting system was developed through Blueprints and MetaSounds.

Technical affordances and limitations are thoroughly considered within *4.4 Game Application* and *5. A NONLINEAR ELECTRONIC MUSIC FRAMEWORK*, specifically *5.4 Limitations*. To summarise, software functionality impacts creative output through the prescribed workflow incorporated into the software through the user interface design. Utilising software for a different purpose can offer an alternate way of thinking about the music composition process and, as such, can promote alternate outcomes. This ongoing issue has been established through *4.4.1 A Brief Timeline*, which discusses the affordances and limitations of software and hardware presented to game composers since the 1970s. The project artefacts benefit from reimagining the use of *Unreal Engine* as a nonlinear compositional vehicle through game mechanics, which provide alternate means to create and affect audio implementation and outcome. Software development is an area that requires constant investigation to keep pace with the broader sector, the rapid expansion of technologies within new realities, game development, and virtual production. The aim of this thesis is to contribute to the ongoing research in this rapidly growing field.

Unreal Engine allows composers to conceptualise in terms of nonlinearity when composing music. Within this realm, there is the opportunity to create music with many potential outcomes. As such, ideas do not need to be curtailed or rejected; instead, they can be interwoven into a ‘possibility’ the player-performer might discover. In *Sound and Music Computing*, Eigenfeldt discusses the difficulty of forming a musical structure with generative systems due to the “highly complex task” (Eigenfeldt, 2016) of composing music. He determines that the issue with generative music systems is due to the “largescale structure: how can generative systems avoid creating music that meanders aimlessly, yet doesn’t require strict architectural forms into which it is forced inside?” (Eigenfeldt, 2016). This viewpoint has been considered within *5. A NONLINEAR ELECTRONIC MUSIC FRAMEWORK*, demonstrating an approach that can be taken when composing nonlinear or generative music systems. Musical genres and sub-genres are reinventing musical structures to reflect the evolution of society and technology. This project demonstrates that interactive and adaptive music can develop a musical structure on the fly within a virtual environment of pre-determined physical boundaries.

4. Develop a nonlinear electronic music composition framework.

This has been achieved through the dedicated chapter *5. A NONLINEAR ELECTRONIC MUSIC FRAMEWORK*. The entire chapter is a framework designed to contribute to the creative experimentation and exploration of nonlinear electronic music. The chapter provides an overview to contextualise the framework and presents a simple diagram to help with the initial decision-making. The chapter presents the affordances of *Unreal Engine*, offers a compositional approach to how nonlinearity can be tackled, and provides insight into potential limitations. Finally, a method that uses the game development pipeline to provide an agile, flexible approach applicable when composing interactive and adaptive electronic music is presented.

With the research questions answered, a focus on future research could continue to investigate nonlinearity in music, spatialisation in virtual or augmented environments, and the development of 4D sound capabilities. As the technologies develop, so should the research. The future and relevance of the research are interwoven in a rapidly growing industry. New realities are becoming more prominent in the technology sector, and sound and music will be crucial to their development. Further research into the advances of nonlinear music composition for all relevant media such as music, gaming, television, and new realities is an exciting and fascinating area of study, and the conclusions this research presents are beneficial in that journey.

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APPENDIX A

This appendix contains information on exhibitions, presentations, publications, and awards.

Festival of Learning	Award	May 2021

Awarded second place at the University of Gloucestershire's 2021 Festival of Learning Poster Competition.

Leeds Beckett University	Presentation	Nov 2021

Presented research progress to game audio masters students at Leeds Beckett University, hosted by course leader Richard Stevens.

Epic MegaGrant	Award	Nov 2021

Awarded a grant of $10,000 in 2021 to conduct research.

EGX	Exhibition	Sep 2022

Exhibited The Machines on the Leftfield Collection stage at the EGX gaming convention 2022.

DAVAMOT	Presentation	Nov 2022

Presented an extended abstract of 'Nonlinear Time in Electronic Music' online at the DAVAMOT Audiovisual Symposium in Sweden.

DAVAMOT	Publication	Jun 2023

Extended abstract 'Nonlinear Time in Electronic Music' was published in DAVAMOT Audiovisual Symposium Notes. Available at:
<https://www.du.se/symposium-notes>