

# SOUND AS A DATA TYPE IN A SPATIAL INFORMATION SYSTEM

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## ABSTRACT

Multimedia techniques are being used to present images, text, digital video and sound data in an integrated spatial framework. This paper focuses on sound as a data type and the ways in which it may be integrated into a GIS.

Sound has both spatial and non-spatial properties. While it may be adequate to use existing data structures to model simple integrations of sound with other spatial data, the development of effective analysis tools will require the use of three and four dimensional data structures.

In particular there is a need to consider the ways in which sound as a spatial object can be modelled. This includes the data needed to define the spatial components of a sound object and how such objects interact with their environment. There is also a need to consider how sound intensity changes within a sound object, both as a result of distance from the source and due to directional effects.

These issues are reviewed in the context of a particular application, that of monitoring and modelling noise pollution around airports.

## INTRODUCTION

In the past five years there has been increasing interest in the use of diverse types of data with information systems in general and in particular within Spatial and Geographical Information Systems. The data types include conventional vector based computer graphics, raster based images, computer animation, digital and analogue video and sound. These data types on their own all offer increased information content when compared to textual data, however it is when the data types are combined to form Multimedia data that the true potential of these diverse data types is realised.

Previous studies into the use of multimedia data with GIS have concentrated on demonstrating possible application areas for multimedia GIS (Lewis, 1991; Parsons, 1992), interface issues and the use of Hypertext structures (Raper, 1991) and have investigated data modelling issues for multimedia data in general (Jackson, 1990; Rivamonte, 1992).

Little work on the use of multimedia data types within GIS has investigated in detail the use and characteristics of specific multimedia data types. In particular the characteristics of sound as a spatial data type have largely been ignored. If multimedia data types are to be used more fully within GIS, data models need to be developed.

This paper aims to illustrate the unique characteristics of sound within GIS as a spatial data type. Sound may be used as part of the user interface of a GIS, as an attribute to other spatial objects and as a spatial object in its own right. It is this last aspect that is of particular significance in the development of integrated analytical

capabilities.

### CHARACTERISTICS OF SOUND

The study of the properties of sound, acoustics, is a complex but well understood area of physics. It is not necessary to discuss all of the physical aspects of sound here, instead some of the principle elements which have relevance to the integration of sound into a spatial data model are illustrated. These are:

1. Frequency
2. Wavelength
3. Intensity
4. Spatial extent
5. Duration

Sound or noise is the result of small pressure fluctuations which are propagated through air. The speed of sound is dependent on environmental conditions, particularly air temperature and pressure. The magnitude of fluctuation or change in pressure caused by sound is relatively small ranging from  $2 \times 10^{-5}$  to 20 Pa compared to the standard atmospheric pressure of 101,325 Pa.

### FREQUENCY AND WAVELENGTH

The sensitivity of the human ear varies depending upon the sounds frequency. The human ear is sensitive to sounds within the frequency range of 20 - 20,000 Hz. There is a marked reduction in the sensitivity to sound below 250 Hz , where pressure fluctuations are felt rather than heard.

The wavelength of sound displays a much larger variation, typically ranging from 17 m at low frequencies to 17.2 mm at the highest. The wavelength of sound is significant as to some extent it controls the prorogation of sound around physical barriers.

If the sound source is in motion, as is often the case , the frequency of the sound perceived at a point may differ from that emitted by the source. This effect is known as Doppler shift. The general effect of Doppler shift is that for a sound source approaching the receiver a rise in frequency will occur, the frequency will decrease as the sound source moves away from the receiver.

### INTENSITY OF SOUND

Although sound is in effect a pressure variation, sound is not usually measured using the SI unit for pressure, the Pascal. Instead the intensity of sound is measured using the decibel (dB), a logarithmic scale more suited to the nature of human hearing. 0 dB is the threshold of human hearing for sound with a standard frequency of 1000 Hz. The scale rises to 120 dB, the threshold of pain, where sound is so loud as too hurt the listener.

### DURATION OF SOUND

The generation and subsequent attenuation of sound is clearly time dependent, in that a source may generate a sound for a specific length of time, which will then travel at the speed of sound to the receiver.

The complex nature of many of these characteristics and their inter-relationships

(Figure 1) makes the handling of sound within a spatial database complex. As a result of this complexity any successful spatial model of sound will have to be a considerable simplification of reality, modelling the variation of a single characteristic such as intensity in space and time.

