Interactive Sonification of Grid-based Games

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Abstract. This paper presents novel designs for the sonification (auditory representation) of data from grid-based games such as Connect Four, Sudoku and others, motivated by the search for effective auditory representations that are useful for visually-impaired users as well as to support overviews in case that the visual sense is already otherwise allocated. Grid-based games are ideal to develop sonification strategies since they offer the advantage of providing an excellent test environment to evaluate the designs by measuring details of the interaction, learning, performance of the users, etc. We present in detail two new playable sonification-based audio games, and finally discuss how the approaches might generalise to general grid-based interactive exploration, e.g. for spreadsheet data.

1 Introduction

Sonification, the auditory representation of data, has become an important sensory channel for rapid data scanning, real-time monitoring and exploratory data analysis [6]. Particularly if the data is structured in time (e.g. time series, process data), sonification is a good choice in order to communicate the patterns by using the auditory modality. However, a very frequent data type consists of two-dimensional grids or matrices of data. In fact, most data sets which are subject to the analysis in data mining can be re-organised to take this form, using columns for features and rows for measurement vectors. Images are also naturally represented by a 2D-grid of measured intensity values. Spreadsheets are another frequent example of grid-based data. Thus it makes sense to investigate how to make such data more accessible by using sonification, or how sound can be used effectively to deliver a concise overview or summary of the data.

However, the sort of overview needed depends highly on the task, and often different task-specific overviews are needed, ranging from overviews that give a rough idea how a grid is filled to very-specific overviews such as ‘what cells form groups with a particular pattern’, row-wise scans, diagonally aligned patterns, symmetries within the grid, etc.

Grid-based games are a special case of grid data in the sense that usually the grid dimension is fixed and only a limited number possible elements of a finite set fill a grid cell. Examples of grid-based games are chess, Chinese checkers, Connect Four, noughts and crosses (or tic-tac-toe), Sudoku, to name a few.

We develop our sonification approaches at hand of grid-based games for the following reasons: (a) there is a very clear task for the players, yet (b) there is a sufficient variety of required overviews so that the task is not trivial, (c) the limited complexity facilitates the designs, and (d) the game itself provides a very useful test environment to evaluate all aspects of the design, from performance and learning to the æsthetics (acceptance, qualitative evaluation).

1.1 Sonifying grid data

When designing grid-based game sonifications, a decision has to be made whether the sonification shall be generic in the sense that it is applicable to a wide class of games, or specific for a particular game. Generic approaches generalise better towards a more wide-spread use, maybe even beyond the scope of grid-based games into tasks such as video data sonification, however, they may not deliver exactly the information that the players need to play the game, or allow to extract these patterns only after longer training.

A mix of sonification techniques that offer both specific and inspection general seems suitable, and puts into the fore that the users will need control over what sonification is to be selected and what parts of the grid to be explored. Indeed, interaction plays an important role in inspecting grids, as can be seen also in visual exploration of grid games, where eye-movements, fixations and saccades are naturally used to serialise and access the information. In a similar fashion we believe that manual interaction is an important (if not the key) ingredient to create successful designs. We present for instance a graphics-tablet based sonification approach where proprioceptive information serves the intuitive understanding of the position in the grid whereas sound conveys the information about the grid content at hand of the 4×4 Sudoku in section 3. Different exploration strategies emerge from such an approach.

To couple interaction to plausible acoustic responses, we use ideas from Model-Based Sonification [2, 4] (MBS). MBS describes how to use excitatory systems in order to create informative sound as result of processes where the user's interaction puts energy into an data-driven sound-capable system. Even without creating a coherent sonification model, MBS might be helpful to create designs that are more intuitively understood.

A key problem in grid-based game sonification is the missing persistence of the grid, as opposed to the persistent visual game board. To create a close analogy to the visual task of adding visual elements on a board, an auditory version can use a stationary sound pattern which is permanently played, allowing players to add sound elements accordingly. Conditions to win a game translate to corresponding auditory conditions within the sound. This analogy might open a window to the design of very interesting new audio games, however, we here keep the focus on grid-based games, and thereby translate the analogy into a rhythmical sonification strategy where, instead of a stationary sound, a repetitive sound pattern is created, which can be regarded as one bar in a repeating sonic loop. We develop this idea into a playable version of Connect Four in section 4.

We discuss our ideas via qualitative experiments with a limited set of users, since we are still within the design phase towards stable sonifications, and we close the paper with outlooks on our ongoing work.

