Sonification of time dependent data

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Abstract. This paper presents the results of experiments with sonification of 2D and 3D time dependent data. A number of sonification means for these experiments have been implemented. An Internet Web site was created where sound sequences were presented and could be evaluated by the participants in the experiment. All participants that performed the tests also needed to fill an evaluation questionnaire. The purpose of the experimentation was to determine how the sonification of two and three-dimensional graphs can support or be an alternative to visually displayed graphs. The paper concludes discussion of the results and the issues related with the experiments.

1 Introduction

Visual data mining is a part of the KDD process [1], which places an emphasis on visualisation techniques and human cognition to identify patterns in a data set. [1] identified three different scenarios for visual data mining, two of which are connected actually with the visualisation of final or intermediate results and one operates directly with visual representation of the data. The design of data visualisation techniques, in broad sense, is the formal definition of the rules for translation of data into graphics. Generally, the term 'information visualisation' has been related to the visualisation of large volumes of abstract data. The basic assumption is that large and normally incomprehensible amounts of data can be reduced to a form that can be understood and interpreted by a human through the use of visualisation techniques. The process of finding the appropriate visualisation is not a trivial one. A number of works offer some results that can be applied as guiding heuristics. For example, [2] defined the Proximity Compatibility Principles (PCP) for various visualization methods in terms of tasks, data and displays - if a task requires the integration of multiple data variables, they should be bundled in proximity in an integrated display. Based on this principle authors have concluded that 3D graphs do not have an advantage over 2D graphs for scientific visualisation (which may not necessarily hold for visual data mining).

Visual data mining relies heavily on human visual processing channel and utilises human cognition overall. The visual data mining cycles are shown in Fig. 1. In most systems, visualisation is used to represent the output of conventional data mining algorithms (the path shown in Fig. 1a). Fig. 2 shows an example of visualisation of the output of an association rule mining algorithm. In this case, visualisation assists to comprehend the output of the data mining algorithms. Fig. 1b shows the visual data mining cycle when visualisation is applied to the original or pre-processed data. In this case, the discovery of the patterns and dependencies is left to the capacity of the human visual reasoning system. The success of the exercise depends on the metaphor selected to visualise the input data [3].

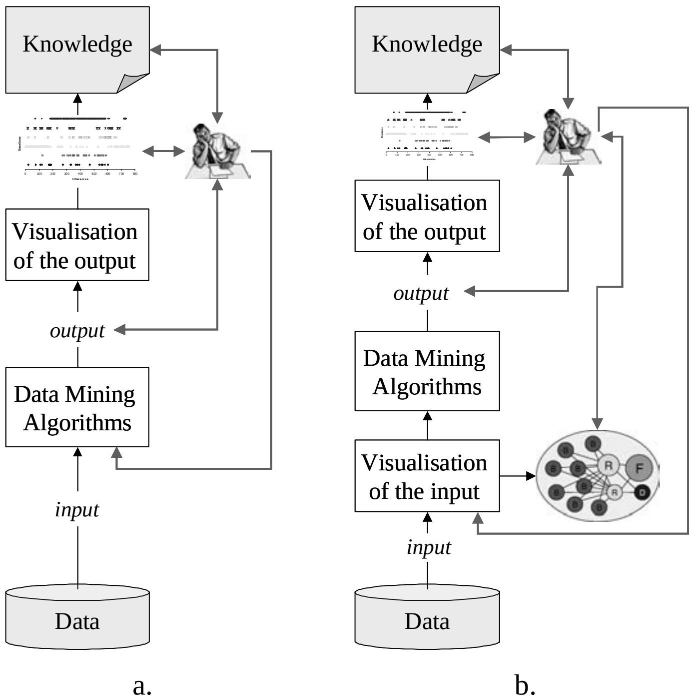

Fig. 1. Visualisation and visual data mining

Although human visual processing system remains a powerful 'tool' that can be used in data mining, there are other perceptual channels that seem to be underused. Our capability to distinguish harmonies in audio sequences (not necessarily musical ones) is one possibility to complement the visual channel. Such approach can be summarised as 'What You Hear Is What You See'. The idea of combining the visual and audio channels is illustrated in Fig. 3. The conversion of data into a sound signal is known as sonification. Similar to the application of visualisation techniques in Fig. 1b, sonification can be used both for representing the input and/or the output of the data mining algorithms.

