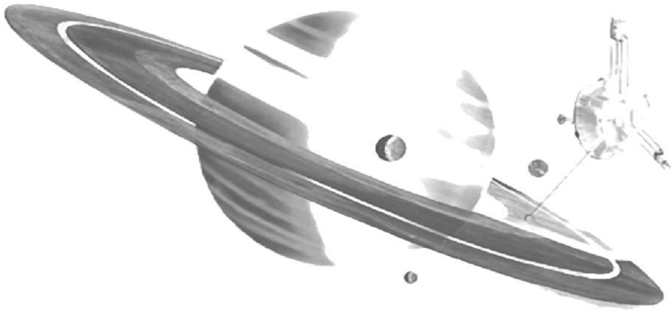

# Chapter 1

# 1. Introduction Of Sonification

## 1.1 Definition Of Sonification

Sonification in one sentence described is the use of non-speech audio to convey information. The expression Sonification comes from the two latin syllables “sonus” which means sound and the ending ”fication” which forms nouns out of verbs which are ending with '-fy'. To “sonify” means therefore to convey the information via sound.

A more detailed definition of Sonification can be split into two important parts: A technique and an intent.

- The technique is the process of mapping numerical data, presumable embodying some relationships in the physical world (in our case space physics) or a model world, to sound.
- The intent is to understand or communicate something about that world.

Both parts of the definition are necessary in order to distinguish the field of Sonification from other fields that involve sound computation.

As a very basic example for Sonification can be seen a Geiger detector which “conveys” information about the level of radiation or even more basically a church bell which “conveys” the current time.

The best known example in space physics was the use of sound for detecting micrometeoroids impacting Voyager 2 when traversing Saturn's rings; these impacts were obscured in the plotted data but were clearly evident as hailstorm sounds[1].

Especially in this example there can be seen the high significance of using audio to display data.

Alone or in combination with visual imaging techniques, Sonification offers a powerful tool of transmitting information. It can improve and increase the bandwidth of the interface "human-computer" and can find a lot of applications in the wide range of information technology.

J. Keller[2] defined in 2003, that Sonification can be categorized in three ways:

- Iconic Sonification: This type of Sonification is when someone maps data to sounds that are associated with certain phenomena. For example, if we gathered weather data, such as cloud cover, temperature, and humidity, to calculate the probability of rain tomorrow, then using the sound of rain to indicate when there is a high probability of rain would be an iconic Sonification.

- Direct Conversion Sonification: This type of Sonification is when someone maps data to sound to listen for patterns that are represented in the data. For example, space scientists map data of waves made up of magnetic and electric fields called electromagnetic waves to sound waves. This direct conversion Sonification can be as simple as taking the frequencies of the waves and making sound waves with the same frequencies, which is most useful as long as the frequencies are at pitches that our ears can hear. Earth's whistler wave is such an electromagnetic wave that scientists have been sonifying for over 30 years.

- Musical Sonification: This type of Sonification is when someone maps data to sound in a musical way. For example, we have created a computer software program that will convert data of very fast particles that have come from the Sun and are captured by an instrument on one of 2 satellites in space, called Helios 1 and Helios 2, to bell-like sounds. Several musicians have used musical Sonification of space data to create quartet or orchestra music pieces.

According to Gregory Kramer[2] Sonification is also very often associated with Audification which is not absolutely correct. In comparison to Sonification, Audification is in detail the direct translation of a data waveform into the audible domain for reasons of monitoring and comprehension. Examples for an appliance of Audification can be found on the website of NASA's Voyager project[1].

1 NASA: http://voyager.jpl.nasa.gov
2 J. Keller's Definitions, 2003, Private Communication
http://cse.ssl.berkeley.edu/impact/vos/beginners.html

## 1.2 The History Of Sonification

The whole field of auditory display and Sonification seems on the first view very young and new but the roots can be found earlier.

The history of auditory representations of data could be said to include actually the research by Pythagoras, Ptolemy, Kepler, Mozart, and Dufay – Sonification in music.

For years data structures have been perceived in sound and these structures have become a basis for musical systems. Predating Pythagoras, who analyzed the structure of harmonics and applied them to musical scales, we see the application of natural law to human-generated sound-producing systems. Pythagoras, referred to his results as "sounding members". Refinements and extensions of this law defined the development of the musical scales in use all over the world, from the Shakuhachi (bamboo flute) of Japan to the diatonically tuned music synthesizers of global popular music. Manipulating sound for musical ends based upon data or mathematically derived structures arises from a distinguished tradition. Early in the Christian era, the astronomer Ptolemy remarked on the elements of musical modulation and wrote widely studied book on harmonics, as did Kepler and Newton.

