Towards Contextual Glyph Design: Visualizing Hearing Screenings

1st Barbara Nascimento Ramos
CISUC – Department of Informatics Engineering
University of Coimbra
Coimbra, Portugal
barbararamos@dei.uc.pt

2nd Catarina Maçãs
CISUC – Department of Informatics Engineering
University of Coimbra
Coimbra, Portugal
cmacas@dei.uc.pt

3rd Nuno Lourenço
CISUC – Department of Informatics Engineering
University of Coimbra
Coimbra, Portugal
naml@dei.uc.pt

4th Evgheni Polisciuc
CISUC – Department of Informatics Engineering
University of Coimbra
Coimbra, Portugal
evgheni@dei.uc.pt

***Abstract*—Data is everywhere, our society shapes itself through it and, with the years passing by, it is becoming greater in dimension. A lot of this data now available is multivariate in nature. The bigger the volume and complexity are, the harder tasks to detect, classify, and measure characteristics and relations within data. Glyph-based visualization is one of the possible techniques commonly adopted in data science to address the representation of multivariate data. Multiple varieties of glyph design have been developed and studied over the past decades. However, little research was done to compare the effectiveness of glyphs designs developed for a specific context of the application. This paper aims to study data glyphs and their applications. More specifically, three visual explorations are produced as glyph design alternatives to represent a dataset related to audiological tests carried out in the population of Portugal. These glyphs were evaluated through controlled semi-structured experiments with users, and a crowdsourced experiment, and then an analysis of the performance result of each of the glyphs is presented, evaluating them in terms of learning and memorization. The results show how the use of metaphors and semantic relations to represent the attributes helps in understanding the glyph and its memorization. Additionally, we identified that the redundancy in encoding data might be beneficial.**

***Index Terms*—Data glyphs design, Glyph-based visualization, Multivariate data visualization**

I. Introduction

With the increasing volume and complexity of data, the ability to effectively analyse it has become increasingly strained [1]. Much of the data available today are multivariate in nature. When it comes to visualisation techniques, there are enumerable approaches that depend not only on the volume and type of data being represented but also on the final objective of the visualisation. In the context of visualising multivariate data, one of the possible techniques is data glyphs.

Data glyphs are composite graphical objects that use their visual and geometric attributes to encode multidimensional data [2]. For example, arrows [3], mostly used in visualising vector fields, are glyphs whose visual variables can be used to encode attributes other than directions. Another more complex, yet efficient example is the star Glyph [4], composed of a number of lines equally spaced and radially arranged, whose lengths encode the magnitude of a given data. These are just a few examples of countless variations of designs for data glyphs. There are multiple types of glyphs with different designs and concepts, exploring a broad spectrum of design solutions, from pictorical representations to abstract ones.

In this paper, we present our study on three different types of design for glyphs: *a metaphorical glyph*, a purely *geometric polygon glyph*, and a variation that is abstract with figurative elements, which we will refer to as *figurative glyph*. Our rationale for choosing three diverse types of designs is to compare their efficiency in representing the same dataset and gather insight on which design options to take in different design scenarios. Further in this paper, we present a study on the impact of the produced glyphs and their components in terms of visual perception and understanding of the underlying data. We evaluate the efficiency of each glyph design through user tests. The results are then analysed to understand how different visual features can be improved and how each one performs in the context of the chosen designs for this study. Our design study follows the methodology for visualisation design and evaluation [5]. A series of stages are executed sequentially, which includes data and task abstraction, design of the glyphs, exploring different visual alternatives, implementation, and evaluation of glyphs through tests with users carried out in person and with the aid of crowdsourcing techniques, through the Amazon Mechanical Turk platform. Finally, the results are discussed, and a set of design guides are derived.

The major contribution of our work is an initial study of the contextual design of data glyphs. More specifically, our work aims to:

1) encourage the design of data glyphs based on the conditions of the specific scenario of application;
2) act as a first step towards the contextual design of data glyphs;

2375-0138/23/$31.00 ©2023 IEEE
DOI 10.1109/IV60283.2023.00026

3) provide an initial study on the efficiency of different variations of glyphs designed for the same data, tasks, and the end user.

The remainder of the paper is as follows. In the following section II the related work is presented and discussed. In Section III, we present the domain of the application, describe the dataset and detail data abstraction. In the next section IV, we present the design of all three glyph designs, including the star glyph, which is used as a baseline. Further, Section V presents the evaluation, including the methodology description, the results, and the discussion. Finally, the conclusions are made in Section VI.

II. Related Work

This section provides an overview of the works that have compared multiple glyph designs developed for the same dataset. We also provide an overview of different glyph designs, similar to ours. However, a thorough survey of data glyphs is out of the scope of this section. A more thorough analysis can be seen in [2], [6], [7].

Data glyphs are a design technique used to represent multivariate data [2]. A glyph-based visualization is a common form of visual design in which a dataset is represented by a collection of visual objects, the glyphs. Glyphs can be considered as small visual elements in which unique data points are individually encoded, assigning their dimensions to one or more tags and their visual variables [6]. Furthermore, due to their small graphical footprint, glyphs are very versatile and can be applied in a variety of different application areas.

