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Sound Space and Edgard Varèse's *Poème Electronique*

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C E R T I F I C A T E

I certify that this thesis has not already been submitted for any degree and is not being submitted as part of candidature for any other degree.

I also certify that the thesis has been written by me and that any help that I have received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

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Abstract

The *Poème électronique* in the Philips Pavilion at the 1958 Brussels World's Fair was an event and site where many late Modernist ideas of sound space converged. This thesis explores the notion of sound space through this convergence; especially the ideas of the composer Edgard Varèse, but also associated ideas of the engineer, architect and composer Iannis Xenakis, and contemporaneous ideas in sound reproduction. In a certain sense, the thesis is not about *Poème électronique*: it is merely taken by the thesis as a starting point and structure for a discussion of sound space.

Poème électronique involved architecture, music, acoustics, electro-acoustics, and by implication, sculpture in a complex synthesis, providing a number of vocabularies or metaphors for exploring sound space. The thesis takes the hyperbolic paraboloid architecture of the pavilion as a metaphor for sound space, functioning primarily through its complex engagement with subjective perception. Similarities between Varèse's ideas and those of the high fidelity movement are noted, and Varèse's notion of an extra dimension in sound space is discussed in relation to developments in stereophony and related psycho-acoustics. A short analysis of Varèse's *Poème électronique* is included, primarily to outline ways that the composition expresses itself in space. The possibilities of sound space are discussed more generally through a review of selected acoustic and psycho-acoustic phenomena, and in the context of philosophical writings on sound and space.

The thesis identifies a number of characteristics important in sound space: surroundedness and directedness; depth and extension; multi-stability and multi-dimensionality; and a sensation of detachment or transcendence. Sound space perception is inhabited by immense diversity and ambiguity.

Introduction

The Philips Pavilion and *Poème Electronique*

Opening on the 17th April, the 1958 Brussels World's Fair was the first major international exhibition to follow the Second World War, and the Atomium remains today as a lasting reminder of the fair. The fair was dominated by a number of issues: the Cold War and rivalry between the United States and Soviet Union; the miracle of modern science and engineering, especially in nuclear technology; the rehabilitation of Germany, Italy and Japan among the world's nations; and the waning of European colonialism. The Atomium stood as a symbol containing the tension between the first two of these issues. Architecturally, the fair was not especially significant, with an over-use of glass curtain walls. Some of the most interesting structures were designed by engineers rather than architects.

The Philips Pavilion was one such structure, designed - under the direction of the architect Le Corbusier - by Iannis Xenakis, who is better known today as a composer. Le Corbusier was commissioned by Philips to create a pavilion that, rather than merely displaying the company's products, would use its technology in an impressive multimedia display. Le Corbusier responded with the idea of a *Poème électronique*, in which light, colour, image, rhythm and sound would be united in an organic synthesis.[1] This event would be held in a 'bottle' containing the 'nectar of spectacle and music'. Xenakis was employed in Le Corbusier's firm as an engineer at the time, but had shown some ambition to work in architecture, so much of the design of the pavilion was delegated to him while Le Corbusier concentrated on projects in India. Xenakis is at pains to point out that his employer's initial specifications for the architectural form of the building were very limited; he quotes these words from Le Corbusier:

> On demande une surface simple et convexe pour le dos du Pavillon Philips, afin de ne pas trop influencer la vue sur le jardin et la verdure qui entourent les construction hollandaises. [sic]
>
> Puisque c'est la nuit dans la 'bouteille', peut importe sa beauté. [sic]

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1 Iannis Xenakis: **Le Pavillon Philips a l'Aube d'une Architecture**, in **Musique. Architecture.**, p126.

> Le Pavillon Philips ne sera qu'un bâtiment qui coûtera très peu d'argent et qui sera plutôt une espèce de structure creuse au canon à ciment sans aucune existence 'architecturale', selon l'expression courante.[2]

Instead of following this advice, Xenakis designed a building that was anything but unassuming.[3] This pavilion was by no means a major pavilion at the fair, but looking much like a half-collapsed tent, and made from steel and concrete, its architecture was extraordinary. The concrete shell was an assemblage of continuously curving surfaces, often meeting at sharp angles, and forming three sharp peaks, pointing in quite different directions. These curving surfaces were formed from networks of intersecting straight lines, yielding dissimilar hyperbolic paraboloids, which provided an inherently strong self-supporting shell.[4] In engineering terms, the audacity and novelty of the design demanded significant research into the structural properties of these surfaces.

With Xenakis' design, Le Corbusier's bottle and nectar metaphor was changed, and the pavilion became a 'stomach' (suggested by the shape of its floor plan), with "four hundred acoustical mouths completely surrounding the five hundred visitors."[5] These visitors were nutrients: consumers were consumed. The selection of such metaphors to describe the sound installation and architecture of the pavilion (rather than the light installation) reflects the powerful sense of enclosure or surroundedness that both architecture and sound can bring. This is one of the most basic ways that sound and architecture worked together in the *Poème électronique*.

Le Corbusier made his involvement in the pavilion conditional on the commissioning of Edgard Varèse for the composition of tape music for *Poème électronique*, to the frustration of the Philips

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2 Iannis Xenakis: **Le Pavillon Philips a l'Aube d'une Architecture**, in **Musique. Architecture.**, p128-9.

3 The design of the Philips Pavilion sparked a rivalry between Xenakis and Le Corbusier, with the latter refusing to acknowledge the former's claim to authorship. The extent of the involvement of each is reassessed by Olivia Mattis in **Edgard Varèse and the Visual Arts**, Chapter 10.

4 An exceptionally elegant and readable account of the geometric ideas referred to in this thesis can be found in D. Hilbert & S. Cohn-Vossen: **Geometry and the Imagination**. The hyperbolic paraboloid is one of only three surfaces that can be constructed by a network of intersecting straight lines, the other two being the flat surface and the hyperboloid of one sheet. See also Figure 8.

5 Jean Petit (ed.): **Le Poème Electronique Le Corbusier**, p 25; as translated in Ouellette, **Edgard Varèse**, p201. Although Le Corbusier mentions 400 speakers, and Varèse mentions 425 speakers in **Spatial Music**, it is more probable that there were only 350 loudspeakers, the number quoted by the Philips engineers.

executives, who would have been happier with a more conservative choice. *Poème électronique* was to be Varèse's only fully electronic work in his main œuvre, as well as the one that most literally realised the moving sound masses that characterised all of his œuvre. A sophisticated electro-acoustic installation provided the means for dramatic spatial movement and differentiation in this work. Hundreds of loudspeakers were mounted on the walls of the pavilion, some in clusters, some forming 'routes' across the walls; and a complex automatic control system distributed the sound between these speakers. Varèse's *Poème électronique* has become established as a major pioneering work in the repertoire of electronic music; it was the culmination of decades of dreaming by the composer about such works.

Varèse's piece was eight minutes in duration, accompanied by a sophisticated show of light and images created by Le Corbusier. The relation between the music and light was arbitrary. This freedom was defined by Le Corbusier to Varèse with the following words:

> You will do just as you wish. I shall leave you quite free, thinking of your music as a presence surrounding a man reading, for example, some book or tale and whose ear catches noises from outside (a barrel organ, a brass band marching past, a revolution coming along the street, up the staircase, smashing in the door).[6]

Le Corbusier developed a visual story in seven sections, entitled: *Genesis*; *Spirit and matter*; *From darkness to dawn*; *Man-made gods*; *How time moulds civilisation*; *Harmony*; and *To all mankind*. The images that he used drew on religious art from many cultures, human skulls and bones, images of combat, bulls' heads, space exploration, and his own architecture, giving a sense of narrative and progress through history.[7] These black and white images were projected directly onto the curved interior walls of the pavilion, upon which a variety of lighting techniques also played. *Ambiences*, which were large washes of coloured light on the walls would create changing atmospheres, also making the black of the images appear coloured. *Tritrous* were narrow and brilliantly coloured beams of light, projected by using a film strip, opaque except for three holes. A red sun, a moon, twinkling stars and clouds were also simulated. At two places on the ceiling were *Volumes*, two fluorescent sculptures, one of a female figure fluorescing red, the other a model of a molecule fluorescing greenish-blue. The larger incandescent lights,

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6 Quoted in Fernand Ouellette: **Edgard Varèse**, p197. Although Le Corbusier did ask Varèse to have "an abrupt and total silence" in the middle of the *Poème électronique* to coordinate with a white light, this did not eventuate, so the sound and light spectacles were developed quite separately.

7 See Jean Petit (ed.): **Le Poème Electronique Le Corbusier**.

projectors, and batteries of coloured and white fluorescent tubes were hidden behind a concrete balustrade, so that only their effect on the walls was visible [Figure 6]. On the audience's side, the floor adjacent to the balustrade was lined with tiles, fluorescing bluish white [Figure 7].[8]

The pavilion had two openings, an audience of up to five-hundred people entering through one while the previous audience left through the other. Xenakis' piece *Concret P-H* was played for the two minutes of audience transition while an introduction in English, French and Dutch was given. *Concret P-H* was a very restrained and delicate piece, consisting of tape manipulations of the 'crinkling' sound of burning charcoal. As its name implies, Xenakis composed this piece in reference to the walls that he had designed: with 'P-H' standing both for 'Philips' and '*paraboloïdes hyperboliques*'; and 'concret' a reference to *musique concrète*, but probably also to the *béton armé* of the pavilion's walls.

The 1958 Brussels World's Fair closed on the 19th of October, and the Philips Pavilion was demolished. Publications, photographs and recordings of Varèse's and Xenakis' compositions remain as documents of an event that was highly influential on electro-acoustic music of subsequent years, especially that involving multimedia installation and ambitious spatial effects.

Approaches

Throughout his mature life, the composer Edgard Varèse conceived of his music in spatial terms. The link between his spatial ideas and those of Cubist artists is widely recognised, and some aspects of his work have been seen as analogous to that of contemporaneous visual artists. Like the artists who influenced him, Varèse was also heavily influenced by scientific thought, especially that of the 'new physics' (with its revolution in concepts of space and time); indeed John Anderson has shown how many of Varèse's statements about his music paraphrase popular scientific texts of his time. Nevertheless, even if Varèse's language about music was constructed through these explicit physical influences, the fact remains that he was always describing music, describing the experience of listening to sound and imagining its form. Several musicologists have recognised this, and have constructed formal analytical frameworks based on spatial characteristics.

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8 L. C. Kalff: **The Light Effects**, *Philips Technical Review*, **20** (2-3), 23rd October 1958, p37-42.

This thesis meditates on a set of closely knit themes, originating in two of Varèse's seminal experiences of sound space. Firstly Varèse described how, in experimenting with sirens, he heard hyperbolic and parabolic trajectories in space. Secondly, he described an experience of listening to a Beethoven symphony in the Salle Pleyel in Paris, where a peculiar acoustic effect made the sound appear to detach from physical space, giving a sense of projection and of added dimensions in space. In Varèse's imagination, each of these experiences anticipated aspects of the sound space of *Poème électronique*. The analysis of these experiences of sound space throughout the thesis finds a number of themes: differences between geometric and body-centred notions of space; involved relationships between surroundedness and directedness in auditory space; the sense of detachment as a process of transcendence where a space of many dimensions can be conceived; and a sound space that is multi-stable - that, like an optical illusion, has more than one stable interpretation.

In the first two chapters, hyperbolic and parabolic forms are discussed as analogies of sound space. Chapter 1 offers a number of late Modernist contexts where connections between sound space and such forms are made: the language of Varèse; world's fair architecture, including the Philips Pavilion; the musical and architectural ideas of Xenakis; Naum Gabo's sculpture; and early advertising for stereophonic products. Hyperbolæ, parabolæ, hyperbolic paraboloids and similar ruled surfaces are shown, for whatever reason, to provide a visual expression of space suited to the Modernist construction of sound space.

Chapter 2 develops a discussion of objectivity and subjectivity in spatial conception and perception. The geometry of visual space is reviewed, leading to an analysis of the hyperbolic paraboloid in perception. As an object perceived, the hyperbolic paraboloid simultaneously emphasises body-centred and geometric spatiality. This almost paradoxical perception gives the viewer multiple levels of spatiality and the implication of transcendence from one to the other.

An analogous duality in Chapter 3 is defined by Don Ihde as surroundability and directionality in hermeneutic auditory perception. While Ihde does not develop this model beyond a very literal approach to auditory space, Varèse's experience in the Salle Pleyel points to a more involved interaction between surroundability and directionality. Here, again, space appears on multiple levels: there is the visual space of the concert hall; the surrounding auditory space of the orchestra; and the sense of a transcendent space within the sound of the orchestra, more differentiated than the mere sense of surroundedness, but having no correlation with the visual space. These ideas are discussed in relation to ideas in the evolution of stereophony, and to the psycho-acoustic notion of auditory spaciousness. Certain writings on sound space of authors including William James, Edward Lippman, Victor Zuckerkandl, Gaston Bachelard and Don Ihde also follow these themes.

In Chapter 4, Varèse's *Poème électronique* is modelled as a process of explosive liberation in sound space. Chapter 5 develops this idea further by outlining ways that the piece presents itself in acoustic and musical space together. Certain aspects of the sounds that begin and end the piece work in parallel with the spatial concerns of the first three chapters. The piece opens with pure surroundedness and closes with a mixture of directionality and surroundedness. This mixture contains a conceptual geometry: Varèse's parabolæ and hyperbolæ expressed in the siren ascents. It also surrounds the listener with loud and deep noise, which nevertheless represents directionality through its association with a jet or rocket. As a whole, the explosive ascent surrounds, but it divides itself into dynamic structures which have certain concrete and symbolic directional implications.

Chapter 5 contains a review of selected acoustic and psycho-acoustic material on the nature of sound space, and especially auditory space. Sound space is characterised by an inherent diversity of spatial experience, ranging from a direct sense of space on and in the body to a more objective sense of directional space. It is also characterised by ambiguity between physical and 'musical' space, and the chapter reviews a major instance of such ambiguity. Thus Varèse's idea of sound space is not the product of arbitrary metaphor, and is much more than the incidental construction of an ambitious imagination.

The concepts in this thesis are often quite fluid: the sound space being discussed has the property of multi-stability, of having more than one form. Varèse's own thought reflects this characteristic by failing to propose any single unified model of sound space. The thesis is concerned with possibilities, and thus involves a degree of speculation. In the thesis, 'sound space' is a loose concept that refers to real, imagined, phenomenal, abstract, musical, acoustic and auditory notions of space.

The *Poème électronique* is at the centre of this thesis because of its special place in the realisation of Modernist notions of sound space. It was the culmination of decades of dreaming of such things by Varèse. It was the inspiration of several projects by Xenakis in subsequent years, and influenced the work of many other composers. It was experienced by millions of visitors. It came at a time when stereophony was emerging as a domestic sound technology. It crystallised the dreams of stereophony, spatial music, musical architecture and architectural music.

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Sound in the Walls

Perhaps in response to the curves of the Philips Pavilion, Varèse made the following intriguing comments, describing one of his formative experiences in his conception of spatial sound:

> I was also fascinated by the experiments of Helmholtz with sirens, described in his *Physiology of Sound*.[9] I made some modest experiments of my own with sirens and found I could obtain beautiful parabolic and hyperbolic curves equivalent for me to the parabolas and hyperbolas in the visual domain. From then on I knew that somehow I would some day realize a new kind of music that would be spatial - from then on I thought only of music as spatial...
>
> The first time I made use of a siren to obtain my hyperbolic and parabolic trajectories was in 1921, in the score of *Amériques*. Later I used one siren in *Hyperprism*, and two in *Ionisation*.[10]

> I studied Helmholtz, and was fascinated by his experiments with sirens described in his *Physiology of Sound*. I went to *Marché aux Puces*, where you can find just about anything, in search of a siren, and picked up two small ones. With these, and also using two children's whistles, I made my first experiments into what later I called *spatial music*….
>
> My first physical attempt to give music greater freedom was by the use of sirens in several of my scores (*Amériques, Ionisation*), and I think it was these parabolic and hyperbolic trajectories of sound that made certain writers as far back as 1925 grasp my conception of music as moving in space. For example Zanotti Bianco, writing in *The Arts*, at that time spoke of 'sound masses moulded as though in space' and of 'great masses in astral space.' Of course, it was still only a *trompe l'oreille*, an aural illusion, so to speak, and not yet literally true.[11]

Varèse was evidently impressed by Zanotti-Bianco's interpretation of his music, which expressed a vision of sound space very close to his own. Part of the Zanotti-Bianco text reads thus:

> If we project an imaginary sound-mass into space, we find that it appears as constantly changing volumes and combinations of planes, that these are animated by the rhythm, and that the substance of which they are composed is the sonority. Might it then be possible to consider a

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9 *Physiology of Sound* (1862) is published in English as **On the Sensation of Tone**, translated by Ellis 1873.

10 Edgard Varèse: **Electronic Music**, 1958, p3-4, as quoted in Parks: **Freedom, Form, and Process in Varèse: A Study of Varèse's Musical Ideas - Their Sources, Their Development, and Their Use in his Works**, p210.

11 Edgard Varèse: **Spatial Music**, 1959, quoted in Schwartz & Childs (eds.): **Contemporary Composers on Contemporary Music**, p205.

> musical composition as a succession of geometric sound-figures; as a resultant of volumes and planes whose successive projections would give birth to architectures of sound whose logic would be given by the equilibrium of their sound vibrations and their forms? It must be understood that we are here dealing with music not from the point of view of its psychological function, but rather from its elementary physical aspect, thus arriving at a sort of musical objectivation. The sound-mass whose weight, whose substance is given by the intensity of sound, would derive its movement from the rhythm which transports it into time. All this is nothing more than a successive step in the direction of that independence toward which music has been tending for ten years or more, toward the objectivation of music - the negation of romanticism - toward the exaltation of music for music's own sake.[12]

Siren-like sounds are prominent in Varèse's *Poème électronique*, in some cases following approximately parabolic trajectories on a logarithmic frequency graph, an element that can be seen, for example, on the spectrographic notation of the piece.[13] In a fragment of Varèse's sketch for *Poème électronique* the final siren-like ascent is labelled "para/hyperboles",[14] and elsewhere he has stated that the effect of siren-sounds producing parabolic and hyperbolic movements in sound space was achieved in *Poème électronique*.[15] John Strawn has noted that in *Intégrales*, a work without sirens, Varèse describes hyperbolic and parabolic trajectories in the parts of conventional instruments.[16] Nevertheless it was in the Philips Pavilion that Varèse first heard his music 'literally projected into space', the sounds tracing routes across the hyperbolic paraboloid surfaces of the building's walls.[17]

That these walls speak today about sound space is reinforced by the many resonances that they have in the fields of architecture, music and sculpture. As an architecture they are part of a

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12 Zanotti-Bianco: **Edgard Varèse and the Geometry of Sound**, *The Arts*, **7**, January 1925 p35-36; quoted in full in Parks: **Freedom, Form, and Process in Varèse: A Study of Varèse's Musical Ideas - Their Sources, Their Development, and Their Use in his Works**, p216-218. Parks shows that Varèse was willing to let Zanotti-Bianco be his spokesperson, quoting him in the program for the first performance of *Ameriques*, and towards the end of his life crediting him with first describing his music as spatial.

13 Refer to the spectrogram in the appendix. A similar spectrogram has been used by Robert Cogan in his analysis of *Poème électronique*.

14 Olivia Mattis: **Edgard Varèse and the Visual Arts**, p240. Figure 52 reproduces this sketch, although the writing is not legible.

15 Florence Parks: **Freedom, Form, and Process in Varèse: A Study of Varèse's Musical Ideas - Their Sources, Their Development, and Their Use in his Works**, p211.

16 John Strawn: **The *Intégrales* of Edgard Varèse: Space, Mass, Element, and Form**, *Perspectives of New Music*, **17** (1), 1978, p153.

17 Edgard Varèse: **Spatial Music**, in Schwartz & Childs (eds.): **Contemporary Composers on Contemporary Music**, p207.

Modernist movement of curvilinear forms enclosing sound installations and auditoria; the walls themselves were conceived in musical terms by Xenakis; and they are reminiscent of sculpture by Naum Gabo, whose works are often filled with latent sound. Similar imagery was used in the early marketing of stereophony. One by one, this chapter takes these spatial constructions - architectures, musics, sculptures and images - in an effort to find a common spatial sense. Varèse's parabolæ and hyperbolæ can be seen in these contexts as part of a common manifestation of sound space in Modernist design. Chapter 2 develops this further by expanding on the perceptual qualities of the hyperbolic paraboloid as an expression of spatiality *per se*.

Architecture, Music: A Lineage

The Philips Pavilion, with its extreme application of hyperbolic paraboloids, suggests relationships between these strange forms and the sonorous world which it enclosed. The pavilion emerged from water like a colossal frozen wave, and might well be compared to Sydney's Opera House, where sound-making is similarly framed by water and architectural waves. These themes of clean curvilinear shell-like architecture, crystalline metaphor,[18] and a watery surround for a space of sound encapsulate many of this thesis' more abstract concepts about sound space. These architectures are simultaneously fluidic, dynamic and geometric. The shell itself is already a powerful acoustic icon. The architectures function through enclosure and surroundedness, the external form advertising the subtleties of the transcendent sound space within. Indeed, the Australian reader might read many parts of this thesis in relation to the Sydney Opera House. Such associations between curvilinear geometry, water, and sound - however powerful - are cultural constructions which have been expressed widely in this way within a style of Modernist architecture that rose to prominence in the 1950s,[19] following earlier trends in sculpture such as that of Gabo and Pevsner. Unlike this, the Nineteenth Century and early Twentieth Century opera

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18 One of Utzon's unrealised designs for the auditoria in the Opera House was based on a crystalline pattern. As discussed elsewhere in this thesis, the Philips Pavilion had a crystal metaphor running through it. See Philip Nobis: **Utzon's Interiors for the Sydney Opera House: The Design Development of the Major and Minor Hall 1958-1966**, p62-75.

19 Robin Boyd documents the emergence of this style in **Engineering of Excitement**, *Architectural Review*, **124** (742), November 1958, p294-308. Utzon's design of the Sydney Opera House, Saarinen's TWA terminal, Stubbins' Berlin Congress Hall, Candela and de la Mora's Virgen Milagrosa church, Le Corbusier's Notre Dame du Haut and the Philips Pavilion are notable pieces of curvilinear architecture dating from this period. It is interesting that Melbourne's Performing Arts Centre, a fairly recent building, should imitate this style with its hyperbolic paraboloidal lattice wings. See also S. J. Medwadowski, W. C. Schnobrich, & A. C. Scordelis (eds.): **Concrete Thin Shells**.

house was more often than not a decorated rectangular prism: such designs were submitted in the Sydney Opera House competition, and would have an entirely different effect on Bennelong Point. While the Philips Pavilion was important architecturally as the first structure to be constructed entirely from dissimilar hyperbolic paraboloids, its form had been suggested in sculpture, and was part of a general trend in public architecture.

As a way of setting up the Philips Pavilion's lineage as sound-architecture (that is, as architecture that suggests ways of listening), we will firstly consider an earlier instance of world's fair architecture: the Theme Centre of the 1939-40 New York fair. It consisted of three main elements: a sphere sixty metres in diameter (the Perisphere), a three-sided obelisk two-hundred metres tall (the Trylon), and a pedestrian ramp in a helix around the Perisphere (the Helicline). The theme centre was painted in dazzling white, the underside of the Helicline clad in mirror-finished stainless steel. The Perisphere itself seemed to hover above a lake, held up by the jets of water which half-concealed the concrete columns that provided structural support. This combination of geometric purity and vast over-scaling created a potent symbol that was extensively marketed, and in its time was compared to the Eiffel Tower for its significance in the history of world's fair architecture. But, clad with gypsum board, the Theme Centre was designed for a short existence, and was demolished after the fair, the structural steel used for the United States' war effort. The theme of this exposition was 'The World of Tomorrow', and the overall architectural style was a hard-edged classical modernity. While many of the pavilions were streamlined, suggesting speed, the Theme Centre's pure geometric form suggested a static perfection.

The spectator followed a set path, ascending one of two large escalators to enter the Perisphere, moving once around the internal perimeter of the Perisphere on a moving walkway, walking across a bridge through the eye of the needle (the Trylon), and making a slow descent on the long curved Helicline. Inside the Perisphere was a model of Democracity, a utopian city of the year 2039. Designed by Henry Dreyfuss, Democracity had the appearance of being utterly ordered, utterly modern. As the spectators were moved around the perimeter of the Perisphere, surveying Democracity, a spectacle of projected light compressed a day into five and a half minutes, accompanied by propagandist music, commentary and images.

The Perisphere also has a place in the history of sound architecture for the way that it surrounded itself with sound. The expanding space between the surface of the water and the sphere surface was used as an extension of a collection of folded horns in a five metre deep pit directly beneath the Perisphere, thus forming a horn with a mouth area of six-thousand square metres, perhaps the largest loudspeaker ever constructed [Figures 13 & 14]. As the central pit was almost invisible, and the Perisphere acted as both a reflector and horn, the sound seemed to come from the Perisphere itself, establishing an invisible sonic aura around the sphere and the lake.[20] This enormous speaker was connected to the central public address system of the fair, on which high fidelity long-playing records were demonstrated several years before their general availability.[21]

The Theme Centre in 1939 had much in common with the Philips Pavilion in 1958. Each contained a multimedia installation for a guided transient audience. Both architectures were exemplary of an extravagant auditory fantasy, unique and site/event-specific, and both were also designed for acoustics. In each there was a utopian civil vision. Both were used as demonstrations of new possibilities in sound technology (in high fidelity and stereophony respectively). Both architectures exploited a sense of immense geometry. The Theme Centre is another example of a sonorous environment enclosed by curvilinear architecture, and surrounded by water. Like the Philips Pavilion, the multi-media installation served to both enclose the spectators and to expand their horizons. The spectator hovered above a landscape that extended to a hazy horizon in all directions. This visual spectacle was paralleled in auditory space; the sphere's walls bounded auditory space, while opening up a universe of sound, which was expressed through the music, the sound reproduction system, and the acoustics of the sphere. The listener was surrounded by sound, but found extensive space in that sound. With its linearity and superficiality, the Trylon stood in stark contrast to the Perisphere. Rather than enclosing, it stood as a solid exterior, a pointer in a free acoustic field, an expression of a geometric and directional space, free from the complexities of resonance.[22]

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20 Arthur Schneider: **Sound Systems at the Two New York World's Fairs**, *Journal of the Audio Engineering Society*, April 1968, p142-143. He writes: "The outside of the Perisphere turned out to be what I believe to be the largest loudspeaker ever constructed. This speaker had a mouth opening of about 200ft, and we nicknamed it 'Big Mouth.' … The design appears to have been quite successful. I recall that many people asked where the sound was coming from because, as one stood on the water's edge, one could see straight through to the other side of the pool."

See also *Architectural Record*, November 1938, p103.

21 **Amplifying Studio Draws Big Crowds**, *New York Times*, Sunday 21 May 1939, p39.

22 The Perisphere was described as "symbolic of the all-inclusive World of Tomorrow" and the Trylon as "a Pointer to Infinity". **Ball and Spike**, *Time*, 9 May 1938, p35. When viewed from its base, the Trylon's taper would have approximated vertical lines of recession in visual perspective, giving the

Even the content of the automated shows of sound and light in the Perisphere and Philips Pavilion shared essential characteristics. One of the main focuses of Le Corbusier's visual presentation was his utopian architectural vision, not dissimilar to Dreyfuss' Democracity. Le Corbusier's brother, Albert Jeanneret would not have been oblivious to this when he wrote of the Philips Pavilion:

> I liked [Varèse's music alone] much more than when linked with the visual elements, because the two together lessen and dissipate each other. The human voice, at the end, takes on the feeling of a song of liberation, the diagrams for the Radiant City appear as programmatical answers to the images of destruction; the shells, the stone figures as elements of possible perfection. One feels a sense of progress in all this already encountered previously, whereas the music on its own is truly a spontaneous creation, endowed with that infinity toward which all music tends. It draws its strength from an originality untouched by a propaganda whose methods have already been encountered elsewhere.[23]

It should be noted that the music in the Perisphere was highly propagandist, culminating in the Fair theme song, the central verse of which was:

> We're the rising tide come from far and wide
> Marching side by side on our way,
> For a brave new world,
> Tomorrow's world,
> That we shall build today.[24]

There was a rich irony on the one hand in the similarities between this ideology of unity and progress and Aldous Huxley's 1932 novel, and on the other in the disintegration that was overtaking the world even as the New York Fair was proceeding. While Le Corbusier's social idealism was more sophisticated than that of Democracity, it too was to remain largely a Modernist fantasy, accompanied by the tension of the Cold War.[25]

The Perisphere was a static bubble rather than a dynamic wave, and it reflected an approach to architecture that was to change significantly in the twenty years that separated the two world's

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sense of an infinitely tall structure extending into the sky.

23 Fernand Ouellette: **Edgard Varèse**, p202, quoting from a letter dated 14 October 1958.

24 Quoted by Francis V. O'Connor in Harrison & Cusker (eds.): **Dawn of a New Day: The New York World's Fair 1939/40**, p62.

25 Xenakis' design for the pavilion - as an expression of 'volumetric architecture' - was a precursor of his own vision of an architectural utopia. See Xenakis: **Musique. Architecture.**, p151-160 (**La Ville Cosmique**). This connection is also made by Louis Marin in **Utopics: The Semiological Play of Textual Spaces**, p263.

fairs. This change is well represented by a comparison with part of the Civil Engineering Pavilion in Brussels in 1958, which reinterpreted the simple gestures of the New York Theme Centre. Perhaps most prominent was the 'beak'; essentially a reinforced concrete Trylon, except that a curve near its base made it extend at an extraordinary angle to the ground. It was cantilevered from a curved concrete enclosure vaguely reminiscent of the Perisphere, which however made no attempt to achieve the completeness of a sphere. An elevated pedestrian walkway was reminiscent of the Helicline, and the utopian Democracity was answered by a relief-map of Belgium that was viewed from this walkway. Aspects of this structure exemplify the architectural transformation from classical (Euclidean) geometry to a more complex curvilinear and geodesic geometry. The 1939 Theme Centre was startling because of the way in which it reified the simplest abstract geometric figures (the sphere, tetrahedron, circle, triangle, line, point, and helix), realising them on such a scale that they seemed more real than the mundane and complex forms of everyday life. The Civil Engineering Pavilion defied classical geometry and gravity, pointing to a higher level of geometry and unifying form and structure. In this there are similarities with other structures in the Brussels Fair [Figures 15-22]. France, the United States, Brazil, the Vatican, and Philips all used tensioned curves as major structural and formal features in their pavilions. The French Pavilion had a cantilevered roof of hyperbolic paraboloids, and the United States' had walls in the form of a hyperboloid of one sheet and a suspended roof. The roofs of the Brazilian and Vatican pavilions curved through suspension and tension. Trylon-like three-sided spikes at gravity-defying angles were also to be found in the French Pavilion and the large 'flying' beak sculpture. They were anticipated in the fair logo, and were suggested by the three peaks of the Philips Pavilion.

Naturally the short lineage that we have traced from the Perisphere did not end with the Philips Pavilion. Aspects of the Perisphere's acoustic design reappeared in the Fountain of the Planets at the 1964-65 New York World's Fair.[26] The Labyrinth pavilion at the 1967 Montreal World's Fair and the Pepsi-Cola and West German pavilions at the 1970 Osaka World's Fair are notable instances of multimedia installations in purpose-built architectures. The Pepsi-Cola and West

26 Arthur Schneider: **Audio-Synchronized Programmer for the Fountain of the Planets, 1964-1965 New York World's Fair**, *Journal of the Audio Engineering Society*, **16** (2), April 1968, p149-156 and John Volkmann: **One Kilowatt Cylindrical Wavefront Loudspeaker with Folded Modular Horn for New York World's Fair**, *Journal of the Audio Engineering Society*, **16** (2), April 1968, p136-140.

German pavilions - designed by Experiments in Art and Technology and Karlheinz Stockhausen respectively - both used a spherical architecture to surround visitors with sound and light. Xenakis also drew inspiration from the Philips Pavilion in his *Polytopes*, which attempted to develop the idea of a fully integrated multi-media event.[27]

Music-Architecture: Hyperbolic Paraboloids

The hyperbolic paraboloid was attractive to Xenakis, who was an engineer and appreciated the possibilities that it had to unify form and structure. Concrete shell structures had been becoming more common - as was evident from some of the architecture at the fair - and Xenakis was excited by the way in which they liberated architecture from the rule of gravity. He saw the Philips Pavilion as a pioneer in a movement towards a ‘volumetric architecture’, in which the floor plan of a building implied little about the shape of the structure above it. The hyperbolic paraboloid was suited to this task because of the simplicity of construction (but not in predictive structural calculations) because of its formation from two sets of intersecting straight lines (for which tensioned cables were perfectly suited), and its inherent strength, being convex in one direction, concave in the other.

Xenakis’ conception of the Philips Pavilion design involves the inclusion of dimensions that are conventionally excluded from architecture. This is brought about through more than one metaphor. As an expression of ‘volumetric architecture’, the pavilion introduces the vertical dimension as an independent factor, where traditional architecture merely translates the floor plan along the plumb line. The independence of the dimensions - apart from the pragmatic need to have a horizontal floor plane - leads to a form where the idea of an absolute dimensional reference scheme is weakened. The rectilinear rule of gravity is minimised. Time is also implicated in the architecture, as a dimension - principally through the idea of trajectory. The ‘sound routes’ on the pavilion’s internal walls are one type of trajectory. Other trajectories include the sense that the ruled lines themselves represent movements, and that by following a personal trajectory, the viewer finds a dynamic subjective architecture.[28] These ideas will be expanded in this section.

