SPATIALIZATION IN SELECTED WORKS
OF IANNIS XENAKIS

A Thesis in
Music Theory
by
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Abstract

The intersection between music and architecture in the work of Iannis Xenakis (1922–2001) is practically inseparable due to his training as an architect, engineer, and composer. His music is unique and exciting because of the use of mathematics and logic in his compositional approach. In the 1960s, Xenakis began composing music that included spatial aspects—music in which movement is an integral part of the work. In this thesis, three of these early works, *Eonta* (1963–64), *Terretektorh* (1965–66), and *Persephassa* (1969), are considered for their spatial characteristics.

Spatial sound refers to how we localize sound sources and perceive their movement in space. There are many factors that influence this perception, including dynamics, density, and timbre. Xenakis manipulates these musical parameters in order to write music that seems to move. In his compositions, there are two types of movement, physical and apparent. In *Eonta*, the brass players actually walk around on stage and modify the position of their instruments to create spatial effects. In *Terretektorh* and *Persephassa*, Xenakis creates the impression of movement by transferring musical material between groups of musicians using techniques developed from musique concrète. These works are further innovative because of the unique seating arrangements in which the space for the performers and audience are superimposed.

In this thesis, graphical analyses of the three works under consideration are presented, demonstrating Xenakis’s early approach to spatial composition. The thesis builds on the work of other scholars and provides more insight as to how these fascinating pieces work.
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Chapter One

Introduction

Iannis Xenakis (1922-2001) holds a unique position in the history of twentieth-century music. Unlike other composers, Xenakis did not have a traditional musical education. Born in Romania and growing up in Greece, he studied civil engineering at the Technical University of Athens. As a result of the civil strife in Greece in the late 1940s, Xenakis fled to Paris where he was employed by Le Corbusier as an engineering assistant. While there, Xenakis approached several teachers, including Arthur Honegger, Darius Milhaud, and Nadia Boulanger in order to further his musical education; they all rejected him due to his unorthodox background, which they considered deficient. Xenakis subsequently turned to Oliver Messiaen, who allowed him to audit his classes at the Paris Conservatory. Messiaen told Xenakis, “You are almost thirty, you have the good fortune of being Greek, of being an architect, and having studied special mathematics. Take advantage of these things. Do them in your music.” With Messiaen’s encouragement, Xenakis developed a mathematical approach to composing music.

1. He quickly took on more responsibilities and eventually collaborated with Le Corbusier on his designs.


Because he integrates mathematical and architectural ideas into his works, Xenakis’s music is unlike that of any other composer. For him, architecture and music are fundamentally similar. Scholars use the same descriptions of genre and vocabulary to describe both music and architecture—words such as Renaissance, Baroque, and Modern, as well as texture, color, and shape. An architect refers to past building designs and unites construction materials and an artistic concept in order to create a building. A composer does the same thing: he unites sounds and durations with an artistic concept to create music. Johann Wolfgang von Goethe (1749–1842) once said, “Architecture is frozen music.” 4 In fact, music cannot exist except in space. Although most composers create their music by starting with a short musical fragment and then developing it, Xenakis wrote music as if he were constructing a building. He starts with a musical edifice, beginning with a preconceived notion of the entire piece, and then proceeds to fill in the details. The precompositional schemes (usually mathematical functions) that Xenakis used to generate his music can be viewed as the foundations to his “musical buildings.”

Much of Xenakis’s music relies on stochastic probability and symbolic logic. A stochastic process demonstrates a behavior that is non-deterministic but also not random. 5 With Xenakis, a probability function, such as one that describes a distribution of gas molecules, can be applied to various parameters of music, such as note densities, pitch ranges, dynamics, articulation, and timbre. Xenakis also applies symbolic logic in his

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5. Stochastic processes model the changes in a random system over time. At any given point, the exact calculation is randomly determined but in relation to a probability function that gives weight for selection of certain results.
pieces in a variety of ways. In what is termed symbolic music, Xenakis combines several pitch sets with Boolean algebra to create pitch groups to be used in his music. In a related process called sieve theory, Xenakis generates complex rhythms or pitch collections by combining multiple series of repeated modulus number sets with Boolean algebra.

This thesis will investigate how Xenakis uses idiosyncratic spatial effects in three of his compositions: Eonta (1963–64), Terretektorh (1965–66), and Persephassa (1969). Spatial sound refers to how we localize sound sources and perceive their movement in space. In fact, musical movement is a metaphor for spatial sound. In a literal sense, all music consists of the movement or displacement of air particles. Scholars such as Hugo Riemann (1887), Richard Cohn (1997), Fred Lerdahl (1994), and Dmitri Tymoczko (2011), among others, have written about musical movement in relation to melodic development as well as registral and pitch space. In the music of Xenakis, two other types of musical movement—physical and apparent—are primary. With physical movement, the motion of the musicians on stage causes the listeners to perceive the location of the sound sources as moving. In Eonta, the brass players actually do this, causing perceived sonic motion. Xenakis manipulates the musical material performed in conjunction with the physical movement to create planned spatial effects. Apparent

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6. Symbolic logic, or Boolean algebra, refers to the logical processes of complement, union (and), and intersection (or).

7. This does bring up the philosophical question of whether written or recorded music has movement.

motion is when stationary musicians “pass” musical material from one group of players to another so that the listener perceives a stationary sound source as moving. Xenakis implements this type of motion in *Terretektorh* and *Persephassa*.

Xenakis likewise achieves spatial effects through the use of dynamics and density. The harmonic content and dynamic level of a sound help the listener determine his or her distance in relation to that source. Using the concept of panning from *musique concrète*, Xenakis will have one group of instruments decrease in volume while another group playing the same musical material increases in volume. From the listener’s perspective, the music will appear to gradually move from the first group of instruments to the second. While dynamics help give an impression of distance, density provides the listener with an idea of size. The larger the number of musical events, the higher the density, and consequently, the larger the sound seems to be. The combined effect of dynamics, harmonic content, and density affect the musical texture. By manipulating these parameters, Xenakis can make the listener perceive music to sound closer or farther away, as well as thicker or thinner. By dynamically changing which group of instruments are playing combined with dynamic and density changes, Xenakis can move sound around the listeners and throughout the concert hall.

The three works analyzed in this thesis are singled out for two reasons. First, Xenakis wrote over 150 works in a span of about 50 years. By limiting this investigation to a short period of his output (fewer than six years), I can focus on the details of how Xenakis employs spatial concepts to shape and structure the sound of these works. Second, not all of Xenakis’s works focus on spatialization. Although spatialization was an integral aspect of his compositions in the 1960s, in several of these pieces, Xenakis
uses other precompositional processes to convey spatial effects. For example, in *Eonta*, *symbolic music* defines the pitch sets, which in turn are a major component of creating texture (an aspect of spatialization). In *Persephassa*, Xenakis organizes durations with a rhythmic pitch sieve. At various points in the piece, the complex rhythmic structure gives the impression of the ensemble going out of sync. This wash of sound from all sides of the audience is an important component of the spatial sound.

Some scholars, most notably Maria Ann Harley (1994), Boris Hofmann (2008), Helen Santana (2005), and Steven Sterken (2001), have previously discussed spatialization in the music of Xenakis. This thesis will extend their work, most notably by discussing the role that dynamics, density, and texture play in enhancing spatialization. As sonic movement is one of the primary musical features of works such as *Eonta*, *Terretektorh*, and *Persephassa*, it would be nonsensical to study these works without considering spatialization.

This thesis broadens the understanding of Xenakis’s music through an investigation of spatialization in three of his works. In addition to employing post-tonal analytical methods such as pitch set theory, I will use sonograms, graphs, and graphic notation to help clarify how Xenakis modifies various parameters of sound, such as dynamics, density, and timbre to create spatial music. Using examples from *Eonta*, *Terretektorh*, and *Persephassa*, I will show how Xenakis, in essence, writes music that moves.

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Following this introduction, Chapter Two of the thesis provides a theoretical context by considering some of Xenakis’s compositional practices and life experiences. Moreover, I shall place Xenakis’s spatial works into a historic context, especially by comparing them with those of his contemporaries. Chapter Three considers physical movement through an examination of *Eonta*, the major work in which musicians move around on stage. Chapter Four covers apparent sound movement by discussing how Xenakis moves sounds among different groups of instruments around and throughout the audience in *Terretektorh* and *Persephassa*. I will also discuss how Xenakis’s early experimentation with spatialization continues in his later works. Chapter Five will provide some concluding remarks and propose some directions for future study.
Chapter Two

Xenakis and Spatialization

Xenakis’s musical approach, which was based on mathematics, logic, and probabilities, was a product of his life experiences. As an engineer and architect, Xenakis thought about music in a manner different from his contemporaries, especially in his approach to spatialization. Before discussing that topic in his music, let us consider his background and the effects it had on his compositional style. After a brief discussion of Xenakis’s life, I will put his approach to spatialization into a historic context. I will also provide an overview of how the human auditory system localizes sound before introducing my approach to analyzing Xenakis’s early spatially oriented compositions.

Iannis Xenakis

Iannis Xenakis was born on May 29, 1922 in Brăila, Romania.1 His mother, Photini, introduced him to music at an early age. She was an accomplished pianist who owned a large number of piano scores. Xenakis’s father, Clearchos, a successful businessman, occasionally took his family to Paris and Bayreuth to see operas. When Xenakis was five years old, his mother became sick during her fourth pregnancy. Both she and the baby died, emotionally scarring the young Xenakis. Xenakis’s mother had given him a flute and wished that he would enjoy music, setting the stage for his future

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vocation. After his mother died, Xenakis’s father poured himself into his work, leaving
his three sons, of whom Xenakis was the eldest, to be brought up by a series of
governesses.

At the age of ten, Xenakis was sent to a boarding school in Spetzai, Greece where
he spent the next 6 years of his childhood. Other boys made fun of him because of his
accent, and he was frequently made the butt of practical jokes. In his isolation, Xenakis
immersed himself in the school’s library, reading everything from Greek classical
literature to Shakespeare. Later, he developed a relationship with the new headmaster,
Esmeade Noël Paton, who encouraged Xenaki’s love of music. Paton owned a
phonograph, and it was at this time that Xenakis first heard the music of Beethoven and
other European composers. He also sang in the school’s choir, took piano lessons, and
studied harmony.

Xenakis left Spetzai at the age of sixteen to go to Athens to prepare for the
engineering entrance exam at the Athens Polytechnic Institute. In addition to studying
math, physics, law, and literature, he studied harmony and counterpoint with Aristotle
Kondourov. After failing the entrance examination twice, Xenakis finally succeeded in
getting accepted to the Polytechnic, but his studies were repeatedly interrupted by World
War II. Xenakis, along with other students, was actively involved in the resistance
movement, wanting to see Greece freed from invaders.² Throughout the course of the
war, Xenakis was imprisoned several times, and in December 1944, in an encounter with

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² Italy invaded Greece in 1940, followed by Germany in 1941. The Italians withdrew in 1943
and the Germans in 1944. The British Army arrived later in 1944.
the British, a mortar explosion nearly killed him. He survived, but the explosion permanently damaged the left side of his face and he lost his left eye.³

Despite the war, Xenakis completed his engineering degree in 1946, nearly seven years after he began his studies. After the election in March 1946 when the right-wing government came into power, Xenakis was forced into hiding because of his involvement in the resistance movement and the Greek Communist party. After several close encounters, Xenakis’s father secured his passage to Italy in 1947. With help, Xenakis illegally entered France in November. He wanted to continue to the United States in order to study music and physics but was unable to because he had no papers and no money. Between the separation from his country and family, imprisonment and wounds from the resistance movement, and the betrayal Xenakis felt from his friends and the Greek Communist party, Xenakis was depressed and disillusioned by politics and society in general.

Xenakis was able to use his engineering degree to get a job working for the architectural firm of Le Corbusier, where he continued to work until 1959. Initially, Xenakis was an assistant doing calculations, but over time, he was able to have a larger role in the creative process.⁴ Le Corbusier encouraged Xenakis to study music in addition to working for him as an architect, and ended up citing two of Xenakis’s projects in his writing about the *Modulor* (golden ratio). Xenakis and Le Corbusier had a falling


out over time as Xenakis increasingly wanted to be credited for his work, especially for his design of the Phillips Pavilion for the Brussels World’s Fair in 1958.