2 Background

In the visual realm, space is used to make salient information of interest. In the case of grid-based games, it organises the items on the grid so that the players can easily make sense of the state of the game. This is also true of data that is visually displayed in tabular format: it makes correlations between two axes clear. We can use grid games to represent tasks that one might perform with grid-organised data, such as in a spreadsheet. Connect Four can represent looking for linear patterns in data while Sudoku can represent cross-correlating subsets of data.

2.1 Traditional methods

A grid-based representation that often gets tackled is the auditory representation of images. This is traditionally done via scanlines. Examples of this can be seen in representations of images where each pixel value is mapped to sound and played in order. More advanced techniques involve finding textures in the image to represent in sound. The difficulty with the scanline approach is the challenge of lining up the rows so that one can understand patterns that are orthogonal to the direction of the scanline. The pattern and auditory texture approach is much closer to what we try to accomplish here with our implementation of Connect Four.

Other pertinent work is research into the sonification of spreadsheet or tabular data. Stockman, Hind and Frauenberger [7] describes a system where visually-impaired users can navigate spreadsheet data by mapping numerical values to a range of pitches. The data is then played serially by row or column. This is meant for generic use; our approach is to look to the specific to inform the generic. Kildal and Brewster [5] describe a method of providing overviews of numerical data in tables by again mapping values to pitches. Here, rows and columns are presented concurrently giving the user quick access to where the highest and lowest values are to be found. The idea of concurrency is one we apply to our implementation of Connect Four.

2.2 Connect Four versus Sudoku

One can generalise grids as $M \times N$ grids with a set of k potential token values. Connect Four is a 7×6 grid with three token types (one for each player as well as the 'empty cell' item). Sudoku is a $n^2 \times n^2$ grid with $n^2 + 1$ tokens (n^2 tokens and the 'empty cell' item). The most common variant of Sudoku is where $n = 3$ or the 9×9 grid.

There are several differences between the games and their grids. Connect Four is a two player game while Sudoku is a single player game. Another difference is that in order to win Connect Four, a pattern of four tokens in a line must be achieved while in Sudoku the tokens must be uniformly distributed. In both games the grids get filled one move at a time. In Connect Four at the end of each pair of turns there are an equal number of each token in the grid while in Sudoku this condition is only properly achieved when the puzzle is completely solved.

Another key difference is that in Connect Four, when tokens are added to the grid, they are placed in the lowest unfilled cell in the selected column while in Sudoku, cells can be filled in any order. The playing of Connect Four is what drives the dominant features of the sonification described in section 4. The columns are primary as their state is what informs the players where tokens may be placed and the rows are secondary as they describe the end position of the token placed in a particular column. Sudoku is less straight-forward: it is the structure of the grid and the rules of the game that are important. Neither the rows, columns or cages (see figure 1) are dominant but rather they must be intercompared so that a player can deduce the value that belongs in each cell.

3 Model-Based Sonification for Sudoku

Sudoku is a single player game where a player must fill all the cells on the grid so that the values in each row, column and cage are unique. The most common form of Sudoku is a 9×9 grid, shown in figure 1. The grid is further subdivided into nine 3×3 sub-grids, called *cages*. Here, we implement an easier version: 4×4 Sudoku.

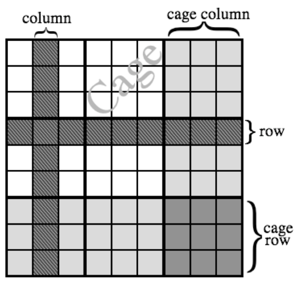

Figure 1: *The Sudoku grid.* The 9×9 Sudoku grid is made up of nine 3×3 sub-grids, called *cages*. Cage rows/columns are horizontal/vertical sets of cages.

3.1 Design and implementation

In the 4×4 grid, there are five possible values for each cell: the four tokens and 'empty'. Each grid has a certain number of cells that have pre-filled-in values. In order to play the game, players need to cross-reference rows, columns and cages in order to deduce what values go into the empty cells. Key information for solving includes where the grid is dense/sparse and where all the items of the same values are present/missing in a row/column/cage/cage row/cage column. To enable flexible self-directed exploration – much as a you would get from glancing – we use a graphics tablet for interaction (see figure 2). We also employ MBS to provide contextual information to the player. Sonification examples are provided at [1].

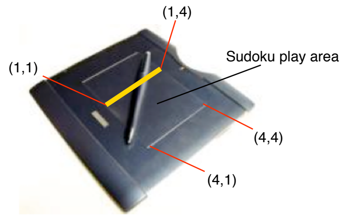

Figure 2: *Playing Sudoku on the Wacom graphics tablet.* Post-it notes defined a square play area.