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27 See Iannis Xenakis: **Notes sur un «Geste Electronique»** in **Musique. Architecture.**, p143-150.

28 Jean Petit’s **Le Poème Electronique Le Corbusier** includes an extended photographic study of the Philips Pavilion which makes plain the special visual properties of its architecture.

Xenakis has often pointed out the connection between the hyperbolic paraboloids of the pavilion and the structure of string glissandi in his composition *Metastasis*, which were determined from a two dimensional ruled line diagram [Figures 23 & 24].[29] Xenakis:

> If glissandi are long and sufficiently interlaced, we obtain sonic spaces of continuous evolution. It is possible to produce ruled surfaces by drawing the glissandi as straight lines. I performed this experiment with *Metastasis* …. Several years later, when the architect Le Corbusier, whose collaborator I was, asked me to suggest a design for the architecture of the Philips Pavilion in Brussels, my inspiration was pin-pointed by the experiment with *Metastasis*. Thus I believe that on this occasion music and architecture found an intimate connection.[30]

Thus while Varèse's sirens gave him auditory hyperbolæ and parabolæ, Xenakis' glissandi give him hyperbolic paraboloids (at least conceptually if not auditorily). This raises questions about direct relationships between sound and architecture (which, after Goethe, has sometimes been called 'frozen music'). While there is a long history of intercourse between harmonic music (in the broadest sense) and architectural proportions (a relationship engendered by resonance), here the relationship is between a music which is graphically conceived and continuous forms.[31] It is easy to see the pavilion as a wave frozen in its dance, but the graphical representation of the glissandi differs in that time is made a spatial dimension. In *Metastasis*, the lines represent movement; in the Philips Pavilion they trace static forces.

Xenakis' *Polytope de Montréal* in the French Pavilion at the 1967 Montreal World's Fair continued his expression of ruled surface geometry [Figures 25 & 26].[32] In this work, a 'transparent architecture' of cables occupied a large void in the pavilion, surrounded by balconies and staircases over several storeys. Xenakis composed a 'music' of light points which followed multiple trajectories across the ruled surfaces, accompanied by a glissando-dominated piece for four orchestras. The play of light points, in bringing a music to the visual forms, has close similarities with his piece, *Concret P-H*, which was played in the Philips Pavilion during the period of audience transition.

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29 See also Michel Ragon: **Xenakis Architecte**, in Fleuret (ed.): **Regards sur Iannis Xenakis**, p30-36.

30 Iannis Xenakis: **Formalized Music**, p10.

31 One should bear in mind that Xenakis had recently designed the 'musical' windows for the Le Corbusier designed monastery at La Tourette, which had more in common with the traditional association between discrete spatial and musical proportion.

32 See Olivier d'Allonnes: **Xenakis / Les Polytopes**.

Concret P-H can be thought of as Xenakis' attempt to literally integrate musical and architectural form in the Philips Pavilion. Xenakis conceptualised a mass of little points or attacks, which were produced by the manipulation of the sound of burning charcoal - creating a very light but intense sound texture. Like the pavilion's architecture, *Concret P-H* is related to an earlier orchestral piece, *Pithoprakta*, in which a large number of seemingly random attacks are distributed so as to produce musical shapes. To Xenakis, it emulated the structure and grain of the building; the rough sound, the rough texture of concrete, its coefficient of internal friction.[33] On the other hand, each of the attacks was a dart, a linear trajectory, just as an infinite number of ruled lines combined in mass to form the *paraboloïdes hyperboliques* (*P.H.*) of the building's shell.[34] This is reinforced by the concrete sound of the attacks, perhaps sounding like a mass of delicate glass rods in constant collision, which might be imagined to be defining a Gabo-like ruled surface. When played from the walls of the Philips Pavilion, this piece created a dialogue. The macroscopic simplicity, consistency and elegance of this music matched that of the architecture: a single theme was carried throughout, with gradual transformations. Again there is a juxtaposition of analogous temporal processes and spatial forms. The combination of both in a single sounding structure permits an exchange: dynamism is imputed in the structure, and spatiality in the sound.

Crystal

Olivia Mattis has developed the metaphor of crystal in relation to the Philips Pavilion.[35] Varèse himself used this metaphor as a way of describing his conception of musical form. Varèse:

> Conceiving of musical form as a *resultant* - the result of a process - I was struck by what seemed to me an analogy between the formation of my compositions and the phenomenon of crystallization. Let me quote the crystallographic description given me by Nathaniel Arbiter, professor of mineralogy at Columbia University:
>
> > "The crystal is characterized by both a definite external form and a definite internal structure. The internal structure is based on the unit of crystal which is the smallest grouping of the atoms that has the order and composition of the substance. The extension of the unit into space forms the whole crystal. But in spite of the relatively limited variety of internal structures, the external forms of crystals are limitless."
>
> Then Mr Arbiter added his own words:

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33 Such is the description given by James Mansback Brody accompanying the Nonesuch recording of the piece.

34 Xenakis composed a 'canon of electrons'. See Nouritza Matossian: **Xenakis**, p122.

35 Olivia Mattis: **Edgard Varèse and the Visual Arts**, p235-249.

> "Crystal form itself is a *resultant* [the very word I have always used in reference to musical form] rather than a primary attribute. Crystal form is the consequence of the interaction of attractive and repulsive forces and the ordered packing of the atom."

> This, I believe, suggests, better than any explanation I could give, the way my works are formed. There is an idea, the basis of an internal structure, expanded and split into different shapes or groups of sound constantly changing in shape, direction, and speed, attracted and repulsed by various forces. The form of the work is the consequence of this interaction. Possible musical forms are as limitless as the exterior forms of crystals.[36]

Mattis and Bernard have shown correspondences with the use of crystal metaphors in Cubism, and with the early writings of Le Corbusier.[37] In a 1924 article, *Towards the Crystal*, Amédée Ozenfant and Charles-Edouard Jeanneret (Le Corbusier) discuss Cubist art in these terms:

> On the whole, and in spite of personal co-efficients, one can detect a tendency which might be described metaphorically as a *tendency towards the crystal*.
>
> The crystal, in nature, is one of the phenomena that touch us most, because it clearly exemplifies to us this movement towards geometrical organisation. Nature sometimes reveals to us how its forms are built up by the interplay of internal and external forces. The crystal grows, and stops growing, in accordance with the theoretical forms of geometry; man takes delight in these forms because he finds in them what seems to be a confirmation for his abstract geometrical concepts. Nature and the human mind find common ground in the crystal as they do in the cell, and as they do wherever order is so perceptible to the human senses that it confirms those laws which human reason loves to propound in order to explain nature.
>
> In genuine cubism there is something organic, which proceeds outwards from within … Cubism was the first to try to make the picture an *object*; the old painting was a sort of panorama - a window open to a scenario.[38]

Mattis observes a crystalline theme in the Philips Pavilion - with the speakers appearing as mineral crystals growing from the walls, and the two crystal-like sculptures at the entrance and apex of the pavilion. These sculptures resembled the Atomium (the fair's theme centre), which is a model of an iron crystal. To Mattis, these "symbolized at once technology and beauty: science and art."[39] She also compares the evolving process by which the pavilion was designed to crystallisation. This metaphor can be aptly applied to the finished pavilion, not so much for its particular shape (the British pavilion fulfilled that criterion better), but because of its structure. The hyperbolic paraboloids of the walls were tensioned structures: their shape and strength were derived from

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36 Edgard Varèse: **Rhythm, Form and Content**, 1959, quoted in Schwartz & Childs (eds.): **Contemporary Composers on Contemporary Music**, p203.

37 Jonathan Bernard: **The Music of Edgard Varèse**, p17-18.

38 Ozenfant and Jeanneret: *Towards the Crystal*, from **La Peinture Moderne**, 1925, pp137-8. Quoted in Fry: **Cubism**, p170-171.

39 Olivia Mattis: **Edgard Varèse and the Visual Arts**, p249.

static forces in the steel cables and concrete shell. In more conventional structures the relationship between strength and shape is less close, and stability is dependent on material bulk and gravity more than internal forces. The dynamic form of the crystal is revealed in the petrified dynamism of the pavilion, its three peaks in frozen explosion like the fair logo, pointing towards infinities like three Trylons. The music that it contained was similarly explosive, and this idea is developed in Chapter 4. In these senses the pavilion shell is a 'resultant', 'proceeding from within'.

When applied to music, the crystal metaphor gives a way of picturing the notions of 'in time' and 'outside of time' and the idea that a piece of music might be thought of as an object in space as well as a dynamic process.[40] The external form is analogous to the piece of music as an object - the resultant - while the dynamic processes are inside time. Xenakis is concerned with these ideas, discussing them with Michel Serres in Xenakis' thesis defense:

> S: "…If there is symmetry, there can be reversibility [of time]…"
>
> X: "No, because there can be order in non-temporal things. That's why it's absolutely essential to distinguish between what is *in* and what is *outside* of time. For example, I'll take a group of keys on a piano (an elementary case). I then have intervals which repeat themselves, but they are never repeated in time; they're there, fixed. The piano keys are on a piano which doesn't move."
>
> S: "Therefore these keys are outside of time?"
>
> X: "Yes, outside of time."
>
> S: "The syntax is outside time?"
>
> X: "Yes."
>
> S: "I suspected that!"
>
> X: "There, I have symmetries because I have relationships; therefore I have repetitions."
>
> S: "Yes. Then order is outside of time?"
>
> X: "There are some orders which can be outside of time. Now, if I apply this idea to time, I can still obtain these orders, but not in real time, meaning temporal flow, because this flow is never reversible. I can obtain them in a fictitious time which is based on memory."
>
> S: "Is the piano a recollection?"
>
> X: "Yes, it is a concrete recollection."[41]

The ruled lines that occur in *Metastasis* are in this fictitious time, which is a spatial dimension.

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40 See Patricia Carpenter: **The Musical Object**, *Current Musicology*, **5**, 1968, p56-86.

41 Iannis Xenakis: **Arts/Sciences: Alloys**, p70-71.

The crystal metaphor is not used by Xenakis to any great extent, although he does use many metaphors from physics in the modelling of his music. He is more demanding than Varèse on the detail of a metaphor, and so finds metaphors that are further from the public's imagination. Varèse's use of the crystal metaphor is partly as an illustration to communicate with his public, explaining aspects of his music in familiar imagery. It is interesting that others should find this metaphor for themselves in their examination of his works, an instance of this being Robert Cogan's analysis of Varèse's *Hyperprism*. Cogan represents *Hyperprism* as a frequency spectrogram, and writes that it

> …vividly pictures the 'movement of sound masses' evoked by Varèse. We clearly see the opacities and rarefactions, differentiations and collisions which he spoke of so often.[42]

Cogan's approach to *Hyperprism* transforms time into space, although this is variant of an extremely common process in Western music.[43] He divides the piece into three sections, each containing roughly similar sequences of musical material. This allows him to conceive of the work as a multi-dimensional crystalline prism. Cogan:

> Each line of the photo can be regarded as one face of a three-sided prism, each face reflecting and reproducing the structure of the other faces.[44]

While the word 'hyperprism' is part of a mathematical rather than crystallogical vocabulary (a reference to four dimensional geometry), Cogan's implied use of it in the crystallogical sense is clearly justifiable. His metaphor gives us a musical object which the viewer (listener) sees from a continuously changing sequence of perspectives, in much the same way as the ruled surfaces of Xenakis demand to be seen. Of the *Polytope de Montréal*, Xenakis writes:

> Trajets de lampes par allumages successifs définissant des perspectives relatives à votre position. Si vous êtes près, vous ne les voyez pas! Chaque point de vue nous donne des aspects différents.[45]

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42 Robert Cogan: **New Images of Musical Sound**, p96.

43 The spectrogram differs from musical notation in that the former uses continuous representation, the latter discrete codification. The spectrogram's transformation of time into space is therefore more fundamental.

44 Robert Cogan: **New Images of Musical Sound**, p96.

45 Iannis Xenakis in d'Allonnes: **Xenakis / Les Polytopes**, p115.

Zanotti-Bianco, in his discussion of Varèse's music, also uses the crystal metaphor to express the idea of multiplicity. To him, the percussion group in the orchestra "penetrates the sound-masses, making them pulsate with a thousand varied and unexpected vibrations with an effect not unlike, in the field of vision, a ray of light striking through a crystal prism, giving it a multiple existence."[46]

We will look at Cogan's work in more detail in Chapter 4.

Sculpture

A couple of years before the Philips Pavilion was constructed, the sculptor Naum Gabo, in designing his *Bijenkorf Construction* for an open space in Rotterdam, was having an experience with engineers similar to the one Xenakis was to have as he designed the Philips Pavilion. The structural calculations for this large scale public sculpture were excessively complex, and only the testing of physical models could confirm the intuitive sense that the structure was sound. This is not entirely coincidental, for Gabo's work was also based on ruled surfaces with complex curvatures, as was much of his work since the mid 1930s. As one of the early Russian Constructivists, Gabo's early works often had a monumental and architectural vision. He was like Xenakis in that his many architectural ideas remained largely unconstructed and his creative energy was channelled into another discipline. The *Bijenkorf Construction* stands as Gabo's largest construction, and is the piece that most effectively realises his architectural vision.

Gabo's interest in ruled surfaces came from a gradually evolving sense of the nature of spatiality. The *Realistic Manifesto*, which he wrote and was co-signed by his brother Antoine Pevsner in 1920, broadly expressed the objectives that Gabo was to pursue in his art through his entire career. One of the most concentrated parts of the manifesto reads as follows:

> The plumb-line in our hand, our eyes as precise as a ruler, in a spirit as taut as a compass … we construct our work as the universe constructs its own, as the engineer constructs his bridges, as the mathematician his formula of the orbits.
>
> We renounce in a line, its descriptive value; in real life there are no descriptive lines, description is the accidental trace of a man on things, it is not bound up with the essential life and constant

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46 Zanotti-Bianco, **Edgard Varèse and the Geometry of Sound**, *The Arts*, **7**, January 1925 p35-36; quoted in full in Parks: **Freedom, Form, and Process in Varèse: A Study of Varèse's Musical Ideas - Their Sources, Their Development, and Their Use in his Works**, p216-8. See also Linda Henderson: **The Fourth Dimension and Non-Euclidean Geometry in Modern Art**, p224-228.

> structure of the body. Descriptiveness is an element of graphic illustration and decoration. We affirm the line only as a direction of the static forces and their rhythm in objects.
>
> We renounce volume as a pictorial and plastic form of space; one cannot measure space in volumes as one cannot measure liquid in yards: look at our space… what is it if not one continuous depth? We affirm depth as the only pictorial and plastic form of space.[47]

Already there is an anticipation of Gabo's constructions after the mid thirties in which taut nylon thread twisted space into elegant curves.[48] These works are extraordinary for their feeling of weightlessness, the lines appearing more as forces than as massive elements. The *Realistic Manifesto* was published in a period when Gabo was exploring spatiality through stereometric construction and vibration. The *Constructed Head* series (1915 onwards) makes extensive use of stereometric construction, so that the figurative head is left with an imaginary skin and a collection of visible cavities between the structural planes [Figure 27]. These cavities are as much a part of the figure as the solid material that defines them, but the boundary between interior and exterior is left open; the viewer's eyes enter the figure. These cavities have an implied acoustic association: the eyes can penetrate the skin in a manner akin to the partial acoustic transparency of many visually opaque bodies (the human body being a case in point), and the cavities themselves set up a pattern of implied resonances through the construction. Movement also is implicated by the transformations that these complex planar relations undergo as a viewer moves around the *Constructed Head*. Steven Nash writes of this work:

> The interplay of light and shadow has become so complex as to change constantly under different illumination and as one moves around the piece. Different compositional aspects of the figure emerge from different points-of-view. And an active dialogue of inward and outward movement, line and plane, highlight and depth, representation and abstraction mitigates against any sense of stasis and seems to define an object in a perpetual state of becoming.[49]

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47 Naum Gabo: **The Realistic Manifesto**, translated by Gabo and reprinted in Bann (ed.): **The Tradition of Constructivism**, p3-11.

48 Pevsner started using ruled surfaces before Gabo, although Pevsner tended to use more noble materials such as bronze. This thesis concentrates on Gabo for the sake of economy. Gabo's use of tensioned ruled surfaces has been traced to the publication and exhibition of such mathematical models in the 1930s, and also to Balla's *Complesso Plastico di Lines-Forza* (1915). Balla's work also uses a stereometric form with similarities to much of Gabo's early work (especially the *Constructed Head* series). See Loïs Relin: **Two Pioneering Sculptures by Balla and Depero, 1915**, *Gazette des Beaux-Arts*, **107**, February 1986, p81-85.

49 Steven Nash, in Nash & Merkert: **Naum Gabo: Sixty Years of Constructivism**, p15. There are clear similarities between this approach to Gabo's work and Xenakis' sense of the importance of the viewer's position in the *Polytope de Montréal* and by implication, in the Philips pavilion. These similarities are reinforced in Gabo's later works with ruled surfaces and tensioned curves, such as the *Baltimore Construction Suspended in Space*. See Nash & Merkert op. cit. p39-40.

The *Kinetic Construction* (1920) represented a more blatant use of movement, open form and sound [Figures 29 & 30]. A vertical stainless steel rod was set into a standing wave through an electromagnet. In this piece form, movement and sound transcended mass and surface.[50] By not being static, solid, opaque and silent, Gabo's sculpture moves away from previous dominant ontological criteria. However Gabo always regarded this pioneering piece as a demonstration of a principle rather than a serious work of art.[51]

The long process that brought Gabo from these early works to use ruled surfaces in his constructions had to do with a gradual sensitisation to the nature of visual space. Gabo:

> The Spheric Theme is the result of many years' research for a constructive method of transferring my perception of space in terms of visual experience of it. The angular structure of the stereometric cube which I applied in my previous constructions since 1915, I found in elementary stereometry. It very soon proved insufficient to many an image which was growing in me where the vision of space as a sculptural element had to play a greater role than in my previous images.
>
> I felt that the visual character of space is not angular: that to transfer the perception of space into sculptural terms, it has to be spheric. I was looking for some kind of an indication in the scientific world, where a method of spheric structure could perhaps be found.
>
> I found no answer in graphic terms in science which would satisfy my vision of space. I consider that in this work of mine there is a satisfactory solution to that problem. Instead of indicating space by an angular intersection of planes, I enclose space in one curved continuous surface. I eliminate angularity in space construction and give space the curved character which it has to my perception. I have used this system since 1936. … There are some who consider my 'Spheric Theme' as an image of infinity. To my mind the image of infinity could not be an image which turns back on itself. I feel in this Spheric Theme continuity rather than infinity.[52]

Gabo's first major experiment with ruled surfaces was his *Construction in Space: Crystal* (1936), which was a close adaptation of a mathematical model in the Institut Poincaré [Figure 31].[53] *Crystal* was constructed from transparent plastic sheet, twisted into torsional planes, with ruled lines marked on the surfaces (as with many of his works, Gabo constructed several variations of *Crystal*,

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50 Len Lye has done a similar piece, *Revolving Harmonic*, which uses more complicated movement. See Lye: **Figures of Motion**, p75-76.

51 See Naum Gabo: **The 'Kinetic Construction of 1920'**, *Studio International*, **178** (914), September 1969, p89.

52 Gabo quoted in Read & Martin: **Gabo**, opposite plate 64. Gabo's symbolism has clear parallels with that of the Perisphere and Trylon.

53 A. Hill: **Constructivism - The European Phenomenon**, *Studio International*, **171** (867), April 1966, p144. Gabo was living in Paris at the time and *Crystal* was exhibited in the exhibition *Origines et Développement de l'Art International Indépendent* in the Musée du Jeu de Paume, 1937.

some using taut line rather than plastic surfaces). As a precursor of the Philips Pavilion, the use of a crystal metaphor applies similarly, although in this case it is reinforced by the crystalline transparency of the sculpture. While the sculpture itself is static, it is seen as the resultant of dynamic internal processes, of forces that are acting within and between the plastic surfaces. The works of Gabo that followed *Crystal* - such as the *Spheric Theme* and *Linear Construction* series - develop this idea in less rigid and more fluid structures [Figures 32 & 33].[54]

Gabo's vision of curvilinear subjective space is by no means unique in art, but his constructions from the mid 1930s are exceptional because of the concentrated way that they meditate on concrete spatiality *per se*. There are obvious external similarities between the Philips Pavilion and Gabo's work. Unity of form and structure, curvilinear geometry, the use of tension, and a new approach to materials are common to both. Gabo and Xenakis shared an interest in dynamic forms; in Xenakis' case this was clearly related to ideas of sound space, but even Gabo's works seem to have some relationship with sound. The *Polytope de Montréal*, Philips Pavilion, and Gabo's taut line constructions are harps, full of latent sound.

Domestic Images of Sound in Space

Images of ruled surfaces, not unlike those of the Philips Pavilion and of Gabo's works, were used in the advertising for stereophony in its early years. This is not to say that such advertising was dominated by images of ruled surfaces; only that these images were used occasionally, and that stereophony apparently was an apt context for their application. Ampex's free *Stereophonic Sound* brochure, promoted in audio magazines in 1957, featured the image of a ruled surface on its cover [Figure 34].[55] Earlier advertisements for Ampex stereophonic sound introduced curvilinearity into the word 'stereophonic' by fitting the stretched letters between two curves [Figure 37]. Ruled lines were also a feature of some Tandberg stereo advertisements,

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54 The *Spheric Theme* was also based on a mathematical model. See Manuel Corrada: **On Some Vistas Disclosed by Mathematics to the Russian Avant-Garde: Geometry, El Lissitzky and Gabo**, *Leonardo*, **25** (3/4), 1992, p337-384.

55 As one of the first major producers of stereophonic equipment, Ampex's use of this imagery is especially significant. While the 1958 version of the brochure abandoned the image of the ruled surface, the words 'stereophonic sound' were fitted between two curves (see for example *High Fidelity*, April 1958, p101).

suggesting a vortex-like surface receding into the page [Figures 35 & 36]. Other companies also used images of ruled surfaces from time to time in their promotion of stereophony.

Naturally, images of ruled surfaces were not restricted in advertising to the promotion of stereophony; these images were fashionable and had many applications. One instance is a phonograph pick-up advertisement from 1955, which used the image of a Gabo-like thread sculpture (by Gerald Farmer) [Figure 41].[56] The sculpture's characteristics of newness, clarity, transparency, fluidity and immaculate delicacy are thus applied to the pick-up. In the same way, the application of ruled surfaces to the promotion of stereophony was intended to emphasise shared characteristics, in this case intense, abstract and deep spatiality. Ruled lines already had a strong association with music through the musical stave, and the curvilinear ruled surface opened up new possibilities in this familiar icon. Stereophony was a 'new dimension in sound'.

The ruled surface imagery in advertising for stereophony is related to two other images: that of receding lines of perspective; and of diagrams of ray propagation. The rationale for receding lines of perspective in advertisements for stereophony is obvious. One such advertisement for a binaural tape recorder employs Stokowski to tell us that it "gives music a spatial sense, parallel to the third dimension of vision" [Figure 42]. Likewise, other advertisements depict receding lines to associate stereophony with visual depth.[57] The common use of curvilinear distortions of words such as 'stereophonic' in advertisements and logos is partly an attempt to write the word in three dimensions, emerging from and receding to depth and *vice versa* [Figures 37 - 39]. Since the addition of a second speaker is - in the most literal terms - a lateral expansion, the association of depth with stereophony may appear puzzling. In one sense this is simply a reflection of the printed medium; perspectival depth is an attempt at a stereoscopic image on the flat page, thus adding an arbitrary dimension in an analogy with stereophony.[58] However the further analysis of depth and stereophony throughout the remainder of this thesis shows that the association between the two extends further than pictorial analogy.

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56 A second such advertisement (showing a different thread sculpture) is found in *High Fidelity*, September 1956, p19.

57 A general survey of advertisements dominated by lines receding to a horizon under a slightly cloudy sky shows that this image is a *cliché* associated with the idea of 'a new dimension in sound'. See for example *High Fidelity*, October 1954, p30 and *High Fidelity*, March 1956, p39.

58 The reader should note that while 'stereo' is commonly taken to mean a sort of double image, it is actually a reference to solidity or hardness (hence the introduction of a third dimension).

The second image - diagrams of ray propagation - can be seen in the Ampex ruled surface image, where all of the ruled lines appear to meet at a point on the lower right. Whether they originate from that point, are focused onto it, or are receding to a vanishing point is not clear.[59] In other advertisements for stereophonic equipment ray diagrams produce patterns not unlike those of doubly ruled surfaces and of two-point perspective [Figures 39 & 44]. While such advertisements may be aiming to illustrate the broadness of the stereophonic listening area, the visual association with perspective and ruled surfaces also emphasises the spatial depth of stereophonic listening.

Sound, Space, Surface

This chapter has collated a number of examples of Modernist spatial construction. The Perisphere and Trylon are antecedents to the Philips Pavilion in several ways. Belgium's Civil Engineering Pavilion captures the transforming process between the two, with curvilinearity being introduced into its Trylon, boundary into its Perisphere, and the two joined in a single cantilevered structure. These two gestures of linearity and continuous curvature are found in a unified form in the hyperbolic paraboloidal shell of the Philips Pavilion. The crystal metaphor provides a way of describing the frozen dynamism in the hyperbolic paraboloid, and an exchange between music and architecture is made possible. Thus sound can be imagined as an abstract construction which might be realised in architecture. This is affirmed in the sculpture of Gabo, where sound, space and ruled surface find an intimate connection. Similar imagery in the marketing of stereophony also affirms such connections.

The Philips Pavilion, as a *tour de force* of the new possibilities of stereophonic sound production, brought these associations between ruled surfaces and spatial sound to the fore. Its 'sound routes', playing on the hyperbolic paraboloidal walls, might be interpreted as one realisation of this dialogue between ruled surfaces and a Modernist conception of sound liberated in space. The curvilinear walls themselves were in sympathy with the abstract imagery of stereophony, and thereby associated with its ideas. Through Xenakis' imagination, these walls were made of sound.

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59 In any case, the laws of reflection are not observed along the top border of the image.

Xenakis' and Varèse's music opened up the walls, projecting ruled lines, parabolæ and hyperbolæ in auditory space.

2

Hyperbolic Paraboloids

A Scientific Imagination

The hyperbolæ, parabolæ, and ruled surfaces that are in the music of Varèse and Xenakis, Xenakis' architecture, the constructions of Gabo and Pevsner, and the early marketing imagery of stereophony approach spatiality in a distinctive way which would have appeared fresh and novel at the time. One common link between most of these instances is what might be called a post-Newtonian scientific consciousness - and a post-Euclidean mathematical consciousness. (In the case of the marketing of stereophony it is more a superficial consciousness of technological ascendancy than of scientific revolution). There were many well known revolutions in scientific thought in the early part of this century, such as Einstein's theories of relativity, new models of the structure of matter and energy, and Heisenberg's uncertainty principle. To artists such as Gabo, these ideas were inspirational, for their spirit as much as for any specific content. Gabo:

> [My new sculpture] had to express a new way of looking at the universe. A new feeling was already going through the universities and among the intellectuals. There was a feeling of time and space, a movement in men's minds.
>
> For instance, I will never forget when I was present at a gathering of scientists and students in, well, about 1911 or 1912 - one of the professors was talking of Einstein's theory. I myself was then studying physics. There was a sharp discussion. I grasped the idea, though I couldn't say exactly what it was about. But there was a feeling of elation in the air.[60]

This "feeling of time and space" was reflected by many artists and artistic movements in different ways, but was not attributable entirely to relativity. Linda Henderson has shown how developments in non-Euclidean and *n-dimensional* geometry were prominent in the popular imagination in the first decade of the twentieth century, while Einstein emerged as a public figure as late as November 1919.[61] The often assumed associations between Einsteinian relativity and

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60 Naum Gabo: **Naum Gabo talks about his work**, *Studio International*, **177** (876), April 1966, p128.

61 Linda Henderson: **The Fourth Dimension and Non-Euclidean Geometry in Modern Art**, p353-365.

Cubist æsthetics has little basis. Gabo's exposure to Einstein as early as 1911 or 1912 (he was studying in Munich) was after Minkowski introduced time as the fourth dimension in the space-time continuum, but before the General Theory of Relativity (in which non-Euclidean geometry was introduced). Hence this moment of inspiration did not include a sense of a curvilinear space, such as the space that he sought in the *Spheric Theme*. The importance of science in Gabo's work is reflected in his writings, which contain an analysis of relations between science and art.[62]

The synthesis of time and space was also compelling for Varèse who, like Gabo, had an education in physics. When Varèse was asked by Georges Charbonnier whether the development of physical sciences affects music, Varèse replied:

> Les sciences physiques ont découvert et découvrent lois et ordres régissant la matière. Lois et ordres qui ont changé et continuent de changer notre civilisation. Je tiens à répéter ces mots d'Einstein : « Notre situation actuelle ne peut être comparée à rien dans le passé. Nous devons changer radicalement nos façons de penser et notre méthode d'action ».[63]

In another context, Varèse stated:

> … how little our music reflects the stupendous physical discoveries that have so fundamentally altered most of our inherited scientific beliefs … Music, the most physical (and most abstract) of the arts should be the first to reflect this revolution, as it could be the art to benefit the most.[64]

His knowledge and consciousness of the 'new physics' is investigated in detail by John Anderson, who shows that Varèse's rhetoric about the convergence of science and art was informed by a knowledge of and active interest in science, and had specific compositional implications.[65] His interest in science was also explicitly related to his quest for new music technologies that would enable his music to be liberated from musical notation and performers, giving him the means to use physical space as a compositional parameter. In this respect he was attracted to the physical understanding of sound that science offered the musician. Varèse:

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62 For example, Naum Gabo: **The Constructive Idea in Art**; in Martin, Nicholson & Gabo (eds.): **Circle: International Survey of Constructive Art**, p1-10.

63 Edgard Varèse in Georges Charbonnier: **Entretiens avec Edgard Varèse, Suivis d'une Etude de l'Œuvre par Harry Halbreich**, p69.

64 Edgard Varèse, quoted in Anderson: **The Influence of Scientific Concepts on the Music and Thought of Edgard Varèse**, p88, from **Edgard Varèse and Alexei Haieff Questioned by 8 Composers**, *Possibilities: An Occasional Review*, **1**, Winter 1947/1948, p96.

65 John Davis Anderson: **The Influence of Scientific Concepts on the Music and Thought of Edgard Varèse**.

> Hoëne Wronsky and Camille Durutte, in their treatise on harmony in the middle of the last century, were obliged to coin new words when they assigned music in its place as an "Art-Science," and defined it as "the corporealization of the intelligence that is in sounds." Most people rather think of music solely as an art. But when you listen to music do you ever stop to realize that you are being subjected to a physical phenomenon? Not until the air between the listener's ear and the instrument has been disturbed does music occur. Do you realize that every time a printed score is brought to life it has to be re-created through the different sound machines, called musical instruments, that make up our orchestras, and are subject to the same laws of physics as any other machine?[66]

We see something of a highly relativistic appreciation of space in the following analogy given by Varèse for the musical structure of *Intégrales*. He asks the listener to:

> …visualize the changing projection of a geometrical figure on a plane, with both plane and figure moving in space, but each with its arbitrary and varying speeds of translation and rotation. The instantaneous form of the projection is determined by the relative orientation between the figure and the plane at the moment. By allowing both the figure and the plane to have motions of their own, one is enabled to paint a highly complex and seemingly unpredictable picture with the projection. In addition, these qualities can be further enhanced by letting the form of the geometric figure vary as well as its speeds.[67]

It is interesting to read this extract in relation to certain constructions by Gabo, especially a suspended piece like *Linear Construction in Space No. 2*. While objectively, such a piece is static, by its very nature it encourages the viewer to walk around it, so that the twisted planes and individual lines of force are in complex and surprising transformations. This dynamic perceptual process appears to be a phenomenological characteristic of curvilinear ruled surfaces.

Likewise, Xenakis' interest in a synthesis between science, engineering and music forms a major influence behind all of his work, and is elaborated on in his monographs. Many of his pieces have been composed in analogy to processes described by science, especially statistical theories such as the atomic kinetic theory of gasses. This model is especially apt because of the dimensional conception of musical space that Xenakis uses, so that 'microsound' structures which are conceptually analogous to the microscopic behaviour of gasses can be constructed in 'pressure-time space', a literally gaseous space (sound is in the air). Xenakis shares Varèse's wish to conceive of and compose music for the ears, by taking into account (and even formalising) the

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66 Edgard Varèse: **Music as an Art-Science**, in Schwartz & Childs (eds.): **Contemporary Composers on Contemporary Music**, p199.

67 Edgard Varèse, interviewed by Fred Grunfeld on radio station WQXR, December 13, 1953, quoted in Waldman: **Edgard Varèse: An Appreciation**, *Juilliard Review*, **1** (3), 1954, p9.

psycho-acoustic dimensions of hearing.[68] To Xenakis, the design of the Philips Pavilion, like his music, was a realisation of a synthesis between mathematics and æsthetic form. Volumetric architecture, as he described it, stood for a revolution in spatial thought not unrelated to the revolution of Riemannian geometry and General Relativity:

> Le système de référence du corps humain ne sera plus l'angle droit et les surfaces planes, horizontales et verticales. Sa sensibilité se façonnera par un espace courbe.[69]

The 1958 Brussels World's Fair, which focussed optimistically on the new possibilities of atomic science and engineering (as the Atomium made abundantly clear), was a particularly apt context for such work to be applied.