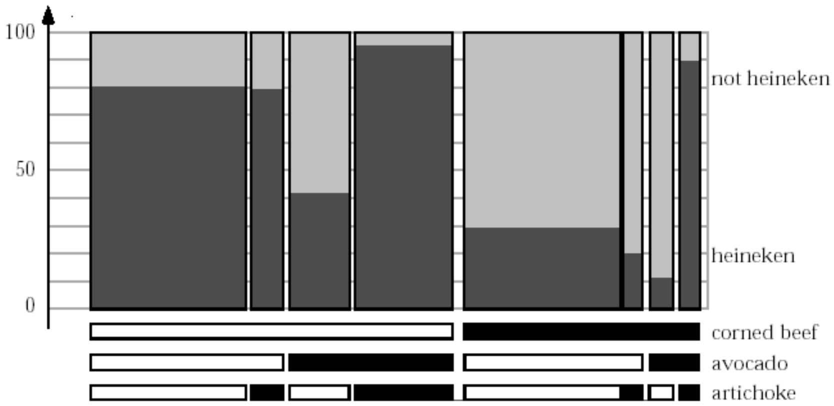

Fig. 2. Example of visualisation of the output of an association rule miner.

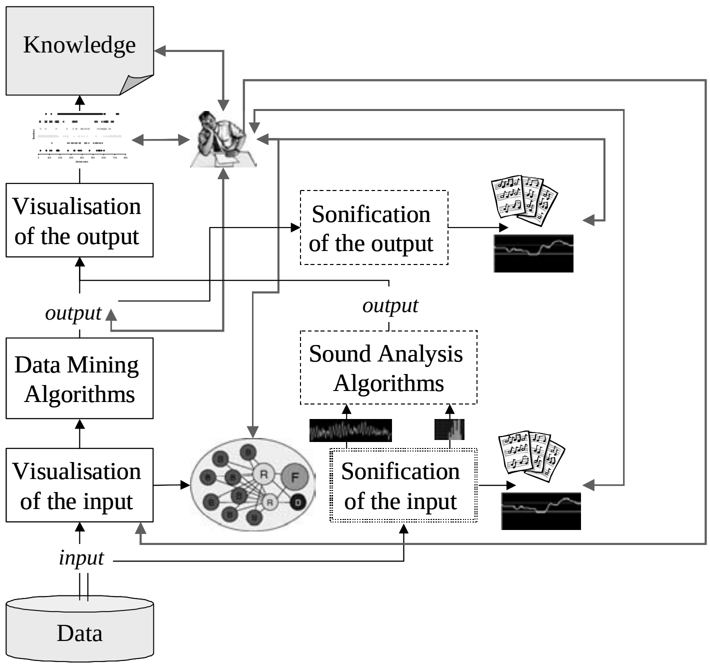

Fig. 3. Combining visual data mining and sonification

In visual data mining, sonification should be synchronised with the visualisation technique. Further, in this paper we discuss the issues connected with designing such data mining techniques and present an example of a practical implementation of combined technique. We briefly discuss the characteristics of the sound that are suitable for such approach, the actual sonification process, the design of the overall combined technique and the results of the experiments conducted with proposed technique.

2 Characteristics of sound for time dependent data representation

Several researchers have investigated the use of sound as means for data representation [4-11]. In this context, the important feature of the sound is that it has a sequential nature, having particular duration and evolving as a function of time. A sound sequence has to be heard in a given order, i.e. it is not possible to hear the end before the beginning[1]. Similarly, a time series depends on time and have the same sequential characteristics. Consequently sound provides good means to represent time series.

3 Sonification

The easiest way to transform time dependent data into sound is to map the data to frequencies by using linear as well as chromatic scale mappings. We call this process a pitch-based mapping. We compute the minimum and maximum data values from the chosen series and map this data interval into a frequency range, chosen in advance. Each value of the series is then mapped into a frequency. To avoid too large, non-realistic intervals, we first discard outliers (see below).

Another pre-treatment is the smoothing of the series. In fact, if we map all the points of a series into a sound, we will hear rather inconsistent sounds. A first treatment consists in smoothing the series by a standard mean, for example, by moving average method. After that, we map the smoothed curve into pitch. Beat drums can be used to enhance the shape of the curve (see below).