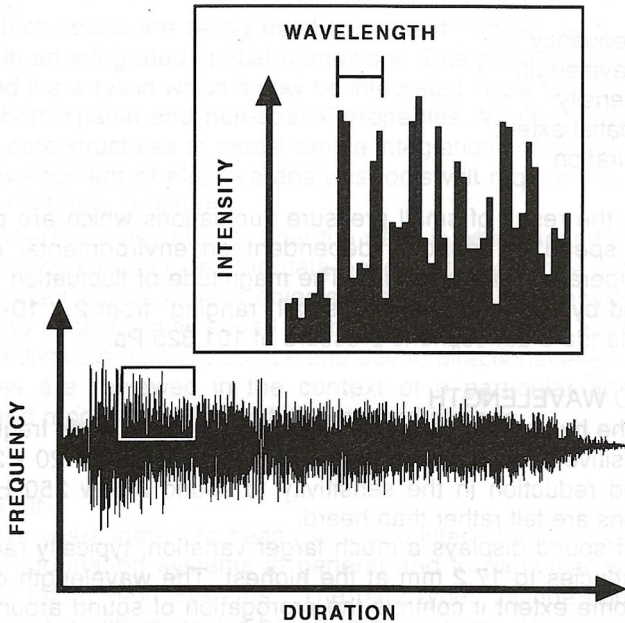


Figure 1 - Sound Element Inter-Relationships

### SOUND IN A SPATIAL INFORMATION SYSTEM

The use of sound in spatial information systems may be divided into two groups. The first is the use of sound as part of the user interface, which may include process-related indicators such as warning beeps when the user has initiated an incorrect or inappropriate command. The more sophisticated interfaces may include spoken prompts, audio help facilities and background music during processing. Such use of sound is not addressed further here.

The second group involves the use of sound as a data item that may be manipulated as an integral part of the spatial database. In this context sound may be handled in two ways:

1. Sound as an attribute to a spatial object. For example, the sound of bells could be added to the spatial location of a church, or the sound of traffic to a busy urban road.
2. Sound may itself be interpreted as a spatial object. Such objects have a three-dimensional existence, but unlike other spatial objects are more difficult to define, have variable characteristics throughout the object and are inherently transient.

These two ways of handling sound in a spatial database are considered further in the following sections.

### SOUND AS AN ATTRIBUTE

The inclusion of sounds which are attributes to spatial entities would seem to be a relatively simple problem. A simple model may be devised which links spatial objects to a sounds in a many-to-many relationship (Figure 2). Each sound will be stored in a digital file and will be characterised by such parameters as duration and volume at which it is to be played.

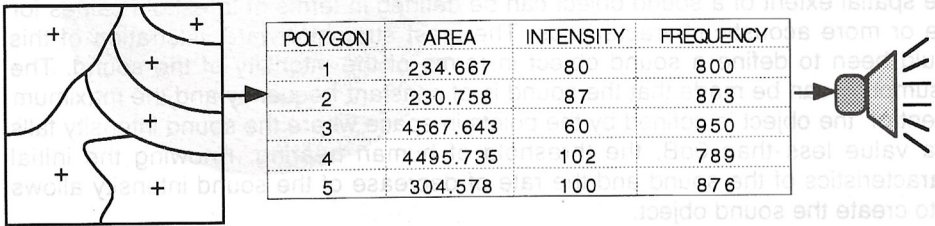


Figure 2. Model for sound as an attribute to a spatial object.

Typically sounds would be accessed as a result of a spatial query which identifies objects to which a sound is attached. The user undertakes the interpretation of the sound as a result of listening to it. An important component in the GIS functionality needed to utilise sound in this way is that of being able to repeatedly play the sound. This recognises that a sound has a finite duration and may need to be replayed many times for the user to fully interpret its meaning.

Alternatively it is possible to query the sound attributes themselves by searching sounds for particular sequences which are indicative of a particular feature or subject. A library of bird calls, linked to positions of sightings, could be interrogated for sequences indicative of particular bird activities and used to display locations of those activities.

### SPATIAL EXTENT OF SOUND

Sound intensity or level decreases with distance from its source due to the geometric dispersion of the sound. This decrease follows an inverse square progression. Assuming the source is non-directional and the atmosphere is of uniform temperature, the radiation of sound into the surrounding area will be equal in all directions forming a sphere.