Ruled surfaces such as hyperbolic paraboloids had a symbolic relationship with spatial concepts associated with relativity and a more substantial one with advances in civil engineering. Varèse believed that the dams on the Colorado River spoke the contemporary architectural language, with their characteristic of rigorous precision so as to exploit forces and materials.[70] That these examples of massive curvilinear geometry should have captured his imagination as an analogy for the potential of music to reflect its own time (especially progress through science and engineering) reflects the power of the geometric image in his mind in an acoustically conceived sound space.

While there is a shared scientific (or meta-scientific) agenda in the associations that we have found with the use of ruled surfaces, there is much more to this issue of why these surfaces held a particular attraction to the artists and promoters in question, all of whom seemed to be motivated by a desire to express spatiality as a thing in itself. As mathematical forms they are attractive because of their relatively simple geometry, which can be approached in several ways (as a series of parabolæ, of hyperbolæ, or of intersecting straight lines); as engineering structures, they are attractive because of their lightweight strength (they are easily formed by tension, and are convex

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68 See for instance, Iannis Xenakis: **Markovian Stochastic Music - Theory**, in **Formalized Music**, p43-78. The Fletcher-Munson equal loudness contours are applied in the construction of a subjective three dimensional musical space in which 'grains of sound' follow trajectories governed by statistical models.

69 Iannis Xenakis: **Le Pavillon Philips a l'Aube d'une Architecture**, in **Musique. Architecture.**, p141.

70 Georges Charbonnier: **Entretiens avec Edgard Varèse, Suivis d'une Etude de l'Œuvre par Harry Halbreich**, p78-79.

in one direction, concave in the other). Their appropriation in art and advertising can on one level be interpreted as the realisation of a general desire for an association with the image or methodology of scientific and mathematical endeavour, and with the spirit of the Twentieth Century scientific revolution. But the surfaces themselves, which are found in mathematical texts from the Nineteenth Century, should not be considered merely as token symbols of mathematical procedures; their immanent æsthetic qualities are the most basic reason for their attraction, as Xenakis indicates in the following passage:

> Lorsqu'on se trouve dans le Pavillon Philips on ne raisonne pas sa géométrie, on subit l'influence de ses courbures. On est sensibilisé à tel point, que si par exemple on introduisait dans les surfaces de sa coque des portions brutalement planes, le résultat aurait été une cacophonie insupportable pour nos yeux et pour notre peau. La rigeur d'une loi abstraite de comportement des volumes est *immédiatement* perceptible. Le « filtre » de la logique n'est qu'un supplément hédonique.[71]

The remainder of chapter is an exploration of this duality of logical, scientific or mathematical thought and the ill-defined "immediate" perception of a hyperbolic paraboloid. Xenakis has already defined the duality in terms of subjective perception and objective conception. Initially the duality is explored in abstract by contrasting Cartesian and phenomenological approaches to spatiality. This leads to a parallel discussion of the nature of visual space, which is then applied to the hyperbolic paraboloid. Finally we ask how these questions of subjectivity and perception might reflect upon a notion of auditory space. We discover one way in which the hyperbolic paraboloid speaks of sound space.

Extension and Depth

In developing this more immediate appreciation of the hyperbolic paraboloid, we will concentrate on the relation between depth and extension in visual and physical space, and then apply aspects of that relation to auditory space. The study of visual space has yielded substantial material on the nature of the subjective experience that Xenakis is describing. This material may also be applied to an understanding of Gabo's work, and certain aspects of Varèse's notion of sound space can even be discussed in these terms. The following passage is not intended to imply that Varèse, Gabo and Xenakis were necessarily opposed to Cartesian philosophy, with its static, rectilinear

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71 Iannis Xenakis: **Le Pavillon Philips a l'Aube d'une Architecture**, in **Musique. Architecture.**, p142.

geometry. It would be truer to state that there is a duality in their philosophies of space: sometimes they use Cartesian frameworks and sometimes a subjective reference.[72] As the following analysis shows, their association with ruled surfaces is a reflection of this duality.

The tension between spatial depth and extension is set up with the possibility of measurement and geometry. Philosophers such as Descartes have polarised the issue by establishing ontological criteria based entirely on extension and associated measurable quantities, at the same time crystallising a way of thinking that has greatly facilitated the development of science and engineering. In Descartes' model of space, it is understood from an objective position; one must remove oneself from space, perhaps as God does, and then impose a three dimensional system of coordinates onto it. Cartesian space is reduced (and deduced) by quantification and digitisation. The first and most fundamental of Descartes' principles of philosophy is the institution of an analogue to digital converter: doubtful things are regarded as false until analytic logic founded on certain things is able to remove the doubt. This binary formal system is the sole determinant of metaphysical truth, as well as physical truth, and hence Descartes deduces physical principles from the former. Space is marked or quantified by the real number system, and this has many implications: it is unbounded in expanse and division, proportions and movements are relative, and there is no distinction between the laws of physics in heaven and earth, nor any variation in the size of the (arbitrary) units. This consistency and universality forms a unique objective and absolute space. The Cartesian mind, separated from body and space by logical doubt, is an objective observer of space.

Descartes' radical reduction of space is recognised by him in the following concise statement:

> I do not accept or desire in Physics any other principles than in Geometry or abstract Mathematics; because all the phenomena of nature are explained thereby, and certain demonstrations concerning them can be given.[73]

In Descartes' formal or mechanistic structure, there are direct equivalences between algebra, geometry, physics and space, and further defined relationships with the mind, God, and truth.

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72 In the case of Xenakis this duality is especially strong, with the strong Cartesian influence in **Formalized Music**, and a simultaneous commitment to an essentially phenomenological approach to perception. It is the latter approach which is expressed in his description of the curved architecture of the Philips Pavilion.

73 René Descartes: **Principles of Philosophy**, *On the Principles of Material Objects*, article 64.

There is no real difference between a space and its true geometric representation, as Descartes believes the two to be in perfect unison. Space is defined as extension in three perpendicular dimensions, and any other properties of a part of space are regarded by Descartes to be secondary products of extension. In this way he reduces every thing, every phenomenon, to lines, shapes, and volumes on a three dimensional (Cartesian) graph. Hence:

> And by this simple enumeration, it is concluded that no phenomena of nature have been omitted by me in this treatise. For nothing is to be numbered among the phenomena of nature, except what is perceived by the senses. However, apart from size, figure, and motion, the varieties of which I have explained as they are in each body, nothing located outside us is observed except light, colour, odour, taste, sound, and tactile qualities; which I have now demonstrated are nothing in the objects other than, or at least are perceived by us as nothing other than, certain dispositions of size, figure, and motion of bodies. Thus, …there is nothing visible or perceptible in this world that I have not explained.[74]

Regardless of any impact that non-Euclidean geometries or Twentieth Century physics may have had on the application of Descartes' model of space, it has proven to be insufficient and unhelpful in many respects because it does not address questions concerning the participation and experience of a person in space. No person is only an objective logical investigator of the universe. To Descartes, depth is simply the third dimension, formally equivalent to the first and second, merely an axis of extension. By contrast, 'depth' has also been used by artists and the phenomenologist Maurice Merleau-Ponty to describe the way in which space recedes and expands around a person. Depth is the immediate experience of space. As Merleau-Ponty is considering areas broader than logical truth, he does not extract the person's mind from the body, nor the body from the world. Merleau-Ponty:

> We grasp external space through our bodily situation. A "corporeal or postural schema" gives us at every moment a global, practical, and implicit notion of the relation between our body and things, of our hold on them. A system of possible movements, or "motor projects," radiates from us to our environment. Our body is not in space like things; it inhabits or haunts space. It applies itself to space like a hand to an instrument, and when we wish to move about we do not move the body as we move an object. We transport it without instruments as if by magic, since it is ours and because through it we have direct access to space. For us the body is much more than an instrument or a means; it is our expression in the world, the visible form of our intentions.[75]
>
> Our organs are no longer instruments; on the contrary, our instruments are detachable organs. Space is no longer what it was in the *Dioptric*, a network of relations between objects such as would be seen by a witness to my vision or by a geometer looking over it and reconstructing it from

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74 René Descartes: **Principles of Philosophy**, *Of the Earth*, article 199.

75 Maurice Merleau-Ponty: **An Unpublished Text**, in **The Primacy of Perception**, p5.

> outside. It is, rather, a space reckoned starting from me as the zero point or degree zero of spatiality. I do not see it according to its exterior envelope; I live in it from the inside; I am immersed in it. After all, the world is all around me, not in front of me.[76]

It is the 'third dimension' itself - depth - that opposes dimensional space; depth radiates from the person in all directions, collapsing notions of dimensional independence, perpendicularity and linearity. Merleau-Ponty:

> The enigma consists in the fact that I see things, each one in its place, precisely because they eclipse one another, and that they are rivals before my sight precisely because each one is in its own place. Their exteriority is known in their envelopment and their mutual dependence in their autonomy. Once depth is understood in this way, we can no longer call it a third dimension. In the first place, if it were a dimension, it would be the *first* one; there are forms and definite planes only if it is stipulated how far from me their different parts are. But a *first* dimension that contains all the others is no longer a dimension, at least in the ordinary sense of a *certain relationship* according to which we make measurements. Depth thus understood is, rather, the experience of the reversibility of dimensions, of a global "locality" - everything in the same place at the same time, a locality from which height, width, and depth are abstracted, of a voluminosity which we express in a word when we say that a thing is *there*.[77]

Elsewhere Merleau-Ponty states this another way:

> More directly than the other dimensions of space, depth forces us to reject the preconceived notion of the world and rediscover the primordial experience from which it springs: it is, so to speak, the most 'existential' of all dimensions…[78]

When our perception of the world is not flat - when our body is caught in and surrounded by space - reductive *a priori* spatial models such as Descartes' remain impoverished abstractions. These two approaches to spatiality work in entirely different ways; they may as well be describing different universes except for the fact that they constantly encounter each other as we live in and measure the same space.

The relationship between depth and extension has been the essential problem of the theory of perspective. One of the major issues in perspective has been how to represent objectively straight lines. Ruled line vanishing point perspective, which dominated for a period from the Renaissance, is based on the premise that objectively straight lines should always be represented by straight lines. This creates paradoxes in some situations: if one is drawing a very wide building

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76 Maurice Merleau-Ponty: **Eye and Mind**, in **The Primacy of Perception**, p178.

77 Maurice Merleau-Ponty: **Eye and Mind**, in **The Primacy of Perception**, p180.

78 Maurice Merleau-Ponty: **Phenomenology of Perception**, p256.

facade from directly in front of its centre, should the fact that the far extremes of the facade recede into the distance - and therefore appear smaller than the centre of the facade - be ignored? Such inconsistencies or inaccuracies might be compensated for to an extent by the relation between the viewer and the finished picture: if the viewer stands at an appropriate position in front of the representation of the facade, the same (or similar) effect will be seen. Nevertheless, the problem of constructing a universal perspective has often been considered as intractable as the paradoxes of musical temperament.

Photography has had a marked effect on the consciousness of perspective, as the variety of effects from the curvilinearity of a wide angle lens to the almost geometric purity of a narrow angle lens is very striking. With the former, there is an exaggerated feeling of surroundedness, which would appear to be related to Merleau-Ponty's notion of depth; with the latter, depth appears to be compressed (this applies more to telephoto than to close-up lenses because in the latter case the shallowness of the area that is in focus creates a sense of depth). This depthless and uncurving perspective approaches the type of graphical representation of space made on the three-dimensional mathematical grid (the so-called 'Cartesian graph'). In narrow angle rectilinear space, the viewer feels removed from the visual field; the viewing position is relatively arbitrary, and this gives a sense of objectivity. In wide angle curvilinear space, the viewer is surrounded by the visual field, and like the pre-Copernicans, has the sense of being in the centre of the universe.

Hyperbolic Visual Space

Perspective is not our concern; it has the double problem of creating a subjective visual representation of a space on an objectively flat surface, that is in turn viewed in subjective visual space. Our concern is only with the single problem of subjective visual space. Perhaps because of the importance of visual models in science and mathematics, science was slow to discard the assumption that visual space and objective space have a common geometry: Helmholtz was the first scientist to seriously explore the subtleties of this transformation. The following survey of the research into subjective visual space gives us a way of understanding the hyperbolic paraboloid as an peculiar expression of spatiality *per se*.

Helmholtz, in his *Treatise on Physiological Optics*, tests subjective curvature in monocular visual space by assuming that an angle between two rays meeting at the eye is proportional to their visual interval (disregarding any depth discrimination).[79] On this basis, a curvilinear representation of a chess-board pattern was produced, which when viewed by one eye directly opposite the centre of the pattern at a distance of ‘A’, appears to be rectilinear [see Figure 45].

The pattern is constructed so that when viewed from the correct position, the vertices of the horizontal and vertical hyperbolæ intersect so as to divide each other into segments each with a visual angle of 10°. That these curves might be hyperbolæ (or at least resemble hyperbolæ) can be appreciated intuitively by returning to the example of viewing a very wide building facade from directly in front of its centre. The facade might be abstracted to two objectively parallel lines, representing the top and base of the building. Subjectively these lines converge at the extremes, the interval between them at its maximum in the centre, where there is maximum curvature. If we abstract the example further, and imagine these two lines extending indefinitely in both directions, as the lines approach each other they approach two points (vanishing points) 180° apart in the visual globe. Thus we have an image of a pair of curves at least a little like hyperbolæ. The curves constructed by Helmholtz are calculated so as to cancel out this effect, and are hyperbolæ of opposite curvature (converging in the centre, diverging in the periphery).

Helmholtz’s monocular hyperbolic visual space is commonly seen in photographs taken with ‘uncorrected’ wide angle lenses. It should be possible to take a photograph of his chess board with an appropriate lens positioned correctly, so that the photographic image shows a rectilinear pattern. The model is scarcely applicable to normal viewing in the near field because of the complexity that binocularity introduces. However at large distances, the two eyes see essentially the same image, and the model might be applied.

Helmholtz writes more about the inconsistencies in the viewing of his pattern than in support of it as a model of monocular vision. While the pattern works well in the central part of the visual field, the peripheral field requires the eye to be a little closer to the pattern for these lines to be straightened; at a distance of A, the peripheral lines appear to retain some of their curvature. Helmholtz’s discussion of this phenomenon is based mostly on subjective experiments, but in the end he explains it as a phenomenon caused by a person’s sense of the effort involved in turning

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79 Hermann von Helmholtz: **Helmholtz’s Treatise on Physiological Optics**, Volume 3, p154-232.

the eye to the extremes of the field.[80] Our concern is not with Helmholtz's explanation, which seems to be less convincing than his description, but with the phenomenon, which is related to the subjective impression that a person sees the world from a position inside their head, not from the surface of their eyes. Helmholtz:

> … the visual globe of each eye, which in the geometrical sense embraces a horizontal angle of about 180°, seems indeed to be much narrower than this. For the farthest objects on the right and left which can be recognized in indirect vision, and which are connected by a straight line passing through the eye, nevertheless always appear to be situated in front of us, as if the direction lines of vision drawn to them made an obtuse or perhaps even a right angle with each other. Especially, on looking up at the sky, where there are no terrestrial objects on the visual globe of known positions and dimensions, the bright field in front of us appears to have an angular diameter of about 90° horizontally, and even less than that vertically, where the eyebrows and cheeks tend to contract the field somewhat. We have the impression of looking at the external world from a certain depth in the head.[81]

This experience of visual space being narrower than Cartesian space also has the effect of deepening the central field, making the peripheral field relatively shallow:

> Since the lateral portions of the visual globe look to us somewhat too high and too small, there is a tendency to consider them as being nearer and as being situated obliquely with respect to the visual axis. Whenever we turn to look toward them, they seem to recede and to become more perpendicular to the line of fixation. This is an illusion that is very usual with me when I am looking at distant objects on the horizon or in the sky. Then the visual globe does not seem to me like a sphere with my eye at its centre, but appears to be more concave than a sphere would be.[82]

Helmholtz also notes that there are subjective differences between the horizontal and vertical scales in the peripheral field, and that while the 'squares' on his pattern above and below the centre are not as high as they are wide when viewed from a distance of A, the equivalent effect is not so noticeable for those on the left and right.

More complex models of visual space have been proposed since Helmholtz, most notably Luneburg's model of binocular space, dating from the late 1940s.[83] Helmholtz discusses some of

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80 Hermann von Helmholtz: **Helmholtz's Treatise on Physiological Optics**, Volume 3, p187.

81 Hermann von Helmholtz: **Helmholtz's Treatise on Physiological Optics**, Volume 3, p184-185.

82 Hermann von Helmholtz: **Helmholtz's Treatise on Physiological Optics**, Volume 3, p183-184.

83 Rudolf Luneburg: **Mathematical Analysis of Binocular Vision**, 1947. See also Robert Hansen: **This Curving World: Hyperbolic Linear Perspective**, *Journal of Aesthetics and Art Criticism*, **32** (2), 1973, p147-161; and André Barre & Albert Flocon: **Curvilinear Perspective: From Visual Space to the Constructed Image**. These writers propose

the phenomena that form the empirical basis for Luneberg's model in another part of the *Treatise on Physiological Optics*, but it was left to Luneberg to develop a detailed mathematical model.[84] His model was based primarily on experimental evidence gathered initially by Hillebrand in 1902 and Blumenfeld in 1913 where subjects in a dark room (usually) with their heads immobile would adjust the position of points of light in so-called 'alley' experiments. In parallel alley experiments, pairs of frontally coplanar points at various depths would be adjusted so that they formed two subjectively parallel lines symmetrical on the horizontal plane around the straight-ahead line of sight. In distance alley experiments, pairs of frontally coplanar points at various depths would be adjusted so that each pair had the same subjective distance between its two points. In both experiments usually the far pair of points was fixed and provided the reference to which the other points were adjusted. In Euclidean space these processes are identical: parallel lines are defined as having a constant distance, never converging or diverging. In visual space, however, the parallel alleys are nearer to the median as they approach the subject than the distance alleys, and this was taken by Luneberg to imply a non-Euclidean space.[85]

Luneberg and his immediate successors, such as Blank, developed a model of binocular visual space, describing it as Riemannian with a constant Gaussian curvature (also known as Desarguesian), of which there are three types; spherical (positive curvature), Euclidean (zero curvature) and hyperbolic (negative curvature). Various experiments, including the alley experiments, appeared to describe a space of negative curvature, hyperbolic space. It should be emphasised that there is no explicit close connection between Helmholtz's monocular space and Luneberg's binocular space. The former's experiment was designed to isolate monocular vision so that, independent of depth, visual angles could be translated into spatial intervals. Helmholtz's concern is with the position of images on the *two dimensional* surface of the visual globe. The experiments on which Luneberg's model is based were intended to isolate the binocular system's ability to locate points in three dimensional space, the way that visual space curves with depth

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different models of visual space and perspective.

84 Hermann von Helmholtz: **Helmholtz's Treatise on Physiological Optics**, Volume 3, p318-330.

85 In a curvilinear model of space, a straight line may be defined as a line that traces the shortest possible path between two points. Such a line is perceived as straight from within the model, but may be seen to be curved in a higher dimensional meta-space.

being the central concern.[86] The model of space in this case is correspondingly three dimensional.[87]

The Luneberg theory is primarily concerned with empirical evidence and the construction of a corresponding mathematical model; there is little emphasis on a causal mechanism that might explain the relationship between experiments and the mathematics. Such an explanation is elusive because of the complex of physical and psychological factors that are involved in perception. Nonetheless, Indow and Watanabe have argued that the elusiveness of such a mechanism does not detract from the theory, especially as the widespread assumption that visual space is Euclidean has no *a priori* basis.[88] Because the data describes a hyperbolic model better than a Euclidean model, the hyperbolic model is the more natural. However the question remains as to the extent to which visual space can be described by a Desarguesian geometry at all.

In the Luneberg model, visual space is mapped by polar coordinates: the 'egocentre' or imaginary cyclopean eye, which is between the two eyes, is the origin of vision. The visual axis is a ray extending away from the egocentre in the sagittal forward direction: the straight-ahead line of sight. In simple terms, hyperbolic space is mapped by a series of trumpet-like surfaces (following hyperbolæ) nested around this axis, flaring in the distance (there is also a slight flare in the near zone as the surfaces approach the viewer). In visual space, subjectively parallel lines approaching the viewer from directly ahead follow these curves. Lines that are parallel in Euclidean space appear in visual space to have reverse curvature; to curve towards each other and meet at a finite point in the distance (where the reversed hyperbolæ intersect). The nested trumpet surfaces may have a roughly circular cross-section that is distorted by the differences between horizontal and vertical vision. Most of the experiments on subjective curvature in visual space have concentrated on the horizontal plane, and the transformations in vertical dimensions are relatively

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86 While many of the proponents of the Luneberg theory have argued that the phenomena that it describes are based entirely on binocular vision, this assumption may be wrong. Blumenfeld observed similar discrepancies between parallel and distance alley in binocular and monocular vision, and Heelan has argued that monocular vision participates in hyperbolic visual space through accommodation.

87 Luneberg's model is described with great clarity by Blank in Sigmund Koch: **Psychology: A Study of a Science**, Volume 1, p395-426.

88 Tarow Indow & Toshio Watanabe: **Parallel - and Distance - Alleys with Moving Points in the Horizontal Plane**, *Perception and Psychophysics*, **35** (2), 1984, p153. Merleau-Ponty shares this approach to discovering the structure of space.

undeveloped. Finally, planes that are subjectively flat and orthogonal to the visual axis tend to be concave (with respect to the viewer) in close proximity, convex at a distance, with the transition at a distance of around 1.5m.[89] This is reflected in the visual impression of close surfaces, flat in Euclidean space and viewed frontally, bulging towards the viewer, or of similar distant surfaces appearing to be concave; in both instances having opposite curvature to the contours that have been described. In the very near zone, where binocular fusion breaks down, the subjective construction of visual space becomes too complex for the model to apply.

It is argued that the parallel alleys, which are affirmed by the subject as being straight lines, follow the longitudinal (front/back) contours of hyperbolic space, which objectively converge towards the viewer.[90] In the near zone these lines diverge again as they approach the viewer.[91] The distance alleys map lateral (left/right) contours of hyperbolic space, which draw further from the visual axis than the parallel alleys as they approach the viewer. Experiments showed that these curves varied significantly from subject to subject, and Luneberg assumed that each individual had a distinctive and stable visual space.

The rigidity of the Luneberg model proved to be problematic when Luneberg's assumption was contradicted by experimental evidence. In several experiments in which subjects performed geometric exercises, a consistent spatial metric could not be determined even for an individual. Patrick Heelan has identified three basic problems with Luneberg's model:

> (1) The model itself lacks flexibility; Luneberg's view that for any individual the curvatures of visual space were fixed personal constants was surely too restrictive. (2) The design of the experiments assumed that visual space was unique for a given individual or caused unhermeneutically by stimuli from the environment; failing to take into account the hermeneutical character of perception, the experiments failed to create for the subjects conditions necessary for a stable visual space. (3) Some data from the experiments express the effect of something like a multistable illusion, at one moment controlled by Euclidean structure and at another by a hyperbolic structure; this could be another indication of the failure to consider hermeneutical effects.[92]

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89 See for instance Tarow Indow: **On Geometry of Frameless Binocular Perceptual Space**, *Psychologia*, **17**, 1974, p58-59.

90 Thorne Shipley: **Convergence Function in Binocular Visual Space**, *Journal of the Optical Society of America*, **47** (9), September 1957, p795-821.

91 See for instance Tarow Indow: **An Approach to Geometry of Visual Space with No A Priori Mapping Functions: Multidimensional Mapping According to Riemannian Metrics**, *Journal of Mathematical Psychology*, **26**, 1982, p204-236.

92 Patrick Heelan: **Space-Perception and the Philosophy of Science**, p50.

Heelan has developed what he has called a hermeneutic visual space, in which under some circumstances a person views the world in Euclidean space, and under others, the same person views the world in hyperbolic space. He argues that hyperbolic visual space is a natural way of seeing the world, but that in our 'carpented' environment we tend to adopt Euclidean vision, so that objectively straight lines are interpreted as being straight. Heelan's viewer is an interpreter of space rather than being restricted to one mode of spatial representation. In Merleau-Ponty's terms, in some circumstances a person will see space in terms of extension, while in others the same person will see in terms of depth. With Heelan's commitment to phenomenology, the problem of finding a causal explanation for his model is not considered significant: his model is based on evidence from visual experience, experiments and figurative art. By making some changes to the Luneberg model, Heelan moves the viewer from the dark room into the real world.

Heelan's analysis of visual space also makes interesting connections between space perception and technology. A hyperbolic world is 'person-related' and 'locally structured'. Technology demands a standard, consistent and universally applicable spatial paradigm, and therefore requires Euclidean space. However, the power of communication technology to collapse distance does not necessarily create a Euclidean space, but transforms our potential for perceiving near and distant zones in hyperbolic space.[93]

While Helmholtz's monocular and Luneberg's binocular hyperbolic visual spaces are not related by their experimental parameters, it is interesting that various writers have attempted to explain the same visual phenomena using the two models. Pirenne, for example, relates the apparent curvature of the sides of a long straight road (the sides curving apart as they approach an observer standing in the middle of the road) to the phenomena that Luneberg's theory addresses, when it can be explained quite simply by Helmholtz's model.[94] Helmholtz used his model of the difference between central and peripheral monocular vision to explain the exaggerated concavity of the empty sky, while Heelan relates it to his adaptation of Luneberg's theory. Heelan argues that as depth perception is a function of both accommodation (monocular focussing) and parallax angles, Luneberg's model may apply equally to monocular and binocular visual space, and that Luneberg had an exaggerated conception of the importance of binocularity in depth

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93 Patrick Heelan: **Space-Perception and the Philosophy of Science**, p254-263.

94 M. H. Pirenne: **Optics, Painting and Photography**, p147.

perception.[95] It would appear that Helmholtz's monocular model addresses certain rarefied visual phenomena, while the Heelan's adaptation of Luneberg's model attempts to model visual perception of space in general, and should therefore include the phenomena that Helmholtz's monocular model addressed. However the complex relationships between these theories might be resolved, and whatever the specific mathematics of visual space, the evidence remains that in certain circumstances, visual space is curved: objectively straight lines follow an approximately hyperbolic geometry in visual space.

Heelan's hyperbolic visual space (like its predecessors) contains a distinction between the near zone and distant zone. These two zones are characterised by different directions of curvature, and are separated by a 'Newtonian oasis', where, broadly speaking, physical Euclidean forms are preserved. In the near zone - which is the area between the viewer and the Newtonian oasis - parallel lines of depth appear to diverge as they recede, as if seen in reverse perspective. Heelan:

> The divergence of parallel lines in the near zone can be experienced by holding a small rectangular card, such as a three-by-five-inch index card, horizontally in front of the eyes. It is best to rest it on one's closed fist and to direct one's gaze at the centre of the far edge of the card. By moving the card outward in depth, one can often locate the turning point where the diverging lines begin to converge: the existence of a turning point indicates, of course, a finite space.[96]

Frontal surfaces in the near zone also appear to bulge towards the viewer, and their size appears to be smaller than it is further away. Heelan notes that the surprisingly large size of very close objects in a wider photograph is not paralleled in natural vision because of this compensating effect. Depth in the near field appears to be exaggerated, so that there is an intense sense of spatial recession.

In the distant zone depth is compressed; three dimensional objects appear to be ironed to a surface facing the viewer. This is essentially the telephoto effect that was mentioned earlier. In a narrow angle view objects approach two-dimensional Cartesian space; but over a wide angle, space surrounds the viewer - there is a global depth. The long flat straight road will appear to bend

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95 Patrick Heelan: **Space-Perception and the Philosophy of Science**, p56. Even though Blumenfeld's study in 1913 obtained the discrepancy between parallel and distance alleys under monocular observation, nearly all of the subsequent theory is concerned with binocular vision. See Blumenfeld: **Untersuchung über die scheinbare Grösse im Sehraume**, *Zeitschrift für Psychologie*, **65**, 1913, p241-404.

96 Patrick Heelan: **Space-Perception and the Philosophy of Science**, p64.

upwards towards the horizon, which appears to be much closer than its physical location. There is a limit to visual space, although the limit varies with context. In total darkness, there is a sense of the darkness being concentrated right around the body or in front of the face. Various frameworks in the illuminated world provide references for the extent of visual space. A distant star is no further than the moon: the night sky appears to be a surface - rather than an infinite depth - so that it meets the earth at the horizon.[97]

This visual space is inconsistent with Descartes' principles of philosophy. The space is centred around the person, it does not extend indefinitely, and the rules that govern the behaviour of objects in the distant zone are different to those that govern behaviour in the Newtonian oasis or in the near zone. This review of the study of visual space has provided us with common language whereby objective and subjective spatial representations are in communication. It is a first step in approaching Xenakis' description of the Philips Pavilion's curving walls without relying entirely on poetry. However these ideas have wider ramifications on the experience of space, and the more esoteric notions of sound space discussed in later chapters would appear to share and extend the dialogue between objective geometry and subjective curvilinearity, as well as the phenomenon of multi-stability. This fundamental discussion of space and perception describes spatial transformations found in Varèse's sound space, which are developed initially in Chapter 3.

Hyperbolic Paraboloids in Visual Space

Heelan's idea of a multi-stable (or quasi-stable) visual space, which at one time might be Euclidean, at another, hyperbolic, leaves us with the question of how a viewer might perceive a ruled surface such as a hyperbolic paraboloid. A principle factor in the visual perception and interpretation of space is the extent to which the space is carpented, or the extent to which a Euclidean geometry in physical space is articulated by structures within it. In a physical space of Euclidean cubes and rectangular prisms - such as the interior of an unexceptional modern office building - the viewer is strongly encouraged to see with Euclidean eyes, finding it difficult to see with hyperbolic eyes. The rectilinear forms that come into view retain their rectilinearity in hermeneutic visual space. In the view from a boat in the open sea, Euclidean space does not present itself, and characteristics of hyperbolic space are easily seen. The sea seems to form a

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97 Tarow Indow: **Alleys in Visual Space**, *Journal of Mathematical Psychology*, **19**, 1979, p240.

bowl around the viewer, and the sky seems to form an inverted bowl, meeting the sea at a horizon that is much closer than it would be in Euclidean space (although it is difficult and probably meaningless to quantify that distance).

The link between hyperbolic paraboloids and subjective visual space is stronger than a shared geometric terminology. We have seen that hyperbolic visual space contains a contrast between near and far zones. In the far zone, depth is compressed or even eliminated: things appear to be flat on the horizon sphere, which surrounds the viewer with a global depth. This transformation separates the viewer from an object on the visual horizon; there is a sense of anonymity and objectivity in a narrow angle field of view. In the near zone depth is expanded and things bulge towards the viewer. The visual objects in this zone are intensely present, and the viewer must navigate through them. Dramatic changes in perspective occur within this zone, and as an object moves or extends between zones.

A ruled surface such as a hyperbolic paraboloid presents the viewer with paradoxes. It is clearly a form that is generated by geometric principles: the regularity and simplicity of its surface (compared with that of a tree for instance) tells the eye that it is conceived through geometry. The grid of intersecting straight lines reveals a simple geometric algorithm: the viewer is shown how to construct the surface. And yet the surface formed by these lines remains enigmatic to the viewer; it is difficult to ‘understand’ the surface as one might a rectilinear plane. Simultaneously concave and convex, and contoured by the subtle continuous changes in curvature of parabolæ and hyperbolæ, the surface eludes the intellectual grasp of a viewer. Intellectually, the hyperbolic paraboloidal surface is only grasped as an algorithm or process, but not as a whole, not as a geometric object.

This geometric surface, then, recreates the interpretive problem of the carpented environment. The surface is seen as a flat surface - the nearest graspable geometric concept - which has been distorted into subtle hyperbolic and parabolic curves. A single set or grid of objectively straight lines affirm the impression that the surface is, in essence, flat but distorted; no such lines can be drawn on a spherical surface. The fact that these distortions may not follow the specific transformations of an objectively flat surface in hyperbolic visual space is less important than the common and general sensation of curvilinear transformation. Thus the hyperbolic paraboloid is seen to exhibit an intense depth as it simulates and exaggerates the subtleties of visual space.[98]

We must remember that the hyperbolic paraboloid is also perceived in visual space: it is not simply a surface in Euclidean space. This may lead not only to exaggerated subjectivity, but also to double spatiality. The viewer is viewing a space that is pre-viewed: the surface depicts subjective space, and this depiction is seen in subjective space. The natural depth of vision 'contains' an additional depth; space surrounds a surrounding space.

The hyperbolic paraboloid confronts the viewer with spatial ambiguity. The surface is clearly geometric, and therefore demands to be seen in Euclidean space. This demand is reinforced, but also subverted, by the subtlety of the surface and by the ruled lines, which set up a two dimensional Euclidean rectilinear grid that is distorted into hyperbolic contours and parabolic profiles, reminiscent of transformations of Euclidean grids in subjective visual space. Even without the grid, the curvature of the surface has these associations, but a single set or a network of lines emphasises this paradoxical effect.

Double spatiality is a phenomenon common to perception. A photograph presents the viewer with two spaces, asking them to imagine themselves as the focus of the space represented in the image, while entertaining the photograph as a piece of paper in real space. Hyperbolic paraboloids also present the viewer with an illusion of space, but in this case both spaces are in three dimensions and there is no specific framing device to separate the two. There is only a lens effect as space is transformed through the surface: the spaces are separable but intertwined. This multiple spatiality suggests added dimensionality as the perceived space exceeds the limitations of the three dimensional model.

Through its simultaneous emphasis of surrounding or subjective space and rectilinear or objective space, the hyperbolic paraboloid contains in a single form the spatial polarity expressed by the Perisphere and Trylon. The Perisphere literally surrounded the viewer in a single continuous form, while the Trylon - "a Pointer to Infinity"[99] - described separateness, linearity and projection.

