CircoSonic: A SONIFICATION OF CIRCOS, A CIRCULAR GRAPH OF TABLE DATA

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ABSTRACT

This paper presents, applies and evaluates "CircoSonic," an interactive sonification of "Circos." It outlines the development of modifying a gaming engine to replicate Circos, a circular graph for comparing pair wise relationships in a 2D data table, with the added capabilities of sonification through interaction.

The developed prototype is applied to a static dataset and evaluated using an insight based methodology. The evaluation uses a muted version of CircoSonic to establish a comparison between visualizations, from which a comparison between visualization and sonification can be extrapolated.

The results demonstrate that with a static dataset, CircoSonic with sound consistently outperforms CircoSonic without sound, and Circos, despite being solely visual, outperforms both versions of CircoSonic. The conclusion is that the visualization component of CircoSonic can be significantly improved and that a move from static to dynamic data may display different results. The investigation of novel visualizations from the perspective of auditory displays needs to be extended to include those which deal with multivariate and dynamic datasets whilst still offering a broader application to diverse data domains.

1. INTRODUCTION

The field of auditory displays, through the course of its development, has used the field of information visualization as a point of comparison, often referring to Tufte [1-11]. Auditory displays aim to accomplish similar goals as visual displays through the alternative, but often complementary communicative medium of sound which affords advantages that are difficult or impossible with vision.

The most common visualizations, such as line graphs, bar graphs and pie charts, have been investigated by researchers of auditory displays and sonification. However, the emergence of novel scientific visualizations necessitates an investigation into less common but more potent visualizations. One emerging visualization exemplary is "Circos," a circular graph for comparing pair wise relationships in a 2D data table [12]. It has been used by "mainstream periodicals and newspapers" [13-16] to communicate to a general audience. Circos (see Fig. 1) was developed for the comparative genomics field as a visualization tool, but is also applicable to other data fields where identifying relationships and the nature of those relationships are of interest. The Circos graph in Fig. 1 (Created with Table Viewer: http://mkweb.bcgsc.ca/tableviewer) is a visualization of the data in Table 1. The graph shows a relationship between
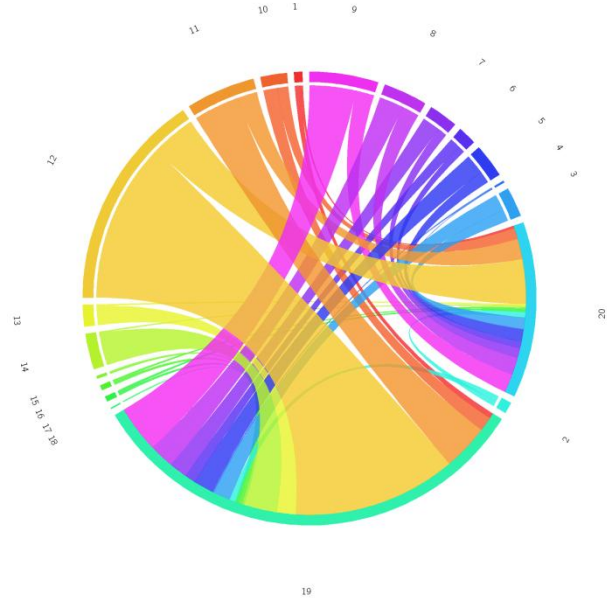
Figure 1: Circos graph - colors represent categories in a table.

	1	2	3	…	10	11	12	…
19	585	605	1740	…	1460	4750	16855	…
20	240	535	1190	…	1170	2090	4620	…

Table 1: Table data used in evaluations (see section 4).

categories 12 and 19, indicated by a large colored ribbon. Ribbons are sized and layered according to data values, such that large values are indicated by large ribbons on top. This paper will investigate an auditory display of Circos - specifically an interactive sonification termed "CircoSonic."