While working for Le Corbusier, Xenakis wanted to continue studying music. After being rejected by Nadia Boulanger and having personal disagreements with Arthur Honegger and Darius Milhaud, at the suggestion of Le Corbusier, Xenakis approached Oliver Messiaen. When he was able to go, Xenakis audited Messiaen’s class at the Paris Conservatoire between 1951–53, where he learned about Messiaen’s compositional approach. It was also in Paris that he met other students of Messiaen, such as Pierre Boulez and Karlheinz Stockhausen. Messiaen’s wide musical interests must have appealed to Xenakis, and as an auditor in Messiaen’s class, Xenakis was exposed to an enormous amount of music. Indeed, according to Ronald Squibbs, the theoretical basis of much of Xenakis’s music can be viewed as an extension of Messiaen’s work.

In the 1950s, Xenakis became interested in musique concrète. He sought out Pierre Schaeffer of the Groupe de Recherche de Musique Concrète, but Schaeffer did not respond until Xenakis sent him a copy of one of his scores. Since Schaeffer did not read music, he told Xenakis that he would show it to Pierre Henry if Messiaen would write a letter on his behalf. At the time, Henry was preparing for a concert of Edgard Varèse’s Deserts, conducted by Hermann Scherchen. Over time, Xenakis developed a special relationship with Scherchen, who later premiered several of his orchestral works and served as a mentor to the young composer until his death in 1966.


Beginning in the 1950s, Xenakis began to publish his musical theories. Articles such as “La crise de la musique sérielle” (The Crisis of Serial Music) of 1955 and “Elements de musique stochastique” (Elements of Stochastic Music) of 1960 first appeared in the *Gravesaner Blätter* before being collected into the first edition of *Musique Formelles* (1963).7 In addition to his musical compositions and architectural projects in later years, Xenakis taught at several universities, including Indiana University and Université de Paris. Throughout his life, Xenakis wrote works for all instrument families, which include solo, chamber, and large ensemble compositions. He is also well known for his research in computer-assisted composition.

*Overview of Spatialization in Music*

Although spatial music is generally considered an outgrowth of twentieth-century compositional approaches, its roots are much older.8 Timothy Schmele points out that space has always been an intrinsic component of music.9 Tribal dance music is among the earliest type with spatial qualities. Dating back several thousand years, a singing dancer’s movements create a mobile sound source. Nearly equally old, antiphonal music (call and response music) also exists in many cultures. This type of music is intrinsically spatial, as it requires at least two sound sources located in different places.

Early spatial music was also an important tool for communication and a vehicle for religious experiences. In Africa, New Guinea, and Central and South America,

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8. This section consists of a survey of spatial music. Many composers produced interesting spatial effects, and a comprehensive list of such composers and their works goes far beyond the scope of this thesis. Additionally, film music and developments that took place after Xenakis will not be discussed.  

people transmitted messages through drum telegraphy. Throughout Europe, alpenhorns were used to communicate messages in mountainous landscapes. In Christian traditions, church officials ordered the tolling of bells to announce services, festivals, events, and even the time of day. In Islamic traditions, horns were sounded from the top of minarets as a call to prayer.

The religious significance of spatialization predates Islamic and Christian traditions. The peculiar effects that natural architectures imposed on sound frequently took on spiritual or religious importance. For example, the effects of sand and wind in the desert or the bizarre echoes heard in caves were frequently misinterpreted by ancient people as coming from deities. In his book entitled *Spaces Speak: Are You Listening?*, Berry Blesser speculates about an early human searching for food and discovering an opening in a mountain that leads to a vast cavern. Sounds that the human made would be transformed by the echoes inside the chamber, making it seem as if the cavern were speaking. Without a scientific explanation, it would be easy to explain the acoustical properties as the cave being alive.

Steven Waller, an acoustic archaeologist, has discovered that there is a correlation between prehistoric cave art and the caverns within which the art appears. Caves that possess strong echoes, which could create percussive hoofbeat-like sounds, were more likely to have paintings of bulls, bison, and deer whereas acoustically silent caves were

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10. Talking drums work by playing a message on a drum that produces loud, low frequencies. When people hear the message, they repeat it from their location to continue the transmission of the message.


more likely to contain drawings of felines. Scholars have suggested that the supernatural phenomena (acoustic effects) were supposed to help attract animals to be hunted.

A discussion of spatial developments would be incomplete without a discussion of ancient Greece, where important developments in philosophy, architecture, and music took place. Arjan de Nooijer has suggested that the Greek interest in string length ratios\(^\text{13}\) and the application of geometry to music, astronomy, and architecture meant that they likely discovered strong connections between music and architecture.\(^\text{14}\) In fact, when discussing a recording she made in the Oracle Chamber in the Hypogeum at Hal Salfieni, Malta, Jennifer Berezan said that “I was singing inside the earth, in a place that had been used for thousands of years for ritual, for oracles, for prophecy. It was obvious that the people who had built it had an incredible understanding of acoustics and the value and power of sound for healing….”\(^\text{15}\) Schmele writes, “Being written for a specific architectural structure, the music becomes (just like the architecture itself is) a spatial piece of work.”\(^\text{16}\)

Spatial approaches to music took a huge leap forward at the end of the fifteenth century when composers started using two spatially separated choirs, a technique called

\(^{13}\) The length of a string determines the pitch that it will produce when plucked. Pythagoras is credited with discovering that simple ratios relate to specific harmonies. He constructed his scale by stacking perfect fifths, which have a ratio of 3/2.


\(^{16}\) Original emphasis. Schmele goes on to say that site-specific composition is one of the prime inspirations for spatial music. See Schmele, “Exploring 3D Audio as a New Musical Language,” 11.
This technique was popularized further by sixteenth-century composers such as Adrian Willaert (1490–1562) and Andrea Gabrielli (1532–1585) at St. Mark’s in Venice, where the combination of a long reverberation time and two spatially separated organs and choir lofts were used. Over time, composers refined their use of cori spezzati at St. Mark’s by employing dynamic, verbal, and other effects utilizing spatial separation. By the early seventeenth century, this technique had become quite common throughout Europe. Notable works include Thomas Tallis’s *Spem in Alium* (1573) composed for the fortieth birthday of Queen Elizabeth I using 40 separate vocal parts split into eight five-voice choirs, and Orazio Benevoli’s 48-voice Mass (1650) scored for 12 choirs, two organs, and basso continuo. Between the mid-seventeenth and eighteenth centuries, antiphonal writing became rare, although there were a few exceptions, such as Bach’s *St. Matthew's Passion* (1729).

Schmele argues that although composers during the Classical period were not particularly interested in spatial antiphony, large-scale operatic works such as Mozart’s *Don Giovanni* (1787) demonstrate spatial characteristics. As with some of the unintentional spatial effects discussed earlier in this section, opera and musical theatre are inherently spatial, as the actors speak and sing from different points on the stage and frequently move while talking.

In the Classical period, there are a few examples of intentional spatial effects in symphonic music. The use of offstage musicians, a technique that would become popular in the late Romantic period, was sometimes used for dramatic effect. In Christoph

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Willibald von Glück’s *Orfée et Euridice* (1762), the composer calls for a second orchestra to be located *derrière le théâtre* (“behind the theatre”) to separate the underworld from the earthly world. Consequently, the offstage ensemble evokes a sense of distance and depth. Two other examples of intentional spatialization during the Classical period are Mozart’s *Serenada Notturna* (1776) for two orchestras and *Notturno* (1777) for four orchestras. In both works, Mozart employs sophisticated echo effects between the ensembles by using motivic repetition in conjunction with diminishing dynamics and the use of mutes to darken the timbre. Karlheinz Stockhausen dismisses Mozart’s use of spatialization by labeling it mere amplification of previously established echo repetitions.\(^{19}\)

In his dissertation, Jason Solomon considers unintentional spatialization in music.\(^{20}\) In his analysis of Beethoven’s Quartet in C-sharp minor (1826), Solomon points out motivic repetitions, places where there is interplay between two or more musicians, and gestures that wrap around the ensemble. While Beethoven probably never considered spatial effects in his music, they are still audible to the listener.\(^{21}\)

Conscious uses of spatialization do not reoccur until the middle of the nineteenth century with Hector Berlioz’s *Requiem* (1837), which makes use of four trumpet ensembles surrounding the audience. These groups serve the programmatic purpose of representing the Apocalyptic trumpets of the Last Judgment. Although Berlioz was clearly thinking about the use of space in music (he referred to it as “architectural

\(^{19}\) Karlheinz Stockhausen, “Musik Im Raum,” *Die Reihe* 5 (1957): 67.


\(^{21}\) In Beethoven’s time, the order of where musicians in a string quartet sat was not yet standardized. Solomon points out that the spatial impression is most effective when the musicians are spaced widely apart from each other and that changing the order of musicians affects the spatial effects.
music”), the spatial distribution of the performers in this case is largely for dramatic effect and is not a critical feature of the work.

As mentioned above, another major development in the nineteenth century was the use of offstage instruments. Composers such as Gustav Mahler would place musicians offstage to complement the sounds of the orchestra. In his Symphony No. 2 (1893–94), he wrote for an offstage ensemble consisting of trumpets, horns, and percussion. Like Berlioz and Gluck, Mahler’s instrumentation has symbolic meaning as the onstage flutes represent the birds singing on earth while the offstage ensemble consists of otherworldly sounds of the Apocalypse.

Charles Ives, who was a contemporary of Mahler, took a similar approach to spatialization. His music can be seen as a complex mix of musical layers. Ives used spatial separation frequently by placing musicians offstage as a means of increasing the contrast of these layers. In The Unanswered Question (1906), Ives contrasts the onstage trumpet and woodwinds with an offstage string quartet. These three distinct sound layers play in different tempos and keys and use different timbres, spaces, and tonalities to achieve Ives’s goals.

Henry Brant (1913–2008) went a step beyond Ives in his use of spatialization, basing much of his compositional methodology on spatial intent. More than half of his compositions have specific spatial instructions. Brant wanted to clarify dense textures through spatial separation, which he achieves by locating instruments with similar timbres near each other in specific, spatially separated locations. As an example, in his Antiphony I (1953), the orchestra is divided into five instrumental groups (strings, percussion, woodwinds, horns, and brass), each located in a different area of the concert
hall. He is also mindful of the differences in the acoustics of concert halls, and specifies how to modify the ensemble’s set up to create the sounds he wants.

In *Millennium II* (1954), Brant uses an effect that he calls *travel and filling-up*. Scored for 10 trumpets and 10 trombones, the instrumentalists form lines along the sides of the performance space. Brant composes music that moves down the length of the ensemble, generating sonic trajectories that fill the hall. Some of his later compositions get extremely complex both in terms of ensemble size and spatial consideration. *Meteor Farm* (1982) is written for symphony orchestra, large jazz band, two choruses, West African drum ensemble and chorus, South Indian soloists, large Javanese Gamelan ensemble, percussion orchestra, and two solo sopranos, and *Brant aan de Amstel* (1984) is written for multiple ensembles located around the city of Amsterdam, including four ensembles floating through the canals.22

The development of new technology was one of the biggest factors for why twentieth-century composers explored spatialization in their music. The invention of the loudspeaker, dating back to the 1860s, meant that sound could be projected from any point a loudspeaker could be mounted. At the 1881 Paris World’s Fair, Clément Ader transmitted binaural concerts from the Paris Opera House to the Fair using two telephone receivers, predating Alan Blumlein’s development of a microphone technique for recording stereophonic sound in the 1930s. For recordings, stereophonic (stereo) sound was quickly adopted and is still the most commonly used format today. A few years later, Walt Disney developed the first surround sound system, called *Fantasound*. Other multi-channel speaker setups were later developed and used, such as quadraphonic sound,

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22. A similar work was written previously by Arsenij Avraamov called *Simfoniya Gudkov* (1922) for the fifth anniversary of the Soviet Union. The work included multiple ensembles and the entire Soviet flotilla in the Caspian Sea.
octophonic sound, and 5.1 surround sound. In France and Germany, and spreading to other countries, musique concrète (associated with Pierre Schaffer and Pierre Henry) and elektronische Musik (associated with Karlheinz Stockhausen and Michael Koenig) developed new technologies for spatializing sound.