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98 Perhaps these curves might also be thought of in terms of perspective (that is, as representations of space). See, for example, Dennis Finch: **Hyperbolic Geometry as an Alternative to Perspective for Constructing Drawings of Visual Space**, *Perception*, **6**, 1977, p221-225.

99 **Ball and Spike**, *Time*, Sunday 21 May 1939, p39.

The grid of the hyperbolic paraboloid describes a linear, projective and geometric space; it is an icon of spatial abstraction and separation. The curvilinearity of the surface enhances subjective perception, where the viewer is surrounded by the world. This tension between two modes of perception is another aspect of the multiple spatiality inherent in the hyperbolic paraboloid. The geometric perception that is emphasised by the grid stimulates the idea of an overall geometry, covering both spatial modes, which by implication must exceed three dimensions.

Such an interpretation of the hyperbolic paraboloid rests on the assumption that the viewer is interested in spatiality. The fact that the particular surfaces in question are stripped down to their geometric essentials is intended to stimulate such an interest, this being in line with the primary interests of their creators. Xenakis was interested in volumetric architecture, and in spatial music; Gabo was interested in space *per se*; and the promoters of stereophony were promoters of space.

We have characterised these surfaces with a 'double depth', higher dimensionality, and an apparent dynamism; all oblique inferences of temporality. The surfaces do not move, but by implying a space that exceeds three dimensions, or by not allowing the eye to settle on the surface as a whole, instead drawing it along marked trajectories (which are seen as literal lines of force), the surface gives movement to the viewer. The impression of acceleration - as the hyperbola or parabola gradually increases in curvature until it suddenly rounds its corner, the curvature then tapering off again towards a straight line - brings the linear trajectories to life. Like any subjective perception of space, when the viewer moves around the surface its apparent form changes, following the change in the centre of space. As parts of the surface become closer or further from the viewer, and are beheld from different aspects, the surface dissolves into a fluid form. However the ruled grid, as a representation of dimensional space, resists dissolution, creating a sort of spatial constant against which the transformation in subjective space is made more apparent. Thus the viewer's movements may also be taken to imply movement within the surface itself. The real sense of a space exceeding three dimensions and the integration of time and space reflects well on the scientific inspiration of the surfaces' creators.

These phenomena are reflected in the language used to discuss the surfaces. Hence Xenakis writes of a viewer's body being sensitised to the curved space of the Philips Pavilion, the viewer having an immediate understanding of the essence of the surfaces without the need for logical abstraction. Such a perception involves the intense participation of the viewer in space: in Merleau-Ponty's sense, it is found in intense depth; in Heelan's sense, it is found in hyperbolic visual space. For Xenakis, these surfaces contained movement which was inferred by *Metastasis* and realised by *Concret P-H*. The spectator's involvement in the space of the Philips Pavilion and the *Polytope de Montréal* was fundamental to their perception.

Gabo's constructions, like Xenakis' pavilion, demand to be looked at as they appear in immediate visual space. The fact that they have associations with mathematical models does not mean that they should be seen as abstract. Gabo:

> [Space] is not what is in the minds of scientists today. In science it's a formula. But for me it is a real element of vision; it is as material as any concrete material.[100]

While the viewer did not have the opportunity to enter Gabo's constructions - as they did the Philips Pavilion - his interest in involving the viewer in the space of the construction was explicit. Initially through stereometric construction, vibrating forms, transparent materials, and eventually massless twisted surfaces of lines and light, Gabo opened up his constructions to the viewer. In relation to his early architectonic works he states:

> What was it I tried to do in these constructions? I transferred myself to the middle of the construction, to be in the middle of space, so to speak. Space is in me, it comes out of me. There are ways in which the artist can make the spectator feel that he, the spectator, is within the sculpture or painting.[101]

Gabo's use of ruled surfaces in his latter works is a testimony to the sense of surroundedness that accompanies their perception.

Hyperbolic Paraboloids and Sound Space

In Chapter 1, hyperbolæ, parabolæ, and hyperbolic paraboloids were found in many contexts as Modernist constructions associated with sound space. Naturally these forms have many more implications, not necessarily connected with sound or space. Architecturally, these surfaces have been used in many types of building, although primarily in large scale or public structures such as

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[100] Naum Gabo quoted in Nash & Merkert (eds.): **Naum Gabo: Sixty Years of Constructivism**, p26.

[101] Naum Gabo: **Naum Gabo Talks About his Work**, *Studio International*, **177** (876), April 1966, p129.

churches, theatres, stadia, and industrial installations (such as the ubiquitous power station cooling tower in the form of a hyperboloid of one sheet). While many of these structures might be conceived of as special containers of sound, this relation is restricted to a certain class of building. The relationship between the music of Xenakis and ruled surfaces is specific to that composer, and has few implications about any general relationship between other composers' music and ruled surfaces. Varèse's interest in hyperbolæ and parabolæ may have some psycho-acoustic significance, but it obviously is primarily an expression of a desire to move from a discrete linguistic paradigm of pitch in music notation to a continuous graphical paradigm, hyperbolæ and parabolæ being icons of graphed space. Similar desires were mirrored by many composers in that period, and were expressed in many different ways.

However, the instances cited in Chapter 1 are neither arbitrary nor contrived, and they represent a refined appreciation of sound space, using hyperbolic and parabolic geometries as visual analogies. Even with their other associations, these forms are significant expressions of sound space in the late Modernist period in question. More than any other period of the Twentieth Century, this was one when the possibilities of sound space were in the forefront of the public imagination.

Our analysis of hyperbolic paraboloids has been in visual space. It almost defies the imagination to conceive of an analogous form in auditory space, although Xenakis has made some interpretations along these lines. If the nature of visual space remains somewhat ill-defined and an area of controversy, all the more so for auditory space. As we shall find in Chapter 5, there is no single simple analogy between visual and auditory space, especially because of the coexistence and interdependence of musical (pitch; loudness; duration) and acoustic (physical space) models. In fact this ambiguity is an important element in the sonorous implications of a hyperbolic paraboloid.

Auditory space, in this case restricted to the listener's interpretation of physical space, may have similar perceptual characteristics to hyperbolic visual space. Von Békésy has found that, like visual space, auditory space appears to have a limited horizon.[102] However research in this area is

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[102] Georg von Békésy: **The Moon Illusion and Similar Auditory Phenomena**, *American Journal of Psychology*, **62**, 1949, p540-552.

extremely sparse, and very little more can be said on specific similarities with the Luneberg/Heelan model of visual space. Nevertheless there is one aspect of auditory perception that invites a general comparison with visual space: hearing is omnidirectional. The directional nature of the visual field allows us to isolate small areas of the 'visual globe', to find things that from a distance appear as precise implementations of ruled line perspective. As directional observers, we can extract ourselves from a space; we are here, it is there, and there is only visual contact between the two. However the hyperbolic model of visual space recognises the artificiality of such perception and attempts to model a space centred on the viewer. The omnidirectional nature of the auditory field places the listener still more firmly in space: auditory space is all around - and even inside - the listener, and the body is much more a participant in space. Other factors such as resonance and diffraction in acoustic space give auditory space a much more fluid and subjective form; these are discussed further in Chapter 5. The very fact that the resolution of auditory space is so vague in many cases draws the space around the listener to an extent that scarcely happens in even near zone visual space.

Through vision and movement, Merleau-Ponty finds his body to be a real participant in the world. Merleau-Ponty:

> Visible and mobile, my body is a thing among things; it is caught in the fabric of the world, and its cohesion is that of a thing. But because it moves itself and sees, it holds things in a circle around itself. Things are an annex or prolongation of itself; they are incrusted into its flesh, they are a part of its full definition; the world is made of the same stuff as the body.[103]

More so than vision, it is sound that surrounds us, dissolves barriers between inner and outer, opens up our body to the world and closes the world around us. More than surrounding us, auditory space gives a sense of double spatiality: the sense of physical space enveloping the listener is in counterpoint with a sense of musical space which transcends the three dimensional world. Because of its temporal base, there is an almost inevitable dynamism in sound space.[104] If the essence of the hyperbolic paraboloid is an expanded sense of subjectivity, surroundedness,

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103 Maurice Merleau-Ponty: **Eye and Mind**, in **The Primacy of Perception**, p163.

104 These ideas of sound space are developed elsewhere in this thesis.

double spatiality, and dynamism, it is beginning to point towards the phenomenal essence of sound space.

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Salle Pleyel and Philips Pavilion

Varèse in the Salle Pleyel

Xenakis' monograph, *Formalized Music*, begins with the following vision of transcendence in art and music:

> Art, and above all, music has a fundamental function, which is to catalyze the sublimation that it can bring about through all means of expression. It must aim through fixations which are landmarks to draw towards a total exaltation in which the individual mingles, losing his consciousness in a truth immediate, rare, enormous, and perfect. If a work of art succeeds in this undertaking even for a single moment, it attains its goal. This tremendous truth is not made of objects, emotions, or sensations; it is beyond these, as Beethoven's Seventh Symphony is beyond music. This is why art can lead to realms that religion still occupies for some people.[105]

As an admirer of Beethoven's music, it is not surprising that Varèse should also have been impressed by a performance of the Seventh Symphony. Listening to the piece in Paris' Salle Pleyel, Varèse appears to have experienced an exceptionally vivid moment of transcendence, which he recalled in 1955 when Georges Charbonnier asked him when and how his ideas on the organisation and projection of sound were born. Varèse:

> Il y a plusieurs anées, un phénomène acoustique auquel j'assistais, et que je décrirai, fut pour moi la matérialisation physique de l'organisation des sons et de leur projection telle que je l'avais mentalement imaginée pendant de longues années. J'écoutais le trio du scherzo de la *VII^e^ symphonie* de Beethoven, à la Salle Pleyel. Cette salle est riche en surprises acoustiques, en raison de sa construction mal calculée. Je pris conscience d'un effet entièrement nouveau produit par cette musique familière. Il me semblait sentir la musique se détacher à tel point d'elle-même, en se projetant dans l'espace, que je devins conscient d'une quatrième dimension musicale. Cette sensation était peut-être imputable à la place que j'occupais dans la salle : place exposée à une surrésonance. Ce phénomène fut une preuve vivante de ce que j'avais conçu bien des années auparavant et que j'appelle « la projection du son organisé ». Par « projection », j'entends la sensation qui nous est donée par certains blocs de sons. Je dirais avec plus de bonheur « rayons du sons », si proche est cette sensation de celle produite par les rayons de lumière émis par un

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105 Iannis Xenakis: **Formalized Music**, p1.

> puissant projecteur balayant ce ciel. Pour l'oreille, comme pour l'oeil, ce phénomène donne un sentiment de prolongation, de voyage dans l'espace.[106]

Varèse also described this experience in a 1936 New York Times article:

> Mr Varèse said that he first realized the possibility of capturing space-rhythms several years ago while he was listening to Beethoven's Seventh Symphony being played in the Salle Pleyel in Paris.
>
> "Probably because the hall was over-resonant," he said, "I became conscious of an entirely new effect produced by this familiar music. I seemed to feel the music detaching itself and projecting itself into space. I became conscious of a third dimension in the music.
>
> "I call this phenomenon 'sound projection,' or the feeling given us by certain blocks of sound. Probably I should call them beams of sound, since the feeling is akin to that aroused by beams of a powerful searchlight. For the ear - just as for the eye - it gives a sense of prolongation, a journey into space."[107]

In this instance Varèse cited the experience in the Salle Pleyel as an illustration of the spatial effect of a sophisticated electro-acoustic installation that he was imagining and yearning for: "… these beams of sound could be made discernible to the listener by artful placing of loudspeakers … in diverse parts of the hall, accompanied by other acoustic arrangements…".[108] The Salle Pleyel gave Varèse a foretaste of the Philips Pavilion.

This illustration may seem highly idiosyncratic; perhaps a hallucination or the product of an overly creative imagination predisposed to spatial interpretations of sound. As Varèse's ideas on sound space were developing long before his experience in the Salle Pleyel, it was definitely informed by years of thinking in those terms.[109] It is unlikely that everyone else in that concert hall had an analogous experience, but it is possible to find some correlation between Varèse's experience and other people's experiences of listening to music. The phenomenologist Don Ihde also listens to Beethoven:

> If I hear Beethoven's Ninth Symphony in an acoustically excellent auditorium, I suddenly find myself *immersed* in sound which *surrounds* me. The music is even so *penetrating* that my whole body reverberates, and I may find myself absorbed to such a degree that the usual distinction

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106 Edgard Varèse in Georges Charbonnier: **Entretiens avec Edgard Varèse, Suivis d'une Etude de l'Œuvre par Harry Halbreich**, p74.

107 **Varèse Envisions 'Space' Symphonies**, *New York Times*, 6th December 1936, Section 2, p7.

108 Ibid. Varèse also hoped that the piece that he was writing (*Espace*) would suggest these spatial possibilities even without electro-acoustic components.

109 While we do not know the precise date of Varèse's experience, his earliest recorded statement on the matter dates from 1936. As the Salle Pleyel was constructed in 1927, it is highly probable that Varèse attended the concert during his sojourn in Paris between April 1929 and September 1933.

> between senses of inner and outer is virtually obliterated. The auditory field surrounds the listener, and surroundability is an essential feature of the field-shape of sound.[110]

Here Ihde is contrasting this 'musical space', which has the character of surroundability, with a directional mode of listening. These two auditory fields might be modelled as surrounding form (perhaps a sphere of indefinite extent) and ray respectively, existing simultaneously as two modes of listening. Thus one can listen to bird calls as a hunter might, hearing directional cues; or alternatively in the 'musical attitude', perceiving them as surrounding presence. It might be within this surrounding space that Varèse finds his sound space in Beethoven's *Scherzo*. However, for Varèse, that transcendent space, in itself, contains and is defined by directional forms such as points, rays, and masses.

Varèse's Sound Space and High Fidelity

One of Varèse's central themes is the rejection of the formal syntax of music, and an emphasis on the sounds themselves. He was utterly opposed to the traditional method of composition where the piece would be 'composed' and then orchestrated; he composed for his instruments directly because he was composing with sounds rather than primarily within a digital structure of intervals. Thus in a letter to Dallapiccola, Varèse writes:

> I'm working a great deal - especially in the sphere of 'sound' which for me is the solid base of music, my raw material. The intellectualism of the interval is a factor which for me has nothing to do with our age and its new concepts. As obsolete as the artificial versification of a Banville. (Not to be misinterpreted. This doesn't apply to artists like Schœnberg, Webern, you and a few others - but to those clever-clever fellows who need crutches…). Do you know this passage from Valéry? "In all the arts there is a physical aspect that we can no longer consider or deal with as we have in the past. Neither space, nor time, nor matter any longer represents for us what it has always represented before. We must accept that all these changes necessarily transform the technique of art, influence even the faculties of invention - influence them deeply enough to modify the conception of art itself."[111]

There was an affinity between Varèse's conception of sound (in the 1920s) and that of the high fidelity movement of the 1950s, making his music of particular interest to some audiophiles. High fidelity was a movement rejecting the notion that a piece of music is adequately represented if its notes can be discriminated in a reproduction, instead demanding that, as far as possible, every

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110 Don Ihde: **Listening and Voice: a Phenomenology of Sound**, p75.

111 Varèse, from a letter to Dallapiccola, dated 7th December 1952, quoted in Ouellette: **Edgard Varèse**, p173.

aspect of the original acoustic event be reproduced. High fidelity placed an emphasis on concrete sound. That high fidelity is an ideological and æsthetic notion more than an inevitable approach to sound reproduction has been demonstrated in a variety of ways.[112] The high fidelity movement began to find popularity in the final years of the forties and early fifties, around the same time that Varèse emerged from a long period of unfulfilled dreams, uncompleted works, a low public profile, and a profound personal frustration. The affinity between Varèse's music and high fidelity was reflected by occasional enthusiasm for his music within the high fidelity movement. In a review of a performance of *Déserts* in 1955, Edward Tatnall Canby wrote:

> Is there anyone who hasn't yet heard of Edgard Varèse? He is the man who suddenly became famous a few years ago as the First Hi-Fi-Demonstration Composer. The demonstration piece was called "Ionisation" and the LP recording that rocketed him to fame included other shockers as well - "Intégrales" (for screaming brass), "Density 21.5" (for flute). … Varèse's hi-fi fame was a bit delayed. He wrote the music 'way back in the middle Twenties, when hi-fi hadn't even hatched from an early-type vacuum tube. But, as we all discovered at several Audio Fairs and a couple of thousand home and sound-salon demonstrations, Varèse is a clairvoyant. Fully a quarter century before the hi-fi boom was even imaginable, this man was able to write the most concentratedly effective demonstration piece for hi-fi equipment yet produced - and competition is pretty hot on those lines right now.[113]

Frederic Grunfeld, writing in *High Fidelity Magazine* in 1954, reinforces this connection with these comments:

> Varèse's music fares eminently better in this frequency-conscious era than it did in days of yore. More people have bought the EMS LP of *Ionization*, *Integrales*, *Density 21.5* and *Octandre* as a high-fidelity demonstration record than for its purely musical content. … Test record or not, sales have exceeded all expectations and Varèse feels at least partly vindicated as a "worker in frequencies." Released as the first commercial disk with a measured range from 14 to 18,000

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112 One example is experiments such as that reported by Roger Kirk in **Learning, a Major Factor Influencing Preferences for High-Fidelity Reproducing Systems**, *Journal of the Acoustical Society of America*, **28** (6), November 1956, p1113-1116. Kirk shows that a listener's preference for the frequency response of a sound reproducing system is heavily influenced by the frequency response that he or she is used to, rather than reflecting an absolute preference for a flat frequency response. At the time, high fidelity components were not predominant, explaining the untrained listeners' general preference for low fidelity reproduction - which correlated with preferences in other studies. A second example is Joseph O'Connell's **The Fine Tuning of a Golden Ear: High-End Audio and the Evolutionary Model of Technology**, *Technology and Culture*, **33** (1), January 1992, p1-37. O'Connell shows that high-end audio is heavily influenced by esoteric (and expensive) factors that have little to do with measured sound quality. See also Oliver Read & Walter Welch: **From Tin Foil to Stereo**, p373-389.

113 Edward Tatnall Canby, **Audio etc**, *Audio*, July 1955, p28.

> cycles, it was five months in the making, a labor of love by the composer and recording engineer Robert E. Blake.[114]

Nor was this the only pioneering high fidelity event that Varèse was involved in. The first stereophonic broadcast in France was the premier of Varèse's *Déserts* (2nd December 1954), employing two distinct transmitters (the two radio stations, Chaîne Nationale and France-Inter) and requiring the listener to employ two receivers, one tuned to each station.[115] Of course the *Poème électronique* was another such pioneering event, described by one high fidelity writer as "the world's most impressive and ambitious audio demonstration."[116]

As a demonstration piece, *Ionisation* is particularly effective because, without any significant pitch material in the conventional sense, a listener cannot even pretend to find any melodic or harmonic material, and is forced to listen to sounds. The sound of sirens is not dissimilar to the sweeps of pure tones used to test the frequency response of high fidelity components, and the percussive attacks quickly expose any problems with transient response. Extremes in dynamic range reveal problems with system noise, distortion and power, and the ensemble, containing instruments covering the entire pitch spectrum, places great demands on the frequency response of the reproduction system. Nevertheless the relationship between Varèse's music and high fidelity stereophonic reproduction is not just about testing equipment. The aspect of Varèse's music that impresses Canby the most is its physical power: "you didn't *like* or *dislike* this stuff, you felt it."[117] Like Varèse, an audiophile took great pleasure in experiencing sound as a concrete force or substance impacting on the body. Thus Canby was attracted to Varèse's description of his piece as 'organised sound' which, while not removing it from the domain of music, places an emphasis on its concrete nature.

It is this relationship between the interests of Varèse and high fidelity that permits us to develop an analogy between Varèse's experience of sound space in the Salle Pleyel and certain trends in the development of stereophonic reproduction.

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114 Frederic Grunfeld: **The Well-Tempered IONIZER**; *High Fidelity Magazine*, September 1954, p40.

115 Marc Bredel gives a colourful description of this performance and broadcast in **Edgar Varèse**, p162-168. The earliest stereophonic broadcasts in the United States, in 1952, also used two transmitters - one AM and one FM - and two receivers.

116 H. Gernsback: **400 Loudspeakers**, *Radio-Electronics*, October 1958, p46.

117 Edward Tatnall Canby, **Audio etc**, *Audio*, July 1955, p28.

Ambiophony and Stereophony

Ihde's notion of surroundability and directivity, as described thus far, might appear to be a strained act of psychological posing or a poetic and philosophical notion, perhaps in the main constructed by the confusion of auditory space with metaphors of visual space. However, Varèse's experience in the Salle Pleyel establishes a dialogue between a phenomenology of sound space and his more abstract accounts of musical space. His experience there can be interpreted as more than a kind of aural hallucination: as an experience related to 'auditory spaciousness', a specific psycho-acoustic phenomenon recognised since the mid 1960s. But even before detailed psycho-acoustic research, the historical development of electro-acoustic technology has reflected the seemingly opposing characteristics of surrounding and directing. While directional reproduction in the form of stereophony has dominated, the existence of technologies that aim primarily to envelop the listener in sound remains of great interest. As has been noted elsewhere, the Philips Pavilion - with its adventurous mechanism for moving sound in space - coincided temporally with the release of stereophonic discs.[118] The Philips company had been involved in comparable installations since the early fifties, especially in *son et lumière* installations at historical sites, but the 1958 pavilion differed in its emphasis on sound *per se* and in the complexity of the sound control system.[119] The *Poème électronique* was falling on ears unaccustomed but sensitised to the spatial manipulation of sound:[120] an exploration of relations between Varèse's conception of spatial music (which was realised in the pavilion) and the philosophy of stereophony and related devices is pertinent.

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118 Stereophonic open reel tapes had been available to the mass consumer market since 1955, but the lower price and ease of use of discs made them significantly more attractive than tapes.

119 According to E. R. Hanson (of the North American Philips Company), the earliest *son et lumière* installations were at Chambord in 1952, and at Chenonceaux and Versailles in 1953. E. R. Hanson: **The Sound System of Sound and Light**, *Journal of the Audio Engineering Society*, January 1963, p32. Writing in 1956, Canby gave a detailed description of a *son et lumière* installation at Vezelay, and also noted that of the five *son et lumière* shows that he saw in France, all were recorded by Philips. Edward Tatnall Canby: **Son et Lumiere - Outdoor Stereo**, *Audio*, October 1956, p78,91-95.

120 Writing about the Philips pavilion sound installation (which he was involved in designing), W. Tak noted: "It was our opinion that the simultaneous perception of three sound patterns issuing from or travelling in different directions would constitute a completely new experience." **Electronic Poem: The Sound Effects**, *Philips Technical Review*, **20** (2-3), 1958/58, p43.

The effect of the acoustically excellent auditorium which was described by Ihde has been simulated throughout the history of sound reproduction under various names: ambiophony, pseudo-stereophony, stereophony (in a divergent sense), and stereo-reverberation. Ambiophony is the least confusing of these terms as it does not refer to stereophony, and will be adopted in this text.[121] The term is attributable to R. Vermeulen, who worked for Philips Research Laboratories in the 1950s, and conducted some early research in this area at that time.[122] It is to be distinguished from the ostensible aim of what we now know as stereophony, which is to reproduce directional characteristics of sound.[123] Manfred von Ardenne described a method of generating ‘stereophony’ in a 1927 article, essentially creating artificial ambiophony by introducing phase differences in the sound of a recording:

> The absence of phase-difference induces us to complain of a 'gramophone-like' reproduction of the loud-speaker, because the music of a full orchestra reaches our ear with the unnatural impression of being produced at one single point in space only. For really natural reproduction, not only the phase difference itself is essential, but it must also constantly vary so as to give the impression of hearing from several points at once, the different points where the instruments are placed…. At first it would seem that there are insurmountable difficulties preventing the solution of this problem. Two distinct transmitters and receivers would have to be employed, and that alone, of course, renders it impossible.[124]

Von Ardenne’s method involves splitting a single signal so that it comes from two sound sources with the same intensity at the listener’s position. One source is close to the ears (headphones are

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121 This term is perhaps a little obscure, but is found in John G. McKnight: **Why Stereo? The Philosophy of Multichannel Recording of Music**, *Journal of the Audio Engineering Society*, **8** (2), April 1960, p87-90. Vermeulen, who the term is attributed to, also used the term ‘stereo-reverberation’, which is less apt because of its references to both stereophony (which can confuse and/or imply an *ersatz* relationship) and reverberation (which has less to do with the phenomenon of spaciousness). Ambiophony is used in the literature most commonly in reference to electro-acoustic installations in auditoria, but in this text it will be used more generally to include installations for sound reproduction in the home. Auditory spaciousness (which is produced by ambiophony) also has been given many names: spatial impression, depth and presence, spatial responsiveness, ambience, apparent source width, and feeling of envelopment. Robert Gorman has a slightly confused (or imprecise) account of ambiophony in the context of home sound reproduction in **The Sound of Ambiophony**, *High Fidelity*, December 1960, p42-44, 125-126.

122 R. Vermeulen joined Philips in 1923, became Director of Acoustic Research in 1947, and their scientific adviser during the 1950s. It is highly probable that he would have had some association with the sound of the 1958 Philips Pavilion.

123 Nevertheless it may be that the etymology of 'stereophony' (stereo = solid, palpable) makes it more apt to describe the feeling of being enveloped in sound rather than the technique of reproducing the directional characteristics of sound.

124 Manfred von Ardenne: **Stereophonic Reception**, *Wireless World*, 26 January 1927, p117-118.

suggested), and the other at a distance of 10 to 15 feet, and the sound from the second source will arrive at the ears with a very slight delay. Von Ardenne continues:

> If these conditions have been fulfilled, a marked improvement in quality of reproduction will be noticed, due to the phase-difference introduced by the distance between the loud-speaker and phones. This phase-difference also varies with the frequency of the sounds reproduced, and thus a constantly varying difference in phase produces the stereophonic effect so superior to ordinary reproduction. The sound-waves seem to reach our ears from all directions at once.

Von Ardenne also describes an analogous method of obtaining the stereophonic effect, using two needles "about 2 1/2 inches apart" in the same groove of a gramophone record. Methods such as these "give the impression of being present at the concert itself."[125] Von Ardenne may seem amateurish and optimistic, especially as multi channel stereophony was demonstrated to the public only six years after his article (binaural reproduction was demonstrated as early as 1881), but the principle of imposing phase differences on a single source remained attractive even in the early 1950s, when the Columbia 360 phonograph was marketed, which distributed a single track recording between two identical speakers, on opposite sides of the cabinet [Figure 46].[126] The initial advertisement reads:

> SWITCH IT ON AND THE WHOLE ROOM PLAYS … You can now hear for yourself the room-filling reality of sound produced by an amazing new instrument playing all records … The ability to radiate sound *around* its listeners inspired the name Columbia 360, the 360 degrees of the perfect circle. Two sound outlets, at each side of the cabinet, create the remarkable effect of 'Hemispheric' Sound.

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125 If this claim seems wildly optimistic (considering the response characteristics of the gramophone in the 1920s), we might also recall the following passage in Evan Eisenberg's **The Recording Angel**, p91:

"In 1913 Edison staged a series of Tone-Test Recitals, designed to prove that 'the Edison Diamond Disc's re-creation of the music cannot be distinguished from the original.' Audiences would hear Maggie Teyte herself singing 'Believe Me If All Those Endearing Young Charms', then her phonographic replica, and evidently many agreed that 'there was no difference between Miss Teyte's voice and the New Edison RE-CREATION of it'."

The relative nature of perceived quality in sound reproduction was explored experimentally in the 1940s and 1950s. See Kirk: **Learning, a Major Factor Influencing Preferences for High-Fidelity Reproducing Systems**, *Journal of the Acoustical Society of America*, **28** (6), November 1956, p1113-1116.

126 The Columbia 360 was marketed in 1953 and 1954 in *High Fidelity* magazine. Major advertisements in *High Fidelity* include: March-April 1953, p8; May-June 1953, p89; July-August 1953, p4; September-October 1953, p36; January-February 1954, p19; and November 1954, p127.

The advertisement pictures the Columbia 360 on a table in the middle of a room - photographed through a fish eye lens, and edited so that the room is roughly symmetrical around the 'instrument'. This effect is not merely of sound being radiated in all directions, but of sound enveloping the listener, as perhaps the sound arrives directly from one speaker, then with a slight delay (phase shift) after the sound from the opposite speaker reflects off a wall, and then with many other single and multiple reflections from the speakers. A year later the Columbia 360 was extended with the introduction of the 'X-D Roving Speaker' - 'X-D' standing for 'extra dimensional sound' [Figure 47]. The X-D was to be placed away from the main 'instrument', thus significantly increasing the complexity of the sound reflections in the room. The X-D provided 'depth', which is emphasised in the advertisement by a striped floor receding dramatically from the viewer. A later adaptation renamed the instrument the Columbia 360K, with "'K' for Kilosphere, a remarkable development that adds <u>2000 high frequency speakers</u> to the famed '360' sound."[127] While it is not clear how the 360K differs technically from the 360, the '2000 high frequency speakers' are a colourful reference to sound reflected from innumerable places all around the room; there are still only two speakers in the instrument itself.[128]

Other ambiophonic techniques such as the use of an acoustic delay line (described in one article as producing "the third dimension in sound")[129] or the use of large numbers of speakers and complex dividing networks[130] competed with and complemented stereophony in the period of its

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127 *High Fidelity*, November 1954, p127.

128 One might speculate that the difference between the two models is a greater high frequency response in the 360K, so that there are more high frequency reflections off the room surfaces. Because of the shorter wavelengths involved, such reflections are more directional and discrete than those of lower frequency sound, and might therefore be imagined as representing 2000 loudspeakers. However the technical information in the advertisement does not necessarily support this hypothesis, with a frequency range of up to 10KHz cited, while a previous advertisement for the 360 cites a range extending to 12KHz (not a significant difference). Nevertheless this discrepancy might be attributed to the recorded medium rather than the amplifier and speaker response, as the 360K advertisement features an open reel tape player rather than an LP turntable.

129 For example, Engineering Department of Radio Craftsmen: **The "Third Dimension" in Sound**, *Audio*, September 1957, p22-23+. This article describes the Radio Craftsmen Model CP21 "Serenade", which combines 360° sound radiation with the 'Xophonic', an acoustic (pipe) delay line with a 50ms delay. While the authors of this article do not recognise the difference between early reflections and reverberation, it is apparent that early reflections and simulated early reflections play a major role in the production of this "third-dimensional sound".

130 For example, C. H. Malmstedt: **"Ersatz Stereo" Unlimited**, *Audio*, February 1961, p20-21+. This article describes the monophonic sound system of Harwell Dyer (an idio-syncratic audiophile): a remarkable assemblage of speakers, cross-overs, amplifiers and equalisers.

introduction and afterwards. The experience of ambiophony is, broadly speaking, of sound surrounding, of being immersed in a sound world; while that of two speaker stereophony paradigmatically is of beholding sound space at a distance.[131]

More serious and sophisticated applications of these techniques were developed for sound enhancing systems in auditoria. Writing in 1956, Vermeulen cited such installations in La Scala and in the auditorium of the Palais Chaillot in Paris.[132] Concealed speakers installed around the walls and ceiling of the auditoria are used to reproduce sound from the stage at a diminished level and with a slight delay so as to simulate an early reflection. The aim is not to increase the reverberation time of the hall (potentially muddying the music) but to increase the number and intensity of lateral early reflections, which are not consciously heard, but are the most important contributor to a sense of auditory spaciousness. According to Michael Barron, such installations did not gain widespread acceptance because of feedback problems, but more recent adaptations of the principle - avoiding or overcoming feedback - including the Delta Stereophonic System (DSS) and the Acoustical Control System (ACS) are now in use in auditoria.[133] In cinema sound, where feedback does not arise, surround sound systems such as THX also employ the principles of ambiophony.

It was not until the mid 1960s that interest in this area began to grow within the discipline of architectural acoustics, and experiments were done to map the psycho-acoustic properties of

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131 It is a strange anomaly that despite an overwhelming agreement in the literature of the primary importance of a sense of being enveloped by sound in music, the dominant paradigm for music reproduction in space is based on directionality. One has to ask whether the success of stereophony has more to do with the way that it can broaden the auditory image than what is often given as its ostensible purpose - directional reproduction. In practice the two speakers in the context of the listening room acoustics combine to produce a degree of ambiophonic effect that is a marked improvement over monophonic reproduction. This was recognised in the early definitive experiments on “auditory perspective” (stereophony) at the Bell laboratories: “The enhanced aesthetic appeal obtained from an auditory perspective reproduction of an orchestra is not due so much to an accurate localization of the various sounds as to a general effect of space distribution, which adds a fullness to the over-all effect”; W. B. Snow: **Auditory Perspective**, *Bell Laboratories Record*, **12** (7), March 1934, p194.

132 R. Vermeulen: **Stereo-Reverberation**, *Philips Technical Review*, **17** (9), March 1956, p258-266. Another version of this article is in *Journal of the Audio Engineering Society*, **6** (2), April 1958, p124-130. See also D. Kleis: **Modern Acoustical Engineering** (in two parts), *Philips Technical Review*, **20** (11), 1958/59, p309-326; **21** (2), 1959/60, p52-72. The Philips Theatre at Eindoven, the Arts and Sciences Hall at The Hague, and the Grand Auditorium at the 1958 Brussels World’s Fair also had such installations.