Before discussing CircoSonic, a background of the literature will be presented in section 2, to identify established and unexplored areas of research. Section 3 will outline the development of CircoSonic from the parsing of information to its interactive sonification. Section 4 will discuss the application of the CircoSonic system to a dataset. Sections 5 will describe the evaluation methodology used to compare the performance of Circos, CircoSonic, and a muted version of CircoSonic. Lastly, sections 6 and 7 will present the results and conclusions of the evaluation.

2. BACKGROUND

This section will review the literature to identify existing, emerging and unexplored areas of research. The areas include visualization and genomics, sonification and genomics, sonification of graphs and spreadsheets, and sonification and gaming.

2.1. Visualization and genomics

The field of comparative genomics commonly deals with datasets of chromosome and genome sequences, which are large but static datasets. These can be analyzed by comparing pairings of data values through visualization. An exemplary example is Krzywinski's Circos [12] which progresses from the conventional straight bar diagrams to a circular ideogram and has become a visualization tool useful to other data domains.

"GenomePixelizer" [17] is a visualization tool that allows comparison between more than one pair of genomes. It stacks horizontal bars in a 2D viewer and links duplicate genomic regions with colored lines. ChromoWheel [18] operates as an internet browser application and enables comparisons of multiple genomes similar to GenomePixelizer. Unlike GenomePixelizer it uses a circular layout and draws links that span the interior of the circle. This prevents connecting lines from intersecting other lines and labels.

Circos, appearing as early as 2007, goes beyond ChromoWheel by drawing ribbons instead of lines. This is a small but significant change because it offers an additional dimension to relationships between categories. Circos is a visualization tool that facilitates "the identification and analysis of similarities and difference" [12]. Whilst ChromoWheel and GenomePixelizer simply identify relationships, Circos identifies and provides a visual sense of magnitude for each relationship.

The utilization and development of Circos is continued by "Circoletto" [19] which is "an online visualization tool based on Circos" that offers functionality of the "Basic Local Alignment Search Tool (BLAST)" [20] and supports calculation of sequence similarities, before presenting them visually in a Circos graph.

"Gremlin" [21] goes further to identify an issue and present a solution for Circos's inability to accurately enable "spatial comparisons across rings of varying radii." It demonstrates that the conventional straight bar diagram is more effective for this task, despite connection lines intersecting each other and producing "visual artifacts." Ekdahl [18] in fact recognized the advantages of both the straight bar diagram and circular ideogram. "The circular layout of chromosomes is advantageous for showing relationships between different chromosomes, as the connecting line never crosses over…While the straight bar representation is popular for showing distributions or populations of objects on a chromosome." [22]

Despite recognizing Circos's short comings, O'Brien [21] still states that Circos is "state-of-the-art in genomic rearrangement visualization." Other visualization tools in the comparative genomics field include NCBI map viewer, TIGR Genome Browser, MIPS Arabidopsis Redundancy Viewer and "gff2ps" [17] and Worm-Base (AceDB) cited by [17, 18].

As the visualization strategies developed by the field of comparative genomics are reapplied to other disciplines, there is a need to consider models that deal with dynamic datasets. The examples in this area lack a dynamic dimension because they have not yet needed to deal with them. There is also little research focused on interactivity beyond simply inputting data and navigating the visualizations. There is scope for research looking into a higher degree of interaction including user rearrangement and remapping of the visualization to draw comparisons between component data. Lastly there is opportunity to represent these datasets and their visualizations using sound. There has been some research done in this area, and will be discussed in section 2.2.

2.2. Sonification and genomics

It has been stated in the Sonification Report [3] that projects such as the Human Genome Project require ways to manage and explore the large datasets they collect. Within the field of auditory displays, there has been some research in parametric mapping sonification (PMS or PMSon) as a means to explore data of genomes, proteins and DNA sequences.

Won's [23] sonification experiment of human chromosome 21, sonifies the presence of CpG islands, "because they indicate areas of interest along the genome." This technique is quite specific and cannot be reapplied to other fields without significant modification. Dunn and Clark [24] similarly experimented with a sonification process specific to DNA sequences, proteins and amino acids. Their application of Morse code is very specific for representation of the English alphabet and again cannot be reapplied other data types.