Stockhausen (1928–2007) was one of the first composers to serialize space as a parameter of music in the same way as pitch, duration, and articulation. In Gesang der Jünglinge (1956), written for a six-channel sound system, Stockhausen projected sound throughout the performance space, making space a key feature of the work. In later works such as Kontakte (1958–60), Stockhausen further developed his spatial techniques by creating detailed sound trajectories. He also wrote pieces such as Gruppen (1955–57) for three orchestras in which he used spatial effects in acoustic works. For the Osaka World Fair’s in 1970, Stockhausen worked with the architect Fritz Bornemann to design the German Pavilion, which housed a spherical concert hall containing 50 loudspeakers in seven rings around the audience. Stockhausen and other composers performed works that utilized this incredible sound system. In his opera Licht (1977–2002), Stockhausen’s approach to spatialization becomes comically theatrical as he has musicians performing on trampolines, flying harnesses, and in helicopters, among other such feats.

Pierre Boulez and Luigi Nono, contemporaries of Stockhausen, were also interested in spatialization. Unlike Stockhausen, Boulez thought that spinning sound around the audience was too theatrical and detracted from the music. Boulez modifies the spatial effect of ensembles by having players relocate themselves within the group.

23. It became five channels due to technical difficulty, and was later mixed to four channels and then two channels because there were no five-channel sound systems.

24. These repositions take place silently and one musician at a time.
Nono developed his opinions on space at a much later time than Boulez and Stockhausen and took his inspiration from the city of Venice. Nono creates the space itself by composing with timbre, rather than placing sounds in space.

Other composers, such as Erik Satie, Edgard Varèse, and John Cage also composed spatial music, and in the twenty-first century, composers still consider sound localization in their work. In Satie’s *Furniture Music* (1917), the composer wanted music to be like wallpaper, visible (audible), but not the focus of the audience’s attention. Both Satie and Cage were interested in having audience members walk around during performances in order to experience their artworks. Varèse’s *Poème électronique* (1958), composed for the Phillip’s Pavilion (designed by Xenakis) and with visuals designed by le Corbusier, was played on a sound system consisting of more than 350 speakers arranged throughout the pavilion—a tour de force in electronic music. Now advances in technology and audiology have made spatial considerations a primary feature of much new music.

*Spatial Hearing*\(^{25}\)

The process of human hearing is truly remarkable. Gareth Loy writes, “The ears detect, analyze, and classify biologically interesting sounds: they compile spectral and temporal information of incoming signals, parse them into various sources, localize these sources in time and space, and construct a model of the auditory scene that surrounds

us.” The human ear consists of three sections: the outer, middle, and inner ear. The pinna (outer ear) helps collect sounds from around the listener, and in addition to the head, torso, and distance between the two ears, helps determine where sounds sources are located. The middle and inner ears transduce vibrations in air into mechanical and eventually neural impulses that the human brain can understand.

There are a variety of factors that facilitate the identification of from where sounds come. Between physical properties (e.g., ear placement, size and shape of the head, pinna, and torso, etc.) and a cognitive framework, humans have developed the ability to identify basic acoustical properties of sound sources (e.g., size, rate of motion/acceleration, type of source, etc.). John Strutt, the third Baron Rayleigh, speculated that if a sound source is located to the side of a receiver, the closer (ipsilateral) ear would receive a louder signal than the other (contralateral) ear. He also realized that higher frequencies decrease in amplitude more quickly than lower frequencies when diffracting around an object, such as the head. Rayleigh grouped these two properties (intensity and diffraction) together and called it the interaural level difference (ILD). Because this theory does not explain why we can localize sounds lower than ca. 500 Hz, there must be more to this situation. Continuing his research, Rayleigh theorized that the difference in phase between the sounds arriving to the two ears, called the interaural time difference (ITD), might also have an effect. These two hypotheses are grouped together and termed the duplex theory because they work together. ILD helps explain why we can localize

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27. This is based on the fact that the sound must travel a longer distance to reach the second ear, and intensity decreases over distance (at the rate $I = P/m^2$, where $I$ is intensity, $P$ is power, and $m$ is distance in meters).
sound sources above ca. 500 Hz (and improves as frequency increases, becoming reliable around three kHz) and ITD explains the localization of sounds below ca. 1000 Hz.\textsuperscript{28}

When sound propagates in a space, it reflects off surfaces, and our ears pick up both direct sound and reflected sound. We tend to localize the first sound wave to hit our ears as the direction from which the sound came. Since the path of the direct sound to our ears is usually shorter than any reflected path, this first wave front usually conveys useful information for localization. The length of time that the human auditory system receives these reflections gives us information about distance (how far away a sound source is) and size (how large a sound source is).

\textit{Methodology}

Because Xenakis had a nontraditional musical education, I will take a similar nontraditional approach to analyze his music. His works, which are created using mathematical calculations and stochastic processes, create masses of sound that evolve throughout the duration of their appearance. In many respects, Xenakis is a timbral composer who wrote with sounds, not notes. Because of this, analytical techniques such as pitch-class set theory are not particularly helpful for analyzing his music. Additionally, as this thesis focuses on Xenakis’s approach to spatialization in some of his early works, the position and movement of the musicians play an important role in his music.

Furthermore, Xenakis’s background as an architect informed his conception of his compositions. Many of his scores could stand alone as visual art.\textsuperscript{29} Similar to Xenakis’s

\textsuperscript{28} Neither theory works particularly well around two kHz, and our ability to localize around two kHz is not very good either.
sketches, this thesis is a visual document. I use a variety of techniques for graphically displaying elements from Xenakis’s music, including harmonic and rhythmic reductions, diagrams that show where the musicians are located, and how the music moves from location to location. I also show charts and tables to help explain the formal organizations of the works.

Color also plays a role in my analysis of works by Xenakis.30 By using colored notes in musical excerpts or colored graphs, I can demonstrate multiple things in a single diagram. I hope that the color never detracts or complicates the analysis; rather, that color enhances and clarifies my interpretations.

Analytical techniques frequently applied to electroacoustic music, such as sonagrams, which display time, frequency, and amplitude, and frequency-amplitude graphs, help illustrate timbral changes. These types of graphs show how the harmonic content of a note or passage of music evolves over time.

Before we examine Xenakis’s music, let us first look at two significant theoretical aspects of his compositional practice, symbolic music and sieve theory.

Symbolic Music

To compose works such as Eonta, Xenakis uses a technique that he created and termed symbolic music, which shares some similarities with pitch-class set theory but is in many respects different. For him, a set is an unordered collection of pitches. In the case of works such as Eonta, octave equivalence does not play a role in the formulation

29. The Drawing Center in New York put on an exhibition in 2010 displaying some of Xenakis’s scores, architectural plans, and sketches, which later went on tour around the United States.

30. If the document you are reading is not in color, contact the Penn State School of Music in order to get a version printed in color.
of these sets. For example, let us say that set A contains the pitches C4, E4, and G4 and set B contains the pitches C3, E4, and G4; they are not equivalent in Xenakis’s theory. Moreover, many of Xenakis’s sets are generally distinguished by non-duplication at the octave.

Xenakis composes symbolic music by using pitch sets to structure a composition. Unlike serial pieces, he chooses which notes from a given set to use and in what order they will appear. What is more, Xenakis does not use every pitch from a set before moving on to another set; rather, he employs pitch sets in a manner similar to the way Messiaen uses his *modes of limited transposition*—a pitch set represents a palette of notes with which Xenakis can compose a section of a piece. Throughout the next several paragraphs, I illustrate how this theory of symbolic music works.\(^3\!

The main premise driving this theory is the use of Boolean algebra applied to pitch sets. Boolean algebra relies on the processes of union, intersection, and complementation to combine sets. To illustrate these principles, let us consider three small sets labeled x, y, and z, respectively.\(^3\!

For Xenakis, the referential set contains all possible pitches playable on a grand piano.\(^3\!

To simplify matters, let the referential set z contain only 12 notes, from C4 to B4. All of the pitches in sets x and y will both contain


\(^3\!\) The sets used in these examples are not derived from Xenakis.

\(^3\!\) Eighty-eight notes ranging from A0 (27.5 hertz) to C8 (4186.01 hertz). In *Eonta*, Xenakis calls the referential set \(Σ\).
pitches common to z, but they may also contain pitches that overlap one another. Let us define set x as the seven-note collection [0, 4, 5, 7, 8, 9, 11] and set y as the nine-note collection [0, 1, 3, 5, 6, 8, 9, 10, 11] (see Example 2.1 on p. 25; also located on this page are Examples 2.2–2.4).\footnote{In this thesis, I use pitch integer notation to represent pitches in the music of Xenakis. Thus, C4 is 0, B3 is -1, C#4 1, Bb3 -2, D4 2, etc.}

The intersection of two sets refers to the elements common to both sets.\footnote{Xenakis and those who have written about his symbolic music have not been consistent in their use of symbols to denote intersection, complementation, and union. Xenakis and some scholars, such as Montague, notate intersection as $A \cap B$, union as $A + B$, and complementation as $-A$ (or sometimes $A$ with a bar on top). (For bibliographic citations of the authors mentioned in this explanation, see n. 31.) Squibbs and Wannamaker simplify Xenakis’s notation by using $AB$ for intersection, $A+B$ for union, and $A$ with a bar for a complement. Chrissochoidis, Houliaras, and Mitsakis simplify Xenakis’s notation in a different way by writing intersection as $AB$, union as $A + B$, and a complement as $-A$. In traditional set theory, and sometimes in Xenakis’s writing, the symbols $\cap$ (or $\wedge$) for intersection, $\cup$ (or $\vee$) for union, and $\neg$ for complement are used. To simplify matters, I have attempted to write things out in prose wherever possible. When this is not possible, such as in Table X, I have opted to use $AB$ for intersection, $A+B$ for union, and $-A$ for complement.}

This concept is the process of conjunction. In Xenakis’s theory of symbolic music, the intersection of two pitch sets creates a subset containing the pitches common to both sets. In its simplest form, the intersection of a set and itself (e.g., x and x) or the intersection of a set and the referential set (e.g., x and z) both generate the original set. Things are little more interesting when two sets with some similarities and some differences intersect. For example, the conjunction of sets x and y is [0, 5, 8, 9, 11] (see Example 2.2). The union of two sets refers to the collection of all the elements contained in both sets. This is the process of disjunction. An example would be the union of sets x and y, which creates the collection of pitches: [0, 1, 3, 4, 5, 6, 7, 8, 9, 10, 11] (see Example 2.3). Note that this collection of pitches does not include the pitch D4, as it does not appear in either set x or y.
Example 2.1: Sets x, y, and z

Example 2.2: The conjunction of sets x and y. The red notes are pitches of x that are part of x•y and the blue notes are pitches of y that are part of x•y. All the pitches of x•y are shown in purple because they are common to both sets x and y.

Example 2.3: The union of sets x and y. The red notes are pitches of x that are part of x+y, the blue notes are pitches of y that are part of x+y. Purple notes are notes that are part of both x and y in x+y.

Example 2.4: The complement of x. Pitches in red are notes of set x.

Complementation, or negation, is the third major aspect to this theory. The complement of a set refers to all the pitches not contained in that set. For example, the complement of set x, or the pitches of ‘not x,’ are [1, 2, 3, 6, 10] (see Example 2.4). The complement of a set relies on the definition of the referential set. Since in this example the referential set is only one octave, there are only five notes that are not contained
within set x. Were our definition of the referential set 88 notes, the complement of x would contain 81 notes.