3.1.1 Representation of the grid

The use of the graphics tablet means that we do not need to provide strong location information. As a result, the grid is not explicitly represented in sound except in the MBS that we use when a player probes a cell of the grid. We use a standard energy flow model as introduced in [2] to describe the effect of each cell upon its neighbours:

$$\frac{dE_{ij}}{dt} = -\lambda E_{ij} + \sum_{(k,l) \in N(i,j)} q \cdot (E_{kl} - E_{ij}) \qquad (1)$$

where q represents the energy flow rate between neighbour cells and λ is the energy loss or the decay of the energy. ij denotes the co-ordinates of the cell and $N(i,j)$ is the set of all cells that neighbour ij.

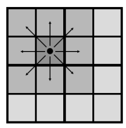

Figure 3: *The Sudoku flow model* When a cell is excited, the energy flows into the neighbouring cells as described in equation 1.

3.1.2 Representation of the cell values

The four values in the grid are represented by pitch. The pitches range evenly from MIDI note 64 to MIDI note 80. When a cell is empty there is a white noise sound that is modulated to sound like the wind. Our initial design had empty cells represented by the lowest pitch, however only players with musical training found this comprehensible. We used SuperCollider3 for all sonifications here, using PlayBuf as sample player and standard techniques for panning and filtering of sound. More information will be provided on our website at [1].

3.2 Playing the game

Players a stylus to explore the grid and enter values on the graphics tablet. There is also a graphical representation of the grid (see figure 4) which provides the limits of the cages. To probe the grid, players either tap or drag the stylus across the grid. When the stylus enters a cell, the cell is injected with energy (as described in equation 1) and the energy flows through the grid. To enter a value, players click a button on the stylus. Each click cycles the current value of the cell to the next value. If a cell is a starting value, nothing happens.

Figure 4: *The graphical interface for Sudoku.* Players interact with the grid using the graphics tablet stylus.

3.3 Discussion

5 men and 2 women played the auditory version of 4×4 Sudoku, two of whom were musicians and one of whom was visually impaired. Their level of experience with playing Sudoku ranged from beginner to advanced.

3.3.1 Player feedback

Feedback for Model-Based Sudoku was varied. We presume that is this partially due to it being a single player puzzle game (a two-player game, on the other hand, engages the players competitiveness and allows them to learn from one another). The general consensus was that while 4×4 Sudoku is quite simple visually, the auditory version was quite challenging and the smaller versions was approximately the right level of difficulty. Here are some of the more specific findings:

First try First attempts were often frustrating, sometimes resulting in starting over. This indicates that different initial solving techniques are needed: mapping out grid density rather than location of similar items. Second games were much smoother.

Tapping vs dragging We assumed that the majority of interaction would be by dragging. However, the majority of players (Players 2, 4, 5 and 7) preferred to tap the cells to excite the grid. Player 2 explained this by saying that the sounds made by the model made this tapping interaction more intuitive. Another explanation is that players were tapping in order to compare only two values at a time.

Draggers For the players who dragged more than they tapped, the stylus and tablet interaction allowed them to quickly scan a row, column or cage by drawing lines or circles in the grid. These players appeared to be the fastest at completing puzzles. We anticipate that this is because a quick scan allowed players to quickly determine which tone was missing or if there were two tones of the same value in the row/column/cage.

Panning One surprise was that both Players 2 and 5 (both tappers instead of draggers) found that the panning was not helpful and in fact was distracting and made it harder to compare values. This possibly indicates that the use of the graphics tablet sufficiently localises a player and the additional cues are unnecessary.

Based the two different ways of interacting with the grid (dragging vs tapping), we expect that a better fitting model will need to be devised to make it more natural for the dragging technique to be used. The faster interaction allows for the patterns that occur to be more quickly absorbed. With a more intuitive model, players can more naturally take advantage of the way we process audio.

3.3.2 Informing grid sonifications

Much like with how direct manipulation and the introduction of the mouse revolutionised graphical user interfaces, the use of the tablet enables the user to a greater degree than keyboard interaction. The tablet interaction contributed more to the success of the 4×4 Sudoku than the use of Model-Based Sonification. With a sufficiently small grid so that the number of values is not overwhelming, stylus interaction gives the user the flexibility to explore the grid as they desire and provides speed that is difficult to mimic with traditional keyboard or 5-way navigation (such as on a mobile phone or a game controller). It also neutralises the problem of strongly localising a user in the grid through sound.