3.1 Detection of outliers

To detect statistically the values of the outliers, a confidence interval is computed at each time t., based on the normal distribution. Once a data value is detected outside the confidence interval, the corresponding time value is stored and sonified at the experiment phase.

3.2 Beat drums mapping

The rhythm of a beat drum increases with respect to the rate of growth of the curve (i.e. the first derivative).

[1] Images and drawings do not have such constraint. Strictly speaking digital sound recording can provide access to an arbitrary section of the sound fragment, even reproduce the sound in reverse order, which is beyond the scope of this paper.

3.3 Stereo panning

Variation of the stereo acoustics is introduced, for example, an increase of the volume of the right speaker and decrease of the volume of the left speaker.

3.4 3D Curve

When the time series is given at each time, not by a single value but by a function of values, we decide to “hear” at each discrete time the function. We can also choose to cut the surface at a certain level and to hear “continuously” the obtained curve as a function of time. We call these transformations respectively horizontal and vertical travelling. An example of a 3D data surface for sonification is shown in Fig. 4.

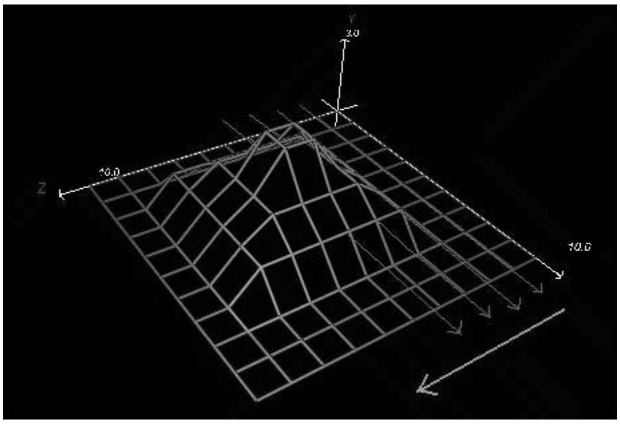

Fig. 4. Example of a surface that can be sonified

4. Prototype implementation

The prototype has been implemented in Java programming language, using the MIDI package of the Java Sound API[2] [12]. The MIDI sequence is constructed before the actual playback. When the designer starts the sonification, the whole sequence is computed. Then computed sequence is sent to the MIDI sequencer for playback.

5. Experimentation

The purpose of the experimentation is to determine how the sonification of two and three-dimensional graphs can complement or be an alternative to visually displayed

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[2] API – **A**pplication **P**rogramming **I**nterface

graphs. An Internet Web site has been created, where sound sequences are presented and can be evaluated by the visitors. The site contains questionnaire that has to be filled in by visitors performing the test. The structure of the questionnaire is the following one:

A. Identification of the user: name, age, gender, title/position, e-mail address. These data are used to identify the subject and to validate the answer.

B. Ability: field of activity, musical experience (instrument played, practicing period), self-evaluation of musical level (from 'no experience' to 'expert level').

C. 2D evaluation: 2D evaluation is divided into three subtasks*:*

Part C.a: **Explanation** about the four sonification techniques used: pitch based only, beat drums, stereo and extreme values detection. Each of them is briefly described and at least one example is given.

Part C.b: **Application test**: four sequences are presented to the user. Each time precise questions are asked:

<u>Question 1</u>: Annual sheep population in England and Wales between 1867 and 1939 (see Fig. 5).

– Were there more sheep in 1867 then in 1939?
– In your opinion, when (which year) did the sheep population reach the minimum?

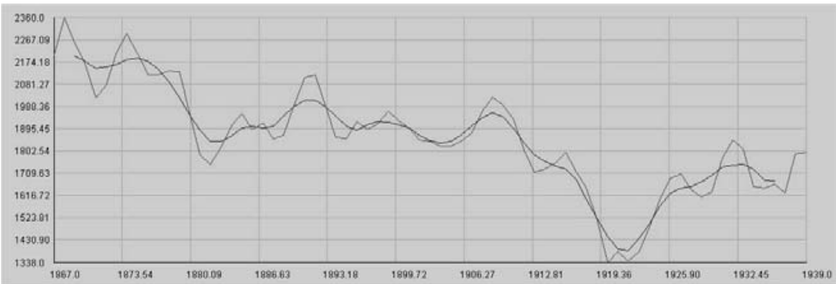

Fig. 5. Annual sheep population in England and Wales between 1867 and 1939

This question aims to evaluate if subject can perceive a global trend in the series and to understand if the relation with the time scale is done. For each sequence, beat drums and stereo mapping are added to enhance the pitch-based sonification.