These approaches to genomic sonification have, like the genomic visualization, been domain specific without a generic reapplication to other areas. Circos, although developed by and for the comparative genomics field, has been reapplied successfully to other areas but remains a solely visual form of representation. There has not been any research, to this author's knowledge, that investigates the sonification of Circos.

2.3. Sonification of graphs, charts, spreadsheets and tables

Since "Circos is general and useable in any data domain" [12] a sonification of Circos should consider sonification research that is general and useable in any data domain. The sonification of graphs, charts, spreadsheets and tables are important because unlike genomic sonification they can be applied and used in any data domain.

In the context of auditory displays and even tactile displays, the most common graph investigated is the line graph. Line graphs and bar graphs are the most common graphs for data visualization and as such their auditory display has been covered extensively [25-31]. A comprehensive summary of design guidelines have been presented by Brown [32].

A less common graph, but of more interest to this paper is the pie graph, since the circular geometry is comparable to Circos. Doush *et al.* [29] present a haptic display of the pie graph; while Franklin and Roberts [33] present a purely auditory approach. Surprisingly the latter demonstrated that a non-spatial display inspired by Morse code achieves better accuracy when compared to a spatial audio display. Doush is

one of the few who investigate comparison of pair wise categories. His force feedback design enables "pair wise comparisons of sections of the [pie] chart…the user can select two sections…and reorder [them] to make the two selected sections adjacent." This interactive rearrangement actually affords comparative sonification of pairs; however it is limited to only one pair at a time. Unlike Doush, Circos visualizes the relationship of all existing pairs. The interactivity employed by Doush is limited to components of the graph, rather than the graph as a whole. Neither of the research by Doush *et al.* or Franklin and Roberts investigates the comparison of multiple pie charts.

Since the data used to generate these simple graphs are usually stored in spreadsheets and tables, it is also important to look at the sonification of spreadsheets and tables. Guidelines for auditory display of tabular data are again presented by Brown [32]. Ramloll *et al.* [34] used musical notes in addition to speech to increase accessibility to numeric information in a table. Stockman [35] discusses the lack of accessible spreadsheet applications and existing screen readers that are commonly used to increase accessibility. Stockman's work effectively compliments speech readers by sonifying numeric values. Stockman [36] discusses Mansur who sonified 2d line graphs, by mapping the x-axis and y-axis to time and pitch respectively, similar to Walker's Sonification Sandbox [30, 31]. Stockman [36] concludes that the "interactive control of the sonification can be considerably improved by removing the reliance on CSOUND and generating all sonifications using pre-recorded sounds." Electing to not synthesize sound and use pre-recorded sound for interactive purposes would enable real-time interaction without latency. This is currently how many game engines render audio, primarily to maintain real-time interaction.

2.4. Sonification and gaming

The potential for computer games to contribute to the field of sonification has already been argued by Coleman [37] who found that sound design is highly collaborative and instrumental to the computer game development process. This is specific to Computer game development rather than modification. The latter is an accessible, low budget solution that requires fewer resources such as time, training and finance. The disadvantage, however is that major customization of the game engine itself is not possible without expertise. In contrast to modifying existing game engines, a ground up approach aims to build a tool customized for sonification. Barri's Versum [38] is an example of a ground-up development where a 3D interactive, visual and aural environment was created for sound sequencing. Versum uses Java, SuperCollider and Max/MSP to achieve what closely resembles a gaming engine without a design orientated editor.