1914 the development of the first reading machine with audible output from Fornier D'Albe was designed as an interfaces for blind users and was a next big step in the history of Sonification. The "Optophone" had a six-tone code and was significantly improved in 1922.

If i talk about the history of Sonification I have also to include the exploration of the wide fields of sonar which will not be explained here furthermore.

The first pioneers of Sonification however who started with Sonification the way we understand it nowadays were Pollack and Ficks[3] in 1954. They published a paper detailing research into the use of abstract auditory variables to convey quantitative information. Using tone and noise bursts, they designed a display that presented eight binary variables encoded as the pitch area of the noise, the loudness of the noise, the pitch of the tone, the loudness of the tone, the pitch/noise alternation rate, the temporal ratio of tone to noise, the total duration of the display, and the stereo location of the display. They also created a display without the noise bursts which yielded six binary variables.

Not later than 1961, Speeth[4] reported the results of experiments that used Audification of seismic data to determine if subjects could differentiate earthquakes from underground bomb blasts. Because of their complexity, seismograms that resulted from these events were difficult to understand and categorize. By speeding up the recordings of the seismic data, the complex wave was shifted into the audible range. For over 90% of the trials, subjects were able to correctly classify seismic records as either bomb blasts or earthquakes. Additionally, by speeding up the playback of the data, analysts could review 24 hours of data in about five minutes.

In 1974 three scientists, Chambers, Mathews, and Moore[5] designed a three-dimensional auditory display at AT&T Bell Laboratories. In an auditory enhancement of a scatter plot, they encoded three data variables as pitch, timbre and amplitude modulation. While no formal testing was conducted, they found that the auditory representation did assist in the classification of the data.

1982, chemist Edward Yeung[6] developed a Sonification technique for displaying experimental data from analytical chemistry. Like most researchers in the field of Sonification he looked for auditory variables that had some degree of independence. He selected two pitch ranges, loudness, decay time, stereo location, duration, and silences between events. Using these variables and no more than two training sessions per subject, Yeung asked the subject to classify detected levels of metals in a given sample. A given data point could belong to none of four categories and Yeung's subjects attained a 98% correct classification rate.

Also in the car industries Sonification became an issue. 1986, a team of engineers, working at Fiat Auto[7], developed and patented a Sonification system for continuous monitoring of various automobile parameters. A plurality of sensor devices were used as control signals for a group of tone generators. Once again the task was real-time, not analysis, and psychometric tests were not conducted to determine the efficacy of the display system.

With the enhancement of the computer hardware at the end of the 80's the slow pace of development in Sonification began to accelerate.

Stuart Smith began to work with a team on Exvis[8] at the University of Massachusetts/Lowell. Exvis is a auditory/visual display tool for representing multidimensional (up to seven dimensions) data. The data variables were encoded simultaneously as the geometric attributes of graphic elements and as the attributes of a synthesized sound. The graphic elements produced data-driven visual textures and the auditory display was triggered by moving the mouse cursor through the graphical representation.

At about the same time, Gregory Kramer[9][10] began work at the Santa Fe Institute on Sonification of complex systems and Clarity's Sonification Toolkit. In searching for ways to enable our perceptual systems to more fully contribute to comprehending complexity, Kramer's work, meanwhile, was pushing the limits of dimensionality. Using data supplied by the mathematician Mayer-Kress, Kramer attempted to represent nine-dimensional chaotic systems (ten-dimensions including time) in an auditory display[11]. He also worked with Apple Computer's ACOT group to produce Sonifications of predator/prey models for education purposes, using both realistic and abstract sounds to represent the dynamic system.

Kramer is also one of the founder of the International Community for Auditory Display (ICAD)[12] which coordinates since the foundation in 1992 the research in the field of Sonification. In October 1992, the first International Conference on Auditory Display (ICAD92) convened in Santa Fe, New Mexico under the sponsorship of the Santa Fe Institute. The ICAD92 brought together 36 researchers, nearly all working with issues of how non-speech audio can be used to convey information. Since 1992 the ICAD has been taken place once a year at several places on this globe and many scientists have been contributed to a steadily growing knowledge base for Sonification.