The fundamental operations of symbolic logic (intersection, union, and complementation) can be combined with each other in more complex expressions to form a greater number of subsets. For example, the intersection of x and the complement of y results in the pitches [4, 7] and the union of the complement of x and y results in the pitches [0, 1, 2, 3, 5, 6, 8, 9, 10, 11]. In some works, such as Herma (1961), Xenakis uses three pitch sets to increase the number of operational combinations. In Eonta, Xenakis chooses two sets, called Θ and Ψ, in addition to the referential set Σ (see Example 2.5). Xenakis marks where sets change throughout the score to aid in its analysis.36

Sieve Theory

In the early 1960s, Xenakis began developing a technique that he called sieve theory for generating sets based on sequences of repeating integers.37 These sieves could then be used as pitch collections, rhythms, dynamics, or other parameters of music. For Xenakis, a sieve represents a collection of integer points on a straight line, generated by the combination of two or more modules or residual classes combined with logical operators. A module is an ordered pair \((M, I)\) that designates a modulus (period) and a transposition level (an integer between zero and \(M-1\)).

36. There are many mistakes in the score and in the construction of the sets, probably derived from Xenakis’s miscalculations and mistakes in the publishing process.

Example 2.5: Pitch sets from *Eonta*

For example, in Xenakis’s sieve theory, the chromatic collection could be written as (1, 0) where the unit is pitch in semitones. This generates the series of pitches (...0, 1, 2, 3, 4, 5...). Likewise, the two whole-tone collections could be written as (2, 0) or (2, 1), which generate the collections (...0, 2, 4, 6, 8...) and (...1, 3, 5, 7, 9, 11...) respectively. More complex sequences of integers can be written using the processes of intersection, union, and complementation. Thus, an octatonic collection can be written as the union of (3, 0) and (3, 1), which generates (...0, 1, 3, 4, 6, 7, 9, 10...).

Multiple sieves can also generate the same sequence of integers. In *Formalized Music*, Xenakis writes that a C-major scale can be generated by the union of (12, 0), (12,
James Harley generates the same C major scale through the following sieve: 
\[ (3, 2) \cap (4, 0) \cup (- (3, 1) \cap (4, 1)) \cup ((3, 2) \cap (4, 2)) \cup (- (3, 0) \cap (4, 3)). \]

Accordingly, sieves generate sequences of integers where their intervallic structure repeats at some modulus. This theory can be viewed as an outgrowth and expansion of Messiaen’s modes of limited transposition. Xenakis’s theory, unlike Messiaen’s, can be applied to generate pitch sequences that repeat at some interval other than the equally tempered chromatic octave. Xenakis frequently uses sieves where the unit is quarter-tones instead of semitones, or generates pitch sieves that repeat at some interval other than the octave. Sieves can also be applied to other musical properties, such as rhythms. The integer output of a sieve can be used as a series of durations to be used in a musical work, such as *Persephassa*.

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Chapter Three

Physical Movement in *Eonta*

*Eonta* was written in Berlin in 1963–64 and was premiered in Paris in December 1964 by the Ensemble du Domaine Musical conducted by Pierre Boulez. The title, which means “beings,” is a tribute to Parmenides.¹ In *Eonta*, Xenakis uses symbolic logic and stochastic principles to generate musical materials for the piece. Scored for piano, two trumpets, and three tenor trombones, this work is characterized by the spatial positioning of the instrumentalists. Throughout the piece, the brass players are directed to perform from specified locations on the stage and direct the bells of their instruments in different directions.

*Spatial Movement in Eonta*

The physical movement of the instrumentalists on stage throughout *Eonta* means that the listeners in the audience perceive musical motion because of timbral modifications imposed on the music by the room.² This perceived movement is distinguished by two types: a stationary source and a moving source. In the first type, the musician remains stationary but modifies the timbre and dynamics of his/her instrument, as well as the direction that it points to create a sense of motion. In the second type, the performers move the location of their instruments by walking to different parts of the stage.

¹. Parmenides was a fifth century BCE Greek philosopher.

². The correlation of visual and auditory components reinforces the perception of movement; however, the timbral effects are sufficient for most listener to experience the movement.
stage. In addition to experiencing timbral and dynamic modulation, the listener also perceives the movement of the sound created from the changing locations of the performers.

For example, let us consider the first entrance of the brass instruments. Xenakis instructs the performers to point the bells of their instruments toward the ground and enter at a very quite volume (ppp). Over the span of approximately 18 seconds, they slowly raise the bells of their instruments to point toward the audience in conjunction with a crescendo to a forte dynamic (see Figure 3.1). Although pitch and articulation remain unchanged, the volume and timbre change with both the 90-degree change in angle and the crescendo.

**Figure 3.1:** Bell movement at the first brass entrance (mm. 40–48)

In order to understand how the harmonic content of a brass instrument’s timbre changes with dynamics and bell position, I recorded the first trumpet part from mm. 40–
48 in a near anechoic environment.\(^3\) The first trumpet part is reproduced in Example 3.1, which also shows a series of graphs that are successive snapshots of the same recording with frequency along the X-axis and amplitude along the Y-axis. The five images show change over time throughout the duration of the audio sample. The third graph in Example 3.1 is a sonogram that displays time along the X-axis, frequency along the Y-axis, and amplitude with color. In this recording, the overall RMS amplitude changes by more than 25 decibels throughout the course of the note.\(^4\)

Throughout the duration of the C4, more partials become audible. By looking at either the sonogram or successive slices of the frequency graphs, it is clear that higher frequency harmonics emerge over time. Additionally, the ratio of amplitudes from partial to partial change over the span of the note. For example, at the beginning of the note, the first and second partials are of near equal amplitude. A short time later, the second partial becomes slightly louder than the first partial. Starting in the third slice, the first several partials cease to become louder and remain at the same amplitude while the higher partials continue to rise in amplitude.

Although the sonograms and frequency graphs are not displayed here, I also conducted tests that isolated both the brass-instrument bell movement and air-stream crescendo. In both cases, the overall volume level and spectrum change was less

\(^3\) An anechoic chamber is a room where all surfaces, including the floor and ceiling, are covered with foam wedges that absorb nearly all sound reflections. All recordings were made with the bell of the trumpet positioned one meter away from the test microphone. Moreover, the trumpet part was recorded multiple times for consistency, and was captured at a high sample rate and bit depth.

\(^4\) RMS, or root-mean-square is a calculation that takes into account a signal of varying magnitude. Since sound waves consist of a series of compressions and rarefactions of air molecules, the magnitudes are both positive and negative. Without calculating the RMS, the average would be approximately zero.
Example 3.1: Example 3.1 includes mm. 40–48 of *Eonta*, a series of frequency-amplitude graphs, and a sonogram showing time, frequency, and amplitude.
extreme.\textsuperscript{5} It is important to note that the frequency response will be different for every individual brass instrument, performer, and performance space. These recordings were made in an anechoic chamber in order to remove the effect that any particular room would have on the sound. In almost all situations the characteristics of the stage and concert hall will affect the amplitude and frequency components of the produced sound.

In the second brass entrance in mm. 55–80, the musicians are directed to rotate in circles while keeping the bells of their instruments parallel to the floor. This movement is similar to the one taking place between mm. 40–48, although there are some key differences. First, instead of a 90-degree rotation from the bell of the instrument pointed at the floor to the bell pointed at the audience, the rotation is a full 360-degree movement in a different plane. For the brass players, turning in a circle will not affect their horn playing in the same way that collapsing their chest and moving their neck will. Second, the opening rotation was accompanied by a steady crescendo while the later passage is separated from the dynamic changes. The dynamics, which are stochastically calculated, do not appear to be synced with the instrumental rotations. Finally, in the first brass entrance, all five musicians perform the crescendo/rotation in unison. The rotations throughout the second entrance are not synchronized.

Benny Sluchin, a trombonist who has premiered some of Xenakis’s music, points out that the second chord is characterized by independent dynamic fluctuations and a global dynamic profile.\textsuperscript{6} The dynamic markings for the brass instruments in the first five measures of the second chord (mm. 55–59) are shown alongside the overarching dynamic

\textsuperscript{5} When the crescendo was isolated, the RMS amplitude change was less than 20 decibels. In the test looking at movement, the RMS amplitude changed less than 12 decibels.

profile in Figure 3.2. Each instrumentalist plays a series of short crescendos and decrescendos that have their own timing and volume level. When grouped together as an ensemble, the overall goal for the brass chord in this passage is a longer crescendo-decrescendo-crescendo effect. The surface-level dynamic changes create a richer texture than that of a simple, synchronized dynamic contour.

**Figure 3.2:** The dynamic profile of mm. 55–59 along with the surface level dynamic fluctuations

<table>
<thead>
<tr>
<th>ppp</th>
<th>ppp &gt; mp</th>
<th>pp &gt; mf</th>
<th>p &gt; f</th>
<th>mf &gt; ff</th>
<th>f &gt; f</th>
<th>f &gt; fff</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppp</td>
<td>p &gt; pp</td>
<td>mf &gt; mp</td>
<td>f &gt; mf</td>
<td>ff &gt; f</td>
<td>f &gt; fff</td>
<td></td>
</tr>
<tr>
<td>ppp</td>
<td>p &gt; pp</td>
<td>mf &gt; mp</td>
<td>f &gt; mf</td>
<td>ff &gt; f</td>
<td>f &gt; fff</td>
<td></td>
</tr>
<tr>
<td>ppp</td>
<td>p &gt; pp</td>
<td>pp &lt; mf</td>
<td>p &lt; f</td>
<td>mf &lt; ff</td>
<td>ff &gt; f</td>
<td>f &gt; fff</td>
</tr>
<tr>
<td>ppp</td>
<td>p &gt; pp</td>
<td>pp &lt; mf</td>
<td>p &lt; f</td>
<td>mf &lt; ff</td>
<td>ff &gt; f</td>
<td>f &lt; fff</td>
</tr>
</tbody>
</table>

Along with the fluctuating dynamics, the brass players rotate independently from one another, keeping the bells of their instruments parallel to the ground. These rotations affect the timbre of the brass instruments because the sounds they produce are highly directional.⁷ Figure 3.3 shows when the brass musicians rotate in comparison to the dynamic profile for the second chord.

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⁷ Both amplitude and the harmonic content of a brass instrument’s sound are products of where the receiver (listener) is located in relation to the bell of the instrument. An on-axis receiver will hear a louder sound with louder higher partials than an off-axis receiver.
Figure 3.3: The brass rotations through mm. 55–80 compared to the dynamic profile.

During mm. 80 and 81, the brass players move from their line along the back of the stage in order to stand around the body of the piano. Their third entrance, mm. 82–92, is performed into the piano. The staccato articulations and loud dynamics excite the piano’s strings, heightening the resonance of the sound, resulting in a timbral effect.

Taken as a whole, the brass players perform three chords between mm. 40–92 of Eonta. In each subsequent chord, the musicians develop the timbre of their instruments through their movement of the bell position and the dynamic level. As they progress through the three chords, the width of each chord becomes more widely spaced. Example 3.2 summarizes the pitch components of the brass instruments throughout this passage.

The second major type of spatial movement in Eonta is associated with a moving source. Xenakis employs this spatial technique during the “promenade” section of Eonta where the musicians are directed to walk freely across the entire stage beginning in mm. 335. When the performers walk around on stage, the physical location of their instruments are actually moving. Consequently, listeners perceive continuous minute changes in sound, which are in turn responsible for how the moving sound sources are localized. From the listener’s perspective, this spatial idea is unique. Although
Example 3.2: Summary of the pitch components of the first three brass entrances, mm. 40–92

<table>
<thead>
<tr>
<th>mm. 40-48</th>
<th>mm. 55-80</th>
<th>mm. 82-92</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1, 3, 6, 10, 12]</td>
<td>[-4, 2, 4, 9, 19]</td>
<td>[-15, -6, 4, 11, 24]</td>
</tr>
</tbody>
</table>

Composers of electroacoustic music frequently create sounds that move through space, few composers create this effect by having the performers walk on stage.