In reality sound sources tend to be directional, for example a jet engine, and the sound produced interacts with the environment. Indeed the environment may be crucial in effecting the geometric extent of a sound. The sound may be reflected from flat surfaces radiating to produce a hemisphere rather than a sphere, however in reality such flat surfaces do not exist resulting in rather complex attenuation of sound.

So far it has been assumed that the air through which the sound has been travelling has been still. Wind and temperature gradients within the body of air will also effect the spread of sound from a source. These atmospheric effects may result in the creation of shadow regions where although relatively close to the

source of sound, the intensity may be low.

### SOUND AS A SIMPLE SPATIAL OBJECT

An alternative to treating sound as an attribute associated with a spatial location is to model sound as a spatio-temporal object. An elaborate multi-dimensional object would be required to represent the full complexity of sound both in terms of its spatial extent and its acoustic characteristics. The object would also need to be dynamic in the temporal sense as both the spatial extent and acoustic characteristics of the sound object will vary with time.

The spatial extent of a sound object can be defined in terms of threshold values for one or more acoustic characteristics. The most straightforward illustration of this would be to define a sound object in terms of the intensity of the sound. The assumption can be made that the sound is of constant frequency and the maximum extent of the object is defined by the points in space where the sound intensity falls to a value less than 0dB, the threshold of human hearing. Knowing the initial characteristics of the sound and the rate of decrease of the sound intensity allows us to create the sound object.

As the sound intensity decreases in a predictable way throughout the object, it is possible to calculate the sound intensity at any given point within the object. To model this the data structure must contain parameters relating to sound characteristics being modelled, the assumptions being made in the creation of the object and the equations being used to calculate rates of change used to define the object.

### SOUND CHANGES THROUGH TIME

A further complexity is added when a single sound of finite duration creates a spatial object which not only has a different sound characteristics throughout its extent but also has different temporal characteristics due to the time it takes to propagate the sound.

As an example, the sound of an aircraft engine at a given location and point in time will create a spatial object. At its furthest extremes this object has not only different sound characteristics but would actually be heard at different times.

Thus it is possible to create a time series of sound objects. If these objects are all from a single fixed source and are identical sounds, given that all other factors are constant, the spatial objects will be identical. But if the source moves and/or the nature of the sound changes, so the objects will be different.

For any given point in space it is conceivable to calculate the temporal change in sound from the intersection of the spatial objects. In this way it is possible to model the variations in sound for a particular place resulting from a series of aircraft takeoffs. This would allow not only extreme noise pollution values to be measured but also such issues as duration of noise within certain criteria.

### COMPLEX OBJECT SHAPES

The shape of a sound object will vary depending upon a number of factors both environmental and those relating directly to the source characteristics. In the simplest case the sound object would be spherical, under realistic conditions the sound will have a very complex shape (Figure 3)

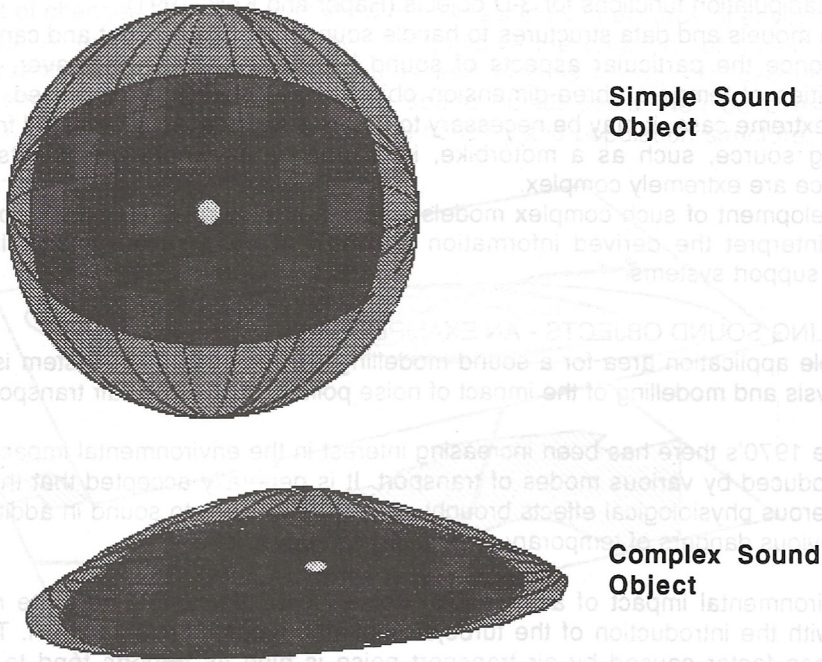


Figure 3. Model for sound as a spatial object.