1990, Scaletti and Craig[13], working at the National Center for Supercomputing Applications, produced a series of Sonifications to accompany scientific visualizations developed there. Their work added Sonification to create a sophisticated sonified data visualization. The data represented both aurally and visually included ozone levels, swinging pendula, and forestry data. By displaying these video tapes to the robust computer graphics community, a new and broader audience became aware of Sonification.

At the same time, Rabenhorst[14] was working with some colleagues at IBM's Watson Labs on an auditory and visual representation of three scalar fields associated with electron density, hole density, and potential throughout the volume of a semiconductor. Like the application Exvis, the user could use a mouse to select the region to be displayed. In the IBM work, two volumetric variables were visualized in high resolution while one was sonified.

As current project i would like to introduce the "Sonification Sandbox"[15]. It is a project of the Psychology Department's Sonification laboratory at Georgia Institute of Technology. Bruce Walker, PhD. is the chairman of this project which is motivated by a need for a simple, multi-platform, multipurpose toolkit for sonifying data. This toolkit can map data to multiple auditory parameters and add context using a graphical interface. It supports visual and auditory renderings of the data and the auditory results can also be exported as MIDI files for archiving the results.

## 1.3 MOTIVATION

### General Aspects For Sonification

The human ears provide a very good alternative and supplementation to the visual way of reception information for visualization and understanding complex scientific data. With Sonification it is possible to display effectively large and multidimensional datasets which could help in finding otherwise hidden correlations and patterns. This will provide users with alternative and additional ways of identifying and extracting physical signatures represented in the data, including selection and inter comparison between datasets.

In addition to improving data exploration and analysis for most researchers, the use of sound is beneficial as an supporting technology for visually impaired people and non-visually-oriented people. And as a third big advantage it can also make science and math more exciting especially for young students because people learn in many different ways.

Further examples of the usefulness of Sonification additionally to visualization are:

- uncovering patterns masked in visual displays
- identifying new phenomena current display techniques miss
- improving data exploration of large multi-dimensional and multi-dataset
- exploring in frequency rather than spatial dimensions
- analyzing complex, rapidly, or temporally changing data
- complementing existing visual displays

- monitoring data while looking at something else (background event-finding)
- improving visual perception when accompanied by audio cues

## Space Science Specific Aspects For Sonification

Complex datasets (*e.g.,* particle measurements varying in energy, look direction, time, and particle species (such as electrons and ions)) have more parameters to be displayed than there are visual ways to distinguish them and are usually examined in a subset of dimensions at a time, thus forcing the researcher to build up a picture in her mind of the whole dataset. The capability of looking at some dimensions while listening to other dimensions allows one to process more information at once and make better correlations. Alternatively, looking and listening to the same data at one time provides two different views, perhaps exposing patterns hidden in only visual displays. The use of sound will allow identification of otherwise "difficult-to-see" patterns, including dynamic outliers such as leading and lagging indicators. Dynamic outliers differ from the rest of the dataset in their dynamics rather than their actual values and are difficult to discover. Also, auditory accompaniment (e.g. movie music) clearly leads to improved visual information reception.

Sonification is in a similar situation to scientific visualization a decade ago but now the progressed computer audio technology makes auditory data representation viable for large number of users. Although there is a rich visualization literature, only a few researchers have published on the use of sound for data exploration and many were limited by the technologies at the time.

## Accessibility

Sonification will provide greatly-improved accessibility to space science data for visually-impaired scientists, perhaps even making possible insights not available through visual displays. Current methods for examining data non-visually are inherently inferior and intrinsically more costly. Reading data values is a tough way to analyze data. Raised plots (whether simple time-series "lines" or "maps" to mimic spectrograms) inevitably require very specialized and expensive hardware and are not readily tied to web services. Since most current workstations have sound generation capabilities, Sonification allows effective data browsing for the visually impaired. With Sonification a large fraction of the CDAWeb data collection will be opened to a completely new and now excluded audience. Both, professional and public. In addition to visually-impaired users many people are aurally- rather than visually-oriented and Sonification provides a powerful new tool for all. Sonification also appeals to the educational community, making science more exciting to students and the general public.
Using sound in exploratory data visualization adds to the scientific research capabilities in NASA, especially in complex multi-dimension and multi-dataset research such as for Earth and space sciences. It is cost effective to add Sonification

tools to extract more knowledge from existing and future data sets and missions and new missions will have even larger and more complex datasets to analyze. Supporting and encouraging the visually-impaired and education communities are important NASA goals.