In addition to localizing moving sources, this physical movement on the part of the performers has the secondary effect of increasing the width of the sound source. When the musicians are stationary and seated for Eonta, the sounds produced by the brass instruments come from the right of the stage and have a fairly narrow width compared to when they line up along the back of the stage (see Figure 3.4). When they gather around the piano, the listener perceives a fairly narrow sound source coming from the left of the stage. During the promenade, the brass instruments produce a sonic width that takes up the entire stage.

The promenade section of Eonta (mm. 335–75) is the culmination of the spatial movement in this work. The brass players are directed to walk freely around a t-shaped section of the stage. Earlier in the work, the musicians were asked to move the bells of their instruments in synchronized and then specified but asynchronous movements. Yet in this section, the musicians are moving independently of one another. The musical material in this section is soloistic and consists primarily of chromatic fragments.

An interesting aspect of this work is how the piano interacts with the spatialization of the piece. While the brass players are able to change the direction of
Figure 3.4: The location of the brass musicians on the stage affects the apparent source width. Figure 3.4 shows the three areas of the stage where the brass players perform and the promenade section below it.8

their instruments and move around the performance space, the pianist does not move with
the piano because it is stationary throughout the entire piece and is able to participate in
spatial changes only by modulating dynamics and density. Even when the brass players
play their instruments into the piano, it is the brass instruments moving their sound to the
location of the piano. In an interview involving Mario Boise and Xenakis, they discuss
the idea of using two pianos to create the impression of movement by cross-fading
(modulating the dynamics) of the same sounds in two locations.\textsuperscript{9} Xenakis said that the
thought occurred to him, but that he felt it would be too cumbersome and challenging to
create a convincing spatial impression with two pianos. A few years later, this is how
Xenakis would approach spatialization in \textit{Terretektorh}.

Another spatial feature of \textit{Eonta} emerges from note durations. In some sections
of the piece, Xenakis repeats the same note duration over and over in a single part but
uses different, irregular durations across the five brass parts. For example, beginning in
m. 82, the durations for the brass chord are between 2–2.66 beats long (summarized in
Table 3.1). By choosing irregular rhythms, changes in the sound parameters, such as
dynamics, take place at different speeds throughout the ensemble. To demonstrate this,
mm. 82–85 are reproduced in Example 3.3.

The asynchronous nature of \textit{Eonta} can be heard in other sections. Beginning in
m. 166, the brass players hold a chord (D4-Eb4-Gb4-E5-A5), which can be viewed as a
continuation of the preceding chordal passage. Aside from the changes in harmony, the
texture is fairly static. One by one, the brass parts change their articulations from
sustained tones to pulsating gestures. These changes take place sequentially from left to

\textsuperscript{9} Iannis Xenakis and Mario Bois, \textit{Iannis Xenakis: The Man and His Music: A Conversation with
the Composer and a Description of His Works} (London: Boosey and Hawkes, 1967), 45.
**Table 3.1:** Duration of the notes for each brass part beginning m. 82 of *Eonta*

<table>
<thead>
<tr>
<th>Part</th>
<th>Duration</th>
<th>Subdivisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trumpet 1</td>
<td>40/15 (2 2/3 beats)</td>
<td>12</td>
</tr>
<tr>
<td>Trumpet 2</td>
<td>36/15 (2 2/5 beats)</td>
<td>10</td>
</tr>
<tr>
<td>Trombone 1</td>
<td>35/15 (2 1/3 beats)</td>
<td>6</td>
</tr>
<tr>
<td>Trombone 2</td>
<td>33/15 (2 1/5 beats)</td>
<td>5</td>
</tr>
<tr>
<td>Trombone 3</td>
<td>30/15 (2 beats)</td>
<td>8</td>
</tr>
</tbody>
</table>

**Example 3.3:** mm. 82–85 of *Eonta* showing the irregular note lengths. In this example, red lines mark the beginnings of notes and show how the dynamic pattern (simplified) becomes offset throughout the passage.

This motion foreshadows the sonic rotations that Xenakis implements in *Terretektorh.*
Example 3.4: mm. 166–72 of *Eonta* showing the transition from held tones to pulsations

Figure 3.5: Cumulative number of beats between each brass instrument’s texture change, mm. 166–77 of *Eonta*
One of the most important aspects of spatialization in \textit{Eonta} is how spatial positioning dictates the formal organization of the work. A chart depicting \textit{Eonta}'s form is shown in Figure 3.6. This interpretation of the form is multitiered, as shown by my interpretation by location, that of Huijstee by texture, and that of Chrissochoidis and others by pitch sets.\footnote{10} I shall address this multitiered reading by considering musical structuring by pitch, texture, and then spatial positioning.

On a surface level, the pitch sets selected by Xenakis make up the first set of structural divisions, although analyzing the work by only investigating pitch sets has its problems. Table 3.2 lists the pitch sets used by the piano, trumpets, and trombones.

\textbf{Figure 3.6:} Formal organization of \textit{Eonta} by spatial characteristics, sonic texture, and pitch set\footnote{11}
### Table 3.2: Changes in pitch sets throughout *Eonta*.\(^{12}\)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Piano</th>
<th>Trumpets</th>
<th>Trombones</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Σ</td>
<td></td>
<td>---</td>
</tr>
<tr>
<td>40</td>
<td>Σ</td>
<td></td>
<td>Σ</td>
</tr>
<tr>
<td>55</td>
<td>-Θ</td>
<td></td>
<td>-Θ</td>
</tr>
<tr>
<td>77</td>
<td>Θ</td>
<td></td>
<td>---</td>
</tr>
<tr>
<td>95</td>
<td>-Θ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>Σ</td>
<td></td>
<td>(-Θ)</td>
</tr>
<tr>
<td>142</td>
<td>-Θ</td>
<td></td>
<td>(-Θ)</td>
</tr>
<tr>
<td>144</td>
<td>Σ</td>
<td>Ψ</td>
<td>---</td>
</tr>
<tr>
<td>148</td>
<td>-Θ</td>
<td></td>
<td>---</td>
</tr>
<tr>
<td>150</td>
<td>Σ/</td>
<td></td>
<td>(-Θ)</td>
</tr>
<tr>
<td>155</td>
<td>-Θ</td>
<td></td>
<td>(-Θ)</td>
</tr>
<tr>
<td>162</td>
<td>Ψ</td>
<td></td>
<td>-Θ</td>
</tr>
<tr>
<td>166</td>
<td>-Θ</td>
<td></td>
<td>(-Θ)</td>
</tr>
<tr>
<td>190</td>
<td>Ψ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>195</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>202</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>206</td>
<td>Σ</td>
<td></td>
<td>Σ</td>
</tr>
<tr>
<td>310</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>322</td>
<td>Σ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>335</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>342</td>
<td>Ψ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>345</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>349</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>365</td>
<td>Ψ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>368</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>375</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>378</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>383</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>388</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>390</td>
<td>-Θ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>393</td>
<td>Σ</td>
<td></td>
<td>Σ</td>
</tr>
<tr>
<td>398</td>
<td>Σ</td>
<td></td>
<td>Σ</td>
</tr>
<tr>
<td>399</td>
<td>-Θ</td>
<td></td>
<td>-Θ</td>
</tr>
<tr>
<td>402</td>
<td>Σ</td>
<td></td>
<td>Σ</td>
</tr>
<tr>
<td>405</td>
<td>Σ</td>
<td></td>
<td>Σ</td>
</tr>
<tr>
<td>460</td>
<td>Ψ</td>
<td></td>
<td>Ψ</td>
</tr>
<tr>
<td>469</td>
<td>-Θ</td>
<td></td>
<td>-Θ</td>
</tr>
</tbody>
</table>

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12. For a more in-depth investigation of the pitch sets used in *Eonta*, see Chrissochoidis et al, “Set Theory in Xenakis’ *Eonta*,” 241–49.
throughout the piece and the measures in which they are employed. Xenakis sometimes uses a single pitch set for periods lasting over 100 measures, while at other times, he uses pitch sets for only a few measures at a time, switching sets at a much faster rate. For example, the sets used to create the brass parts between mm. 335–75 (-(ΨΘ+(−Ψ-Θ))), ΨΘ+(−Ψ-Θ), Ψ, −Ψ, and −ΨΘ) change as frequently as every three measures, while the first 55 measures of the piece are all generated by the same set (Ξ).

The pitch sets do not necessarily change in all parts at the same time (see Table 3.2). The pitch sets used for the brass and piano are usually different and Chrissochoidis, Houliaras, and Mitsakis use this information in their analysis of the formal organization. For them, large section breaks occur when there are simultaneous set changes across all the instrumental groups. While the brass and piano parts are usually generated from different pitch sets, the trumpets and trombones frequently play pitch materials from the same sets, although in mm. 349–93 they play material from different sets. Specifically, from mm. 349–65, the trumpets play material derived from set -(ΨΘ+(−Ψ-Θ)), while the trombones play material from ΨΘ+(−Ψ-Θ). From mm. 368–75, the trumpets play pitches from −Ψ, and the trombones ΨΘ+(−Ψ-Θ), and from mm. 375–78, the trumpets −ΨΘ and the trombones −(ΨΘ). Although the trumpets and trombones share common pitch sets for most of the piece, the actual music played by each instrument is quite different, as Xenakis exploits each instrument’s range, timbre, and performance technique.

A second way of interpretating the formal organization of Eonta involves investigating the non-spatial aspects of the textures created by the musical material.

13. A complete list of the pitch content of the sets and subsets used in Eonta appears in the Appendix.

Although changes in pitch set and in texture are often concurrent, they do not always agree with each other. Changes in musical texture are not dependent on changes in pitch set, and changes in pitch set frequently occur without a change in texture. Theodore van Huijstee reads nine sections in *Eonta*, while Kurt Stone divides the work into 14 sections, with both scholars basing their interpretations on changes in texture.\(^{15}\)

Finally, I find that the large-scale divisions in formal organization are delineated by changes in spatial positioning. In *Eonta*, the location of the brass players, and whether or not they are moving while playing, creates six distinct sections. The silences that follow several of these sections further reinforces this interpretation (see Table 3.3).

**Table 3.3: Formal organization of *Eonta* based on the location of the instrumentalists**

<table>
<thead>
<tr>
<th>Section</th>
<th>mm.</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1</td>
<td>0–80</td>
<td>Brass at back of stage</td>
</tr>
<tr>
<td>Section 2</td>
<td>80–95</td>
<td>Brass at piano, audience left</td>
</tr>
<tr>
<td>Section 3</td>
<td>95–309</td>
<td>Brass seated audience right</td>
</tr>
<tr>
<td>Section 4</td>
<td>309–35</td>
<td>Brass at piano, audience left</td>
</tr>
<tr>
<td>Section 5</td>
<td>335–75</td>
<td>Brass moving around center stage</td>
</tr>
<tr>
<td>Section 6</td>
<td>375–481</td>
<td>Brass seated audience right</td>
</tr>
</tbody>
</table>

It is interesting to ponder how many ways different ways there are to analyze this piece. Although I think that spatial positioning is the most important aspect in the formal division of *Eonta*, all the analyses mentioned above are valid. Moreover, listening to a recording of *Eonta* does not do justice to the spatial positioning and could weaken a listener’s interpretation of the work. Stereo recordings insufficiently capture the auditory information that correlates to the locations of the instrumentalists. It was unusual at the time to write music that involved moving musicians, and this compositional practice has

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not become more popular after Xenakis either. Xenakis was disappointed by the theatrical aspect of his composition and did not write another piece in which the musicians actually move during the performance. Instead, he wrote pieces such as *Terretektorh*, where the music is perceived as moving while the performers remain in place, a subject I will turn to in the next chapter.

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16. Xenakis thought that *Eonta* was too theatrical, but yet his *Polytopes*, which are examples of *Gesamtkunstwerk*, are all about theatrics. In these pieces, Xenakis creates laser and light shows that, with the accompanying spatial music, thrill the eyes and ears.
Chapter Four

Apparent Movement in *Terretektorh* and *Persephassa*

Xenakis wrote *Terretektorh* (1965–66) as the result of a commission to write an orchestral work to be performed by the Orchestre Philharmonique de l'ORTF, under the baton of Hermann Scherchen at the 1966 Royan Festival. Having recently composed *Eonta* (1963–64) where the musicians walk around the stage while performing, and experimenting with stochastic textures created by percussion instruments spread throughout an ensemble (*Hiketides* [1964] and *Oresteia* [1965–66]), Xenakis continued his experiments with spatialization in *Terretektorh*. The title of this piece means “construction by action” and refers to orchestra kinetics, that is, movement within the orchestra. In this work, scored for 88 musicians spread semi-stochastically in a circular space around the conductor, the sonic material is characterized by its movement throughout the ensemble. In addition to a new orchestral layout, the audience is seated among the performers.