133 Michael Barron: **Auditorium Acoustics and Architectural Design**, p347-352.

auditory spaciousness. That research resulted, for example, in an innovative and successful design for the Christchurch Town Hall, opened in 1972, based largely on optimising the real early reflections (without electronic enhancement).[134] Since then the theoretical analysis of auditory spaciousness caused by lateral early reflections has developed so that mathematical relationships have been established between the amount of auditory space occupied by a sound, the relative amount of lateral energy in the hall, and the degree of incoherence of the signals between the two ears.[135] Vermeulen's hypothesis that early reflections are much more important than reverberation in the creation of spacious auditory experience has been verified.[136] It has also been possible to experimentally differentiate between types of spaciousness: the sense that a sound source is *wider* than its visual extent is caused predominantly by high frequency lateral reflections (above 3KHz); whereas the sensation that a sound source is occupying more space in the front-back dimension, or that it is enveloping the listener, is caused predominantly by mid range and low frequencies (below 3KHz).[137] Other research has differentiated vertical and horizontal spaciousness.[138] While the entire frequency spectrum has been shown to be important in lateral early reflections for auditory spaciousness, low frequencies (especially below 200Hz) have been shown to have a particularly strong effect.[139] At one extreme of acoustic design - where there are no lateral reflections - a sound source may occupy an extent of auditory space comparable to its image in visual space (although such comparisons are problematic). At the other, the source may remain the same size in visual space, but will surround the listener with sound, extending in all directions. In the intermediate situation, the sense of spaciousness occurs together with the sense of the directional position of the source.

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134 A. H. Marshall: **Aspects of the Acoustical Design and Properties of the Christchurch Town Hall, New Zealand**, *Journal of Sound and Vibration*, **62** (2), 1979, p181-194. See also various references in Michael Barron: **Auditorium Acoustics and Architectural Design**.

135 M. Barron & A. H. Marshall: **Spatial Impression due to Early Lateral Reflections in Concert Halls: The Derivation of a Physical Measure**, *Journal of Sound and Vibration*, **77** (2), 1981, p211-232.

136 Jens Blauert & Werner Lindemann: **Auditory Spaciousness: Some Further Psychoacoustic Analyses**, *Journal of the Acoustical Society of America*, **80** (2), August 1986, p533-542 and **Supplementary Psychoacoustical Results on Auditory Spaciousness**, *Acustica*, **59**, 1986, p292-293.

137 Ibid.

138 M. Morimoto & Z. Maekawa: **Effects of Low Frequency Components on Auditory Spaciousness**, *Acustica*, **66**, 1988, p190-196.

139 Ibid.

On a detailed level, the effect of auditory spaciousness may be explained psycho-physically. The interaction of the direct and reflected sound is different at different frequencies (and hence wavelengths) because of constructive and destructive interference, producing the effect of a different comb filter at each ear. The major components of binaural directional discrimination - interaural level difference, interaural phase delay and interaural group delay - are affected in this way. This causes different parts of the frequency spectrum to have different but constant positions in auditory space (as Von Ardenne recognised).[140] It is not surprising that complementary comb and similar filters have formed the basis of many ambiophonic installations.[141] But even those without electronic comb filters (such as Von Ardenne's headphone and loudspeaker combination or the Columbia 360) surround the listener in sound through the complex interference patterns that they establish.[142]

Sound Detaches in the Salle Pleyel

Let us return to the Salle Pleyel. Varèse was aware that his experience of the Beethoven symphony was caused by a strange acoustic effect: he had speculated that the hall might have been over-reverberant - but acoustic measurements in the hall at that time show that it was rather under-reverberant.[143] Built in 1927, it was the only large auditorium built for music anywhere in

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140 Jens Blauert: **Spatial Hearing**; p349-350.

141 See for example Manfred R. Schroeder: **An Artificial Stereophonic Effect Obtained from a Single Audio Signal**, *Journal of the Audio Engineering Society*, **6** (2) April 1958, p74-79; or Tenny Lode: **Stereophonic Reproduction**, *Audio Engineering*, January 1950, p15+; or C. H. Malmstedt: **"Ersatz Stereo" Unlimited**, *Audio*, February 1961, p20-21, 81-82.

Also Jens Blauert: **Spatial Hearing**, p248-250.

142 Early reflections contributing to a sense of spaciousness have delays ranging from approximately 10ms to 80ms and more (with a single reflection for delays longer than 50ms the strength of the reflection must be less than the direct sound or an echo effect occurs). This means that a sound path between approximately 3.4m to 34m longer than that of the direct signal is likely to induce a sense of spaciousness. Hence Von Ardenne's suggestion of a separation 10 to 15 feet between the listener (with headphones) and the speaker. It is easy to envisage how delays of this order would occur in a room with the Columbia 360. See Jens Blauert: **Spatial Hearing**, p354.

143 When the Salle Pleyel was completed in 1927, the reverberation time of the empty hall was 4.0 seconds, 2.2 seconds with 2000 people. This was considered excessive, and was reduced slightly with the addition of some absorptive material. But in 1928, a fire in the hall provided the opportunity for more acoustic renovations, and carpeting and felt reduced the empty hall reverberation time to 1.75 seconds. With a capacity audience of 3000, the reverberation time then was 1.45 seconds, exceptionally short by concert hall standards. See Vern Knudsen: **Architectural Acoustics**, p544. Varèse almost certainly had his experience during his sojourn in Paris between April 1929 and September 1933, after the 1928 renovations. Like several other people cited in this thesis, Varèse might not have been using the idea of reverberation in its precise acoustic sense, instead using it to

the world between the years 1900 and 1948, but it turned out to have disappointing musical acoustics. It is exceptional in the history of concert auditorium design in the degree to which it was designed as a directive space.[144] It had a parabolic ceiling, flaring towards the back, designed for a single early reflection of the sound from the stage onto the audience [Figure 50].[145] This early reflection was not intended to induce a sense of spaciousness, but was merely intended to reinforce the direct sound with as short a delay as possible. Having a fan-shaped floor plan, reflections from the walls were less prominent than in the rectangular Nineteenth Century hall [Figure 51]. The Salle Pleyel was a realisation of a Modernist philosophy of listening influenced by the notion of transmission, of sound travelling from the source to the a large number of listeners in as simple and direct manner as possible. It shares this philosophy of 'pure' transmission with the mainstream of the high fidelity movement (as the term itself indicates), and Varèse also expressed an analogous philosophy in his wish to do away with the performer as a medium between the composer and listener. Such a hall is intended to emphasise clarity at the expense of ambience, and is very well suited to public speaking, but is unusual as a hall for music. The lower part of the frequency spectrum suffers in such an acoustic, with the result that the music may be described as harsh. Nevertheless, in its clarity, it is more suited than its Romantic predecessors to the more rhythmic and precisely articulated *avant garde* music of its time.

While the parabolic ceiling reflected the sound well over the entire audience area, the reverse was also true, with all the noises in the audience being focussed onto the stage, making it an ungratifying and difficult venue to perform in. In addition to that problem, the performers were initially faced with a strong echo from the back wall of the hall with a delay of approximately 200ms.[146] These problems were ameliorated with the installation of absorptive material at the back of the hall and with an irregular screen around the performers. In 1932 Vern Knudsen wrote of the ceiling reflections:

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describe any transformation of a sound in a space.

144 A very similar design was proposed in 1927 by Le Corbusier for the Debating Chamber of the League of Nations as well as in his later design for the Palace of the Soviets. See Michael Barron: **Auditorium Acoustics and Architectural Design**, p81-84.

145 The parabolic ceiling was replaced in 1981 when the hall was extensively renovated.

146 Leo L. Beranek: **Music, Acoustics & Architecture**, see p325 and p455. Some of Beranek's conclusions in the passage on page 455 have been re-evaluated in the light of more recent research; see Michael Barron: **Auditorium Acoustics and Architectural Design**, p36-42.

> This reflected sound is not delayed enough to produce an echo, but because of the great height of the ceiling some of the reflected sound is delayed enough to produce a slight interfering effect in the central portions of the parquet. This interference, however, cannot be detected by the ear except during very rapid movements.[147]

Here we can begin to see why it was the *Scherzo* - with its strongly articulated scales and arpeggios - that caught Varèse's attention and stimulated his imagination.[148] Nevertheless it was in the *trio* that Varèse's image of sound rays and masses occurred. The *trio*, in D major (the *presto* is in F major), is a complete contrast to the *presto*, consisting of a peaceful and simple melodic and harmonic structure, with the dominant note (A) sustained throughout. The alternation between the highly contrasting *presto* and *trio* sections would have produced perceptibly different psycho-acoustic spatial effects, resulting in a sort of framing process that drew attention to what might otherwise have been insignificant aspects of the sound.

The position of the Salle Pleyel in the theory of auditory spaciousness is peculiar. It was designed primarily as a directional rather than a surrounding acoustic space, but it is distinguished from a purely directional space (an anechoic space) by its ceiling, which set up strong primary reflections with delays of 67ms and less - well within the range of the early reflections which produce a sense of spaciousness. These reflections differed from those considered in the theory of auditory spaciousness in halls in three ways: they were sometimes too strong, interfering audibly with rapid passages; they were mainly on the vertical rather than lateral plane; and there was only one major reflection to an audience member. The last difference is not so important as it has been shown that a single reflection is sufficient to create a sense of spaciousness. The second difference is significant because it means that the reflected component of the sound would have been quite similar at the two ears for a listener facing the orchestra, thus contributing less to a sense of spaciousness. But we must not assume that the listener's head is a dummy, firmly fixed in its orientation towards the orchestra - least of all Varèse's head. Varèse had a strong interest in listening to sounds around him, so it would not be unexpected for him to move his head in order to explore from different angles the effect of the strange interference produced by the single early reflection from the ceiling in the *Scherzo* (and even more so as he began to have the spatial

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[147] V. O. Knudsen: **Architectural Acoustics**, p542,544.

[148] The reader should listen to the third movement of Beethoven's Seventh Symphony should it be unfamiliar.

experience that he described). He was conscious of an acoustic peculiarity, and would have been inclined to explore it. Such head movements would be accompanied by changes in the spatial impression, and with such a strong reflection these changes could be marked: Varèse's description of sound detaching itself is not surprising.

To elaborate further, we have already noted the effect of the different comb filters at each ear, which can disperse the frequency spectrum in auditory space. Jens Blauert:

> Real musical signals have a "running" spectrum of amplitude and phase that changes constantly. In other words, the level and phase differences between the direct frontal sound and the reflected component of each ear input signal vary over time. The variation is different for each ear, so the interaural time and level differences change constantly as a function of time. The result may be called "temporal incoherence". The listener perceives a fluctuation in the lateral displacement of auditory events or else spatially broad, diffusely located auditory events.[149]

The specific effect of sound moving around auditory space, its position depending on its frequency, would change as the listener's head moved, creating quite a complex spatial impression. If there is only one early reflection, the comb filter effect is likely to be more pronounced than if there are more, which together would average out the filtering effect. With the head at an angle, the Salle Pleyel - with its single strong early reflection - would have produced this effect, more than a more conventional auditorium with multiple early reflections. Again, the lack of reverberation would have exposed the effects of the reflection more than in a conventional auditorium. Quite apart from the comb filter effect, the strength of the reflection may also have produced an image shift, lifting the auditory image above the orchestra in the same way as a pair of speakers can position an apparent sound source between them.[150] The spatial impression is made still more complex by the different effects that parts of the frequency spectrum have on the extent of spaciousness: high frequencies broadening the image, low frequencies deepening it. Blauert and Lindemann:

> … test signals in which the lateral reflections only contained components below about 3 KHz were rated to be predominantly expanded in depth (i.e., in the front/back dimension). … As soon as the lateral reflections contain components above about 3 KHz the perception of broadening of the auditory events becomes prominent. We have to consider, however, that, in longer pieces of music than used here, sections with different spectral composition will follow one after the other;

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149 Jens Blauert: **Spatial Hearing**, p349.

150 Such an effect is discussed by Georg von Békésy in **The Moon Illusion and Similar Auditory Phenomena**, *American Journal of Psychology*, **62**, 1949, p540-552. His model of the auditorium is remarkably similar to the Salle Pleyel in its emphasis on a single early reflection from the ceiling.

> thus expansion in depth and width will both occur perceptually when the means for broadband lateral reflections are provided.[151]

In the light of these comments, the Beethoven *Scherzo* is an interesting piece, with its dramatic changes of register in the fast sections, alternating with the lower register *trio*. The rapid leaps from octave to octave and the almost hocketed way in which the music is played in the fast section could conceivably stimulate sudden shifts in auditory space. To a creative and imaginative listener, the sound of the orchestra might be moving around in space, expanding and contracting in width and depth. The swell in the latter part of the *trio* would have caused a dramatic intensification of any spatial effects that were discernible in its initial part. Varèse's description of a sound that 'detached itself' from the visual orchestra is the beginning of this experience.

The point here is not that Varèse was experiencing auditory spaciousness within the conventional parameters of auditorium acoustics. What has been described is an experience at an extreme of 'spaciousness', where there is only one excessively strong early reflection from the wrong direction, producing an effect that would not normally be desirable in the concert hall, but which gave the creative listener a remarkable experience. The combination of all the factors mentioned above would have provided ample opportunity for Varèse's fertile imagination to construct the image of sound space that he did. The lack of correlation between three dimensional physical space and the virtual sound space heard by Varèse suggests the invocation of an additional dimension; a spatial depth that cannot be perceived except in sound; an entirely distinct space coexisting with physical space.

There are similarities between the advertising hyperbole of the Columbia 360 and Varèse's colourful description of his experience. While the Columbia 360 fills the room and surrounds the listener with sound, this experience is accompanied by a geometric vision of clean straight lines as well as the notion of an extra dimension in space - depth. Varèse, in the 'over-resonant' hall, describes his experience in terms of an extra dimension, the sense of infinite depth expressed by light rays in a similarly geometric vision (rays are clearly defined and straight). In these examples of auditory spaciousness we are presented with a Perisphere and Trylon: a juxtaposition of a

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151 Jens Blauert & Werner Lindemann: **Auditory Spaciousness: Some Further Psychoacoustic Analyses**, *Journal of the Acoustical Society of America*, **80** (2), August 1986, p541.

continuous surrounding space and a highly demarked projective space. This same pattern is found in the two advertisements for the Columbia 360 [Figures 46 & 47], the first presenting a spherical surrounding space, the second a projective space. The experience of being surrounded by sound carries with it a sense of a second spatiality where directional sensations that do not correspond to visual space may be heard. This double spatiality within a single sound is comparable to the double spatiality of the hyperbolic paraboloidal surface.

Like the Salle Pleyel, the Philips Pavilion was designed acoustically to be a directive rather than a surrounding space, although not a directional space in the sense of the Salle Pleyel (where sound was intended to travel in one direction only). Xenakis' choice of the complex shape of the pavilion was partly an attempt to subdue wall reflections. Xenakis:

> [Surfaces with different radii of curvature] also seemed suitable for meeting the *acoustic* requirements. To allow complete freedom for creating a wide variety of spatial impressions with the aid of loudspeakers, the aim was to avoid as far as possible the uncontrolled acoustic contributions due to reflections from the walls and which are audible either as isolated echoes or as reverberation. It is known that parallel flat walls are dangerous in this respect, because of repeated reflections; parts of spherical surfaces are equally inappropriate, since they can give rise to localized echoes.[152]

W. Tak describes the range of this "wide variety of spatial impressions":

> The listeners were to have the illusion that various sound-sources were in motion around them, rising and falling, coming together and moving apart again, and moreover the space in which this took place was to seem at one instant to be narrow and "dry", and at another to seem like a cathedral.[153]

Tak, who was in charge of the sound installation, was, not surprisingly, aware of Vermeulen's work on 'stereo-reverberation' (ambiophony) and considered the Philips Pavilion installation to be similar in that they both were based on "bringing about a difference between the 'acoustic' environment and the real one"; on creating a discrepancy between auditory and visual space.[154] Hence we may distinguish between the literal projection of Varèse's music into space - from points on the ceiling and movements along the sound routes - and the additional dimension (depth?)

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152 Iannis Xenakis: **The Architectural Design of Le Corbusier and Xenakis**, *Philips Technical Review*, **20** (1), 1958/59, p3.

153 W. Tak: **Electronic Poem: The Sound Effects**, *Philips Technical Review*, **20** (2-3), 1958/59, p43.

154 The difference between ambiophony and the Philips Pavilion installation was, according to Tak, that in the case of the former the audience should be unconscious of the effect of the installation.

lent to the sound by the changing artificial reverberation and reflections, creating a space independent of physical dimensions that is nevertheless heard in physical space. Alternatively this distinction may be expressed simply as between directive and surrounding sound. And as we have seen, surrounding sound may ‘contain’ another directive space. But to Varèse it was simple:

> For the first time I heard my music literally projected into space.[155]

Surrounding Sound and Roundness

Auditory space has been widely accounted for in surrounding and amorphous imagery. Edmund Carpenter and Marshall McLuhan’s short and general account has such a characterisation of auditory space, making a commonly cited link between the omnidirectionality of hearing and its relatively amorphous surrounding form. Carpenter and McLuhan:

> The essential feature of sound, however, is not its location, but that it *be*, that it fill space…. The concert-goer closes his eyes.[156]

In a more thorough analysis of the perception of space, William James has considered spatial listening to be most adept at sensing the “original sensation of space”, which is the basis of spatial perception in all of the senses. James describes this sensation, which is “indescribable except in terms of itself”:

> It must now be noted that the vastness hitherto spoken of is as great in one direction as in another. Its dimensions are so vague that in it there is no question as yet of surface as opposed to depth; ‘volume’ being the best short name for the sensation in question.[157]

> In general, sounds seem to occupy all the room between us and their source; and in the case of certain ones, the cricket’s song, the whistling of the wind, the roaring of the surf, or a distant railway train, to have no definite starting point.[158]

In this amorphous original sensation of space we may, nevertheless, discriminate between different spaces: the reverberations of a thunderstorm are heard to be more voluminous than the

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155 Edgard Varèse: **Spatial Music**, in Schwartz & Childs (eds.): **Contemporary Composers on Contemporary Music**, p207.

156 Edmund Carpenter & Marshall McLuhan: **Acoustic Space**, in Carpenter & McLuhan (eds.): **Explorations in Communication**, p67.

157 William James: **The Perception of Space**, *Mind*, **45** (1), 1887, p2.

158 William James, op. cit. p3.

squeaking of a slate pencil, although James cites examples in his experience where a small sound was mistaken for a large one.

This type of account of auditory space was tested and affirmed experimentally by Sandra Palef and Rand Nickerson in the late 1970s.[159] That experiment showed that subjects would linguistically encode visual space according to discrete dimensions, whereas their code for auditory space appeared to be unitary or undifferentiated. Jon Frederickson has done further analysis, finding close similarities between auditory space and psychoanalytic space in Wilfred Bion's theory of projective identification.[160] The mental space described by Bion "is a non-visual, non-three-dimensional space lacking definition or limits." Frederickson proposes that there are at least four levels on a continuum of subject-object differentiation in the literature on auditory space: "(1) separateness - hearing something outside oneself; (2) fluid space - sensing a streaming toward oneself; (3) being absorbed by sound; and (4) becoming filled with sound."[161] A listener might listen for directional cues, perhaps in trying to locate a sound source in the visual field (1). Particularly in the case of music, there may be a sense that the auditory space transcends physical space, and sound is flowing toward the listener (2). There may be a sense of being totally enveloped or cocooned in sound (3). Or the sense might be of one's body becoming the very vessel of sound (4).[162] Frederickson also refers to Patricia Carpenter's essay on the musical object, which includes a similar exploration of subjectivity in sound space.[163]

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159 Palef & Nickerson: **Representing Auditory Space**, *Perception and Psychophysics*, **23** (5), 1978, p445-450. These authors cite the following description of auditory space by Milton:

"A dark illimitable ocean,
without bound, without dimension,
where length, breadth and height
and Time and place are lost."

160 Jon Frederickson: **Psychoanalytic and Auditory Space**, *Psychoanalysis and Contemporary Thought*, **9** (4), 1986, p641-651.

161 Jon Frederickson op. cit. p644.

162 In this author's experience, these four levels seem to work in different ways. For instance in a recent performance of electro-acoustic music there was a very strong sense that noisy sound was streaming toward oneself, that mid-range tones were occupying a fairly tight static space all around the head (a sort of cocoon), and that loud low frequency sounds were resonating in the body. In such a powerful piece it was difficult to listen on the first level (separateness).

163 Patricia Carpenter: **The Musical Object**, *Current Musicology*, **5**, 1968, p56-86.

In a project similar to Frederickson's, Martin Nass has found musical space to be a manifestation of certain states described by psychoanalysis.[164] To him, sound is an enveloping experience, music has a holding and immersing power, "often resulting in an ambiguous state of cognition in which discrimination between inside and outside becomes less precise." Nass suggests that the non-discursive form of music is an important element in this sort of cognition, and that there is a close relation between musical sound and physical contact and a person's sense of their own motility. He relates these to an early form of cognition in childhood that remains in maturity, existing side by side with later cognitive acquisitions.

Victor Zuckerkandl gives one of the more extended accounts of an auditory space in his monograph *Sound and Symbol* (especially pages 293-377). His account is based on music and musical tones (in a very conventional and Romantic way), and it is in musical tones that auditory space is found: everyday noises engender an unremarkable sense of directionality, while tones give a sense of a space that is surrounding and flowing into the listener. Writing only a few years after Zuckerkandl, Peter Strawson conducted an influential thought experiment in his *Individuals*, in which he conceived of a being whose only sense was hearing; asking whether such a being could have a conception of space. Significantly, his model of hearing is constructed around pitch. His conclusions are negative: he concludes that such a being would have a solipsistic existence, having no way of distinguishing itself from the universe around it.[165] Presumably without Strawson's knowledge, Zuckerkandl conducted almost the same thought experiment, arriving at an opposing conclusion.[166] His listener hears sound as coming from the world: the listener is caught up in the flow of sound, but still retains a sense of self and otherness. Zuckerkandl's approach was not impeded by the dry logic of Strawson's Anglo-Saxon philosophy, but was informed by his passion for music: Strawson's 'No-Space' was entirely speculative; Zuckerkandl's auditory space was experiential, if Romantic.[167] Zuckerkandl:

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164 Martin Nass: **Some Considerations of a Psychoanalytic Interpretation of Music**, *Psychoanalytic Quarterly*, **40**, 1971, p303-316.

165 Peter Strawson: **Individuals**, p59-86.

166 Victor Zuckerkandl: **Sound and Symbol: Music and the External World**, p271-292, especially p287-288.

167 Zuckerkandl maintains that pure auditory space is experienced when we listen to music. Thomas Clifton, in his monograph **Music as Heard**, criticises Zuckerkandl's assumptions and methods. See p138-139.

> The space of tones, then, is a placeless depth surrounding the hearer or, more properly, directed toward him, moving toward him, from all about. The depth of this space is not the depth that, together with height and width, makes up the three dimensions of visual space. Height, width, depth - there are no such distinctions in auditory space. Here there is only the one "from . . ." - which, if we like, we may call the one dimension of auditory space.[168]

It is notable that in this passage Zuckerkandl is applying the notion of depth in a manner very similar to Merleau-Ponty, who is not concerned as much with auditory space as with visual body-centred space. The analysis of the hyperbolic paraboloid as an icon of sound space in Chapters 1 and 2 is apparently loosely connected to the issue of sound as surrounding in this chapter - because of this notion of depth. The curves of the surface begin to surround the viewer in a manner akin to surrounding sound.

In the literature of auditory space it is striking how rapidly experience is reduced to very large questions about being and becoming or the 'thing itself'.[169] An unfathomable depth seems to reside very close to the surface of auditory space. Other aspects of auditory experience yield substantial amounts of material between fundamental ontological questions and immediate experience; for example, the disciplines of linguistics, information theory and musicology provide so many levels of appreciation that fundamental questions are normally avoided entirely. With visual space such questions may also be avoided by the vast constructions of perspective and geometry. The 'shallow depth' in auditory space is a reflection of its nature, as well as a reflection of the undeveloped field of auditory space analysis. Many texts on auditory space start by justifying its very notion, usually by contrasting it with visual space - some authors even seeing a need to justify the notion of spatial hearing -, so, not surprisingly, only a little intermediate material is covered.[170] Yet the fact that the study of auditory space is at such a basic level is also one indicator of its nature in human experience.

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168 Victor Zuckerkandl: **Sound and Symbol: Music and the External World**, p290.

169 Joachim-Ernst Berendt's monograph, **The Third Ear: On Listening to the World**, is another striking instance of this.

170 Edward Lippman's article, **Spatial Perception and Physical Location as Factors in Music**, begins, "It may not seem possible for spatial perception to play any role in an auditory art, but hearing is not the only sense involved in music, and - surprising as it may seem - even hearing is capable of providing considerable spatial information on its own account". *Acta Musicologica*, **35**, 1963, p24-34.

The image of the sphere, and the notion of being surrounded are remarkably common in the discussion of auditory space. The sphere and associated notions of roundness are used to visually characterise the auditory sense of surroundedness. Ihde describes an auditory aura, filling space around a body with its 'excess', as well as surrounding the listener in an enveloping presence. Ihde:

> The sparrow's song in the garden presents itself *from* the garden. But if I put myself in the "musical attitude" and listen to the sound as if it were music, I may suddenly find that its ordinary and strong sense of directionality, while not disappearing, recedes to such a degree that I can concentrate upon its surrounding presence.[171]

Ihde develops this theme by referring to Paramenides.

> He characterized the limit thusly, "Being is complete on every side, like the mass of a well-rounded sphere." A phenomenology of the auditory field rediscovers these characteristics of experience.[172]

In all the texts that have been referred to, there has been a sense that in sound space, distinctions of self and object begin to collapse (and in Strawson's case, collapse completely). Through this collapse, the listener finds fundamental aspects of being (Strawson's text excepted). In Frederickson's words, "a listener undergoes meaning".[173] Yet this idea is captured most elegantly in a text that is not specifically about sound; in Gaston Bachelard's *The Phenomenology of Roundness*.[174] That short essay collects disparate and often isolated statements and fragments of poetry - by Karl Jaspers, Van Gough, Joë Bousquet, La Fontaine, Jules Michelet and Rainer Maria Rilke - all meditating on the roundness of being. Bachelard quotes the following fragment from Rilke:

> (*…Ce rond cri d'oiseau*
> *Repose dans l'instant qui l'engendre*
> *Grand comme un ciel sur la forêt fanée*
> *Tout vient docilement se ranger dans ce cri*
> *Tout le paysage y semble reposer.*)
>
> …This round bird-call
> Rests in the instant that engenders it

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171 Don Ihde: **Listening and Voice: a Phenomenology of Sound**, p76.

172 Don Ihde: **Listening and Voice: a Phenomenology of Sound**, p80.

173 Jon Frederickson: **Psychoanalytic and Auditory Space**, *Psychoanalysis and Contemporary Thought*, **9** (4), 1986, p649.

174 In Gaston Bachelard: **The Poetics of Space**, p232-241.

> Huge as the sky above the withered forest
> Docilely things take their place in this call
> In it the entire landscape seems to rest.[175]

This fragment captures in poetry the roundness of being in the roundness of sound. Here there is a sense of the attractiveness of surrounding sound, whether expressed by an 'acoustically excellent auditorium', by an elaborate ambiophonic installation, or simply by the way in which we can rest in the call of a bird or into a piece of music drawing its round aura around us. The auditorium or bird call do not create the sense of envelopment by themselves, but they may strongly encourage that sense. As we have seen in our reappraisal of Varèse's experience in the Salle Pleyel and in the theory of auditory spaciousness, there is a sense that a surrounding sound can open up a second spatiality. Rilke's bird call, in which all things rest, has a world within its sound. Bachelard expresses this more explicitly:

> The world is round around the round being.[176]

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175 Rilke: **Poésie**, quoted in Gaston Bachelard: **The Poetics of Space**, p238. Readers may also wish to refer to Rilke's poem **Gong**, which in both of its versions (October 1925 and November 1925) contains a wonderfully vivid picture of resting in sound, of being in roundness.

176 Gaston Bachelard: **The Poetics of Space**, p240.

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Varèse's *Poème Electronique*

Whatever the psycho-acoustic and philosophical bases for Varèse's concept of sound space, his music remains music. *Poème électronique*, as a piece of music, speaks to us of Varèse's sound space. We have already found aspects of this sound space in the Philips Pavilion itself, expressed through the ruled surfaces that formed its walls. The Salle Pleyel has also given us an insight into Varèse's conception of sound as a projection or as an extra dimension, and its role as a precursor to the Philips Pavilion in Varèse's imagination has been noted. Now we must listen to *Poème électronique*, trying to hear how the piece lives in space.

Approaches

It has become standard practice to analyse Varèse's notated work through a hermeneutic application of his spatial vocabulary, especially of masses and planes of sound. John Strawn, Florence Parks, David Bloch, Jonathan Bernard and Robert Cogan are among the authors who have interpreted Varèse's music in the language of space.[177] Strawn's analysis of *Intégrales* treats the piece partly as a simulation of acoustic (physical) space; he is concerned with how certain devices in the sound of the piece might express positions, movements, masses, and transformations were they heard as such (rather than as originating from a static group of musicians). His approach draws on psycho-acoustic theory as well as conventional musical notions to conceive of a conceptual and phenomenal sound space in which *Intégrales* exists.[178]

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177 Strawn: **The *Intégrales* of Edgard Varèse**; Parks: **Freedom, Form and Process in Varèse: A Study of Varèse's Musical Ideas, Their Sources, Their Development, and Their Use in His Works**; Bloch: **The Music of Edgard Varèse**; Bernard: **The Music of Edgard Varèse**; Cogan: **New Images of Musical Sound** and **Varèse: An Oppositional Sonic Poetics**.

178 Strawn's subsequent studies have included a detailed investigation into musical timbre. See, for instance, Strawn's monograph **Sound Color**.

Parks and Bloch use Varèse's metaphors to define a number of elements in his music that are differentiated in terms of texture, timbre, rhythm, and pitch in his notated works. In their discussion of space, there is a particular tendency to explore the ideas of sound plane and sound mass. Bloch illustrates the spatial structure of Varèse's music with a three-dimensional drawing of musical volumes in a short section of *Hyperprism*.[179] Bernard's spatial interpretation of Varèse's music is much more formal, and is represented by the transcription of notated music onto two-dimensional graphs, where the type of pitch and rhythm relationships that interested Varèse can be seen more clearly. This graphical approach has been taken further by Cogan, whose spectrographic representations of *Hyperprism* and *Poème électronique* might be seen to imply an inherent spatiality in sound. While Cogan is very aware of the subjective nature of his transcriptions, he does consider the spectrograms to show some of the spatial images that Varèse described. Unfortunately Cogan's analyses are quite short, and while he does delineate a detailed method for using the spectrographic representations in analysis, he does not apply the method in detail to Varèse's works.

At the time of writing, there are two published analyses of *Poème électronique*.[180] Lawrence Ferrara published an article in 1984 that uses *Poème électronique* to give an example of the possibilities that phenomenology offers music analysis.[181] While much of the article consists of a listing of events in the piece, it draws some interesting conclusions about the way in which the piece speaks about its time. Ferrara finds that the piece raises issues concerned with technology, human existence, religion, time, and primitivism in the context of the Modernist movement of the mid Twentieth Century. In the piece these themes are juxtaposed in a non-discursive form, giving us one view of "what it is to *be* a modern man". Finding no general unifying progressive structure

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179 This illustration is similar to conceptions of sound held by the *musique concrète* school; see for instance Abraham Moles: **Information Theory and Esthetic Perception**.

180 In addition to these, Olivia Mattis has a chapter of her doctoral dissertation, **Edgard Varèse and the Visual Arts**, on the Philips Pavilion and *Poème électronique*. This is mostly an illuminating re-appraisal of Le Corbusier's relationship with Varèse, as well as Xenakis' role in the project. Brian Mair has written a Masters thesis with a transcription and analysis of *Poème électronique*, although it was not available to this author (Brian Mair: **The 'Poème Electronique' of Edgard Varèse: Analysis and Transcription**, Masters thesis, CUNY, Queens College, 1967, cited in Florence Parks: **Freedom, Form and Process in Varèse**, p458). At the time of writing, Roberta Lukes was completing her doctoral dissertation on *Poème électronique*, part of which is a transcription and analysis of the composition (Harvard University).

181 Lawrence Ferrara: **Phenomenology as a Tool for Musical Analysis**, *Musical Quarterly*, **70**, 1984, p355-373.

in *Poème électronique* suits the purposes of the analysis, as its context is an attempt to show how phenomenology might be very useful in the analysis of an otherwise elusive composition. Ferrara's picture of a non-hierarchical sonic collage may reflect the experience of a listener, but this chapter will argue that large scale processes can be heard in the piece. Ferrara's article also contains a discussion of the philosophy of music analysis and certain problems that phenomenology might solve.

Cogan's analysis was published in 1991, together with the Neuma remastered recording of *Poème électronique*.[182] Cogan's distinctive analytical techniques are developed in his 1984 monograph, *New Images of Musical Sound*, and Bernard had suggested that Cogan's techniques might be applied to the piece in Bernard's monograph, *The Music of Edgard Varèse*. Cogan's analysis has a central theme: the oppositional character of Varèse's music, as demonstrated by the piece. He substantiates this with quotes from Varèse, as well as by finding regions in the piece where two main types of timbre can be said to be in opposition. Cogan's interest in sonorous oppositions was expressed more generally in the latter part of *New Images of Musical Sound*, where he adapts elements from structuralist linguistics (phonology) to devise a system to describe musical sound.[183] Ferrara's argument that pre-conceived analytical methods produce results that speak as much about the method as the piece would seem to be borne out by Cogan's article, but it is also probable that Cogan was attracted to *Poème électronique* precisely because it reflected his theory so well.[184] Cogan divides the piece into two main sections and a coda. In each section a pair of timbres is in opposition: sirens and bells in Part One; oscillators and voices in Part Two; and sirens and the pipe organ in the Coda. He also finds that certain divisions in the piece form golden section ratios, in solidarity with Le Corbusier's architectural æsthetics.