Grimshaw [39] conceptually compares a First Person Shooter gaming engine to a sonification system conveying player interaction. Furthermore the potential modification of existing computer game engines for the purpose of sonification has been explored [40, 41]. Game engines have been recognized for their potential to offer real-time collaborative virtual environments [42] using both visualization and "auralization." Both Grimshaw and Le Groux [40] use the Torque Engine while Nguyen [41] uses CryEngine.
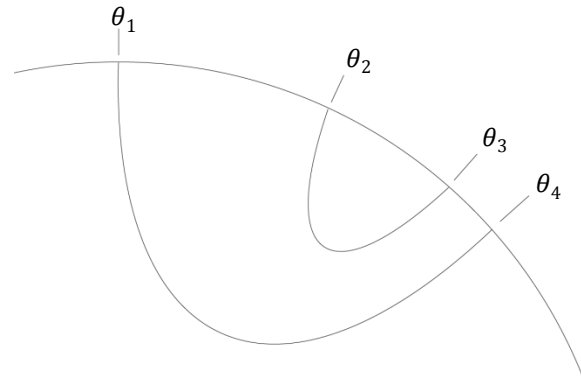

Figure 2: Four angles needed to draw a ribbon.

Many game engine developers offer a level editor, sandbox or toolkit that enables interaction in 3D virtual environments, interaction with real-time dynamic data streams and multimodal feedback. The next section will discuss in detail the use of a gaming engine as a sonification tool.

3. DEVELOPMENT

This section will outline in detail the development of the CircoSonic system. Areas covered in this section include data preparation, drawing the graph, sound parameters, interactivity and sonification.

3.1. Data preparation

The software used is Crysis Wars Sandbox 2, which implements Crytek's CryEngine 2 [http://crytek.com]. Coupled with the FGPS [http://fgps.sourceforge.net] the game engine is capable of reading XML format. Tabular data from a spreadsheet application, such as Excel needs to first be converted to XML. The XML file is read by Crysis Wars Sandbox 2 and each cell value is stored as a variable in game. When two categories in the table are paired (e.g. column/row 4, row/column 2), four angles are calculated to draw the labels and ribbon (see Fig. 2).

3.2. Drawing Circos in Crysis

A Circos graph consists of geometric components such as labels and ribbons; design components such as spacing, color and transparency; and text components such as category headings (see Fig. 3). Using a game engine allows a Circos graph to be drawn in real time from an external XML file. Although this paper discusses CircoSonic's application to static datasets for the purpose of comparative evaluation, its application to dynamic datasets is planned in future work.

The labels around the perimeter are constructed by spawning thick arcs, which include a tick mark with specified translation and rotation in 3D space. Labels draw to the nearest degree and labels smaller than a degree are not drawn. Label headings are drawn as text objects adjacent to each label.

Ribbons link two labels and identify a relationship. They are constructed by stacking thin arcs that are drawn by

spawning a template arc (90 degree arc). The template arc is positioned and rotated before being scaled it in the local x-axis (span) and local y-axis (height).

Colors of both labels and ribbons are selected from a prepared color palette. Colors of labels can either be assigned chromatically or diversely. Ribbon colors are assigned according to the dominant label's color, which is found by comparing the size of a ribbon's two labels. Spacing is added between each row-set for readability and can be specified in numerical units or degrees of rotation. Transparency is uniformly adjustable for all colors and allows readability of intersecting ribbons.

Drawing these in a virtual 3D environment allows multiple Circos graphs to be drawn and overlaid. Circos isolated only allows a side by side comparison of graphs. In the next section the interaction and sonification of a stacked set of Circos graphs will be discussed.

3.3. Interaction and sonification

CircoSonic's sonification is dependent on user interaction. One Interaction, namely rotation, directly affects the sonification by exciting sound. Whilst other interactions such as toggling spin speed, selecting octave and mapping method, indirectly affect the sonification by defining the parameters for selecting what sound to play.

When a user rotates a graph, each label is sonified as it touches a virtual needle fixed at twelve o'clock. The size of the label determines the value to be sonified whilst the user defined parameters determine how the value is sonified.

3.4. Sound parameters and preparation

The static sound parameters include timbre and volume, whilst the dynamic sound parameter is limited to tone. The user defined parameters include octave, tempo and mapping method. All sounds are musical tones of the western chromatic scale and were generated from MIDI before being compressed as an FMod library [http://www.fmod.org] for compatibility with the game engine. This strategy of pre-recording sounds affords real-time interactivity without latency.