In most cases it would be impossible to take into account all the various environmental aspects when modelling a sound object. However it is necessary to consider the particular problem of directional sound.

To model a sound object for a particular directional sound, there are two basic approaches:

1. Assume that the directional function is such that the sound object defines a cone, or at the extreme a hemisphere, beyond which sound heard directly from the source is considered to be inconsequential. Within the cone the changing characteristics of the sound would be calculated as for a non-directional sound. This inevitably introduces errors at the margins of the object.
2. To assume a spherical spatial object that has not only changing characteristics with distance from the object but also has a defined line of maximum sound, away from which the sound characteristics diminish in a predictable manner. This is potentially the more accurate method but is also more complex.

#### MULTIPLE SPATIO-TEMPORAL OBJECTS

A particular characteristic of interest in the modelling of sound is the reflectance of sound from objects. It is possible to model the intersection of a sound object with a surface, to build-in absorption factors and to create secondary sound objects based on reflectance.

This inevitably leads to the handling of multiple spatial objects and their intersection. This problem has been addressed in a geological context with the

development of three-dimensional topological data structures and the defining of spatial manipulation functions for 3-D objects (Raper and Kelk, 1991).

The data models and data structures to handle sound information exist and can be applied once the particular aspects of sound have been added. However, the complexities of temporal three-dimension objects have not been addressed. To take an extreme case, it may be necessary to model a series of sound emitted from a moving source, such as a motorbike, in a urban area where the effects of reflectance are extremely complex.

The development of such complex models would inevitably raise questions about how to interpret the derived information and how to build such systems into decision support systems.

### MODELLING SOUND OBJECTS - AN EXAMPLE

A possible application area for a sound modelling spatial information system is in the analysis and modelling of the impact of noise pollution caused by air transport.

Since the 1970's there has been increasing interest in the environmental impact of noise produced by various modes of transport. It is generally accepted that there are numerous physiological effects brought about by exposure to sound in addition to the obvious dangers of temporary or permanent hearing loss.

The environmental impact of air transport noise increased rapidly from the mid 1950's with the introduction of the turbojet engine into commercial aviation. The disturbance factor caused by air transport noise is high as airports tend to be located relatively close to centres of population, and the major source of aircraft noise is from jet aircraft at take off and landing.

The exposure on the ground to noise from aircraft is largely controlled by two factors, the acoustic characteristics of the aircraft and by the manner in which the aircraft is operated.

The acoustic characteristics of aircraft has improved considerably over the past 15 years with the introduction of high by-pass ratio turbofan powered aircraft such as the Airbus A320 and Boeing 757 & 767.

The noise exposure around airports can vary to a large extent depending upon the particular departure and arrival profiles flown by aircraft and by altering ground handling operations. The ability to change departure profiles of aircraft is limited as the aircraft use high or full power at take off and for the initial stages of climb out. However it is possible to reduce thrust relatively quickly once a safe height has been reached and continue to climb at reduced power, at Heathrow airport aircraft departing must reduce power at 1000 feet ((Bragdon 1987)). By altering the operational runway at regular intervals and altering departure routes it is possible to minimise the environmental impact to the area surrounding the airport.

With existing models of departure profiles it is difficult quantify the effect of changing departures routes and profiles in terms of the numbers of houses effected and their exposure to noise.

Integrating the existing models for flight profiles with a spatial information system

handling sound as discussed in this paper, it would be possible to quantify the effect of changes to profiles and allow more meaningful measures of environmental impact. A suggested methodology might involve the creation of sound objects representing different departure routes and profiles taking into account local environmental characteristics. These sound object could then be overlaid on spatial datasets containing data on local housing and population structures (figure 4).