While these two analyses appear to be highly contrasting, they share the characteristic of being unusual and distinctive approaches to musical analysis, and both authors state a certain allegiance

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182 Robert Cogan: **Varèse: An Oppositional Sonic Poetics**, *Sonus*, **11** (2), Spring 1991, p26-35. Another version of this article accompanies the Neuma recording of *Poème électronique*.

183 Robert Cogan: **New Images of Musical Sound**. In Part II Cogan develops "the Theory of Oppositions", which is modelled on phonological oppositions in structuralist linguistics.

184 Varèse states: "In my own works, for instance, rhythm derives from the simultaneous interplay of unrelated elements that intervene at calculated, but not regular, time lapses. This corresponds more nearly to the definition of rhythm in physics and philosophy as 'a succession of alternate and opposite correlative states.'" **Rhythm, Form and Content**, in Schwartz & Childs (eds.): **Contemporary Composers on Contemporary Music**, p202.

to phenomenology. For Ferrara this allegiance dominates the analysis; for Cogan it is one of several philosophies underlying his approach. Cogan shows little interest in applying the disciplined investigative methods of phenomenology, but draws on the ideas of subjectivity that phenomenology offers (as does this thesis).[185] While Ferrara is careful to distinguish the respective limits of discrete and continuous representation, Cogan's reapplication of distinctive feature theory from a discrete phonemic system to the continuous sound spectrum can only form a partial analogy because of fundamental differences between music and language.[186] Ferrara is emphasising concrete sound and continuities within the music and its context; his emphasis is on the meaning of the piece, on analogue processes. Cogan expresses the importance that he holds for oppositions in a quote from Peirce: "A thing without oppositions *ipso facto* does not exist."[187] This self-consciously self-reflexive statement reflects more on the digital structure of language than the nature of existence (although Descartes might not discriminate between them): when Cogan promotes the idea of oppositions, he is promoting digitally structured thought.[188] Neither analysis is exclusively analogue or digital as that would be an impossibility, but the emphases are towards the extremes. That the first two published analyses of *Poème électronique* should be based on such differing perspectives reflects the piece's distance from conventional musicological language.

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185 This mixture of phenomenological and Cartesian influences is especially interesting because of its similarities with aspects of Varèse's, Xenakis' and Gabo's æsthetics. These three artists each combined scientific and mathematical discipline with a call for art to be appreciated on an immediate level.

186 For another perspective on this problem see John Strawn: **Robert Cogan: New Images of Musical Sound**, *Computer Music Journal*, **10** (1), 1986, p97-99, and the subsequent ill-tempered exchange between Cogan and Strawn in *Computer Music Journal*, **10** (4), 1986, p9-13.

187 Robert Cogan: **New Images of Musical Sound**, p124-125. Actually Cogan is quoting Jakobson and Waugh, who quote Peirce in their monograph, **The Sound Shape of Language**. Cogan supports this quote with others from Trubetzkoy, Anaximander and Heraclitus, and also finds support in Plato and Hegel.

188 Anthony Wilden's **System and Structure** includes a chapter in which basic differences between analogue and digital are concisely expressed (p155-195). The analogy between linguistics and music is not as direct as Cogan implies. The distinctive feature theory that he draws on is a digital model of a digital aspect of language - the limited set of discrete (defined and arbitrary) sounds in a language or dialect. His model of music reapplies this type of model to an explicitly open (analogue) system, where any conventional pre-defined arbitrary sound tokens do not necessarily correspond to his. His 13 distinctive features can describe a music of 8192 'phonemes'. Cogan begins to respond to these issues on pages 141-146 and page 172 of **New Images of Musical Sound** and in his reply to John Strawn's review of that book, *Computer Music Journal*, **10** (4), 1986, p9-10.

***Poème Electronique*: An Electro-acoustic Work**

Poème électronique is elusive, existing in a reduced form on two very different stereophonic recordings.[189] The recordings are charged with the memory of and mythology around Varèse's dreams and the Philips Pavilion, inviting the listener to long for a long-demolished architecture. The Columbia recording makes a crude attempt at recreating the architecture by adding artificial reverberation to the entire recording. In a high fidelity response, the Neuma recording has no added reverberation and an expanded amplitude range through the use of noise reducing applications and the benefit of the digital medium. Any relationship between the spatial movements in the Philips Pavilion and those on the stereophonic recordings can only be tenuous. However the Neuma recording makes a more extreme use of the stereophonic field. One thing that various statements about the piece do tell us is that Varèse intended it to be powerful:

> Those who were fortunate enough to hear the *Poème électronique* in Brussels, or *Déserts* in New York, when Varèse himself regulated the intensities and volume to be emitted by the loudspeakers, will know what Varèse meant by that phrase 'be subjected to a physical phenomenon.' The sounds did, in fact, do violence to the listener's body. The sound was concrete, and present, no longer a thing of chiaroscuro but a wave displacing air in order to strike us.[190]

> [The light projections and the sounds in the Philips Pavilion] were simultaneous but independent. Thus no violence was done to the music when it was performed here [in New York] without the visual accompaniment as part of a concert of contemporary music at the Village Gate. The only violence was to the audience. Three times this listener almost jumped out of his chair as sharp, high-pitched crashes shot forth from what seemed to be a monstrous tweeter in direct line of fire. The fourth time he clasped his hands to his ears, not out of protest at the sounds, which were fascinating in themselves, but to stave off physical pain.[191]

In a similar vein, H. Gernsback, in describing a performance of the *Poème électronique* in the Philips Pavilion, writes that, "Often, the intense spine-tingling reverberations overwhelm you as the sound impinges on you from all directions at once, only to numb you in turn with extremely high shrieking, whistling eerie echoes."[192] In his articles on early performances of *Déserts*, Canby

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189 The third recording, Attacca Babel 9263-2, was not available to this author at the time of writing.

190 Fernand Ouellette, **Edgard Varèse**, p191-192. One is reminded of Roland Barthes' essay, *Rasch*, where the musical beat is pictured as a force physically beating the human body.

191 Edward Downes: **Rebel from Way Back**, *New York Times*, 16 November 1958, Section 2, p11, referring to the New York premiere of *Poème électronique*.

192 H. Gernsback: **400 Loudspeakers**, *Radio-Electronics*, October 1958, p47.

also writes much about the loudness of the taped interpolations, referring to sound "loud enough to assault" and "lethal beams of sound".[193] Varèse's understanding of sound as physical entity was expressed very directly when *Poème électronique* was played. He stated that the listener should be like a piece of blotting paper; firstly absorbing, then vibrating, and finally drawing their conclusions.[194] Another writer seems to have caught onto Varèse's theme of music being "the corporealization of the intelligence that is in sounds" in his description of the *Poème électronique*:

> Here, one no longer hears the sounds, one finds oneself literally in the heart of the sound source. One does not listen to the sound, one lives it. The unparalleled perfection of the acoustical system and the daring but successful score created by Varèse have brought such perfection to this element of Le Corbusier's *Poème électronique* that the other elements seem to lose all suggestive power. One 'sees' the play of moving and changing colours, but at no point is one 'bathed' in a coloured atmosphere. The images are there in front of you, but you never feel yourself inside the image. The father of the *Poème électronique*, M. Le Corbusier, is before all else an architect and a painter, and consequently an artist who sees form rather than movement. He is therefore probably less aware of the extreme possibilities of electronics, certainly less aware, in any case, than M. Varèse and his technical assistant ... By the use of moving sound they have succeeded in liberating their score from the shackles of reality. The other scores were not conceived in this absolute sense, and that is the cause of a certain imbalance.[195]

Through the acrobatic sound installation, through sophisticated use of equalisation and reverberation, through a spatial understanding of musical material, and through sheer force, Varèse's *Poème électronique* realised his dream of opening up a world of space to the listener.

A Beginning and an Ending

Analyses of Varèse's works almost always refer to his statements about rhythm as a generator of form, form as a dynamic process, as a 'resultant' of a process analogous to crystallisation. *Poème électronique* can be understood in many ways, and like all of Varèse's pieces, the very direct way that it speaks to the listener invites analysis based on its immediate aural perception. While some deep structures may be found, such as the golden sections cited by Cogan, Varèse encourages the listener to understand the work, like all his music, primarily through listening and the aural

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193 Edward Tatnall Canby: **Audio etc.**, *Audio*, October 1987, p78. See also Edward Tatnall Canby: **Audio etc.**, *Audio*, July 1955, p28, 37.

194 Georges Charbonnier: **Entretiens avec Edgard Varèse, Suivis d'une Etude de l'Œuvre par Harry Halbreich**, p27.

195 Quoted & translated in Fernand Ouellette, **Edgard Varèse**, p201-202, from J. O., **Le Poème électronique**, *Radio et T.V.,* No.5, May 1958 pp349-355.

imagination. Like a many-faceted crystal, the surface of *Poème électronique* can be understood from many perspectives, but primarily through sound. A dynamic form is immediately apparent in *Poème électronique* if we consider how it begins and ends.

The tolling bell that begins the piece has many implications. *Déserts*, Varèse's previous major composition, also begins with a bell (orchestral tubular bells).[196] In his attempt to define what Varèse meant by 'sound mass', Bloch uses the concept of a bell, and quotes Gilles Tremblay:

> Let us listen to a large bell.
>
> What do we hear? Grosso Modo a group of principal sounds forming a resonating phase, median, and later a sharp resonating phase provoking rapid beating; and finally a grave phase that we call "hum" and the sound seems to be continued. These phases heard simultaneously form the sound body… This notion of "sound body" also comprises the idea of timbre, attack, intensity and emission mode, but these elements are each responsible and mutually interactive…[197]

Citing other writers, Bloch argues that the harmonic structure of bell tones often resembles vertical pitch structures in Varèse's music, as well as that of other early Twentieth Century composers such as Stravinsky. To Bloch, the "extreme density of a bell" exemplifies Varèse's concept of a sound mass, while the "relative thinness" of a single sustained tone exemplifies a plane of sound.

The tolling bell also speaks about the environment in which the piece was composed and installed, the Netherlands and Belgium having a long history in bell making and a landscape full of church bells. Varèse's interest in listening to the sounds of his environment is well documented, and it is more than likely that any interest that he had in bells was stimulated by the plenitude of bells in his working environment. One Nineteenth Century account (preceding the construction of modern tall buildings) states that one hundred and twenty-six bell towers could be seen on a clear day from the steeple of Notre Dame at Antwerp, including the great towers of Brussels and Mechelen.[198] Varèse also had a professed interest in stonemasonry, which at an early age had given him a way of imagining sound masses, so his attraction to ecclesiastical sites while composing *Poème électronique* might have been strong. The bell that begins *Poème*

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196 Varèse also composed *La Procession de Vergès* in 1955, a tape piece for a sequence in Thomas Bouchard's film *Around and About Joan Miro*.

197 Gilles Tremblay: **Leçons en mouvement**, *Liberté* 5, Montreal, September-October 1959, p30-31. Translated and quoted in Bloch: **The Music of Edgard Varèse**, p189.

198 H. R. Haweis: **Music and Morals**, p410-480.

électronique would have been heard by the audience in Brussels in the context of this weight of history and monument. Its sound pointed to a stable past in the context of a futuristic world's fair and pavilion. The potential metaphoric linking of this late Modernist installation with its local environment is certainly striking.

High and low frequencies in the pavilion were divided between 'high note' and 'low note' speakers [Figure 6]. Two-way reproduction systems have been a standard technique for creating efficient reproduction over the entire frequency spectrum, but the way in which it was layed out in the pavilion reinforced spatial differentiation between high and low. The low note speakers were mounted behind the concrete balustrades that separated the audience from the lighting and projecting equipment near the pavilion walls; the high note speakers were arranged in clusters and 'sound routes' on the pavilion shell [Figures 6 and 7]. While there is much discussion of spatial effects such as 'circulating sound' in relation to the high note speakers, there is no mention of spatial differentiation among the low note speakers, and, studying the accounts that we have, it can be inferred that the low note speakers acted together as a general source for all low sound.[199] Again, this is an application of a standard technique in sound reproduction that relies on the fact that low frequencies are not directional (or at least not controllably so) in enclosed spaces because of dispersion through diffraction and the resonances that they set up. Thus low sound in the pavilion had a very close association with a sense of surroundedness because of four factors: the concrete shell provided a reverberant space in which low frequency directivity was impossible; the low note speakers probably acted together for all low sound; the low note speakers were heard indirectly - entirely through diffracted and reflected sound; and the distribution of the speakers over a large and resonant area would have created a strong sense of auditory spaciousness, with many slightly delayed sounds from all directions following each sound. A relationship that we will develop further in Chapter 5 between bass, surroundability, and being inside was reinforced by the sound installation of the pavilion.

The tolling bell in the pavilion would have taken on these properties, and because of its loudness and the prominence of low frequencies (the 'hum'), it would have given the impression of filling

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199 The Philips corporation has apparently not kept detailed records of the sound installation, and were unable to shed light on this in personal correspondence. However, the placement of the low note speakers behind the balustrade - so that all of their sound propagated indirectly to the audience - also indicates that no spatial differentiation was intended.

the space. Despite the obvious distance at which the bell was recorded the audience would have had the sense of being surrounded or enclosed by the bell, a sense that would easily have been reinforced by the bell-like shape of the pavilion. On the domestic recordings, the bell is distributed equally to the two channels, and there is a similar effect, though smaller in extent.

The explosive heterophonic ascent of sirens at the end of *Poème électronique* speaks of the future, of movement and energy, of rockets travelling to the stars. This is an exterior space free from obstructions and boundaries. This ending begs comparison with that of *Density 21.5*, where a sequence of nine notes rises from the flute's lowest note to its highest, with a crescendo to *fortissi-issimo*. Jonathan Bernard:

> Like Varèse's other endings, the purpose of this final ascent is not to close off by emphasising the limits of the medium, not to reach a climax by neatly summing up, but to suggest the limitless possibilities of musical space. Varèse's phrase "open rather than bounded" is nowhere more appropriate. Like other musical compositions, *Density 21.5* must end somewhere, but the "journey into space" may go on, in however figurative a sense.[200]

When the René Le Roy recorded *Density 21.5* in 1950, Varèse asked him to play the final ascent into a piano while Varèse depressed the sustaining pedal, so as to produce sympathetic vibrations on the piano strings.[201] This effect might be conceived of as a wake trailing a rapidly moving object, and the imagination might be similarly applied to aspects of the explosive ascent in *Poème électronique*. *Poème électronique* finally explodes into space on several levels: movement on sound routes mapped by a rise in pitch and in loudness; spatial movement in the pavilion; the roar of a jet or rocket engine accelerating past the speed of sound; and the anticipated debouchment as the audience left the pavilion for a relatively unbounded world. Writing in the New York Times in 1958, Edward Downes quoted Varèse:

> "Ever since I was a boy I have had claustrophobia," said Mr Varèse. "Most music sounds to me terribly enclosed, corseted, one might say. I like music that explodes into space."[202]

The sound of a rocket is in sympathy with the images of rockets in space found in Le Corbusier's projected images, and with the ideology of the Brussels World's Fair, with its utopian vision of

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200 Jonathan Bernard: **The Music of Edgard Varèse**, p232.

201 The Neuma recording of *Density 21.5*, by Pierre-Yves Artaud, uses the sustained piano effect. Neuma CD 450-77.

202 Edward Downes: **Rebel from Way Back**, *New York Times*, 16 November 1958, Section 2, p11.

explosive (nuclear) technology (expressed for instance by the explosive star of the fair logo and the Atomium, which was one of several pavilions exhibiting nuclear science).

Of course the final explosive ascent is not just an ascent. The heterophonic and primarily ascending movement of tones is accompanied by an explosive descent that begins with the sound of a distant jet, which gets louder and decreases in pitch. This is added to by a dense roar, lower in pitch, which begins shortly before the ascent. The dense roar expands downwards in pitch, and when the fundamentals of the ascents are cut out, leaving sustained upper partials, the upper range of the roar is also filtered out, leaving only very deep and very shrill sound. The Philips Pavilion's high and low note speakers would have created an expanding spatial separation between these two sounds in sympathy with their pitch separation. In the Neuma recording of *Poème électronique*, the ascent is centred and movement in the stereophonic field is restricted to the noise accompanying the ascent, which as it descends, moves from one channel to the other, and finally to the centre. Centring the ascent is a way of emphasising its importance as a cadence and maximising its loudness. With the distant jet in channel 1, the dense roar beginning in channel 2, and the lower roar in both channels, there is a sort of stereophonic cadence beneath the ascent: a movement from distant peripheral sound (lacking in low frequencies), to close but peripheral sound, to close surrounding sound.

By just listening to the gestures that begin and end *Poème électronique*, we have identified two contrasting forms and three types of sound. The bell has connotations of stability, history and substance (or mass). The heterophonic ascending sirens have connotations of dynamic movement, energy, and the future, and are accompanied by a descending roar. The bell is rather low in pitch, but remains in its place; the sirens ascend from the lower mid range to the high range; and the roar descends from the upper mid range to the lowest area in the audible frequency range. The piece may be said to begin at a grounded mid range and to finish at the extremes.

A Dynamic Form

It is essential that the reader be familiar with Varèse's *Poème électronique* when this section of the thesis is read. The section makes frequent reference to parts of the piece. To understand these references the reader will need to consult the spectrographic transcription in the Appendix, which has times marked on it. A useful exercise in familiarisation is to listen to the composition several times while following the transcription.

If the two gestures that begin and end the piece are taken as two extremes in its spatial expression, an intelligible and useful form can be found, coinciding in many ways with Cogan's model.[203] Cogan divided the piece into sections that were each characterised by two contrasting timbres or textures. It is also reasonable to divide the piece into sections that are articulated by dynamic structures epitomised by the two extremes of the tolling bell and the explosive ascent.[204] This allows the definition of four main sections, although they should not be thought of as rigidly independent. Perhaps they might be thought of as four different aspects in a continuum. The four sections start at 0s, 155s, 340s, and 420s.[205] These will be called Sections 1 to 4 respectively.

Each of the four sections might be subdivided into two main parts, which will be labelled 'a' and 'b' in this analysis. The sections begin (in part a) with material that primarily reiterates, develops, transforms, and sometimes undermines the sound that begins the piece - the tolling bell. The sections end (in part b) with material that pre-empts in various ways the sound that ends the piece - the explosive ascent. The position of the sections and their subdivisions are marked on the spectrogram in the Appendix.

These sectional and subsectional divisions are by no means strict. In many cases the beginning of one division overlaps with the ending of another. Material that, according to the above generalisations, belongs in one part of a section may penetrate the other part. Material may also be highly ambiguous, and may be heard in relation to both the beginning and end of the piece, or to neither. Nevertheless many of these exceptions can be understood as extensions of the proposed general structure rather than as problems with it.

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203 The model proposed here fits well with Cogan's conclusions about golden sections in the composition. The present author has identified a number of additional golden section proportions in the structure proposed in this analysis, most notably: Section 3 begins approximately at the golden section of the interval between the beginning of Section 2 and the end of the piece; Section 4 has the same relationship with Section 3; and the final ascent begins at the golden section of Section 4. The question of whether such proportions have any significance is beyond the scope of this study.

204 Florence Parks also used this as the basis for the division of *Poème électronique* into two sections; **Freedom, Form and Process in Varèse**, p377.

205 Times refer to those on the spectrogram in the appendix of this thesis. There may be slight differences between these times and those given on Cogan's spectrogram, and the times used here match more closely the clock recorded on the Neuma disk itself. In any case, all times are rounded to the nearest 5 seconds.

Four Beginnings

In isolation, the beginning of *Poème électronique* (Section 1a) appears to be wildly eclectic, with sounds that seem to be as contrasted as possible. To Cogan, this is the essence of the piece:

> In a similar way, the immediate local sonic interactions are also determined by the principle of sonic opposition. The *Poème* begins with the tolling of a *grave* bell-like spectrum… What follows the tolling bell? Not a similar sound, but rather a highly contrasting one: a *clipped, percussive noise-band* tapping… The tapping is then followed by an *oblique* wash of siren-like sounds, first climbing and then falling through many octaves of audible space -- a vivid contrast to the preceding *level* tolling and tapping alike.[206]

To the naïve listener, this enormous range of material - which continues through large parts of the piece - can make the piece difficult to reduce into coherent forms. However when Sections 1a, 2a, 3a, and 4a are compared, their similarities seem to invite the idea of a degree of formal congruence. The tolling bell, various synthesised tones of stable pitch, pipe organ sounds, various clicks, pops and tapping sounds, and the sound of what seems to be ecclesiastical chanting or singing are major elements in these parts, often shared between parts, or else having associations with sounds in the other initial parts. Figure 53 shows only a few of these elements in these parts of the composition: the tolling bell, synthesised tones, pipe organ tones and clusters, and acoustic percussion sounds. All of these sounds are related, and this section of the thesis will discuss these relationships.

The siren frequency sweeps that are heard soon after the tolling bell in Section 1a break any sense of sectional continuity. They have a much stronger association with the explosive ascent than with the tolling bell, and are therefore an exception to the general structure given above. There is no similarity with the other three initial parts, and the siren might be thought of as an intrusion, serving partly as an anticipation of the piece's ending, so that within its first thirty seconds the scope of the piece is already articulated in miniature. This is just one example of how the formal divisions that we make are not exclusive, and should be thought of as penetrable.

Partly because of this dramatic intrusion, the formal significance of Section 1a is only established during Section 2a, which parallels the first in many ways. The second, without any siren sweeps, sounds more continuous as a more or less static disposition is maintained throughout. Features

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206 Robert Cogan: **Varèse: An Oppositional Sonic Poetics**, *Sonus*, **11** (2), Spring 1991, p33.

including the tolling bell, various clicks, pops and noise bursts, and synthesised tones with an increasing (or reverse) envelope follow roughly the same sequence in the two fragments. In the second fragment, the significance of the synthesised tones is extended by confusing them with notes from a pipe organ (on a diapason or flute stop). Thus the bell, with its ecclesiastical connotations is related through the pipe organ to the synthesised tones, all three having long sustained envelopes. A similar mixing of synthesised tones and organ notes occurs in Section 3a.

While the tolling bell naturally has a decreasing envelope, the tones have a generally increasing envelope in the first three initial parts. In Parts 1a and 2a, this creates a symmetry, with the tones acting as a palendromic answer to the bell. In the third fragment there is no tolling bell and the synthesised tones that begin it might be thought of as substituting for it. In these transformations from bell to organ to synthesised tones there are spatial transformations from an imagined deep interiority to a still ecclesiastical, but more open space (a space that is both larger and has more sonorous possibilities), to an explicitly artificial space that can only exist on the surface of the pavilion. The synthesised tones, because of their unmistakable artificiality, draw the listener from an imaginary depth to the surface, which is mapped by the clusters of speakers and sound routes. The unnatural-sounding increasing envelopes reinforce this process.

The various clicks, pops, noise fragments, percussion sounds, and short tones that punctuate the beginnings of the four sections act as very modest contractions of material that is found elsewhere in the piece. In these other parts of the piece, metallic crashes, percussive sounds and other noises have a much larger role, often forming very dense textures. At the beginnings of the four sections, these sounds are comparatively sparse and clean. The short tone attacks that occur in Sections 1a, 2a and 3a establish a link between the percussive sound of the piece in general and the sustained tones that characterise these parts. It is only in the third and fourth parts that the sound of percussion instruments is used, replacing the staccato synthesised attacks in the first two parts. The percussion in Section 3a is obviously an overlap from the end of Section 2, but it also speaks of how the cathartic descent in that section has changed the piece, as it moves towards the final explosive ascent. Several formal similarities can be found between the four parts in the way that percussive and noisy sounds are placed.

Little has been said about Section 4a thus far because it is much more of a transformation of the others than a return to them. The male chant returns the listener to the world engendered by the tolling bell (the sounds themselves even share many characteristics). However the organ does not return with tones, but with aggressive clusters that are fragmented by tape manipulation, with envelopes very similar to fragments of complex tones, noises, and industrial sounds that are heard in some of the more dynamic parts of the piece. The high frequency noise attacks between the chant and the organ reinforce this relationship by merging into the high organ clusters. The sampled character of the pipe organ makes the listener jump between a heavily enclosed reverberative space and the opaque surface of the technology. Meanwhile, the percussion is louder than before, in both union and juxtaposition with the fragmented organ, and this is augmented in the Neuma recording by complete channel separation of the two. After some high 'pips', the organ finally crashes. In the fourth initial part, the ecclesiastical space is remembered, but then fragmented and finally merged into the more industrial, futuristic and primitive material that characterises the latter parts of the four sections and ultimately concludes the piece.

Even though the four parts of the piece that we have been considering do not emulate each other to the extent that one would find in a Classical sonata form, some broad similarities are shared through the sense that the parts are primarily directed toward the development of material inherent in the sound of the tolling bell. The ambiguity between the imagined ecclesiastical space and the synthesised or sampled sound creates spatial shifts, perhaps loosely analogous to Varèse's experience of detachment. The sound of an acoustic space, albeit simulated, is established, but then subverted; and the listener finds herself/himself in a second space. In Section 1a, the link between the tolling bell and synthesised tones is not properly established; they are merely juxtaposed. In Section 2a, the link is established by the inclusion of pipe organ tones, and it is here that ambiguity becomes significant. In Section 3a, the tolling bell is missing, but the ambiguity between tones is reinforced. Section 4a re-emphasises ecclesiastical space, but also drives the ambiguity further by cutting up an aggressive and noisy pipe organ, which has much in common with textures in the latter parts of the sections. In this way, this sense of detachment, which undermines the initial stability, is gradually introduced and expanded through the initial parts of the four sections.

Five Endings

We have described the beginnings of the four sections in relation to the stability that is established by the initial sound of *Poème électronique*. The latter parts of these four sections appear to work in relation to the final sound in the piece, the explosive ascent. However these latter parts are formally much less consistent than the initial fragments, and this reflects the material that they draw on. Their sound might be generally described in terms of the final ascent - dynamic and explosive - but the complexity implied by this generalisation is reflected by an enormous variety of material. This material includes every kind of percussion sound, siren-like sounds, industrial sounds, mechanical bells, human voices, and much more. Noise and ascending and descending sound play important roles in these parts of the composition, and they have obvious connections with its final gesture.

The 'three-note motive' stands out in any listening to *Poème électronique*. This motive, initially iterated three times, begins what we have designated as Section 1b. Here and elsewhere it functions as a prelude to the dramatic siren ascents that follow. Thought of in this way, Section 1b might be subdivided into two main parts, each beginning (approximately) with the three-note motive and ending with a siren ascent (Section 1b(i) spanning 55s - 90s and Section 1b(ii) spanning 90s - 150s). The similarity between the short tones that precede the first instance of the three-note motive and surround the second instance also gives the sense that the material following 90s is a rearticulation of material from 40s onwards, albeit greatly transformed.

The material between 70s and 90s - which is largely factory sounds, and mechanical bells, ending with the sirens - follows a generally ascending path. A very similar ascending sequence of industrial sounds occurs between 390s and 400s, in a similar position within Section 3. This latter sequence lacks the siren ascents, but begins with a jet-like sound anticipating the beginning of the final explosive ascent (which does have sirens). These fragments in Sections 1 and 3, together pre-empting every component of the piece's conclusion, confirm the importance of the final ascent as a model for other material in the piece.

Between 90s and 120s, the piece is much more stable, and with the return of previous material (and material similar to previous material), it seems to act as a second starting point for the ascents in Section 1. The low reverberative tones a perfect fifth apart around 110s may even remind the listener of the bell tones that began the piece. A shimmering ascent to past 120s is a gentle anticipation of the dynamic material that follows. Soon after 120s a mixture of short complex tones, noises and percussion sounds enter, soon to become an accompaniment to the meandering ascent of another siren-like tone. This is followed by a violent siren ascent, which falls away as Section 1 finishes.

We have seen that both the details and the general form of Section 1 can be understood as an elaboration of elements inherent in the first and last gesture of the piece. Relationships between Section 2a and the beginning of the piece are clearly heard and have been discussed already. The relationship between Section 2b and the explosive ascent is more obscure, as there are no dramatic siren ascents, and no other distinctive ascending gestures. In fact, rather than ascending, Section 2b descends in a noise-dominated cathartic climax to the lowest part of the audible range. This can be thought of as the inversion of, as an answer to, the ascending gesture that otherwise dominates; as well as a reference to the descending noise that accompanies the final ascent. Unlike the ascents elsewhere in the piece, the descent in Section 2b is protracted, perhaps beginning at 215s and ending at 335s. It takes the form of three steps separated by the two crashes after 250s and at 275s. Despite its length and the variety of noises involved, it is held together by a single continuous element: the male voice. This voice is very important because it is the first directly human sound in the piece, and it produces a profound transformation in the piece's character and meaning: here the piece touches the human body the most. In the Neuma recording the importance of the voice is recognised by centring it, while the material that accompanies it is sourced from the periphery of the stereophonic field.

The male voice initially meanders up and down, but follows a large scale descent that continues after 275s, where the slowed-down recording of the voice merges with low-pitched percussion. To Edward Downes, "something like a slowed-down human voice seemed to sigh: 'Oh, god …,' the pitch of the final vowel sinking gradually into the bottomless depths of a booming echo chamber."[207] It is in this descent that we have the strongest sense of the digestive metaphor expressed by Le Corbusier - the pavilion as a stomach, the audience surrounded by 'four hundred acoustical mouths'.[208] Indeed, the auditory image of the male voice as it descends (through tape manipulation) is of a voice and a mouth that is becoming enormous, or of a

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207 Edward Downes: **Rebel from Way Back**, *New York Times*, 16 November 1958, Section 2, p11.

208 Jean Petit: **Le Poème Electronique Le Corbusier**, p25.

transformation of vocal sounds into digestive sounds. If this imagery needs reinforcing, it receives it through the scranching sounds that accompany that section of the piece (these sounds are significantly more prominent on the Columbia recording than on the Neuma recording). The sounds in this section are loud and low, and can be described as having great volume and presence, receding to silence at the end. To the extent that it ever can be, the audience is 'digested' between 285s and 340s.

There is an overlap between the first and second parts of Section 2: the second part begins with the entry of the male voice at 215s, but elements from the first part punctuate it at 235s, and the entry of the male voice is accompanied by a resonant percussion instrument that is reminiscent of the bell. Other bell-like sounds can be heard elsewhere in Section 2b and to that extent, the bell is being transformed into a moving entity in the descent. Certain aspects of Section 2b encourage it to be thought of as an opening up or expansion of the decay inherent in the bell sound, in particular the two crashes (250s and 275s), which are followed by a gradual decay, through very low sound to silence. In the case of the tolling bell, this decaying process is heard as part of a stable entity (the bell, as a conceptual object, remains intact); in Section 2b, the decay is more extreme, on a much larger scale, and subdivided into smaller sound entities: here we listen to the process of decay rather than to any stable entity. Echoes of the three-note motive are also heard in this part of the piece: at 215s (as the male voice enters) and at 285s (after the second crash), again strategically positioned at the beginning of a general movement in pitch.

Section 3b has two basic ascending gestures, the first of which (390s - 400s) has already been discussed in relation to the explosive ascent and similar material in Section 1b. The soprano ascent that concludes Section 3 answers the descending male voice that dominated the latter part of the previous section. This 'song of liberation' does not swallow the listener, but ascends and recedes from the listener.[209] Regardless of the absolute pitches involved, the human voice makes this ascent sound as if it reaches higher than any of the other ascents (except, perhaps, the final one), and this is reinforced by the sense of recession created by a reduction in loudness right at the end, which can also be described as an even more marked reduction in auditory volume (in the sense of Chapter 5). In the Philips Pavilion this sense of ascension (or at least

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[209] Albert Jeanneret described the soprano as a 'song of liberation', quoted in Ouellette: **Edgard Varèse**, p202.

elevation) was also incarnated by the sculptured female figure that was suspended high in one of the pavilion's peaks, near its exit.

The three-note motive returns in Section 4b as a prelude to the final ascent, functioning in the same way as elsewhere in the piece. In Section 1 it became progressively more distant by becoming quieter and more reverberated. In Section 4 it approaches the listener again by being heavily reverberated first, and then dry. On the Neuma recording all but the last of the three-note motives in the piece are centred (including the pseudo-three-note motives in Section 2b), the last one being panned entirely to one side. Together with the sudden dryness of the sound, this gives it a distinctive sense of immediacy. The listener has the sense of a return that is both musical and spatial, of having been on a journey and arrived back to the start, or of observing as the music went on an elaborate journey in space, and returned to conclude its program. The way in which the three-note motive articulates the movement of the piece encourages the conception of two basic elements: the bell and associated material that precedes the first articulation of the three-note motive; and the explosive ascent that follows the final articulation of the three-note motive.

We have identified a number of structural features in the latter parts of the four sections. The material is complicated and often noisy, but there is a unifying sense of movement which is connected to the final gesture in the work. This movement takes place on many scales, from the miniature ascents of the three note figure to the extended descent in Section 2b. These parts of the piece have the same type of spatial ambiguities that we have linked with Varèse's experience of detachment in the discussion of the beginnings of the sections, but here such ambiguities do not dominate. In the initial parts of the sections, these ambiguities are emphasised through the refined juxtaposition of material, around the theme of ecclesiastical space. In the latter parts of the sections, there is such a proliferation of material that detachment in this sense is less important. However, Varèse's experience of sirens as an expression of sound space is clearly very important in Sections 1b, 2b, 3b, and 4b. Apart from movement of sound between speakers, a correspondence between movement in pitch and movement in sound space (whether imaginary or not) is the most important spatial aspect here. The form of the composition in these parts is essentially created through dynamism. Surroundedness at the low extreme and detachment at the high extreme accompany the ascents and descents: these ideas are developed much further in Chapter 5.