3.5. Keyboard interaction

Users can rotate each circular graph using the num-pad keys on a keyboard. The three graphs can be rotated separately or collectively. The speed of rotation is toggled using the "shift" key, holding down to increase speed and releasing to decrease speed. With increased spin speed, the tempo of the sonification provides an overall sense of the dataset. With decreased spin speed, the detailed sections of the data can be interrogated more closely. The zoom is changed by using the "plus" and "minus" keys, which moves the camera position respectively closer or farther from the graphs.

3.6. Mouse interaction and mapping methods

A mouse enabled text based interface (see Fig. 3) allows the user to define parameters which affect the sonification. The "active" check box allows users to select which graphs are
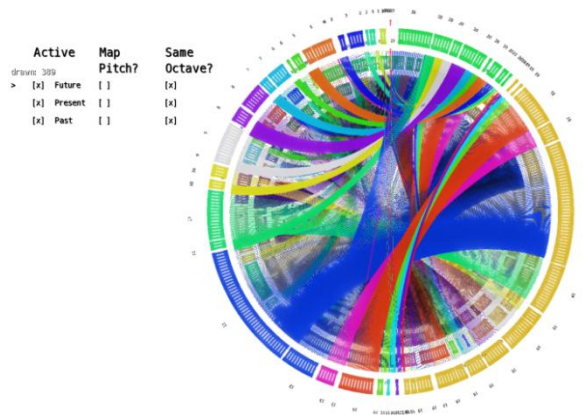

Figure 3: CircoSonic in a modified computer game engine.

revealed or hidden. This gives users an option to reduce visual loading to aid cross graph comparison.

The user can select from two mapping methods to determine the musical tone to play. The first method maps values to a linear but inverse progression of chromatic tones. A high value will sound a low tone, and a low value will sound a high tone. The second method maps values to tonality in accordance with [41, 43] in which the circle of fifths is used to determine a non-linear spectrum of tones. The aim of this method is to allow users to listen to what sounds "out of key". For example a C4 and a C4 will indicate values of no variance, whilst a C4 and F#4 will indicate values of maximum variance; furthermore a C4 and a G4 will indicate values of minimal variance.

User can also select, using another check box, to play graphs in the same octave. When selected, all graphs will play in a middle octave. When deselected, each graph will play in a different octave; the top graph in a high octave and the bottom graph in a low octave.

These user defined parameters ultimately affect how the sonification will sound and can be changed real-time whilst rotating a graph.

3.7. Timbre and volume

The timbre used was concert grand piano and the volume was set to a fixed dB. Volume did change dynamically as a consequence of user interaction. As a Circos graph is rotated quickly, any similar data values will play the same tone. The effect is multiple sound sources playing the same tone which seemingly increases volume. This enables users to use volume as an indicator of data point frequency.

CircoSonic has the ability to represent data in both visual and aural forms which identifies relationships and convey their biasness. CircoSonic only sounds upon excitation through user interaction and can be used to compare multiple Circos graphs. The next section will discuss the application of CircoSonic to a real dataset.

4. APPLICATION

The developed system CircoSonic was applied to a dataset of historic, current and projected water availability of the Murray Darling Basin (MDB). The MDB is the catchment system serving the largest river in Australia, the Murray-Darling River.

The MDB dataset used is publically available [44]. The data is in the form of a table and presents eight cases in various stages of development (without development, current development, future development) and climate (historical, recent, wet, dry and median 2030), which are further broken down into sub-categories (water inflow, losses, end flow, diversions, groundwater losses, average surface water available, and relative level of surface water use – all given in giga-litres per year except for the last which is given as a percentile). For this paper only three of eight cases have been selected: (1) historical climate without development, (2) historical climate with current development, (3) projected climate for 2030 with future development. The water inflows (see Fig. 1, category 19) and losses (Fig. 1, category 20) of the 18 catchments (Fig. 1, categories 1-18) are transferred to a separate spreadsheet in preparation for importation into the game engine.