*Persephassa*, which will be discussed after *Terretektorh*, was written for the French ensemble Les Percussions de Strasbourg for the 1969 Shiraz Festival held in Iran at the ruins of the Persian city of Persepolis. Following the precedent set by *Terretektorh* and continued in *Nomos gamma* (1967–68) to mix the seating of the ensemble and audience, *Persephassa* is written for six percussionists arranged in a hexagon surrounding
the audience. As this piece is a percussion work, it is primarily concerned with rhythm, but the spatial positioning of the performers is significant.

**Terretektorh**

As mentioned above, in *Terretektorh*, the area in which the audience sits is overlaid with the performance space, and as such, the musicians and audience occupy the same space (see Figure 4.1). The musicians are situated in a circular area scattered throughout the performance space, separated into eight wedge-shaped sections and divided into six rings. Traditional instrumental sections (e.g., vln. 1) are no longer grouped together. In this seating arrangement, each audience member has a different aural perspective of the music. At a concert with a traditional setup, the listener will be approximately equidistant from all of the instrumentalists, but when located inside the ensemble, such as in a performance of *Terretektorh*, certain musicians will be located much closer, and therefore will sound much louder than others (see Figure 4.2). When located in the direct field of sound (close to a sound source), loudness increases at a high rate as the distance from the sound source decreases. Thus, if one were seated in the outermost ring of sector F of Figure 4.1, the nearby trombone would sound much louder than the piccolo in the outermost ring of sector B, even if the dynamic of the trombone were softer than that of the piccolo. Likewise, sitting near the center of the ensemble gives the listener a completely different perspective than sitting near the exterior.

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1. In Xenakis’s orchestral works, each string player has a unique part, so in *Terretektorh* there are 30 distinct violin parts.

2. Although this is true for traditional concert arrangements as well, since the listener’s position in the room inherently has a psychoacoustic effect on what the listener hears, positioning oneself within the ensemble has a much more pronounced effect.
Figure 4.1: Disposition of the orchestra and audience in *Terretektorh*.

**Figure 4.2:** Distance between a listener and the orchestra for a traditional setup and that of *Terretektorh*.

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The relative location of listeners to the musicians means that the balance of various instruments will change drastically from location to location. In fact, at the premiere and some other performances, audience members are given camp stools on which to sit, and are allowed to move about the performance space throughout the work. As one moves around the ensemble, one’s aural perspective changes dynamically and drastically. Although most likely distracting to the performers, experiencing music by moving through it, just as one would experience architecture by moving through a building, is Xenakis’s intention. In *Formalized Music*, Xenakis writes, “Terretektorh is thus a ‘Sonotron’: an accelerator of sonorous particles, a disintegrator of sonorous masses, a synthesizer. It puts the sound of the music all around the listener and close up to him. It tears down the psychological and auditive curtain that separates him from the players when positioned far off on a pedestal…”

Another unusual aspect of *Terretektorh* is the fact that each musician is responsible for a variety of percussion instruments in addition to his or her normal instrument. Musicians are given maracas, whips, woodblocks, and three registers of sirens. Xenakis writes stochastic clouds of sound for these instruments in addition to the pitched material of the typical orchestral instruments. Xenakis elaborates on these stochastic clouds:

…a shower of hail or even a murmuring of pine-forests can encompass each listener, or in fact any other atmosphere or linear concept either static or in motion. Finally the listener, each one individually, will find himself either perch on top of a mountain in the middle of a storm which attacks him from all sides, or in a frail barque tossing on the open sea, or again in a universe dotted about with little stars of sound, moving in compact nebulae or isolated.


5. Ibid.
In *Terretektorh*, the musicians do not move around the stage as in *Eonta*. Instead, Xenakis borrows a technique called *panning* from electronic music that gives the aural impression of movement. In a stereo sound system, panning works by manipulating the volume of a signal going to the left and right speakers. An equal amplitude signal applied to both speakers creates a phantom image, or virtual sound source, halfway between the two real sources. Manipulating the volume between the two speakers will cause the phantom image to drift toward the louder side. In a system with more than two channels, panning can take place between any two channels. Xenakis applies this technique to *Terretektorh*, basically treating the orchestra as an 88 source sound generator.

In the first section of *Terretektorh* (mm. 1–75), Xenakis smoothly rotates a single pitch (E4) around the string instruments located in the outermost two rings 12 times. The offset between each group’s note onset, along with crescendos and decrescendos, facilitates the consistent movement of the E4 around the ensemble. Considering the aural perspective of the audience, this rotation will be more apparent depending on the listener’s location. A similar example would be watching “the wave” at a sporting event. A person in the stands has a different perspective than someone on the field.

Xenakis adds variety to the E4 rotation by changing the speed that it spins around the ensemble. The first rotation (mm. 1–9) takes place at a constant rate, moving between groups at a rate of four beats and with the accent occurring in a uniform place within the note on the fifth beat (see Example 4.1). Maria Anna Harley describes this movement as both circular in space and time, since it moves around the ensemble in a
Example 4.1: Opening rotation of *Terretektorh*, mm. 1–9

circle and has a constant temporal structure. In subsequent rotations, the temporal durations change, although the spatial locations remain the same. In Xenakis’s representation of time, these non-linear patterns are modeled as spirals.

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The second and third rotations are examples of Archimedean spirals, the first in acceleration, and the second in deceleration (see Figure 4.3). In the second rotation, the length of time that each group plays decreases from 22 beats to six over the course of 16½ measures (mm. 8–24). The speed of rotation increases as does the strength of the dynamics, which progress from mp to f. The length of time between the accents also decreases. The third rotation is the exact opposite of the second; the length of time each group plays increases from eight beats to 20 over the course of 11½ measures (mm. 23–24).

**Figure 4.3:** An Archimedean spiral

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7. An Archimedean spiral is one that moves away from a fixed point with a constant speed along a line, which rotates with constant angular velocity. In the polar plane, it can be described by the polar equation \( r = a + b\theta \).

8. The second group sustains for two beats longer, yielding 24 beats.
The dynamic continues to increase in loudness, this time from \textit{f} to \textit{ff}, and the length of time between the accents increases.

The fourth set of rotations can be described as a hyperbolic spiral (see Figure 4.4).\textsuperscript{10} The rotation in \textit{Terretektorh} (mm. 32–45) decreases from 32 beats to 1½ beats. Its dynamic profile rises from \textit{ff} to \textit{fff sfz}. Before the last set of rotations, the music in mm. 46–51 takes a short break from the spirals, as the sound moves from the inside of wedges G and H to their boundaries. In mm. 46–47, the E4 is maintained in all.

**Figure 4.4:** A hyperbolic spiral

\footnotetext[9]{As in the first rotation, the second, and in this case subsequent groups, play for a shorter amount of time than the first group.}

\footnotetext[10]{A hyperbolic spiral or reciprocal spiral is the opposite of an Archimedean spiral. It starts an infinite distance away from a point and winds faster as it approaches that point (although it never reaches the point). It can be described by the polar equation $r = \frac{a}{\theta}$.}
instruments of wedge H instead of just the outer strings. Beginning in the center, each ring of instruments accents the E4 sequentially in eighth notes toward the exterior of the ensemble and then back again (see Figure 4.5). In mm. 48–49, the music in wedge G makes the same movement, but with whips instead of the pitched E4. Following these wedge-shape movements, the rotations continue.

**Figure 4.5:** Movement from the edge to the center and back in wedges G and H, mm. 46–47 of *Terretektorh*. Black arrows show the first set of movements, gray the second.

The last eight rotations are logarithmic spirals (see Figure 4.6).\(^{11}\) Beginning in group H and moving toward group A, the last 8 rotations (mm. 51–75) increase in speed with each subsequent rotation. The longest of these rotations lasts a total of 38 beats, while the final and shortest rotation less than a half measure in its entirety. The first 3½ rotations decrease in volume from **fff sfz** to **pp**, and the last 4½ increase back to **fff sfz**. All the rotations in the first 75 measures are summarized in Figure 4.7.

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\(^{11}\) Compared to an Archimedean spiral, the distance between each rotation in a logarithmic spiral increases by a geometric progression, where in the Archimedean, the distance is constant. The logarithmic spiral can be described by the polar equation \( r = ae^{b\theta} \).
In addition to the rotations throughout the first 75 measures, the rest of the orchestra overlays textures with the rotations. Between mm. 10–24 and 55–75, the rest of the musicians play their maracas. They are not given any rhythmic suggestions, and the result is a dense cloud of high-pitched noise. In mm. 49–50, the entire ensemble joins the sounding of the E4 by playing accented quarter-tones. This acts in conjunction with group G and H’s wedge effects, interrupting the spirals before the logarithmic rotation climax.
Figure 4.7: Summary of rotations in the first 75 measures of Terrektorh
In addition to using spatial rotations and movement toward/away from the center of the ensemble, Xenakis creates timbre-spaces in *Terretektorh*. Timbre-spaces are created by groups of instruments spread throughout the performance space performing similar musical material. At the beginning of the work, the E4 that was rotated around the ensemble was one timbre-space, and the maracas played by the rest of the ensemble create a second. Later in the piece, these timbre spaces are increasingly developed, overlaid, and transformed.

A spatial movement toward the center of the ensemble follows the opening rotations in mm. 75–82. Each ring of instruments begins playing, creating a sound-complex that spans the entire orchestra. The entrances of each wedge are slightly offset from one another, smoothing the process of the sound build up by spiraling in toward the center (see Figure 4.8). Again, let us consider different listener perspectives. A listener

**Figure 4.8**: Spiral around the ensemble and toward the center, mm. 75–82 of *Terretektorh*. Each group of short to long bars represents a wedge and each individual bar represents a ring of instrument in that wedge.
near the periphery of the ensemble would probably hear the ensemble increasing in volume as more musicians begin to play. The spread of sound toward the middle of the ensemble might not be easily perceived. A listener near the center of the ensemble would perceive the sound as moving toward him or her as musicians located nearer them join the chord.

The arrival chord is unstable, and the texture soon begins a chaotic transformation. Many of the pitches move up or down by quarter-tone or semitone, and the string instruments begin to play small-ranged glissandi. Throughout the duration of the glissandi, some of the musicians are instructed to drop out and play their whips, a sonority that soon becomes the primary texture. The whips and other small percussion instruments (maracas and wood blocks) used by the entire ensemble have markedly different sonic characteristics. They all produce sounds in different registers and have different timbres and dynamics. These characteristics are summarized in Table 4.1 and Figure 4.9. Xenakis exploits the variety of textures created by large numbers of these instruments. Since they are distributed over such a large area, the minute variations in sounds create amazingly rich textures. The sheer number of sources is almost overwhelming, much like the sound of cicadas on a summer evening.