Beginning and Ending: Surroundedness and Detachment

Poème électronique begins with an amorphous surrounding space and ends with a dynamic mixture of surrounding and directional sonorous forms. Here there is a further correspondence with Varèse's vision of sound space in the Salle Pleyel. In both there is an impression of projection into the unbounded vastness of cosmic space. This is achieved through a simultaneous sense of infinite depth (through surroundedness) and of precisely defined directional structures - rays in the Salle Pleyel, sirens in *Poème électronique*. In the latter, the impression of projection into cosmic space also works on the level of representation: the sound is heard, in part, as that of a rocket or jet. In fact it is this noise that fills the space and envelops the listener while the sirens create another sense of projection into the sky.

Poème électronique's movement from simple surroundedness to this transcendent projective space may be taken as a metaphor for the experience of auditory spaciousness as it was discussed in Chapter 3. Auditory spaciousness presents space on at least two levels apart from physical or visual space. The listener has the general impression of envelopment, but a transcendent space can also present itself, where sounds appear to come from specific places unrelated to their physical source. The movement in *Poème électronique* from bell to explosion might thus be thought of as an illustration of this transcendent process.

In the discussion of hyperbolic paraboloids we were also concerned with the simultaneous perception of great depth and geometric space, and a type of transcendence. The geometry at the end of *Poème électronique* is of parabolæ and hyperbolæ (at least in conception), and its association with the hyperbolic paraboloids was probably intended (there are also striking coincidences, presumably unintentional, in the design of the Salle Pleyel's ceiling and the profile of the final siren ascents). Of course the architectural hyperbolic paraboloids were Xenakis', not Varèse's, but his choice of a curvilinear sound geometry together with immense auditory depth would appear to be an apt conclusion to the piece.

5
Sound Space

As we have found in preceding chapters, Varèse's notion of sound space was not a simple matter: based on a mixture of concrete experiences and metaphors, it encompassed several of these without defining any consistent overall model. Chapters 1 and 2 developed the metaphor and experience of parabolic and hyperbolic trajectories in sound space. Chapter 3 gave another instance of metaphor and perception interacting in Varèse's language, in the Salle Pleyel. The analysis in Chapter 4 was mainly concerned with two types of spatiality: a duality of represented and synthesised acoustic space; and the dynamic 'musical' space exemplified by the siren sounds. Varèse's image of music exploding in space was important in that chapter. While the spatiality of the siren has been accepted throughout the thesis, there has been no real attempt to explore why this analogy between music and space should work. This is part of the problem of Chapter 5.

Essentially the problem is of ambiguity. Martin Nass, who was cited in the last part of Chapter 3 for his comparison between auditory space and certain cognitive states, argues that ambiguity is a positive aspect of hearing. Nass:

> The cognitive quality of the hearing experience is of necessity a more ambiguous one since the symbols used can reflect varying nuances of meaning and are experienced through the auditory sphere, an area that in itself is more easily transformed into ambiguous experience than is the visual sphere. In fact, the auditory experience can facilitate the ambiguity by the very nature of its less precise definition. … Hearing is one sensory modality wherein ambiguous experiences may be tolerated and embellished through fantasy activity.[210]

The ambiguity that is our present concern stems from the fact that acoustic space and musical space are both heard through the ears. The ears interpret frequency, amplitude, temporal intervals, and various types of binaural difference, all of which may be indicators in musical and

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[210] Martin Nass: **A Psychoanalytic Interpretation of Music**, *Psychoanalytic Quarterly*, **40**, 1971, p308-309.

acoustic space (although binaural difference is less significant in musical space). In auditory space, the distinction between these two is a matter for hermeneutics, and the imaginative listener may choose to interpret both as equally valid in a hybrid space. Overall, such a space is more differentiated than the amorphous auditory space described by James and others: physical and musical dimensions combine to produce a multi-dimensional and multi-stable space.

This ambiguous or multi-stable sound space is reflected in much of Varèse's discussion of space in his compositions. This chapter demonstrates how frequency in particular has inherent spatial implications, not only in terms of position in space, but also in terms of the nature of space. Varèse's idea of a sound mass in his instrumental works, for instance, is a reflection of these implications. Similarly, the spatial sense of parabolæ and hyperbolæ in the sound of a siren is developed in the following pages.

We have also touched on the idea of an added dimension in other parts of the thesis. Added dimensionality comes through an attitude of inclusiveness, of not fragmenting auditory space into components such as musical space, 'real' acoustic space, and a third space of auditory 'illusions'. Auditory space is approached as a single phenomenon, containing multiple dimensions, spaces within spaces, and a sense of multi-stability. Here we may refer to Varèse, who possesses such an attitude when he states:

> We actually have three dimensions in music: horizontal, vertical, and dynamic swelling or decreasing. I shall add a fourth, sound projection - the feeling that sound is leaving us with no hope of being reflected back, a feeling akin to that aroused by beams of light sent forth by a powerful search light - for the ear as for the eye, that sense of projection, of a journey into space.[211]

Other writers have emphasised the metaphorical basis of the sense of projection: John Anderson has shown how Varèse probably adopted this imagery form A. S. Eddington's *The Nature of the Physical World*, a popular science book published originally in 1928;[212] and Jonathan Bernard has also shown a correspondence with the ideas of the artist Apollinaire.[213] In the third chapter of this thesis, this fourth dimension was related to the psycho-acoustic phenomenon of auditory

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211 Edgard Varèse: **The Liberation of Sound**, quoted in Schwartz & Childs (eds.): **Contemporary Composers on Contemporary Music**, p197.

212 John Anderson: **The Influence of Scientific Concepts on the Music and Thought of Edgard Varèse**, p115-117.

213 Jonathan Bernard: **The Music of Edgard Varèse**, p18.

spaciousness. Varèse's sense of musical space, which was structured or given expression according to the dimensions of notation, included a sense of auditory space, which had not conventionally been considered together with musical pitch, duration and loudness. A formal model of this space would be elusive because of the subtle, multi-dimensional and highly subjective nature of auditory spaciousness, while other components of the space are already highly formalised. Conventionally auditory spaciousness had provided a site for music, but had not been a defined part of the music.

However, in the context of electro-acoustic works that exploit movement in acoustic space a comparable hybrid space has been given a much more explicit and articulate expression. The cohesion of this space is not fully established: at times it is thought of as unified, but it is often more useful to think of two perceptual modes and two corresponding perceptual spaces in coexistence (however this would seem to be largely because of a logistical problem with multi-dimensional graphing, notation, recording and reproduction). Hence the discrepancy in the distribution of sound in space between the recordings and original installation of Varèse's *Poème électronique* is an acceptable compromise to the present day listener, perhaps comparable to the piano reductions of orchestral works in the Nineteenth Century. In such reductions, the pitches, durations and dynamics are seen as essential to the work, while the timbral and spatial aspects of orchestration are seen as attributes, like colours in Locke's ontology. One ostensible project of the high fidelity movement has been to broaden the range of elements essential to music - in sympathy with the æsthetic concerns of composers such as Varèse. The recordings of *Poème électronique* retain a sense of a dynamic spatiality that is limited by technological convention. Spatiality is seen to be important, if not essential to the music (*Poème électronique* was also released as a monophonic recording), but also reducible. In this there may be little difference to the compression of the dynamic range that is evident in the analogue recordings, or in fact to the general inevitable sense of loss associated with any reproduction of something that is not purely digital in its original form.[214] Thus we have a multi-dimensional conceptual space including musical and acoustic spatial attributes, although the relations between these dimensions in auditory space are still undeveloped.

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214 Walter Benjamin is one author who develops this idea of loss, in his essay **The Work of Art in the Age of Mechanical Reproduction**, included in **Illuminations**.

The following discussion is a review of material concerned with auditory space perception, allowing us to begin to map a hybrid perceptual space formed from a combination of musical (or more generally, abstract sound) and acoustic spaces. It is an exploration of the ambiguities of auditory space which make the characteristics of multi-stability and transcendence possible. These characteristics are also inherent in auditory space because of the inadequacy of a single model of space - even, for instance, to account for the perception of acoustic space in isolation. The discussion concentrates on the roles of frequency and pitch in acoustic and auditory space for the purposes of economy and unity.

Perception of Acoustic Space

Directionality

The listener can only be an interpreter: there is no absolute perceptual reality. The listener finds ways of understanding auditory space, and these might be expressed as models. The human body is the ground on which all perception stands, and such models are constructed as sound interacts with the body in a number of ways. In this section of the thesis we explore auditory perception through several models, drawing on those of physical acoustics as abstracted analogies of auditory experience. Such analogies are justified by their fruits, and are reflected in the thought of Varèse, who frequently emphasised the importance of physical acoustics in music. The gap between auditory space and physical acoustics is bridged by psychological acoustics.

In the first section of this thesis the structure of subjective visual space was reviewed, along with associated problems of perspective. Clearly auditory space, similarly, is not structured according to Euclidean geometry, but is based on polar coordinates, originating at the centre of hearing or at the two ears. The omnidirectional nature of hearing means that it is all the more futile to conceive of oneself as an alienated observer of a space; sound space is all around the hearer, and the hearer naturally finds herself/himself at the centre of space. Even this is an excessively simplistic reduction because of the complexity of the factors that give us a sense of auditory depth and direction. In the visual domain there is nothing directly analogous to the auditory sense of inside-the-head locatedness. In the auditory domain we hear sounds that are sourced in our body, transmitted through our body (especially through bones and the eustachian tubes), and sounds that are heard to be sourced within (because of physical interference with the pinnæ, impossible binaural effects, or internal resonances). The complexity of the external acoustic environment -

with its resonances, refractions, diffractions, reflections, penetrations, constructive and destructive interference, and variation in the speed of sound - far exceeds that of the optical environment. While, in James' sense, auditory space is a very fundamental expression of spatiality, in a more definite appreciation of space, sound is usually relegated to the role of an accompaniment in a visually and tactually defined space (consider Locke or Descartes). Quite apart from ontic questions (and the comparative status of object and event), this relegation is related to the complexity of both acoustic and auditory space, the comparative sparseness of the auditory field in many situations, and to the imprecision of auditory perception relative to visual and objective space.

In respect to the latter of these, it is evident that the advantage of omnidirectional perception that hearing gives us is mitigated by the large minimum audible angle, which varies enormously with the position of the sound source relative to the head.[215] Most sensitivity is for lateral differences in front of the head, where the minimum audible angle might be as small as 1°. So-called 'hyperboloids' or 'cones of confusion' extend away from each ear, on the surfaces of which little directional discrimination is possible. Narrow hyperboloids of confusion enclose an area around the aural axis, within which any directional discrimination is scarcely possible (but where our sensitivity to amplitude is greatest, especially at high frequencies). Wider hyperboloids of confusion (the widest being the median sagittal plane) map surfaces on which the ear is very insensitive to directional difference, except at high frequencies.

The accuracy of directional discrimination is heavily dependent on frequency or frequency spectrum. At high frequencies the pinnæ provide a means for front-back discrimination. Interaural level differences are a cue for directional discrimination on the horizontal plane at frequencies above 3KHz, while phase differences are a cue below 1KHz. Interaural time differences primarily relate to attack transients, and thus to high frequencies. Directional sense is vague for pure tones between these frequencies.

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215 Much of this part of the thesis is concerned with well established psycho-acoustic and acoustic observations. The reader may wish to consult standard texts on psycho-acoustics such as von Békésy: **Experiments in Hearing**; Blauert: **Spatial Hearing**; Buser & Imbert: **Audition**; Bregman: **Auditory Scene Analysis**; Gelfand: **Hearing**; Handel: **Listening**; McAdams & Bigand: **Thinking in Sound**; Moore: **Psychology of Hearing**; Schubert: **Psychological Acoustics**; Tobias: **Foundations of Modern Auditory Theory**; or Yost & Neilsen: **Fundamentals of Hearing**.

These standard data on auditory perception are measured under experimental conditions in the neutral environment of an isolated anechoic room. In the complex environment outside the anechoic room our directional perception is dependent on the varying characteristics of sound propagation.[216] The general directional characteristics of sound in the environment have an enormous impact on the way in which we conceive of sound space; in particular, we find a mixing of two basic conceptions of propagation which might be contained in the terms ray and wave. Here there is an obvious analogy with optics. However a quick comparison of the range of optical and acoustic phenomena (in the range of human perception) shows fundamental differences, and makes apparent some of the scope and limitations of both optical and visual analogies of sound. Unlike many other areas of science, the basic conceptualisation of acoustics has not suffered major revolutions since being formalised by ancient Greek philosophers, who established the theory of sound as a wave.[217] By comparison, the wave model of light is recent (initially from Huygens). This contrast reflects the more intuitive association between wave motion (with its fluidic connotations) and sound. The range of the visual spectrum is comparatively small - the highest frequency (corresponding to violet light) is less than double the lowest frequency (red light) - nearly an octave by analogy. The wavelengths of light waves are extremely small (between $7x10^{-7}$m and $4x10^{-7}$m) and frequencies extremely fast (between $4x10^{14}$Hz and $7.5x10^{14}$Hz) , so small and fast that we are normally blind to or unconscious of wave-like properties. In any case our sense of colour does not give us the impression of a linear gradation from high to low frequencies, but more of a cycle of colours: red and violet are closer than many other pairs of colours corresponding more closely in frequency. We see in a medium which is for most purposes instantaneous, with infinitesimal grain and relative consistency: wave theory is a remote abstraction. On the other hand the highest sound may be one thousand times the frequency of the lowest, and one thousandth its wavelength. With frequencies ranging from the threshold of

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216 The acoustic material presented here is well established. The reader may wish to consult standard texts on acoustics such as Barron: **Auditorium Acoustics and Architectural Design**; Beranek: **Music, Acoustics and Architecture**; Cowling & FFowcs Williams: **Sound and Sources of Sound**; Forsyth: **Buildings for Music**; Hall: **Basic Acoustics**; Johnston: **Measured Tones**; Lindsay: **Physical Acoustics**; Lindsay: **Acoustics**; Meyer & Neumann: **Physical and Applied Acoustics**; or Stephens & Bate: **Acoustics and Vibrational Physics**.

217 Aristotle, in *De Audibilus* and *De Anima*, describes sound in a way that resembles wave theory. The relevant extracts are presented in Lindsay's anthology, **Acoustics: Historical and Philosophical Development**, p21-24.

rhythm to unimaginably rapid oscillations, we hear a marked change in character from one octave to another (the auditory range is conventionally given as 20Hz - 20 000Hz). A cycle of pitch is repeated up to ten times over the auditory spectrum, which as a whole is experienced as stretching between high and low. Wavelengths range between perhaps 17 metres and 1.7 centimetres, giant at one end of the scale, miniature at the other.

While the precise significance of these comparisons is only made clear by a detailed study of the psychology of perception, we have a general sense of relative consistency in visual perception, and of great difference in auditory perception; accompanied by a sense that the body lives in the world of sound, but is on quite a different scale to light. The wide scale of sound is reflected in the variety of acoustic models that may be applied to describe the behaviour of audible sound: sound may be a wave, a field, a ray, and an alternating current. The field model, and especially the ray model, are by far the most practical ones in optics, particles and waves being remote from experience. Each of these models of sound propagation represents a conceptual mode of listening that is not unrelated to listening in a more immediate sense. We can use these models to expand upon relations between auditory experience and the listener's sense of spatiality.

It is interesting to briefly note a further significant acoustic model: the particle model. Historically, light has tended to be modelled as particles called corpuscles and now photons; only recently has it become appropriate to describe sound as particles, called phonons by analogy. At the highest frequencies of acoustic vibration it becomes physically impossible to detect the wave properties, but detection and measurement of energy is still possible.[218] These 'sounds' are explored experimentally in crystal lattices, having the most tenuous relationship to sound in human hearing; here we are concerned with frequencies above 100GHz. Modelled upon the photon, the phonon has an equivalent set of mathematical quantum relationships. There is a close relationship between the random vibrations, by which heat is modelled, and the ordered vibrations, which we call sound: the thermal oscillations of a crystal lattice can be described as a phonon 'gas', modelled on the same principles as the kinetic theory of gasses (as temperature increases, the lattice vibrations increase, so the gas pressure increases in the crystal). A phonon source, which is simply hotter than the general phonon gas, produces a broad spectrum of sound

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218 E. Meyer & E.-G. Neumann: **Physical and Applied Acoustics**, p365. See also J. A. Reissland: **The Physics of Phonons**, and G. P. Srivastava: **The Physics of Phonons**.

particles without phase coherence, in a manner analogous to most visible light sources. A stream of these particles can scatter other particles such as photons.

The brief outline above is sufficient for our purposes, illustrating, starkly as it does, an extraordinarily remote way of theorising about sound. It raises questions about the nature of reality in physical theory: the phonon is just as real as any other particle in quantum physics, which is shown by the ways in which it interacts with other particles. On the human scale there seems to be little correspondence between audible sound and notions of particle, excepting instances such as structuralist linguistics, where sound is digitised in distinctive feature theory; and corresponding approaches in music theory: however these exceptions are not physical theories, but information theories.

Ray geometry is a simple and intuitive model of sound propagation, adopted from optical geometry. This model is only thoroughly applicable when wavelengths are much smaller than the scale of the physical elements in the inquiry, and therefore tends to be more useful in describing the behaviour of high than low frequency sound. Rays travel in straight paths unless reflected, absorbed or refracted by a change in the medium.[219] The closeness of the analogy between optical and acoustic geometry is evident from the technologies that they share: reflectors (including the parabolic ceiling of the Salle Pleyel) and lenses may function in both media.[220] The Salle Pleyel's architect, Gustave Lyon, had a conception of sound based entirely on the ray model, and it is apparent that, in its formal simplicity, the model had an attraction to the Modernist movement. It is not coincidental that the actual acoustics of the Salle Pleyel reflected the hall's theoretical basis, favouring high sound; as well as complementing the contemporary modern music with its movement from massed string sources to much more localised wind and percussion sources, and from deep tonal resonances to precisely articulated percussive attacks. In this way it is interesting that this hall should have provoked the image of a ray in Varèse's mind.

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219 Refraction of sound may seem to be remote from our experience, but it does occur in wind and temperature gradients, when we may be surprised at how well or badly sound travels.

220 An acoustic lens, like an optical lens, requires a medium that changes the velocity of the wave. See Winston Kock & F. K. Harvey: **Refracting Sound Waves**, *Journal of the Acoustical Society of America*, **21** (5), September 1949, p471-481, and Winston Kock: **Seeing Sound**. In nature analogies between echo and visual reflection, or between the acoustic effect of a temperature inversion and a mirage can easily be made. Many of Kircher's acoustic fantasies in **Musurgia Universalis** are an application of a visual ray model of sound propagation.

The field model of sound propagation was favoured by Sabine in his analysis of auditorium reverberation, which had more application to Romantic notions of performance. This model is a loose adaptation of electrical, magnetic and gravitational field models. Here one is not concerned with the path of a sound ray, but with the total energy produced by a multitude of rays or waves. The idea of acoustic fields fits well with the surrounding auditory space that was discussed in an earlier section, except that reverberation is less of a contributor to auditory spaciousness than early lateral reflections (which can be modelled in distinct rays). Nevertheless, the auditory impression of spaciousness is of a field - the early reflections are not recognised as discrete sounds. Hence the field model has been appropriated by writers such as Ihde and Zuckerkandl in their descriptions of phenomenal surrounding space.

Because of the extensive applicability of electrical engineering, it is convenient to use an electrical analogy in describing the behaviour of sound in some contexts. This analogy is thorough, with acoustic equivalents to electrical resistors, capacitors, inductors and transformers, but is limited (or made more complex) by the scale of the components relative to the wavelengths of sound. A primary application of this analogy is in sound-carrying pipes and ducts, in which chambers, constrictions and absorptive (resistive) material may be designed to act as acoustic filters. The analogy is also applied to the design of speaker enclosures, in which acoustic circuits are tuned to complement the mechanical and electrical circuits of the speaker system. The analogy has more general application, for instance, where sound moves between media or from a bounded to an unbounded space, acoustic impedance is used to model the proportion of sound reflected and transmitted. As dynamic theory predated electrical theory, dynamic circuits were used initially as a way of modelling and conceptualising their more abstract electrical analogues. Now that electrical engineering is highly developed and well understood, the analogy is more often used the other way.[221] In 1959, the electro-acoustic analogy was extended with the invention of no-moving-part fluidic amplifiers and switches.[222] Fluidic components exploit various characteristics of fluid motion such as the tendency for a stream to attach itself to a surface, the deflection of one jet by another, and the formation of vortices and turbulence. Various arrangements of digital gates or proportional amplifiers may be thus constructed, and small scale fluidic digital computers and

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221 R. W. B. Stephens & A. E. Bate: **Acoustics and Vibrational Physics**, p412.

222 Eugene Humphrey & David Tarumoto: **Fluidics**, p3-7.

continuous controllers have been constructed, having applications where electronic circuitry would be dangerous or unreliable. The electrical analogy, especially when incorporating fluidics, is ultimately a model of information transfer.

Having outlined a variety of higher acoustic models, we return to the wave model, which is the most fundamental of them; the other models (with the possible exception of the phonon model) can be seen as abbreviated methodologies for modelling what would otherwise be impossibly or unnecessarily complex wave behaviour. The wave model becomes important in its own right when the scale of elements in the environment undermine a higher level model. When the wavelengths of sound are comparable to or larger than an object, aperture or observer, wave behaviour such as diffraction, interference and scattering may be observed, leading to a much more ‘fluid’ conception of the behaviour of sound in space than ray geometry gives. Here there are parallels between sound and low frequency electromagnetic radiation such as radio waves. They share technologies such as the horn and the Yagi antenna, and lenses made from arrays of discrete metal elements may function equally for sound and microwaves. (The refraction of radio waves from the ionosphere is also paralleled by the refraction of low frequency sound from the ozone layer or smaller scale temperature inversions). Because of its relation to wavelength, this fluid wave-space is most important to us at the lower frequencies of sound, and may be irrelevant at the highest frequencies.

Resonance is perhaps the most immediate manifestation of sound’s wave characteristics, giving us a sense of sound space with no direct analogy in optics. We perceive relationships between the sound pitch of a thing and its size, shape, hardness and mass; we have a sense of the substance of things and of the power of enclosure. We can begin to conceive of a sound-wave-world which is marked by changes in acoustic impedance (causing reflection and then resonance) and absorptive characteristics (preventing reflection and causing dampening). This world does not map directly onto the space of visible objects: common boundaries have different characteristics and many boundaries are not shared. If resonance gives a sense of acoustic body many ‘empty’ spaces in a visual model are perceived to be sounding bodies in themselves. The change of acoustic impedance at the mouth of a pipe forms a partially reflective barrier, causing resonance, and giving a sense of the enclosed volume as a sounding body.

Each of these models engages with discrete and continuous forms in distinctive ways. In the particle model sound is material and atomic; in the ray model sound is linear, projective and geometric. The field model engages with a continuous space in a way that in some instances is constructed from a summation of ray or wave models, and in others avoids explanatory sub-models, simply reporting on the variation of frequency spectrum and sound pressure in a space. The electro-acoustic analogy allows us to think of sound on two levels: in terms of the microscopic design of acoustic elements and the macroscopic interaction of discrete elements, through which sound travels as a current, providing a highly controlled communication medium. On a macroscopic scale the wave model is concerned largely with continuities, but when we model the microscopic basis for wave motion, we return to the atomic kinetic theory of gasses.

On a more practical level, our quick survey of acoustic models has emphasised the importance of physical scale in differentiating a directional ray space from an enveloping and perhaps resonating space. This is not intended as an attempt to assign a definitive scale from high to low in relation to directionality and surroundability; if listening is influenced by the acoustic environment, the general perceptual environment, psychological states and hermeneutic preconceptions, such a scale is beyond imagination. In some contexts low sounds are heard to be quite directional - sensitivity to direction through interaural phase difference is quite effective. In other contexts - in fact in the more common contexts for listening to low sounds - the low sounds are reinforced through resonance in the listening space, and as the sound is not directional, any sense of directionality is the product of psycho-acoustic illusion.

We have found in the acoustic models a tendency towards simple geometric and even digital conceptualisations of sound in its high range, and towards more elusive and fluid conceptualisations in its low range. These have some correspondence to our intuitive conception of sound.[223] At the high extreme we have an image of a space of rays, well defined boundaries, and simple laws of interaction. The intuitive language applied to high sound matches the metaphors of physical acoustics: a high space where sharply defined forms are clear. Its directional characteristics are perceived through intensity differences. It is a space well suited to a geometric appreciation. The phonon model represents the ultimate reduction of sound to simple

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223 See, for instance, the work of Alf Gabrielsson on the subjective terminology in describing speaker frequency response.

and discrete forms. At the low extreme we can scarcely escape images of immersion in a fluid substance. The sound moves our body as the ocean might. We can find zones of loudness and quietness, but they do not reflect geometric patterns, caused as they are by diffraction and interference.

Thus an auditory space that reflects these properties of sound has a proclivity towards diversity - much more so than visual space, which is comparatively consistent. This is one compelling factor that brings multi-stability to auditory space. Like Xenakis' account of the Philips Pavilion's curves, auditory space is simultaneously geometric and immediate.

Depth Perception

Auditory depth perception has proven to be a difficult area to model because of the many factors involved, and because of its demonstrated inaccuracy in comparison to visual depth perception. It is self evident that with increasing depth, loudness decreases; this is related to the dispersal of sound energy, which in a free field expresses an inverse function between distance and sound pressure level. As loudness correlates roughly with sound pressure level, in a sense this is analogous to the diminution of visual objects with distance, where a similar hyperbolic function is expressed. However a given loudness alone gives us no indication of whether an object is, in an absolute sense, loud and distant or quiet and close; although both familiarity with the object and a movement away from or towards the object allow the observer to begin to make this judgement. To further confuse matters, the rate of sound dispersal varies from source to source, depending on their directionality: sound from an omnidirectional source disperses much more quickly than that from a highly directional one (such as high frequency sound from a sufficiently large parabolic reflector). Here the analogy with visual perception does not apply as we are perceiving loudness (which may be analogous to total brightness) rather than apparent (perspectival) size. Accurate auditory depth perception based on loudness, familiarity and movement alone may be impossible in the case of a highly directional sound source, let alone a focussing sound source.

In reality such limitations are not put on our perceptual processes, and the perception of auditory depth is aided by other auditory factors, as well as by other senses. Binaural difference (in time, phase and intensity) and frequency spectrum characteristics also provide aural cues to depth perception. The former of these relates mainly to the near field, as it is only there that the normal binaural differences due to the direction of the sound source are changed by the acoustic obstruction of the head. Pinnæ effects and binaural spectrum differences may also have some import on depth perception in the near field. In specific environments particular reflection patterns and reverberation may give a sense of depth.

The role of frequency spectrum in depth perception was for a long time a source of confusion: some authors observed that a relative reduction in high frequencies indicated increased depth, while others observed the same effect for a relative reduction in low frequencies.[224] Both of these observations have been shown to be correct, and they have been brought together in a more comprehensive model by distinguishing the processes by which the spectrum changes occur. The attenuation of high frequencies over distance in a free acoustic field is caused by the absorptive properties of air, the extent of which are heavily dependent on absolute humidity (or relative humidity and temperature). Low frequencies are absorbed much more slowly, and in the case of loud explosions, may be audible over very extended distances. The effect of the absorption of high frequencies by the air may be audible over a distance of several metres, and becomes noticeable over longer distances.

The attenuation of low frequencies with distance has been attributed to two things. Von Békésy has noted the effect in his experiments, and has explained it through an analysis of particle velocity in a spherical sound field.[225] His analysis shows that with a smaller sphere - or a closer position - the low frequency content increases. However his analysis has been the subject of some debate, a debate which this text need not enter. The phenomenon is also at least partly attributable to the frequency characteristics of the ear, which is relatively insensitive to low amplitude low frequency sound, but as the amplitude increases, the sensitivity increases at a greater rate than for higher frequencies. This means that as a sounding object recedes into the distance and thus becomes quieter, the low frequencies will become inaudible more quickly than higher frequencies.

As these two tendencies for high frequency and low frequency attenuation with distance rely on different processes, they speak in different ways. High frequency attenuation begins at a distance of several metres and extends as far as the audible field, whereas low frequency

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224 See Paul Coleman: **An Analysis of Cues to Auditory Depth Perception in Free Space**, *Psychological Bulletin*, **60** (3), 1963, p302-315; and Jens Blauert: **Spatial Hearing**, p116-131.

225 Von Békésy: **Experiments in Hearing**, p301-313.

attenuation occurs noticeably within the near field. Coleman relates high frequency attenuation to the far field, low frequency attenuation to the near field.[226] However in the complex listening environment the various spectral components may respond in differing ways: in a resonant space, the low frequencies will be much more apparent than in a free field; and when minor acoustic barriers or partial absorbers are between the listener and source, the high frequency component will be prematurely attenuated. It would make sense for us to extend Ihde's description of the sound field by dividing it into three general components: the high, the low, and the medium fields.

These distinctions give us a slightly more complicated notion of auditory depth because of the differing ways that sound in the three frequency ranges interacts with or expresses the environment. We have already made the distinction between a vectorial notion of space, which was associated with high sound; and a fluidic notion of space which was associated with low sound. We can also identify an intermediate or mid-range sound space, which remains when the high and low are lost. Mid-range sound propagation is neither dominated by ray geometry or by diffraction and interference, and is less prone to omnidirectional dispersion than low sound, or to absorption by the atmosphere than high sound. At low sound pressure levels, the ear is most sensitive to sound in the middle of its frequency range. In many contexts, it is the mid-range sound that is heard furthest from the source. At close range, thunder covers the entire frequency range; further away the high frequencies are greatly attenuated while the bass still rumbles through the listener's body, dominating in audition; but at a great distance, both high and low frequency components are absent (in audition) and the thunder is a dull roll.[227] Similarly, at close range, a person's voice is characterised by its depth in the breathy and voiced sounds, and by the prominence of sibilances in fricative, plosive and affricative phonemes and in the little sounds of saliva. At distance the extremes of the range are attenuated (although not necessarily at the one rate), and the voice is characterised mainly by the mid range. The environment can influence and alter this pattern: listening to a speaking person through a wall or around a corner emphasises the bass; while listening directly to someone speaking through a horn in the open air emphasises the mid to upper part of the sound spectrum.

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226 Paul Coleman: **An Analysis of Cues to Auditory Depth Perception in Free Space**, *Psychological Bulletin*, **60** (3), 1963, p302-315.

227 The frequency sweep from high to low that characterises thunder at an intermediate distance has to do with the attenuation of high frequencies as the sound refracts and reflects in the atmosphere.

The intermediate sound tends to have more symbolic functions: communication, digital encryption, and reductive analog transformations (consider the frequency range of cheap telecommunication systems such as the telephone). It is this sound that tends to travel furthest relative to the limits of audition. The project of high fidelity was, in part, overthrowing the dominance of the mid-range over the extremes, bringing sound from the distance into the listener's presence. Varèse, too, was keen to extend the sound of his compositions to the extremes of pitch.

The difference between high, medium and low frequency sound can be expressed in terms of surface and body. High sounds are associated mainly with small sound sources and percussive onset transients. In the latter case they are heard as representing the collision between two surfaces (what Ihde terms the duet) because they die away quickly after the impact, while lower sounds may continue to resonate. Because the lower sounds sustain longest, especially when listening at close proximity, they are heard as the sound of the thing more than the sound of the event; the sound of the interior more than that of the surface. The increase in low sound that occurs as one moves very close to a resonating object gives the sense that one is listening, more than before, to the fundamental sound inside the object. Water gives us the same sense (although partly for other reasons) of an association between surface and high sound, body and low sound. Submerged in a body of water, the frequency spectrum is markedly biased towards the bass, and the listener's body feels like it is almost part of the water - he/she is inside. Above the surface the bass may still be very strong in rough water, but the ears also find the highest sounds with a multitude of little splashes. A frequency spectrum dominated by mid-range sound may be taken as neither surface or body, but as hearing indirectly or at a distance.

Thus we can conceive of an involved notion of auditory depth that through loudness and frequency spectrum gives a sense of a sounding body's position in the specific environment of the listener, who is conscious of that environment through all their perceptual, memory, imaginative and deductive processes. There is a certain sense of immediacy and intimacy when the sound is loud and both extremes of the frequency spectrum are strong, and immediacy leaves with the high sound, intimacy with the low. An overall diminution in loudness and in the relative loudness of both the extremes gives a sense of separation. Research such as that by Gabrielsson, where a multi-dimensional vocabulary for sound quality is developed, would seem to suggest that these very broad generalisations might be further refined. However as we have been dealing with a vague notion of high and low - which in the general contexts is fairly constant, but with respect to particular sounding bodies may be subject to transposition - the definition of a psycho-acoustic vocabulary to describe the spatial significance of parts of a many-segmented spectrum would be difficult and involved.