A demonstration of this application is included in the supplementary materials as videos displaying the sonification and its interactivity. In the next section the evaluation will compare three systems using the same MDB dataset.

5. EVALUATION

The method of evaluation will be outlined in this section. See section 6 for discussion of the outcomes.

An insight based methodology is used to evaluate CircoSonic, similar to [21] in which Circos was compared to Gremlin. By employing this methodology a direct comparison between Circos and CircoSonic is established, and an indirect comparison of CircoSonic to Gremlin is accommodated. A muted version of CS was included to establish a comparison between visualizations, from which a comparison between visualization and sonification could be extrapolated.

5.1. Insight based methodology

An insight based methodology [45, 46] quantifies the performance of a system based on qualitative insights generated by a participant using the system. In this case the three systems being compared are Circos (C), CircoSonic (CS), and CircoSonicMuted (CSM). The Circos graphs evaluated were generated using table viewer (see Fig. 1).

In accordance with [21], an "insight" is defined to be "a unique, individual observation about the data by a participant" and can be further categorized by complexity:

Type A: Simple - discernible from textual analysis.

Type B: Detailed - not readily apparent through textual analysis.

Type C: Detailed Contextualization - involving cross-referencing of observations or knowledge base.

5.2. Hypothesis

The hypotheses for the evaluation comparing C, CS and CSM are:

H.1: CS will outperform C at generating a higher average number of (a) total insights and (b) type C complex insights.

H.2: CS will outperform CSM at generating a higher average number of (a) total insights and (b) type C complex insights.

5.3. Pilot evaluation

The pilot evaluation analyzed insights per second over two 5-minute sessions, however it became apparent that this awarded an undue bias towards the non-interactive visualization since it was less time sensitive than the interactive sonification. Listening to and interacting with CS and CSM required an investment of time which effectively reduced the rate of generated insights, whilst potentially increasing the end total of generated insights during an unrestricted session. For this reason, the sessions were re-conducted in the final evaluation as open-ended sessions (see section 5.5).

5.4. Participants

There were eight participants including a mixture of female and male, Master graduates and PhD students (see Table 2). None had eyesight or hearing impairments and all demonstrated simple comparative pitch and volume recognition. Music expertise was not a requirement since the link between music expertise and performance of sound perception tasks has not yet been established [47]. All eight had little to no experience with both Circos and CircoSonic. Some had previously been exposed to the dataset. Each of the participants was allocated a group number that determined the order in which they would use each system (see Table 3).

	sex	edu	group	data familiarity
P1	f	PhD	1	yes
P2	m	M	1	yes
P3	m	PhD	2	yes
P4	f	M	2	yes
P5	f	M	3	yes
P6	f	M	3	no
P7	m	M	4	no
P8	f	M	4	no

Table 2: Participants (P1-8).

5.5. Session protocol

Each participant performed consecutive sessions in which they were exposed to two of the three systems (C, CS, CSM). Each included (a) 15 minutes tutorial and explanation, (b) an open-ended session using one system, and (c) an open-ended session using a different system. The tutorial covered how to read C and listen to CS, in that respective order, and used example datasets unrelated to the datasets given in the sessions. The

explanation covered the format of the sessions, background on the dataset and instruction to make observations during the sessions by thinking aloud. Each session was recorded on audio with the consent of participants and concluded when the participant stated they could not make any more observations. The order in which participants were exposed to each system considered a potential learning curve and the effects of fatigue (see Table 3).

group	1st	2nd
1	C	CS
2	CS	C
3	C	CSM
4	CSM	C

Table 3: The order in which each group used the systems.

5.6. Assessing insights

Observations made by participants were assessed against the definition of an "insight" (see section 5.1). Insights were categorized by complexity into type A, B and C and quantified by counting.