Question 2 aims to identify whether extreme values are detected. Question 3 aims to identify whether seasonal trend can be detected. Question 4 is focused on trend identification. For each question, the subject must specify the number of times he listened to the sonified data before answering the question.

Part C.c: **Subject preferences**: four other questions aim to evaluate subject preference:

1. Choice of instrument for pitch mapping. The user is asked to hear the sonification of the same data, but with different MIDI instruments for the pitch mapping. The user is asked to grade on the scale 0 to 10 the different instruments (acoustic grand, steel string guitar, violin, synthstrings 2, pan flute). The instruments proposed are very different and belong to a specific MIDI group such as piano, guitar or to string group.

2. Choice of instrument for drums mapping. Different instruments for the beat drums mapping are presented and have to be marked (Celesta, Slap Bass 1, Timpani, Tinkle Bell, Woodstock).

3. Choice of sonification technique. The subject has to give his opinion on the different mapping techniques: pitch, beat drums, stereo mapping, extreme values detection and on the sonification in general. The four levels are proposed: useless, sometimes useful, always useful and essential.

4. Open question: "Please tell us what you think about our project, our applications, this web page or anything else that comes to mind".

D. 3D Evaluation. The same schema is used for 3D curves: explanation about the sonification method, the application test (3 questions), subject preferences. The sonification method is based on a cutting of the initial surface following some direction: vertical (see Fig. 6), horizontal (see Fig. 7) or diagonal.

Each 2D line obtained by the cutting process can be heard, similar to the 2D case. The different lines, proposed one after the other, are separated by a specific sound. Beat drums can still be added to pitch mapping.

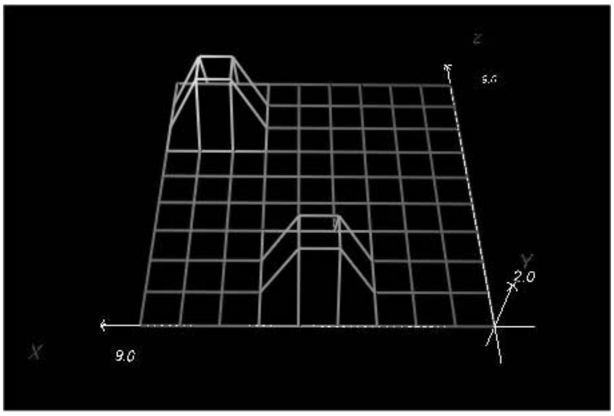

Fig. 6. Data for vertical travelling

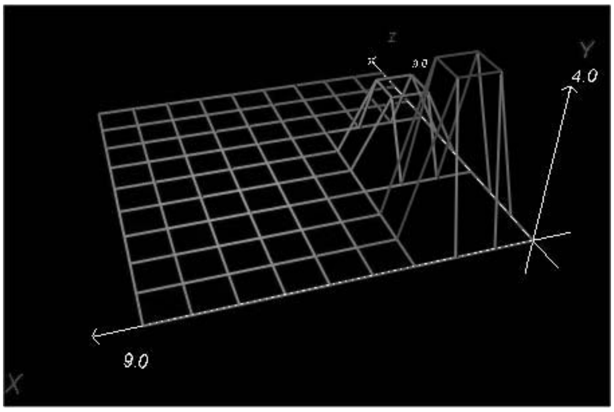

Fig. 7. Data for horizontal travelling

6 Results

Below we present the results of the experiments.

6.1 The sample

23 visitors answered the questions for the case of a 2D visualisation and 18 visitors - for the case of 3D visualisation. A large part of the sample (9) includes people working in the computer science area, who have limited musical experience or no experience at all. To see if people with musical experience get a better score, we have compared the average score in both groups. The influence of the musical and computer science background on the results is presented in Table 1 and Table **2**, respectively. The score obtained for each question is the number of good answers, normalised on a

score out of 100. The average score is the mean of the scores for the different questions.

Table 1. The influence of musical background on results

	2D sonification		3D sonification
	Av. score/100	**N**	**Av. score/100**
Musical background	76	9	40
No experience	66	14	42
		23	

The same comparison was done for computer scientist.