Perception of Musical Space

Pitch Space

The analogy between the pitch spectrum and vertical space is perpetuated so strongly and blatantly by music notation and associated language that it is extremely difficult to separate analogy from phenomenon. A consequent debate about the nature of pitch space can be traced through the literature, some authors arguing that the assignment of 'high' or 'low' to a pitch is an arbitrary convention, others that it reflects on a common experience of pitch. The nature and extent of such an experience has also been a subject of debate. It has been pointed out that in some cultures the assignment of pitch on a vertical scale is reversed: a 'high' pitch is one produced by a tall (or high) pipe or string; in other words, a low frequency.[228] More trivially, in ridiculing any intrinsic association between pitch and verticality, Berlioz long ago reminded his readers that the piano keyboard is a horizontal scale, and that the cellist must descend the fingerboard to play so-called high notes.[229] Yet these and other inconsistencies are very minor in comparison to the overwhelming tendency in Western musical culture to describe high frequencies in metaphors of elevation, and low frequencies in metaphors of depth. Both of these inconsistencies arise in part from differences between tablature and notation: the question of whether one conceives of music in terms of an instrument's physical interface with the player or in terms of an abstract universal theory of sound that is loosely related to psycho-acoustic experience.

There is no doubt that when Varèse heard hyperbolæ and parabolæ as he experimented with sirens, he was applying the formal analogy suggested by musical notation, which has been taken

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[228] Edward Lippman: **Music and Space: A Study in the Philosophy of Music**, p146-147 and Victor Zuckerkandl: **Sound and Symbol: Music and the External World**, p156. These authors cite Semitic and ancient Greek music.

[229] Cited in Carroll Pratt: **The Spatial Character of High and Low Tones**, *Journal of Experimental Psychology*, **13**, 1930, p279.

to a logical conclusion by certain types of spectrographic notation. His working sketches of similar curves for the *Poème électronique* confirm this interpretation: a parabola seems to be expressed as a function of pitch (log frequency) and objective time [Figure 52].[230] In his recollections about the sirens, he makes a connection between them and the general sense of spatiality in all of his pre-electronic works, which he calls, "only a *trompe l'oreille*, an aural illusion, so to speak, and not yet literally true."[231]

Many physical explanations have been offered for this very pervasive spatial metaphor. The feeling of low sounds resonating in the chest and high sounds in the head (in the roof of the mouth and the nose) when one is singing is an immediate parallel. Similarly, the rumble of low sound is often carried by and felt through the feet on the ground or floor. Intense low sound is felt through sympathetic vibrations in the entire body, whereas intense high sound is often felt as it distorts in the ear or as the delicate tissues in the head vibrate in sympathy. High sound, with its short wavelengths, is easily obstructed by obstacles, and hence tends to travel better when further from the ground - where there are less obstacles (hence the relative positioning of woofers and tweeters on the face of a speaker cabinet). In any case, little things, which tend to have high pitched sounds, are generally found higher in space than big things (the bird in the air and the whale in the sea). One might speculate that there may also be a loose relationship between the vertical scale of pitch and the way in which the pinnæ filter sound according to the physical elevation of the source with respect to the listener.[232]

Psycho-acoustic theory suggests that Varèse was, as he states, experiencing an aural illusion rather than only interpreting the sound of the siren in terms of a preconceived analogy. Pratt's experiment, published in 1930, presented listeners with an arbitrary succession of tones (at five pitches in octave relationships: 4096Hz, 2048Hz, 1024Hz, 512Hz and 256Hz) from arbitrary positions on a vertical scale, and compared the physical and perceived locations of the sound. In every observer, the apparent position of the tones was higher with higher frequency and lower

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230 Varèse's curves are similar to those in the spectrogram in the Appendix.

231 Edgard Varèse: **Spatial Music**, 1959, in Schwartz & Childs (eds.): **Contemporary Composers on Contemporary Music**, p205.

232 Robert A. Butler & Krystyna Belendiuk: **Spectral Cues Utilised in the Localization of Sound in the Median Sagittal Plane**, *Journal of the Acoustical Society of America*, **61** (5), May 1977, p1264-1269. This paper describes a notch in the filtration of the pinnæ which moves down to lower frequencies with lower elevation.

with lower frequency.[233] These results were contradicted by those of an experiment by Dimmick and Gaylord in 1934, where no correlation was made between pitch and position on the vertical scale.[234] The subjects in that experiment reported no more than confusion, arriving at their answers by guesswork. Nevertheless another experiment in that year by Otis Trimble concurred with Pratt's results, but Trimble speculated that they may have been caused more by differences in timbre than in frequency - he did not use pure tones, and the low tones were harmonically more complex than the high ones.[235] A thorough reinvestigation of these results was conducted by Roffler and Buttler in 1967, confirming Pratt's results and showing that the phenomenon was not caused by linguistic associations between pitch and height, nor was it caused by visual cues (although they did have an influence on the magnitude of the phenomenon), and presumably the tones were pure because of the higher standard of technical equipment at that time.[236] Roffler and Buttler were able to show that height might be either related to gravitational verticality or to height defined by body orientation when the two did not coincide. Whilst not ruling out the possibility that the correlation might be based on subtle associative cues that their experiments could not eliminate, they saw fit to lend support to Pratt's conclusion that, "… prior to any associative addition there exists in every tone an intrinsic spatial character which leads directly to the recognition of differences in height and depth along the pitch-continuum." Pratt also suggests the following application of this phenomenon to music:

> We usually think of movement as the change in spatial location of an object which during the change is recognised as the same object or quality. But in musical movement it appeared as though the qualities changed while the spatial location was constant. From the present results, however, one would have to argue that musical movement resembles any other kind of movement to the extent that when different pitches are presented successively they change their spatial location with respect to one another.[237]

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[233] Carroll Pratt: **The Spatial Character of High and Low Tones**, *Journal of Experimental Psychology*, **13**, 1930, p278-285.

[234] F. L. Dimmick & E. Gaylord: **The Dependence of Auditory Localization upon Pitch**, *Journal of Experimental Psychology*, **17**, 1934, p593-599.

[235] Otis Trimble: **Localization of Sound in "Auditory" Space**, *British Journal of Psychology*, **24**, 1934, p320-334. Pratt's results also had incidental support in the results of S. S. Stevens in an experiment on auditory volume with a congenitally blind subject conducted in 1934. Stevens: **Are Tones Spatial?**, *American Journal of Psychology*, **46**, p145.

[236] Suzanne K. Roffler & Robert A. Butler: **Location of Tonal Stimuli in the Vertical Plane**, *Journal of the Acoustical Society of America*, **43** (6), 1968, p1260-1266.

[237] Carroll Pratt: **The Spatial Character of High and Low Tones**, *Journal of Experimental Psychology*, **13**, 1930, p284-285.

In this statement, we can see the beginnings of a concept of spatial music like that of Varèse: where sound masses move up and down metaphorically and perceptually, where hyperbolic and parabolic trajectories can be drawn in sound and space together. This sense of position in space is by no means as strong as for normal auditory localisation in the horizontal plane; the trend in the experiments occurred in the context of a fair degree of uncertainty on the part of the subjects. However it is not unreasonable to conclude that a listener who is sensitive to auditory space would experience this movement to some extent, and may choose to foster their sensitivity to it.[238]

The question of the spatial character of high and low tones is discussed in detail by Lippman in his 1952 doctoral dissertation, and while he was aware of the experiments of Pratt and of Dimmick and Gaylord, he was not aware of Trimble's work, nor of the work that was to be done in 1967.[239] Hence Lippman's discussion places greater weight on the negative results of Dimmick and Gaylord, but then explores linguistic and other relationships between pitch and the terms 'high' and 'low'. He concludes:

> The application of the terms *high* and *low* to tonal experience, then, can be explained partly by the existence of an attribute of tones which has come to be called "highness" (*Tonhöhe*), but the peculiar suitability of these terms to pitch - which we do not feel is the case for loudness, for example - is evidently due to the host of extrinsic factors associated with pitch. But it is due also to a remarkable resemblance of the pitch series to space. This resemblance has the same status as the qualitative change we experience as a result of tones of increasing frequency in that both of these are intrinsic properties of music; but a resemblance to space, like the qualitative change, does not in itself give highness and lowness.[240]

To Lippman, pitch is inherently spatial, but the verticality of the pitch scale is not intrinsic, it is a Western interpretation of that spatiality. In other cultures that relationship is not made, or else is reversed (as in ancient Greek and Semitic culture, where height is associated with the height of a pipe or a string and notes are labelled in descending order).[241] This view is not necessarily in conflict with the experimental results referred to above, as it reflects differing attitudes to what is important in music. In Western culture - especially in certain aspects of Modernism - pure auditory experience is emphasised, whereas in other cultures the emphasis may be on singing, dancing,

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238 This would also be the case for the more complex apparent movement of tones reported by Blauert, where a tone of varying frequency is heard to move around and over the head. **Spatial Hearing**, p107-116.

239 Edward Lippman: **Music and Space: A Study in the Philosophy of Music**, p45, 135-156.

240 Edward Lippman: **Music and Space: A Study in the Philosophy of Music**, p156.

241 See also Zuckerkandl: **Sound and Symbol: Music and the External World**, p361-362.

or on symbolic systems represented in part by the physical form of the instruments.[242] To Varèse, pure auditory experience was paramount.

Zuckerkandl's *Sound and Symbol* has many parallels with Lippman's text, although it is based more on philosophical than on psychological literature. It has an involved discussion of this issue, initially refuting the notion that pitch has any but a metaphorical relationship to high and low in space - after all one might equally adopt the terms 'light' and 'dark'. In the latter part of his analysis his argument is all but reversed.[243] High tones are not heard as coming from above, nor low tones from below; they come from the same place, from all around the listener (he is discussing musical listening, and seems to concur with Ihde about the two modes of listening). Nevertheless Zuckerkandl argues that high tones have the quality of 'above', low tones have the quality of 'below'; and that, similarly, light belongs in the heavens, darkness in the depths. Thus movement in pitch in a piece of music is both formally and qualitatively analogous to spatial movement.

We should not leave this discussion without a brief mention of more complex relationships between pitch and space that have been documented by Blauert and others.[244] Blauert has observed that a sound of increasing or decreasing pitch, presented from anywhere on the median sagittal plane, appears to follow a path around, above and through the head, its position determined by its pitch. In Varèse's siren experiments, he was not listening to the tone bursts that were the basis for Pratt and his successors' experiments, but to continuously varying tones. It is probable that Varèse's spatial experience was more involved than ascending and descending motion, although his ability to interpret the experience was limited by his concept of pitch.

Loudness and Volume

Although we might associate the siren principally with continuous pitch modulation, the modulation applies equally to loudness. The mechanical siren is traditionally constructed with two discs, one rotating and one fixed, both with regularly spaced holes in a circle around the axis of rotation.[245] The two discs are flat against each other, and as one rotates, the holes of the two

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[242] Edward Lippman supports this view, Lippman: **Music and Space: A Study in the Philosophy of Music**, p146-147.

[243] Victor Zuckerkandl: **Sound and Symbol: Music and the External World**, p349-362.

[244] Jens Blauert: **Spatial Hearing**, p45, 107-116.

[245] Such sirens are described and illustrated in Helmholtz's **On the Sensations of Tone**, which was

discs alternately coincide and mismatch, opening and closing holes through the combined discs. This allows regular puffs of air from a pressurised chamber behind the discs to escape, and the faster the rotating disc moves, the higher the frequency of the sound produced by these puffs. The chamber is pressurised by a fan rotating at a fixed gear ratio to the handle of the siren. With both the rotating disc and fan connected to the handle, their speed of rotation is proportional, meaning that a low tone will always be quieter than a higher tone.

As an auditory dimension, it would seem that loudness is weaker than pitch. There has been no significant debate about the spatiality of loudness. In music notation, loudness is specified in the broadest of strokes in a linguistic rather than spatial representation. However acoustic measuring technologies have fostered the notion of amplitude (which is related to loudness) as a dimension in a three dimensional abstract space. The assumption, which we have seen Varèse make, that this space is relevant to auditory perception, is common in this century, and was especially attractive to the *musique concrète* movement in its attempts to define aural objects.

Nevertheless, in a very direct sense, loudness has a very close association with spatiality through auditory depth perception. It is loudness more than anything else, that the naïve listener will cite as an indicator of auditory depth, and loudness has been used from time to time by composers to simulate depth in this way. In respect to this it should also be noted that the timbres of most instruments are quite different at *pianissimo* and *fortissimo*, and these changes of timbre (both perceived and measured) may also simulate the desired spatial effect. The mode of loudness representation in music notation might thus be partially attributed to the flat page's lack of accommodation for spatial depth representation (as well as to our relative lack of ability to quantify loudness).

The auditory sense of volume, which Stumpf, James, and many others have described, is not the same as loudness.[246] If, as James indicates, volume is the most basic sense of spatiality, we would expect it to be describable as a product of various spatial dimensions. When we speak of

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Varèse's inspiration in his experiments with sirens.

246 There appears to have been little, if any, recent research into auditory volume, with articles dated from the 1930s still being cited as current (for example in Buser & Imbert: **Audition**, published 1987/1992). The curious reader might consult the work of the following authors, listed in the bibliography: Gilbert Rich, H. Banister, Paul M. Zoll, S. S. Stevens, Edwin G. Boring, H. M. Halverson, Knight Dunlap, Garth J. Thomas, and Edward Lippman.

volume, the difference between the perception of 'musical' and acoustic sound space is all but dissolved: volume is a description of a sound's apparent extensiveness, and while James applies it to the perception of acoustic space, other writers have applied it to the perception of abstract sounds. Stevens, who did a large amount of definitive experimental work in this field, has attempted to construct a scale for auditory volume in relation to frequency and amplitude. Other studies have also examined binaural phase difference in relation to volume.[247]

It would appear to be fairly obvious that the louder a sound is, the lower (in pitch) a sound is, and the more spacious a sound is, the greater its volume. The research confirms this, and like other subjective attributes, the functions for volume are not linear. Thomas has derived equal-volume contours over a large part of the hearing range, graphed in terms of loudness (in sones) and pitch (in mels), showing this relationship.[248]

Stevens has called volume a 'dimension', so as to avoid the ontological connotations of the term 'attribute'.[249] Nevertheless, attribute is the current term - probably a more sensible term for general use as it avoids the spatial metaphor, allowing it to be thought of along with pitch, loudness, clarity, density and roughness as an attribute of tones.[250] The attribute of density (a 'solid and dense' sound, a 'delicate and diffuse' sound) appears to complement volume; increasing amplitude and frequency both producing an increase in density.[251]

The notion of auditory volume is useful in an understanding of Varèse's idea of a sound mass. Since the characteristics of frequency spectrum and amplitude are two of the important determinants of a sense of volume, there appears to be a psycho-acoustic basis for Varèse's terminology. Thus the sound of tolling bell has great volume in auditory space, as a Varèse-ian

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247 H. M. Halverson: **Diotic Tonal Volumes as a Function of Difference in Phase**, *American Journal of Psychology*, **33**, 1922, p526-534.

248 Thomas, Garth J.: **Equal-Volume Judgements of Tones**, *American Journal of Psychology*, **62**, 1949, p182-201.

249 S. S. Stevens: **The Volume and Intensity of Tones**, *American Journal of Psychology*, **46**, 1934, p397-408.

250 This term is used, after Boring, in Buser & Imbert: **Audition**, p82-84.

251 S. S. Stevens: **Tonal Density**, *Journal of Experimental Psychology*, **17**, 1934, p585-592; Edwin G. Boring: **The Relation of the Attributes of Sensation to the Dimensions of the Stimulus**, *Philosophy of Science*, **2**, 1935, p236-245; Edwin G. Boring: **Sensation and Perception in the History of Experimental Psychology**.

sound mass, and in the object that it symbolised. It is interesting that the term 'density' should also be shared by Varèse and the psycho-acoustic study of auditory space, although it is not clear if he attached any precise meaning to the term. The siren, with its approximately parallel increase in amplitude and frequency, is unlike many other sound sources in that it approximates (in the broadest sense) the equal volume contours. It presents the listener with a sound that has unusually little change in volume as its pitch changes. Varèse's interest in sirens may have had as much to do with auditory volume as with subjective spatial movement associated with pitch.

Depths and Depth

Merleau-Ponty finds depth in the night:

> Night is not an object before me; it enwraps me and infiltrates through all my senses, stifling my recollections and almost destroying my personal identity. I am no longer withdrawn into my perceptual look-out from which I watch the outlines of objects moving by at a distance. Night has no outlines; it is itself in contact with me and its unity is the mystical unity of the *mana*. Even shouts or a distant light people it only vaguely, and then it comes to life in its entirety; it is pure depth without foreground or background, without surfaces, and without any distance separating it from me.[252]

This account of depth has much in common with the surrounding depth that we have found to be an important aspect of sound space. Ihde and Zuckerkandl describe music in the same way. The Philips Pavilion itself makes this connection with the 'night' that it contained (it even had twinkling stars overhead). As McLuhan and Carpenter have noted, "the concert-goer closes his eyes",[253] and the staging of concerts frequently imposes a sort of night on the audience as the lights dim.

However, our survey of auditory space has found a number of 'depths' raising the question of whether they are all aspects of the one depth. In Chapter 3, we frequently encountered 'depth' in the description of auditory spaciousness. A low pitched sound may also be said to be deep, in concordance with the vertical metaphor and its phenomenal effect. A voluminous sound may be called deep; and because volume is partly determined by pitch, such a description may not be separable from vertical depth. Nevertheless, the sense of volume-depth is one of being faced with or surrounded by a large sound, the sense of being inside; a spatial sense that is not entirely

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252 Maurice Merleau-Ponty: **Phenomenology of Perception**, p283.

253 Edmund Carpenter & Marshall McLuhan: **Acoustic Space**, in Carpenter & McLuhan (eds.): **Explorations in Communication**, p67.

determined by pitch. Depth seems to be used in a different sense when referring to a sense of great recession - here we may have an impression of a vast empty space expressed through the sound of an apparently distant source. In fact this sense of depth is similar to that of volume-depth in that in both we are made sensitive to a vast surrounding space, either by a sense of fullness or emptiness.[254]

These applications of 'depth' refer to a common sensation: that of being in space in its immediacy. This is a direct sensation of spatiality that has no need for an accompanying geometric abstraction. This is the same depth as Merleau-Ponty's night, that same depth which he says destroys Cartesian space. In that night there is no perspective, but points of light outside perspective.[255] It is a sense of one's own body in vastness, whether, should the space be measured, that vastness be a large open space, a smaller surrounding space (internal depths), or simply the feeling of space resonating in the body. Varèse appears to have grasped something of this depth with his image of a powerful searchlight projecting a beam into the sky, with no hope of its ever returning. When sound creates spatial sensations exceeding the limitations of visual perception, exceeding the limits of geometry, it can be said to be an experience of depth. We call sounds of low pitch, large volume or which express large space deep because such sounds make our corporeal position plain to us. A low or loud sound shakes and envelops the body; a distant but reverberant sound gives a sense not unlike vertigo - of a surrounding emptiness.

To Merleau-Ponty, body-space is the site of meaning:

> To sum up, what we have discovered through the study of motility, is a new meaning of the word 'meaning'. The great strength of intellectualist psychology and idealist philosophy comes from their having no difficulty in showing that perception and thought have an intrinsic significance and cannot be explained in terms of external associations of fortuitously agglomerated contents. The *Cogito* was the coming to self-awareness of this inner core. But all meaning was *ipso facto* conceived as an act of thought, as the work of a pure *I*, and although rationalism easily refuted empiricism, it was itself unable to account for the variety of experience, for elements of senselessness in it, for the contingency of contents. Bodily experience forces us to acknowledge an imposition of meaning which is not the work of a universal constituting consciousness, a meaning which clings to certain contents. My body is that meaningful core which behaves like a

254 'Depth' in musical space is applied by Thomas Clifton to a metaphorical sense of foreground and background in the sound of a piece of music. Clifton: **Music as Heard**, p178-182.

255 A well known discrepancy in theories of linear perspective is that the stars are beyond their vanishing point.

> general function, and which nevertheless exists, and is susceptible to disease. In it we learn to know that union of essence and existence which we will find again in perception generally …[256]

Merleau-Ponty's analysis of body space and depth shows that music - to be meaningful - must be more than an intellectual construction: it must speak to the body.[257] Such 'body language' has many forms; theatrical gestures, dance, concepts of movement in music, using the body in performance and listening, vocal music, or the use of physical instruments in 'body space'.[258] In the case of Varèse, spatiality is expressed in two ways: through a discourse of pseudo-mathematical spatial concepts; and through the phenomenal realisation of spatiality in sound. The former involves an alienation of the body: hence Varèse's wish to do away with performers, discarding their role as interpreters with all of its corporeal implications. It is the latter that speaks to the body. To Varèse, music is "the corporealization of the intelligence that is in sounds."[259] Music is physical, intellectual, and corporeal.

Towards a Sound Space

This chapter has outlined some ambiguities inherent in sound space where acoustic and musical spaces intersect. By mainly considering pitch - a primary element of musical space - we find several qualitative associations with acoustic space. In general, low pitched sound tends towards describing a fluidic wave-space, which simple geometric or dimensional models fail to describe. This space is similar to many of the ideas expressed in the last part of Chapter 3 (*Surrounding Sound and Roundness*). When combined with loudness and binaural incoherence, a low sound may have a sense of immense volume, giving the listener a very basic sensation of body-centred non-dimensional spatiality. Furthermore, through associations with depth perception, low sound speaks of intimacy, interiority or the acoustic excess of a sounding body. Low sound spills into a sounding body's immediate vicinity, evaporating rapidly with increasing distance, and it is low

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256 Maurice Merleau-Ponty: **Phenomenology of Perception**, p146-147.

257 Naturally there are cases where meaninglessness *per se* becomes meaningful, where the body may be implicated by a deliberate exclusion.

258 Merleau-Ponty discusses the body-space of an instrumentalist, giving the example of a pipe organist at an unfamiliar organ, describing how the instrument, the body and the music become one. **Phenomenology of Perception**, p145-146.

259 Edgard Varèse, referring to Hoëne Wronsky and Camille Durutte in Varèse: **Music as an Art-Science**, in Schwartz & Childs (eds.): **Contemporary Composers on Contemporary Music**, p199.

fundamentals that characterise the sound of a body's interior. One has a sense of being inside the sound. Low sound speaks of continuity in space: boundaries are blurred, objects are opened, barriers are transparent, solid things take on a fluidic character. There is a connection between physical depression and depth in pitch which may be experienced, and is strongly reinforced by language and technology. This sensation of profundity is also the site of surroundedness and profound questions of meaning.

High pitched sound tends towards describing a space that approaches the nature of visual space: a space of rays, specular reflections off hard surfaces, and geometry. Ihde's bird hunter uses his ears as eyes. High sound also gives a sense of immediacy, different to the intimacy given by low sound. Here there is the sense of close and unobstructed perception, a perception more of the surface than the body. Objects and boundaries are sharply defined, allowing discrete perception. Again the correspondence between perceived physical elevation and high pitch is reinforced through language and technology. Small auditory volumes and high auditory densities tend towards the high extreme.

Sound in the mid-range of the pitch scale provides a diminished sense of spatiality: indirect and symbolic perception are optimised in this range, tending to reduce the importance of spatial perception. The project of extending the frequency range of music to its extremes - which was shared by Varèse and the high fidelity movement - was a reaction against the dominance of indirect and symbolic notions of sound; it was a fundamental approach to sound which was well expressed by spatial models.

Varèse's *Poème électronique* and the sound installation of the Philips Pavilion were concrete executions of sound space, and the phenomena discussed in this chapter apply. The design of the sound installation appears to accentuate or exaggerate the differences that have been discussed. As noted elsewhere, there was maximum spatial differentiation within the high frequency installation, but a unitary approach in the low frequency installation. The low speakers, mounted behind the balustrades, followed the outline of the floor plan - in the shape of a stomach - and as we have seen, these speakers find their most important role at the moment of digestion in *Poème électronique*. This metaphor is especially apt for low frequency sound for several reasons. Low frequency directional perception in enclosed spaces is usually undifferentiated, in the Philips Pavilion exceptionally so. The sense of space is more fluidic than geometric. The enhanced sense of auditory spaciousness at low frequencies (with the multiple laterally delayed sounds from the low speakers) discussed in Chapter 3 would have applied strongly at the moment of digestion, and this sense of auditory envelopment reinforced the metaphor. We have also noted that low frequencies are an indicator of intimacy or interiority in auditory depth perception. Being digested is an ultimate image of surroundedness: the space is totally enclosing to the extent that it invades one's body. The factors mentioned above were combined with the power of physical vibration on the listeners' bodies, with physical effects on their own digestive systems.[260]

The psycho-acoustic association between pitch and physical elevation was also reinforced in the Philips Pavilion: the high speakers were high, the low speakers low. Notwithstanding the specific movements of sound across the walls of the pavilion, any large range movement in pitch would have been accompanied by movement of the apparent sound source as the sound was distributed between the two sets of speakers. Perhaps the best examples of this movement are the sirens, which in some cases move rapidly over several octaves. In this way Varèse's auditory parabolæ and hyperbolæ were literalised, so that less sensitive listeners might begin to hear them. The "song of liberation" is another instance where apparent movement inherent in the sound may have been reinforced by the sound installation, in this case moving up towards the suspended female figure. At the end of the piece, the separation between the roar and the sirens would have also been apparent on the vertical scale, making the roar a ground from which the sirens were projected.

The design of the high space in the Philips Pavilion also appears to reinforce the psycho-acoustic factors discussed in this chapter. The relationship between high sound and surface was strengthened by the way in which this sound traced the surfaces of the pavilion, while the low sound filled it. Xenakis' composition, *Concret P-H*, in which there was no low sound, was expressed almost entirely through the hyperbolic paraboloid surfaces from which its name derived. The piece's associations with ray geometry (expressed through ruled lines) were emphasised by its high tessitura. The acrobatic movement in Varèse's *Poème électronique* also occurred in the medium to high sound range, and in the high space of the pavilion. Relationships

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260 Lawrence Smith & Donald Laird: **The Loudness of Auditory Stimuli which Affect Stomach Contractions in Healthy Human Beings**, *Journal of the Acoustical Society of America*, **2**, 1930, p94-98.

between geometry and high sound were initiated by the design of the speakers on the walls - in the shape of crystalline prisms. The atomic or crystalline sculpture at the pavilion's apex further emphasised the association between elevation and discrete or geometric forms; by contrast, the low sound came from around a mass of spectators enclosed by a stomach.

These differentiations between high and low are preserved to some extent on the domestic recordings. Partly for pragmatic reasons, most loud deep sound is centred on the Neuma recording; this gives the sound the power of both speakers, which is needed at low frequencies. Most of the dramatic movements and juxtapositions in the stereophonic field are in the mid and high range, where speaker power is more than adequate. Even if the reason is partly pragmatic, the fact that this difference matches a general sense of qualitative difference between high and low sound is significant. The difference between high and low is also almost inevitably subtly reinforced in another way, with the relative placement of woofers and tweeters on domestic speaker cabinets

As an electro-acoustic work, *Poème électronique* blurred distinctions between musical space, physical space, and space represented in the recorded material. The sound of the piece moved around the pavilion, sometimes focussed, sometimes enveloping. Musical height and physical height were confused by their coincidence. Auditory, physical and connotative volume also coincided. There was a sense of being inside a bell or a stomach, but also of listening at a distance through a reverberative space, and then an open space. Sound was sometimes heard on the surface of the pavilion, sometimes filling it with a physical presence, sometimes in a transcendent space beyond the surface. Sound space is at once amorphous, many dimensioned, transcendent, and imagined.

Concluding Remarks

This thesis meditates on a small set of themes, originating in Varèse's experience of sirens as movement in sound space, and in his experience of space in the Salle Pleyel. *Poème électronique* is essentially given as an example of how these experiences speak of sound space on several levels. The five chapters approach this problem in quite different ways, but generally arrive at similar conclusions.

The first two chapters see the development of two contrasting - perhaps opposing - levels of spatial expression, combined in the subtle form of the hyperbolic paraboloid. Its associations with science or mathematics and with a sense of body-space serve to elaborate this duality. However, the role of scientific and mathematical paradigms is not simple: they provide a formal grounding in space rather than in language, but the abstract conceptions and concrete experience of this space present another instance of this duality. Even in abstract, these spatial models point towards continuity; a move away from the more abstract discrete linguistic models of music (such as serialism), but a move that appears to formalise elements of continuity otherwise contained in phatic expression. The paradox of perception presented by the hyperbolic paraboloid offers two levels of spatiality (at least) to the viewer, giving the opportunity for transcendence from one to the other.

Again in Chapter 3, space appears on more than one level: as an amorphous surrounding presence and as a differentiated space of extension. The Salle Pleyel is a site of transcendence from visual space to a detached sound space. Caught between musical and physical space, this detached space opens up the possibility of an auditory space that is multi-stable on several levels. The sense of envelopment is an essential part of this transcendent auditory space.

Varèse's *Poème électronique* is many things, and Chapter 4 explores ways in which it reflects these experiences of sound space. The composition begins with pure surroundedness and opens out to explosive liberation. This debouchment is taken as a process parallel to the phenomenon of projection in the Salle Pleyel. The piece also has different, and in some ways analogous, processes of transcendence in space within the bell-like material. Varèse's experience of sound space in sirens is clearly important in parts of *Poème électronique*, most of all at the end.

Chapter 5 addresses auditory space in its own terms, providing a more systematic account of the multi-stability described in the other chapters. Musical and acoustic space are inexorably linked, leading to ambiguity. Another ambiguity is caused by the diverse nature of auditory experience. Many of the metaphors in the earlier chapters are shown to have close associations with auditory experience. As a sound installation, *Poème électronique* was designed to emphasise ambiguities between musical and physical space.

As a meditation on the nature of sound space, this thesis establishes the importance of subjectivity in auditory space's conception and experience. Yet auditory space is not the exclusive domain of subjectivity: the thesis draws extensively from the study of visual space. There is no claim that auditory space is somehow absolutely different and unrelated to other sensory spaces; the difference is in tendencies and extents. For a number of reasons, a sense of surroundedness, associated with depth and subjectivity, is comparatively easily found in auditory space. In identifying this as the "original sensation of space", James proposes that auditory space has a fundamental place in spatial perception. Since Bachelard and Merleau-Ponty approach meaning through this sensation of space, the importance attached to auditory space by Varèse is clearly much more than the consequence of an overgrown metaphor.

The thesis also shows how this apparently amorphous spatiality is the site of ambiguities which allow the construction of highly defined spatial images within the surrounding sound. The very lack of definitive forms in surrounding sound allows subtle psycho-acoustic phenomena, *a priori* musical models and visual and haptic notions of space to interact in the listener's construction of a higher spatiality. The thesis has concentrated on a limited selection of such psycho-acoustic phenomena: the subjective spatial implications of interaural incoherence caused by lateral early reflections; the implications of frequency on directionality and depth in acoustic space; and the possibility of pitch and volume as spatial attributes in themselves. In these ways the idea of a transcendent spatiality is shown to have some grounding in the processes of hearing.

Sound is a medium that can dissolve of boundaries between solidity and fluidity, interior and exterior, world and self, object and process, ray and wave, time and space. Other dualities are expressed in special ways through sound; such as large and small, or high and low. The range of sound perception is immense. A phenomenally based sound space shares many aspects of visual space, but extends spatial experience into areas scarcely known in conventional vision.

Sound space is immensely varied, expansive, and multi-stable: reality and the imagination co-exist intensely in it.

While Varèse was exceptional as a composer who, at an early stage, concentrated on spatial metaphors for describing his music, the works of many other composers raise similar questions. Many composers of the latter half of the Twentieth Century adopted spatially based notation, used innovative electro-acoustic devices, employed spatial juxtaposition in instrumental works, or used space in other ways. Some of La Monte Young's works use auditory space in exceptional ways by refining and sensitising the listening process. Many artists have used sound in their works, often taking advantage of its special properties in spatially based works. The sound installations is now well established as an art form. The auditory implications of such work are still largely unexplored.

Appendix

The spectrographic representation of musical works has been extensively used by Robert Cogan, most notably in *New Images of Musical Sound*.[261] The spectrographic representation of *Poème électronique* in this Appendix is intended to be used much like a musical score in the discussion and analysis of the piece. This spectrogram is essentially the same as that used by Cogan in his analyses, except that it is on a larger scale and also represents the stereophonic distribution in the Neuma recording of the piece (the two channels are in contrasting colours). Each page of the spectrogram represents a 30s interval, with an additional few seconds overlapping the beginning of the following page (the overlap is tinted green). The resolution of the spectrogram is limited by the particular software that was used to create it. In particular there is a significant amount of vertical blurring due to ratio between the sample rate and the frequency on the graph becoming excessive. The spectrogram has three horizontal layers which were sampled separately at different sample rates. The overall amplitude of the signal is also shown above the spectrogram. The two channels were sampled separately, and the composite images were produced with image editing software. For the purposes of this thesis, the spectrogram is simply a rough notation of *Poème électronique*, and there is no particular need for additional resolution here.

The original recording of *Poème électronique* was on three audio tracks that were distributed through a sophisticated switching process between the hundreds of speakers in the Philips Pavilion. The Neuma recording, represented in this Appendix, conforms to the requirements of domestic stereophonic equipment, distributing the sound between two tracks. In many ways the relationship between the original sound distribution and that on the domestic recording can only be arbitrary, although certain congruences are noted in the main body of this thesis. However, the stereophonic spectrogram does give us an idea of which simultaneous sounds were spatially separated in the pavilion, even if it does not show their specific position and trajectory there.

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261 John Strawn cites several other instances of spectrographic notation of music including works by Rösing, Abraham Moles, Fritz Winckel, Hugh LeCaine, Mantle Hood, Alan Merriam, and Rainer Wehinger. He also emphasises the similarity that spectrographic notation has with many instances of notation in Twentieth Century works. See John Strawn: **John Strawn's Reply**, *Computer Music Journal*, **10** (4), 1986, p13.

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