The typical type A insights included the identification of size differences or similarities over the 3 graphs, the recognition of ordering, and the recognition of biasness or equality between values. Typical type B insights included the recognition of changes to ordering, recognition of changes to biasness and articulating the ratio of biasness. Typical type C insights were limited to conclusions drawn by cross-referring the above types or using their knowledge base to contextualize the information.
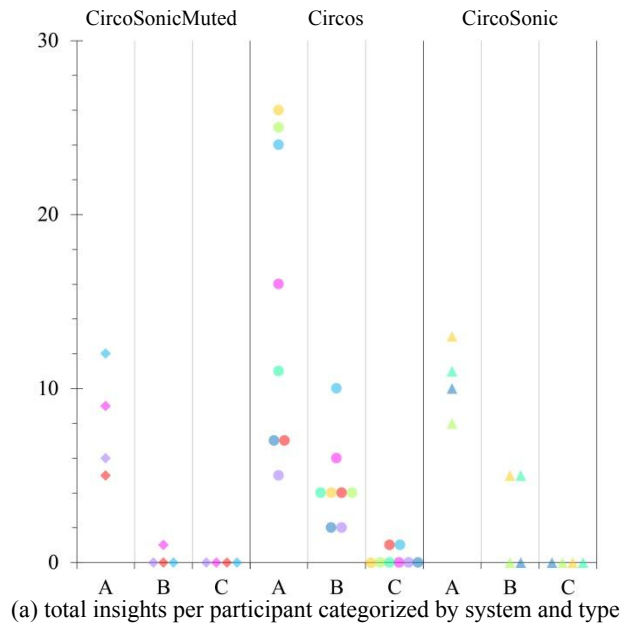
6. RESULTS

The results of the evaluation are presented in Fig. 4. All charts show CSM, C and CS respectively from left to right. Fig. 4 (a) shows the number of insights made by participants, separated into type A, B and C insights. Fig. 4 (b) shows the total insights of each participant with the averages indicated by a cross. Each participant is represented with a different color that corresponds between Fig. 4 (a) and (b). Lastly, Fig. 4 (c) shows the average component breakdown of categorized insights.

The results show that across all three systems C outperformed both CS and CSM, despite C being non-interactive and solely visual. C achieved a higher number of total insights and a higher number of insights per category for type A, B and C.

There were two participants who performed better on CS than C, which is a marginal but promising result. These two participants were members of group 2, which may suggest that participants who used CS first were subject to more fatigue than their counterparts in group 1.

For all participants, type A insights were the most common and type C were the least common. This is in line with expectations since all participants were equally inexperienced at C, CS and CSM. Even though both CS and CSM failed to generate any type C insights, CS did consistently outperform CSM at generating a higher number of type A and B insights and consequently a higher number of total insights.

(a) total insights per participant categorized by system and type
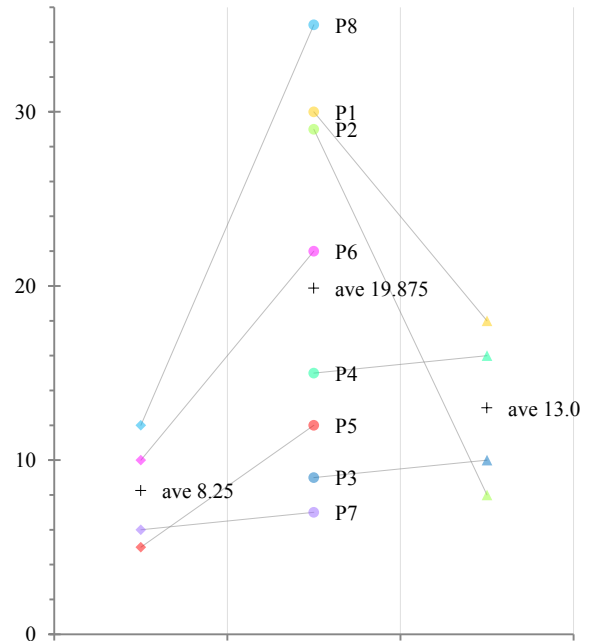
(b) total insights per participant categorized by system
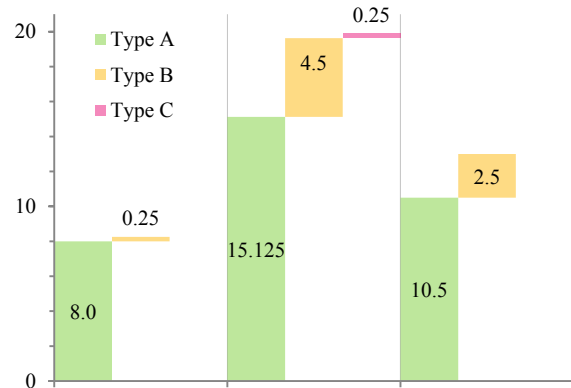
(c) average insights per system categorized by type