3.4 Scaling up to 9×9 Sudoku

The 4×4 implementation of Sudoku does not scale up well to 9×9 Sudoku. The main problem is that there are simply too many values to remember. We require a new model that lends itself better to the larger grid. The main concepts here are generating models that can support the cross-hatching technique – where players cross-correlate values in rows, columns and cages to deduce values – and also categories and order the values used in the grid. The problems that occur in the 9×9 Sudoku grid inform us how to alter the model that was used for sonifying the 4×4 grid.

It is clear that we need to develop specialised overviews and filters to allow users to focus on different parts of the grid. Key information is about what is present or missing and picking out items of similar values. What this implies is that players must be able to apply certain filters in combination as they interact with the grid or prompt overviews to be played. However, it is also important not to lose the advantages from the direct interaction provided by the graphics tablet. For example, were the player interested in an overview of a row, tapping to the left or right of that row could play an overview of the row where tokens are played in a predefined order using the graphical interface and panning to re-enforce their positions. To query where a particular token is present, players could select the token from a list and use gestures in each cage to determine if it is present. Another filter could be used in combination with a the token filter to show where the token is missing. Finally a filter that only displays where the empty cells are could highlight where the grid is dense or sparse. To solve the problem of the large number of values to be entered, sounds that can be vocalised can be used. This enables the player to self-organise the tokens and these can then also be used as input removing the necessity to make mappings between tokens and their graphical representation. Vocal sonifications have been successfully used in the sonification of EEG data [3].

Given the complexity of the sonification and interaction needed, we have tabled our work on Sudoku for the time being and are focusing on the second game we implemented: Connect Four.

4 Rhythmic Connect Four

Connect Four, a Milton Bradley game, is a two-player game on a 6×7 grid where each player tries to line up four game tokens while blocking the other player from doing the same. The traditional Connect Four grid is shown in figure 5. The auditory version of this game is based on adding sound events to a rhythmic pattern. Sound examples are provided on-line at [1].

4.1 Design and implementation

The important features of Connect Four are the columns and the locations of tokens, especially where there are several of the same value in a line. Knowing what is around a token is therefore very important as well as being able to focus on each token individually.

4.1.1 Representation of the grid

We represent the grid in a short looping sound so that players can think about the entire grid and understand where tokens are in relation to one another. The aim is to provide all the information quickly enough so that the players can reason about it as a whole with the distinct parts making up a pattern that they can work with. The end result is that the grid is like a short bar of music. We then punctuate this bar of music with two drum sounds to help players localise themselves within each loop. A stronger (or louder) drum plays at the start of the grid and the softer (or quieter) one occurs at the fifth column of the grid. Our initial design did not include the second drum however, it was quickly apparent that when the grid is sparse, it did not have the energy or liveliness for which we were aiming nor was the localisation strong enough. This aim also drove the rate of our auditory display. We experimented with grid lengths of 0.7 to 3.5 seconds. Less than a second was found to be quite manic and over two seconds a bit too slow. Our preferred length was 1.4 seconds with 0.2 second pause between loops, coming to a total of 1.6 seconds.

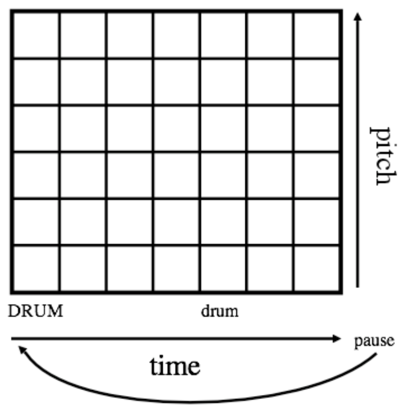

Figure 5: *The sonification of the Connect Four grid.* The row determines the pitch of a token and the column drives when the token plays. Two drum sounds punctuate the auditory grid at columns 1 (louder drum) and 5 (softer drum). There is a short pause – the length of a column – at the end of the grid.

4.1.2 Representation of the columns

The columns in the grid are evenly spaced in the auditory grid loop. The values in each column are presented concurrently. The pitch of each value is determined by the row, where the bottom row is mapped to a low pitch and the top row is mapped to a high pitch. The pitch intervals used can greatly affect the æsthetics of the auditory display. We experimented with several intervals, such as ‘neutral’ or ‘jazzy’. While the neutral pitch interval allows for the greatest separation of the notes (MIDI pitch 52, 56, 59, 61, 64, 68) [1] the jazzy interval (MIDI pitch 52, 54, 57, 59, 62, 67) was the most engaging and least irritating after many repetitions.