Table 2. The influence of computer science background on results

	2D sonification		3D sonification
	Av. score/100	**N**	**Av. score/100**
Computer science	72	11	41
Others	69	12	40
		23	

Having a musical or a computer science background gives a minor advantage in using sonification of 2D curves. The differences are not significant. We do not observe any difference for the 3D sonification case. The way 3D case has been implemented is rather complex and uses a good spatial representation. Musical or computer experience has a minor influence on the result in this case.

6.2 Results in 2D

The following questions were included in the questionnaire, targeting 2D sonification:

Qu1 Annual sheep population in England and Wales between 1867 and 1939
- 1.1 Were there more sheep in 1867 than in 1939?
- 1.2 About which year did the sheep population reach the minimum?

Qu2 Daily morning temperature of an adult woman during two months
- 2.1 Did she have fever during the period?
- 2.2 If yes, for how long did she have the fever?

Qu3 Monthly electricity production in Australia between January 1956 and August 1995
- 3.1 Is the electricity production in Australia lower in 1956 than in 1995?
- 3.2 How would you categorise the evolution of electricity production in Australia: as linear or as exponential?

3.3 Is the evolution of electricity production in Australia characterised by seasonal trend?

Qu4 Monthly Minneapolis public drunkenness intakes between January 1966 and July 1978 (151 months)

4.1 Were there more intakes in 1966 than in 1978 ?

4.2 Is the evolution of public drunkenness intakes linear?

The results are summarised in Table 3.

Table 3. Summary of the results for 2D

		Correct	Wrong	No idea
Qu1	1.1	17	5	1
	1.2	17	6	-
Qu2	2.1	23	0	0
	2.2	13	10	0
Qu3	3.1	22	1	0
	3.2	12	11	0
	3.3	16	6	1
Qu4	4.1	20	2	1
	4.2	19	3	1

6.3 Results in 3D

The following questions were included in the questionnaire, targeting 2D sonification:

Qu1 A 3D graph containing 2 bumps has been sonified. The selected mapping is the vertical travelling and the sonification starts from the bottom right corner.

- If the grid below (3 x 3) represents the graph, where are these 2 bumps located?
- Do they have the same height?

Qu2 Same kind of questions with respect to horizontal travelling.

Qu3 Same kind of questions with respect to diagonal travelling.

The results are summarised in Table 4.

Table 4. Summary of the results for 3D

		Correct		Wrong	No idea
		2 correct	*1 correct*		
Qu1	1.1 Trend	4	6	8	-
	1.2 Value	11		4	3
Qu2	2.1 Outlyers	4	6	8	0
	2.2	12		33	0
Qu3	3.1 General trend	1	11	6	-
	3.2	10		6	2

7 Discussion

There are some issues related to the design of the experiments that could have influenced the outcome of the experimentation:

- In a graphical representation, if you want to identify a particular point, you need to find the information concerning that point on each axis. In the experiment, we provided little information about the scale (for example, see Fig. 6 and Fig. 7). The wording gives the limits for the time period. The lack of scaling information could have caused some difficulty in identifying particular points or sub-periods.
- The outcomes in the case of sonification of a 3D graph are worse than in the case of 2D. It is necessary to take in account that the sonification of a 3D graphical representation is more difficult then the sonification of a 2D graphical representation. A possible reason could be that the sonification technique is based on visual representation and does not use sound properties, but surface properties, as seen in a 3 axis referential.

An important issue becomes the correspondence between visual and audio representations of the data. Consistent representations should provide audio representations that allow transitions from 3D to 2D projections in terms of corresponding sound representations.

8 Conclusions

Overall, the results of the experimentation on sonification of time dependent data leave optimism for further investigation of sound as medium for presenting information. The sound can be an effective complementary interface to the visual interface for data representation. Similar results were presented by Alty [5] for people with disabilities. On the other hand, the experimentation with sonification of surfaces in

3D space did not efficiently support the visual representation and certainly could not replace it (at least for the way it had been implemented).

In general, this experimental work contributes to the research efforts on bringing other (non-visual) channels for information and data processing. This research area, that can be labelled as ‘perceptual data mining’, is focused on interactive systems that support rich perceptual – visual, audio, tactile – interaction between the human and the data representation. Such systems are expected to play significant role in assisting data understanding and supporting pattern discovery process, utilising human information processing capabilities.

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