Figure 4: Results of evaluation.

6.1. Discussion of insights

The most common insight made was identifying maximum value. This was actually maximum value proportionally to the whole set, since the size of a ribbon is relative to the whole circle. Minimum value was also recognized, however it was almost always after maximum. This could be an effect of the tutorial which demonstrated how to recognize maximum values before how to recognize minimum values. Both the identification of maximum and minimum values was categorized as a type A insight.

A common type B insight was the recognition of changes in ordering. This was only possible using system C, which automatically reordered the layering of ribbons based on size. CS and CSM did not feature this ordering mechanism. Another common type B insight made between the past, present and future datasets was the recognition that there were significant changes between past and present, and only minor changes between present and future.

There were only two type C insights made. One was the recognition that proposed changes for the future were insufficient to restore historic patterns. The other was the conclusion of a distributed increase to supply the significant loss of inflow into two catchments. These were made by two participants of different groups using C.

7. CONCLUSION

The only hypothesis found to be true was H.2 (a): CircoSonic outperformed CircoSonicMuted at generating a higher number of total insights. Neither CircoSonic nor CircoSonicMuted generated Type C insights (that is context referenced insights, see section 5.1) in the evaluation.

The comparison of Circos to CircoSonicMuted suggests that the visual component of CircoSonic heavily underperformed, limiting its overall performance. The sound component of CircoSonic consistently improved the generation of insights beyond CircoSonicMuted, which demonstrates that CircoSonic with sound performs better than CircoSonic without sound. One of the most significant strengths of Circos is the automated ordering of ribbons based on their size. The difference between the orders in which ribbons are layered is clearly noticeable and generates more insights as a consequence. CircoSonic's layering and transparency needs to be developed further if its visualization is to perform as well as Circos.

The results of the evaluation suggest that when representing a static dataset for the purpose of data mining, a static visualization is more appropriate than an interactive visualization/sonification. An evaluation involving dynamic data may show different results, however Circos does not currently support dynamic datasets.

8. FUTURE WORK

This paper has presented the development of an interactive system to explore table datasets through visualization and sonification. It has been applied to a static dataset, however it is planned that the same system be applied to a dynamic dataset. There is currently a gap between Excel and Crysis which requires data to be reformatted into a custom XML format. It is planned that this gap will be filled by reading directly from Excel via Open XML format. There is also scope to explore sound parameters such as timbre, and mapping methods such as frequency and volume. The positioning of CircoSonic within a gaming engine also lends itself to be extended to an ambisonic or collaborative/interactive system.

CircoSonic is currently being applied to pedestrian movement and natural surveillance in the field of architecture. The keyboard and mouse interactivity presented in this paper has since been developed further to include the ability to control rotation using the Apple iPhone and UDP.

The novel visualization Circos is but one emerging scientific visualization that requires investigation from the perspective of auditory displays. The investigation of novel visualizations from the perspective of auditory displays needs to be extended to include those which deal with multivariate and dynamic datasets whilst still offering a broader application to diverse data domains.

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