4.1.3 Representation of the tokens

Each token was represented by an instrument. We used a vibraphone and an electric bass in our implementation. The pitch interval for each instrument is modulated to fit the instrument better. These two instruments are very different sounding and their envelopes are diverse making them easier to tell apart. Additionally, each token plays in a different speaker. These differences allow the players to pay attention to each token alone.

Additionally, we use brilliance to indicate when there are several tokens in a row. Minimum brilliance corresponds to a player’s token all on its own and maximum brilliance is applied to four of a player’s tokens in a line (game is over). If the game is won, the winning combinations has maximum brilliance while the brilliance of all other tokens is set to the minimum. This use of brilliance highlights tokens that have the potential to win the game and gives a clear indication when the game is over.

4.2 Playing the game

The interface for playing Connect Four was graphical (see figure 6). Each player has a slider allowing players to drop their tokens into the grid. The value of the slider represents the columns in the grid. Each player also has a button; until this button is pressed, the player’s move is not committed. This allows each player to move their tokens and hear the effect of their move before making a final decision for the turn.

4.3 Discussion

We performed an informal evaluation with five different players: four men and one woman, two of whom were musicians and one of whom was visually-impaired. Their ages ranged from the late twenties to the mid fifties.

[1]using the SuperCollider3 `.midicps` method

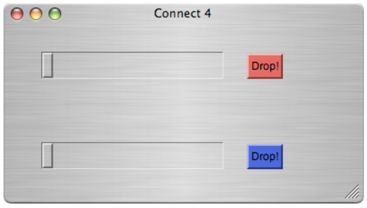

Figure 6: *The graphical interface for the Connect Four game.* Each player uses their slider to select columns and the button to enter values in the auditory grid.

4.3.1 Player feedback

The general feedback from the informal evaluation of the game, which used the graphical interface shown in figure 6, was quite positive. Here are some of the most frequently mentioned topics:

Playability Most players felt that with a little practice, the game would be quite playable.

Engaging rhythms Players found the sounds æsthtically pleasing. Players as well as bystanders would find themselves moving along with the beat.

Losing the beginning of the grid Players would often get confused about where the grid began in the sonification. The first token placed in the grid seemed to take the players’ focus away from the drum beat.

Graphical interface Several players used the position of their opponents slider after their move to figure out where the last token was placed. Player 2 commented that they felt this was a cheat.

Masking The higher pitched tokens overpower the lower ones, especially in the case of the vibraphone. We hypothesised that this may be in part because the players are not taking advantage of listening to a single players tokens by listening to one speaker at a time.

Playing patterns Players either tended to experiment with several moves before committing while others selected a column right away. It is unclear what drives this behaviour and whether it has a correlation to successful game play.

Interaction The slider did not always make it clear when the player moved from one column into the next. This was addressed by adding column delimiters to the interface as shown in figure 8.

4.4 Informing grid sonifications

Our rhythmic Connect Four contains several pieces of design knowledge that can be applied to other sonifications of grid data.

Looping through the grid The technique of making the grid into an auditory loop – be it column-wise as we have done or not – shows promise for providing a grid overview. This is similar to other work in auditory overviews [5], but instead of the column being sonified at the request of the user, it is repeated to continuously remind the user of the state of the grid. We believe this to be a technique that can help overcome the lack of persistence in the auditory channel. Here, we have implemented this technique and players of the Connect Four game found it useful and engaging.

What remains to be tested is the limitations of this technique. Our sonification was limited to seven columns with a maximum of six values to represent while most data sets encompass many more than that. It remains to be seen whether the technique is dependant on the number of columns presented or on the duration of the sonification. We envisage this technique being extended to comparing data sets as well, provided an overview of each data set could be presented as we have presented columns here.

Identification of a pattern Connect Four has a clear pattern that determines if a player has won: four tokens of the same kind in a line, be it in rows, columns or diagonally. We use brilliance here to highlight where this pattern occurs in the data and where partial patterns occur. This technique allows us to essentially apply a filter to the data. In our case here, we had a very simple pattern to match. We envisage that this can be extended to many different patterns with the potential of several patterns being applied in turn to show different aspects of the data.

4.5 Formally evaluating Rhythmic Connect Four

Due to the positive user feedback from Rhythmic Connect Four, we are currently taking this work forward and have just completed a formal evaluation of the interface with some minor changes. In this study 7 pairs of players each played 3 games and were interviewed about their experience. We focused on how they used the audio to inform their playing strategies. The results of this evaluation will be reported in further publications however we describe preliminary results here.