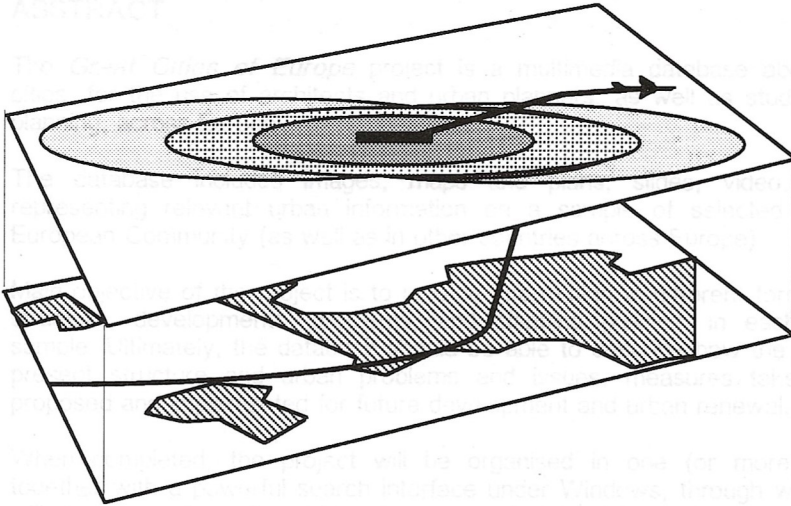


Figure 4 Analysis Methodology

## BIBLIOGRAPHY

- Bragdon, C. R. (1987). Control of Airport Noise Impact. Transport Noise Reference Book. Cambridge, Butterworth & Co. 20/3-20/20.
- Jackson, J. (1990). Developing an effective Human Interface for Geographical Information Systems using metaphors. ACSM/ASPRS Annual meeting, Denver, ACSM/ASPRS.
- Lewis, S. (1991). Hypermedia Geographical Information Systems. Second European Conference on Geographical Information Systems, Brussels, Belgium,
- Parsons, E. (1992). The Development of a Multimedia Hypermap. AGI'92, Birmingham, UK, Association for Geographic Information.
- Raper, J. (1991). Spatial data exploration using Hypertext Techniques. Second European Conference on Geographical Information Systems, Brussels, Belgium,
- Raper J. F. and Kelk B. (1991) 'Three-dimensional GIS' In 'Geographical

Information Systems. Volume 1 Principles. Eds Maguire D. J., Goodchild M. F. and Rhind D. W., Longman, London pp299-317.

Rivamonte, L. (1992). A Multimedia primer for GIS. URISA 1992 Annual Conference Proceeding, URISA.

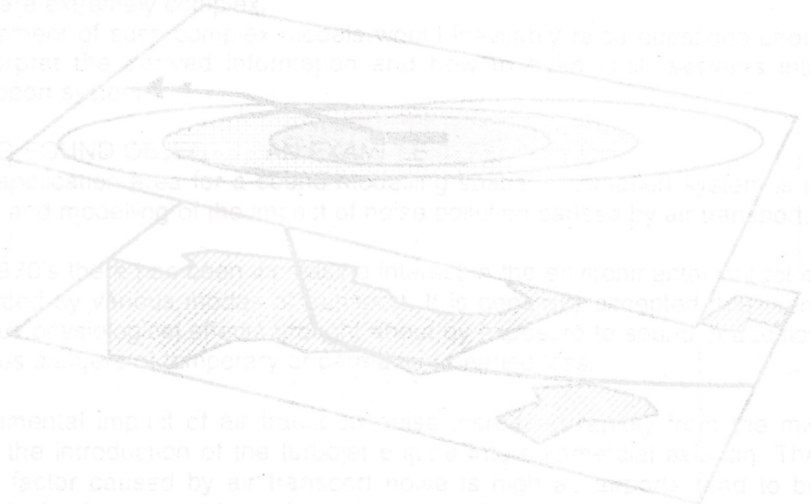


Figure 4 Analytic Methodology

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Braddon, C. R. (1987). Control of Airport Noise Impact. Transport Noise Reference Book. Cambridge, Butterworth & Co. 223-232.

Jackson, J. (1990). Developing an Effective Human Interface for Geographical Information Systems using metaphors. ACSM/ASPRS Annual Meeting, Denver, ACSM/ASPRS.

Lewis, S. (1991). Human-Computer Interaction Systems. Second European Conference on Geographical Information Systems, Brussels, Belgium. The theme of the conference was 'Human-Computer Interaction in GIS'.

Palmer, E. (1987). The Development of a Multimedia Hydrant. AD192. Birmingham, UK. A report for the Geographical Information Systems Centre, Birmingham.

Paper, J. (1991). Spatial data exploration using HyperText Techniques. Second European Conference on Geographical Information Systems, Brussels, Belgium.

Paper, J. R. and Kirk B. (1991). Three-dimensional GIS in Geographical Information Systems. Volume 1 Principles. Eds Maguire D. J., Goodchild M. F. and Rhind D. W., Longman, London pp299-317.