Table 4.1: Summary of small percussion properties

<table>
<thead>
<tr>
<th>Name</th>
<th>Register</th>
<th>Timbre</th>
<th>Dynamic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maracas</td>
<td>Medium-High</td>
<td>Granular; Unpitched</td>
<td>Quiet</td>
</tr>
<tr>
<td>Whip</td>
<td>High</td>
<td>Impulse; Unpitched</td>
<td>Loud</td>
</tr>
<tr>
<td>Woodblock</td>
<td>Low-High</td>
<td>Long Impulse; Pitched</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Figure 4.9: Time aligned sonograms and amplitude-time graphs of a single maraca shake, whip crack, and woodblock hit respectively. Note the differences in transient and frequency response, energy distribution, and overall length.
Let us now consider some non-percussion timbre-spaces and how they interact with each other.\textsuperscript{12} In addition to the timbre-spaces created by percussion instruments, Xenakis writes similar musical material in instruments based on register, performance technique, and instrument family. Starting in m. 119, the high winds begin to sustain a long chord that lasts until m.195. Although in this case the entrance is not a spiral, the onset of each different instrument is offset to smooth the transition. Moreover, throughout the chord, Xenakis writes accents that spiral around the ensemble similar to those earlier in the piece. The position of these instruments and the path of the first accent movements (mm. 134–44) are shown in Figure 4.10, alongside their opening sonority.\textsuperscript{13} This high-pitched chord forms a sonority that remains static over which other timbre-spaces are superimposed.\textsuperscript{14}

A string glissandi timbre-space frequently interjects itself throughout mm. 111–60.\textsuperscript{15} Sometimes the glissandi are grouped by the section in which the musicians are seated, such as sectors A and E from mm. 129–35, F from mm. 137–39, G in m. 139, and B and D from mm. 146–48. On other occasions, they appear in almost the entire orchestra simultaneously as a single gesture, such as in mm. 155–160 (see Figure 4.11). In this instance, the gesture is a slow downward and then fast upward motion that uses all

\textsuperscript{12} Helena Santana calls these timbre-spaces “constellations,” referring to the groupings of timbre and configuration. I think that constellation is a good description, as the individual points of sound are perceived as a group (timbre-space) similar to the perception of a group of stars as a single entity. See Helena Santana, “Terretektorh: Space and Timbre, Timbre and Space,” 24.

\textsuperscript{13} A few of the instruments change octaves at some point during the chord, such as fl. 1’s change from C7 to C6 at m. 133.

\textsuperscript{14} The high winds timbre-space actually begins during a section of the whip timbre-space.

\textsuperscript{15} Glissandi are a signature sonority in almost all of Xenakis’s works and are featured prominently throughout much of Terretektorh.
Figure 4.10: Location of the instruments that form the high wind timbre-space alongside their opening timbre and an accent movement pattern (starts with the piccolo in B)

Figure 4.11: Trajectory of the string glissandi, mm. 155–60 of *Terretektorh*
sixty string instruments, and is reminiscent of the massive string glissandi first employed in *Metastaseis* (1953–54).

Beginning in m. 146, a low brass and woodwind texture begins to form. It begins in the bass clarinet (G, fifth ring) and contrabassoon (C, sixth ring) at two opposite poles of the ensemble. Starting in m. 165, other low instruments begin to join the texture. Figure 4.12 shows the evolution of this timbre-space between mm. 146–281. The texture of this space is a mixture of sustained tones, sometimes with undulating, rhythmic pitch changes. This low timbre group becomes the primary timbre-space around m. 195 after a short maraca texture (mm. 176–97), during which the high woodwind texture stops.

As the piece progresses, Xenakis develops the timbre-spaces. For example, at m. 216, he introduces a medium register timbre-space consisting of sustained string sounds. Xenakis subsequently modulates the register by having the musicians play higher pitches and introducing a tremolo effect at m. 222. The pitch is raised further in m. 226 before Xenakis turns the chord into descending glissandi in m. 237, leading back to a new low, sustained chord. This timbre-space is soon invaded by a new one, that of sirens, in m. 258. As with some of the other timbre-spaces, Xenakis uses dynamics and accents to give the impression of the movement of the sonority around the ensemble.

For Boris Hofmann, *Terretektorh* is characterized by a building of tension. The piece begins in a relaxed state on a single pitch. As it is rotated around the ensemble, this pitch moves faster and faster until the rotations cannot be sustained and the whole ensemble enters with rhythmic pulsations. The glissandi and timbre-spaces that follow

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16. Santana reads this low brass and woodwind part as a melody, but since it mostly moves by half step, it is not particularly melodic. See Santana, “Terretektorh: Space and Timbre, Timbre and Space,” 24.

Figure 4.12: Spatial positioning and evolution of the low brass and woodwinds timbre-space

create antithesis that continues to increase the tension throughout most of the piece. The ending, a static chord, can be viewed as the piece arriving at a standstill. Hofmann sees the last glissandi that precedes the final chord as establishing a virtual space that the
listener can only understand after experiencing the spatial aspects appearing earlier in the work.

All in all, Terretektorh contains a wide variety of sonorities and sonic development. The diversity of playing techniques and instrument changes create evolving timbres that are much like a color gradient: the transitions are numerous and layered so smoothly that the listener is barely aware of the changes. Finally, dynamics play a crucial role in facilitating rotations and transformations.

Persephassa

After the success of Terretektorh, Xenakis wrote another orchestral work where the musicians are spread throughout the audience. In this new work, Nomos Gamma (1969), Xenakis expands the percussion section from three musicians spaced evenly around the periphery of the ensemble to eight musicians circling the ensemble. The musical material of Nomos Gamma is quite different from Terretektorh, but the conclusion of the work shows the direction of Xenakis’s creative path from Terretektorh to Persephassa. At the conclusion of Nomos Gamma, Xenakis rotates a drum roll around the outside of the ensemble, much like the opening rotation of a single pitch in Terretektorh, thereby predicting the final rotations in Persephassa.

Persephassa is scored for six percussionists arranged in a hexagon surrounding the audience (see Figure 4.13). Each percussionist has a collection of instruments created from four different materials: skins, wood, stone, and metal. In some ways, the scoring

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18. The brass section is also larger.

19. There are actually three percussionists in Terretektorh. Their musical material is almost exclusively slow, metric rotations.
Figure 4.13: Disposition of the performers and audience for *Persephassa* \(^{20}\)

persephassa

**NOMENCLATURE DES INSTRUMENTS**

**ET DISPOSITION DES 6 PERCUSSIONISTES**

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*Les MEUX sont désignés et classés en 6 bandes de haut en bas de la partie supérieure.*

*Les APLAUS sont des feuillets en acier très minces de dimensions 50x25 cm, reliés par une agilité en les tenant à la main.*

*Les SIMANTRA METALLIQUES sont des tubes d'acier fermés très durs de 40 cm de diamètre environ.*

Sur 10 de longueur et un fil de fer suspendus et qu'un frappe avec une balle de triangle ou une tête de métal.*

*Les SIMANTRA sont des paires de bois très durs et denses de 40 cm de longueur suspendus, frappés avec une balle de bois ou une baguette à tête dure ou métallique.*

*Les GALETES DE MER sont arrondis, de la taille d’une main posée sur un coussin, et qu’un frappe avec un doublet de galettes de même taille environ.*

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of *Persephassa* can be viewed as a simplification of techniques used in *Terretektorh* and *Nomos Gamma*—the ensemble size is reduced as are the number of timbres employed. At the same time, the detail in the variation of timbres is more refined and subtle as the slight differences of the sounds produced by the different collection of instruments played by each percussionist is more nuanced.

There are several important spatial techniques employed in this piece. Xenakis writes sonic material that sounds simultaneously in all parts at once, appears in imitation, involves ostinati and hocket techniques, or that is rotated sequentially from part to part. What is more, Xenakis’s approach to rhythm and meter is progressive. He writes complex rhythms generated by sieves and at points, writes all six parts in different tempi and subdivisions of the beat. Let us now considers some instances of these techniques.

The very first sonic events of the piece involve synchronization across all six musicians. The percussionists play rolls on pitched drums with a similar dynamic profile (crescendo-decrescendo-crescendo). The following material involves events scattered around the ensemble, with a primary emphasis on percussionist A. Throughout this introduction, there are distinct points in which the ensemble comes together (see Figure 4.14). At this point, the texture is sparse; only 86 beats spread throughout the first 148 beats (37 measures) contain sound—just over 60 percent of the total time.

The texture becomes denser when the first rotations start. Unlike the complex accelerating and decelerating spirals of *Terretektorh*, in *Persephassa*, Xenakis returns to using circular and semi-circular rotations. Xenakis rotates a drum roll from B to E in mm. 38–41, and from F to D in mm. 43–46. Xenakis again uses dynamic envelopes to
Figure 4.14: Reduction of the first 42 measures of *Persephassa*
amplify the audience’s perception of the apparent movement from one location to another.

The first full rotation appears between mm. 99–103 from A to E. In this rotation, each percussionist performs a complex, one-measure polyrhythm consisting of duple, triple, and quintuple elements. Consequently, the polyrhythmic elements that emerge create a motive, which projects this 5:3:2 ratio. Over the course of the following 25 measures, Xenakis develops these 5:3:2 rhythmic elements by having the collective ensemble perform complex permutations on them. In the midst of this texture, he begins rotating strings of steady and consecutive drum hits (see Example 4.2).

Xenakis rotates these simple figures in semicircular and circular motions; he also layers multiple rotations on top of each other, adding a new rotation almost every measure. Multiple rotations are distinct from one another for several reasons. Each rotation is heard on a set of differently pitched drums and begins and terminates with different percussionists.21 Moreover, each rotation has its own set of durations (e.g., six triplets, five quintuplets, two quarter notes, etc.). The rotations are layered along with an increasingly dense texture. By m. 131, the rotations stop because the non-rotating texture becomes too dense. The sonic material is then transformed into a homogenous texture in which all six percussionists play at once, three in triplets and three in quintuplets.22 In m. 145, the steady notes stop, replaced by concurrent tremolos (nuage) in all six parts. The

21. Each musician has a different collection of skin drums that have their own timbres and pitches. Each single rotation uses similar drums across the ensemble, and each rotation occurs in a differently pitched drum collection.

22. Percussionists switch between triplets and quintuplets every beat, but the balance of triplets and quintuplets is maintained throughout the passage.
Example 4.2: Reduction of mm. 125–31 of Persephassa showing the rotations

final section of Persephassa is a culmination of spatial rotations and will be discussed below.

In addition to rotations, Xenakis writes rhythmic figures that are presented in imitation. In this work, rhythmic figures are generated using the sieve theory mentioned in Chapter 2, which is capable of producing complex rhythms by combining durations with symbolic logic. The first example of this technique of rhythmic imitation appears at m. 151. Percussionist D plays a seven-measure rhythmic passage that is duplicated in the
other percussion parts, which subsequently begin at different times (see Example 4.3). Part A starts 5½ beats into the pattern at m. 151, and starts the pattern again in the last beat of m. 155. Part B begins in the last beat of m. 154, C, the second beat of m. 157, E, the third beat of m. 156, and F, the first beat of m. 153. In m. 162, all six percussionists play a fragment of the rhythmic sieve before breaking into a complex passage not derived from that sieve.

Example 4.3: Rhythmic imitation mm. 151–61 of *Persephassa*. The third through seventh beat of each sounding of the sieve are shown in red.
Another clear example of this use of rhythmic sieves and imitation appears in the passage beginning in m. 221. Because each musician is playing in a different tempo, the duration of each sieve presentation is slightly different. Xenakis also presents the sieves in augmentation and diminution. As James Harley points out, it is clear that these patterns are meant to be recognized by the listeners, and the counterpoint of multiple percussionists playing the same material in different tempi creates an extraordinary effect.

Performing in different tempi and layering different periodicities is a further abstraction of rhythm that Xenakis explores in *Persephassa*. From mm. 62–110, each musician plays steady pulses. They start synchronized, playing on beats one and three. Starting almost immediately, each musician begins playing notes with a different periodicity. For example, at m. 63, B’s periodicity becomes 9/10 and at m. 67, E’s becomes 5/6. The effect is that each musician plays in their own time, and the ensemble time becomes increasingly frayed. Hofmann writes that “Time is not of universal validity but depends on space and the position of the recipient. … [In] music there is no reliable time[,] each listener gets his own experience.”

Later in the piece, starting in m. 191, a similar effect is produced, but this time from tempo manipulations instead of periodicity changes. The six percussionists play steady quarter notes at four beats per minute (bpm). After nine beats into the section, D, E, and F start playing at 42 bpm. Shortly after that, B switched to 58 bpm. More tempo

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23. At this point in the piece, all six percussionists are playing in different tempi. The measure number listed here is marked in the score, although it marks a point where the measure lines for the six parts line up, thus it is not indicative of a single measure.


changes take place, and the overall effect is the same: the global tempo unravels as each musician plays in their own time.