To address the naturalness of the interaction and to focus more on the auditory aspects of the game, the interface was moved to the graphics tablet. This allows two players to sit opposite each other (see figure 7) and to divorce the sonification from any visual representation. The two main differences that resulted from this changes was that (1) players were not aware that the column selection area was a slider and (2) that after selecting a column, the other player could not see where their opponent had played. The graphics tablet layout is shown in figure 8. This allowed players more freedom in their interaction and also pushed them to rely more on the auditory feedback rather than looking at where their opponent placed a token throughout their move.

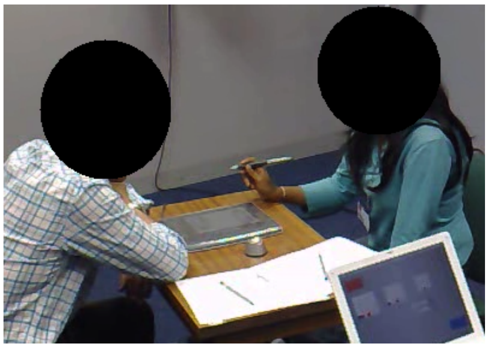

Figure 7: *Two people playing Connect Four.* The players trade off the stylus and use areas on the tablet to play in a column, as show in figure 8.

Figure 8: *The interface for the Connect Four game on the graphics tablet.* The interface is inverted, allowing players to sit opposite each other as shown in figure 7.

The training we performed as part of the formal evaluation addressed several of the problem we noted earlier. One such problem was losing the beginning of the grid or sound loop. We trained players to listen for the louder drum beat and found no indication that this was a problem during the evaluation.

Another problem was the vibraphone instrument overpowering the electric bass instrument. We addressed this by boosting the volume of the electric bass so it was not so easily overpowered and by training players to listen to a single players token at a time (as each player has their own speaker). A problem reported in this second evaluation was that the higher pitched tones overpower the lower ones. We will look at this issue further as we complete our full analysis.

5 Conclusion

In this paper, we have presented some new approaches for the sonification of grid-based games. These grid games represent use cases of data displayed on a grid allowing us to develop techniques that can be transferred to related applications, such as real-time video stream sonification, spreadsheet sonification for visually-impaired users, or the generalisation to 3D grids. These are attractive follow-up steps on our research agenda towards a better exploitation of sonic interactions for grid-structured data types.

We introduce an interactive sonification of 4×4 Sudoku grids using direct interaction with a graphics tablet. The Sudoku grid can inform on how we might sonify sets of data and how they cross-correlate. The sonification design was straightforward, following the Model-Based Sonification idea that data parametrises acoustic systems, and that movement on the grid excites these systems. Thereby the sounds indicate quite directly what state a grid cell is in. Interestingly, users start quickly to develop strategies to explore the 4×4 grids which we haven't anticipated beforehand, such as drawing circles in cages, or doing quick line-scans, or tapping on cells. Due to the limited complexity of the grid, this direct interaction is suited to allow users to solve the Sudoku. However, scaling the problem to the 9×9 Sudoku fails for two reasons: the user's memory is exceeded with the many items, and the proprioception is not enough accurate to understand exactly what cell is being inspected. To better solve the 9×9 Sudoku, possibly more specific sonification designs need to be developed.

The Connect Four game represents grid data where linear patterns occur. A rhythmic sonification approach was developed for the game, which can now successfully be played with the visual display playing a very minor role. It exemplifies an auditory display in good analogy to visual games where the board is persistent for both players – here the persistence is created by a looped sonic pattern which serialises the grid column-wise. First comments from players are promising, however, we need to conduct user studies in order to investigate the potential of learning to better understand the grid set-up.

We are confident that by focusing on grid-based games we will be in a very good position to evaluate sonification designs and to compare the effectiveness of different designs. These games thus represent an ideal platform to examine sonic interactions. We hope to make the games attractive so that players enjoy to play and generate valuable data for us voluntarily.

Our next steps in this work is to complete our analysis of the formal evaluation of Rhythmic Connect Four and to integrate some of findings from Sudoku to strengthen its implementation. This will include a whole spectrum of grid inspection: direct cell-based interaction, localised region overviews and overall summaries into a coherent interactive sonification system. This demands that we structure the sonifications so that the information obtained via the different approaches can easily be fused into an increasingly accurate mental image of the grid.

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