The culmination of the work is a tour de force of spatial rotations. Xenakis builds from a single rotation into a frenzy of multiple rotations. It starts with the rotation of a single drum hit from A to F at a slow tempo (30 bpm) played on skin drums. After two full rotations, the musicians start a second (concurrent) rotation in the opposite direction, from F to A played on metal simantras. After 2½ rotations, a third one going from D toward C played on cymbals begins. Throughout this section, Xenakis increases the tempo slowly to 196 bpm and superimposes up to seven layers of rotation (see Example 4.4).

As a whole, Persephassa is a culmination of Xenakis’s exploration of rhythm, pulse, meter, and space. Unlike Eonta and Terretektorh, formal organization is not directly related to spatialization. His use of rotation, imitation, rhythmic sieves, permutation, ostinato, and synchronization/desynchronization is an impressive feat, not to mention the fact that the ensemble would have considerable difficulty playing together due to the distance between each musician and lack of a conductor. In this work, Xenakis overlaps and transforms textures, but some aspects are clearer than in other works.
Example 4.4: The first four layers of rotations, mm. 352–64 of Persephassa
Example 4.4: The first four layers of rotations, mm. 352–64 of Persephassa (continued)
Chapter Five

Conclusion

As reflected by his music and theories, Xenakis's occupation as an architect and background in math and engineering had profound effects on his approach to composition. In many of his works written during the 1960s, Xenakis incorporated spatial movement as a key structural component of his music. The use of sonic rotations, as well as physical and apparent movement around performances spaces, in the works discussed in this thesis are innovative and exciting.

In *Eonta*, the musicians physically move around the stage and direct the bells of their instruments in specified directions, modifying dynamics and timbre to create localization effects. Subdivided into two types—stationary and moving, the actual movement of the performers is a major feature of this work. As argued in Chapter Three, I interpret the movement of the musicians as delineating the formal organization of the work.

In *Terretektorh* and *Persephassa*, Xenakis rotates sound around the ensembles in mathematical spirals. In both of these works, the musicians remain stationary and the impression of sound movement is achieved through physical panning. Time offset crescendo-decrescendo volume envelopes are applied to multiple instrumentalists located in different places to create the perception of movement. Additionally, in *Terretektorh*, Xenakis creates timbre-spaces in which groups of instruments perform similar material.
These timbre-spaces are transformed, overlaid, and developed throughout the work. In *Persephassa*, the synchronicity or lack thereof between the percussionists becomes a new focus in addition to the spatial rotations.

Although they are some of the more popular and frequently performed works, *Eonta, Terretektorh*, and *Persephassa* are not Xenakis’s only spatial compositions. Likewise composed during this time, and briefly discussed in this thesis, was *Nomos Gamma*. While the spatial aspects of all four pieces are fundamental to their construction, Xenakis employs other compositional techniques, such as symbolic music and sieve theory. In his later works, Xenakis turned his attention to other possibilities, thus spatial rotations became less of a factor in his music. Yet, I would argue that space and spatialization ultimately remained prominent in Xenakis's compositional approach.

Starting in the late 1960s and continuing for most of the rest of his life, Xenakis began creating *polytopes*, multimedia compositions involving music, light, and architecture. In these works, Xenakis created spatial artwork that teased both the eyes and ears of the audience. A few scholars, including Maria Anne Harley and Sven Sterken, have written about these works, but not from a theoretical standpoint; consequently, they deserve further study. Unfortunately, one of the biggest challenges to interpreting these pieces is reconstructing the light shows that go with the music, something that is a huge obstacle to further investigation.

Although *Eonta, Terretektorh*, and *Persephassa* are written for different types of ensembles, they have some characteristics that extend beyond their spatial aspects. Musicians who have performed these works agree that Xenakis's music is raw, intense,

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and exhausting to play. It requires talented musicians with great stamina because it is so physically demanding. I would argue that pushing the musician's abilities to their absolute limit is a major factor that characterizes Xenakis's unique music.

The visual analysis techniques used in this thesis can be applied to other works by Xenakis and other twentieth-century composers. Sonograms display timbre in ways that other techniques cannot. While the diagrams that show movement are specific to the compositions for which they are used, this style of graph can also be employed to show other musical parameters. For example, one could track motivic repetition and development by plotting where motives are sounded on an orchestral layout map. Moreover, I strongly believe that color can aid in analysis, as different colors can be used to denote multiple layers of musical activity, such as rotations. Thus a single figure can show many things. Juxtaposing multiple aspects of analysis on top of each other is more informative and easier to comprehend for the reader.

One of the biggest problems with these spatial compositions is the fact that so much of the impression of movement is lost when the pieces are recorded and reproduced on a stereo sound system. However, there are at least two solutions to this problem. First, these pieces should be performed more frequently. They are truly amazing pieces to hear live, and I hope that anyone who has had this experience would agree. In the absence of live performances, I think that new recordings in 5.1 or binaural surround should be produced (see Appendix B). Recording and mixing in these formats will better capture the spatial aspects of Xenakis's compositions, and the recordings will be far superior to those in stereo. Moreover, recordings that can simulate motion through the
space, and thus allow listeners to hear different aural perspectives of the ensemble, would be an informative teaching tool, as well as provide a unique listening experience.

Nearly 50 years have passed since Xenakis composed *Eonta*. Despite the passage of time, the works discussed in this thesis are still fresh and exciting, and the enthusiasm of those interested in Xenakis has only grown over the years. In the final analysis, I have striven to lend insight into how Xenakis’s early spatial compositions are constructed and perceived, yet I realize that this thesis is only a small part of a much larger picture of a truly great composer.
Appendix A

Pitch Sets from *Eonta*

The following list contains all the pitch sets and subsets uses by Xenakis in *Eonta*. It is written in pitch integer notation.¹ Xenakis makes many mistakes in either the construction or application of the sets. As such, some pitches appear in sets that they mathematically should not (e.g., -35 (C#1) in Θ and -Θ).

Σ  
all chromatic semitones from A0–C#8

Θ  
[-35, -30, -29, -24, -22, -19, -16, -13, -12, -11, -9, -8, -2, 1, 5, 6, 8, 11, 12, 14, 15, 16, 18, 19, 20, 21, 22]

Ψ  
[-29, -19, -16, -14, -13, -12, -9, -4, -2, 0, 1, 2, 4, 5, 6, 9, 11, 12, 14, 15, 16, 18, 19, 20, 21, 22]

-Θ  

-Ψ  
[-34, -31, -28, -27, -26, -22, -20, -19, -11, -10, -6, -5, -3, -1, 0, 4, 7, 8, 9, 10, 13, 14, 16, 17, 18, 20, 22, 23, 24, 28, 29, 32, 34, 35, 37, 39, 43, 48]

-(ΨΘ)  
[2, 3, 8, 16, 21]

Ψ+Θ  
[-19, -17, -16, -14, -13, -12, -9, -8, -4, -2, 1, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 16, 18, 19, 20, 21, 22, 23]

-(Ψ+Θ)  
[-37, -34, -32, -31, -28, -26, -21, -20, -15, -11, -10, -8, -7, -5, -3, -1, 0, 2, 4, 7, 10, 15, 17, 24, 29, 30, 32, 35, 37, 44, 45]

-ΨΘ  
[-28, -27, 8, 13, 18, 22, 23]

-(-ΨΘ)  
[-11, -10, -9, -8, -7, -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 17, 20]

-(Ψ-Θ)  
[-4, -2, 8, 10, 11, 13, 14, 15, 17, 18, 22, 23, 24]

-(-Ψ-Θ)  
[-29, -27, -19, -18, -17, -16, -14, -13, -12, -9, -8, -4, -3]

¹This list is adapted from Chrissochoidis et al, “Set Theory in Xenakis’ Eonta,” 241–49.
\[\Psi \Theta^-(-\Psi-\Theta) \quad [-29, -27, -20, -19, -18, -17, -15, -12, -11, -10, -8, -7, -6, -5, -2, -1, 0, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 23, 24]\]

\[-(\Psi \Theta^-(-\Psi-\Theta)) \quad [-4, 1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24]\]

\[\Psi \Theta^+\Psi \Theta^2 \uparrow \quad [-13, -10, -9, -8, -5, -4, -3, -1, 1, 2, 4, 5, 6, 7]\]

\[-(\Psi \Theta^-\Psi-\Theta) \quad [-39, -36, -35, -33, -26, -25, -23, -22, -21, -20, 2, 4, 33, 38, 40, 41, 42, 43, 44, 45, 48]\]
Appendix B

Stereo and Binaural Recording Simulation

The following computer code, written in SuperCollider, demonstrates the superior spatial impression projected by binaural recording over that of stereophonic.\(^1\) Unlike traditional stereo audio, binaural audio takes into account ITD and ILD as it simulates a three-dimensional soundscape. In this demonstration, SuperCollider is used to synthesize a woodblock-like sound located in eight different positions of a four-channel sound system.\(^2\) As most people do not have access to a quadraphonic sound system, the four audio channels are mixed into a conventional two-channel, stereo audio file.

Two audio files are provided: in the first (Audio Example B.1, CD track 1), the left-front and left-rear speakers are mapped to the left channel, and the right-front and right-rear to the right channel. In this example, it seems as if the audio is moving in an arc in front of the listener. In the second audio file (Audio Example B.2, CD track 2), the four channels have been processed with a binaural panner, which mixes the four channels to a two-channel format that preserves some of the auditory cues, which allows one to localize sounds perceived to be occurring from behind. For best results, these audio examples should be listened to with headphones.

\(^1\) http://supercollider.sourceforge.net
\(^2\) Left-front, center-front, right-front, right-center, right-rear, center-rear, left-rear, left-center.
Figure B.1: SuperCollider code that simulates sounds in eight locations surrounding a listener

```objective-c
//define a woodblock-like sound as the sound source; outputs 4-channel audio
(SynthDef(\wood, {
arg freq = 900, xpos = 0, ypos = 0;  //pass frequency and position
var sound;  //\(x\) and \(y\) as arguments
sound = Klank.ar(  //sound source is a bank
  \[[1, 2.89, 4.95, 6.99, 8.01, 9.02], 1, 1\],  //of resonant filters
  Decay2.ar(Impulse.ar(0), 0.01, 0.1),  //excited with an impulse
  freqscale: freq, decayscale: 0.025);
DetectSilence.ar(sound, doneAction: 2);
sound = Pan4.ar(sound, xpos, ypos);  //pan sound source in 4 channels
Out.ar(0, sound);
}).send(s));
~rand = {100.rand}  //function that picks a random number between 1-100

//define a task that plays a woodblock sound with a root frequency between 900-
//1000 Hz every 0.3 seconds, rotating sequentially through eight locations
(t = Task({
  var waitTime = 0.3;
  5.do({
    //leftFront
    Synth(\wood, \[freq, (900 + ~rand.value()), \xpos, -1, \ypos, 1\]);
    waitTime.wait;
    //centerFront
    Synth(\wood, \[freq, (900 + ~rand.value()), \xpos, 0, \ypos, 1\]);
    waitTime.wait;
    //rightFront
    Synth(\wood, \[freq, (900 + ~rand.value()), \xpos, 1, \ypos, 1\]);
    waitTime.wait;
    //rightCenter
    Synth(\wood, \[freq, (900 + ~rand.value()), \xpos, 1, \ypos, 0\]);
    waitTime.wait;
    //rightBack
    Synth(\wood, \[freq, (900 + ~rand.value()), \xpos, 1, \ypos, -1\]);
    waitTime.wait;
    //centerBack
    Synth(\wood, \[freq, (900 + ~rand.value()), \xpos, 0, \ypos, -1\]);
    waitTime.wait;
    //leftBack
    Synth(\wood, \[freq, (900 + ~rand.value()), \xpos, -1, \ypos, -1\]);
    waitTime.wait;
    //leftCenter
    Synth(\wood, \[freq, (900 + ~rand.value()), \xpos, -1, \ypos, 0\]);
    waitTime.wait;
  });
});

//play the example in four channels
(t.play;
```
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