Data glyphs have a long history. One of the first glyphs designed within the 1950s was the metroglyphs, which use line length to encode data [6]. An example much discussed in the literature is the Chernoff face, a glyph that encodes values through the characteristics of a cartoon face, such as the length of the nose or the orientation of the eyebrows [8]. Another well-known type of glyph is the Star Glyph [4] which uses the length of evenly spaced rays emanating from the center. Over the years, many different glyph variations have been introduced to better fit certain types of data or to solve specific tasks more effectively [6].

Over time, glyphs of the most diverse types have been recorded. Some are only recommended for specific applications such as fluid flow visualization [9] or time visualization [10], others, however, are more general purpose [4], [11], [12]. Besides their design, the placement of the glyphs has also been addressed by the research community. Glyphs can be placed in many different ways: in a grid [10], [13], in a map [14], in a node-link diagram [15], [16], among others [1]. More recent research also suggests automatic approaches to glyph creation [17], [18]. In our study we focus on three distinct glyph designs: i) metaphorical, more specifically faces, ii) figurative and iii) geometric. Hereafter, we focus on different examples by glyph design.

Maguire et al. [19] suggested the importance of establishing a metaphorical association between a visual channel and the concept or concepts to be codified. Metaphorical visual representations allow domain-specific coding using "natural mapping". This natural mapping can make it easier for users to infer the meaning of the glyph and require less effort to learn and remember. Groh et al. [20] underline the importance of the metaphor for memorability and intuitiveness of visualizations. Lakoff and Johnson [21] state that metaphors structure the common conceptual system of our culture, so we are able to take those concepts we already know and apply them to new problems. Examples of metaphors applied to glyph design are, landscape metaphor to represent large datasets [20], leaf glyphs to represent forest fires [22], and glyph flowers for visualizing Web search results [23]

Regarding the abstract variations of glyph design, these make use of geometric primitives in the construction of glyphs, however, without conveying any additional meaning or metaphorical association. There are numerous design variations of this type of glyphs [6]. The designs can be roughly separated into two groups of layouts: circular (or radial) and rectilinear. In the circular construction, the glyphs use a polar coordinate system, for instance, Star Glyph [4], which evenly distributes the axes in the angular dimension and expresses the values with the radial position, usually connected with a line. Another variation of circular construction is a radial construction, for instance, Pie-chart-like glyphs [24], where each element is laid out along the circumference. In the rectilinear construction, the glyphs express data using the two dimensions of the Cartesian coordinate system, for instance, Profile glyph [11].

There are several studies that evaluate the performance of different variations of glyph designs applied to the same dataset or type of data. The majority of the experiments focus on comparing metaphoric glyphs with abstract ones. Siirtola compared a metaphoric glyph design that resembles a car with an abstract face representation in the setting of visualizing car data [25]. The experiment shows that a car glyph is slightly better in terms of accuracy, but with the cost of task execution times. The work of Li et al. [26] is another experiment that compares Rose Shape glyphs against an abstract polygon glyph to visualize multi-dimensional data about the education level in the US. Their results indicate that using metaphors enhances the fluency of information processing, and increases the confidence of interpretation and judgement while increasing the difficulty of perception. The study of Fuchs J. et al. [10] investigates the performance of different temporal glyph designs applied in a small multiple setting. They compared four glyph designs—Line Glyph, Stripe Glyph, Clock Glyph, and Star Glyph [4]—in terms of accuracy and efficiency, as well as user confidence and preferences. The results show that the glyphs performed differently depending on the task and data type. Another important conclusion is that both the accuracy and efficiency of tasks depend on the chosen design.

III. Data and Domain

Hearing loss is a significant public health concern that can impact physical, mental, and social well-being [27]. Age-related hearing loss is a global issue affecting approximately

5% of the world's population [28]. Hypoacusis, whether mild or profound, can lead to communication difficulties and reduced quality of life [29].

Regarding the average hearing thresholds, values above 35dB are already considered hearing loss [28], and losses caused by noise exposure or ageing are irreversible. To diagnose hearing loss, a medical consultation and additional tests, such as a pure tone audiometry exam, are necessary [27]. According to the Bureau International d'Audio Phonologie [30], the determination of the degree of hearing loss is carried out through the average of the hearing thresholds of the frequencies, obtaining multiple degrees of hearing impairments. The data offered to the project is from Evollu, a Portuguese audiology company, that has collected data on the hearing loss of users in Portugal, including demographic information and audiogram results.

A. Data and Task Abstraction

The dataset consists of 36 attributes that encompass all the characteristics of Evollu's screenings. These attributes are divided into five groups: the patient profile, test results, device characteristics, partner identification, and post-screening status. Based on meetings and goal alignments with Evollu, the main tasks are to analyse different patient types and the status of the user within the service process. The glyphs design focuses on the representation of the first, second, and fifth attribute groups, i.e. user profile information, test results, and post-test status.

The status attribute includes information on contacts with the patient after the test, represented by numerical codes that were grouped into eight categories: i) contacted successfully, ii) contact failed, iii) appointment scheduled, iv) missed appointment, v) service performed, vi) purchase made, vii) purchase not made, and viii) no test with interest in the experience. Age information is obtained from the date of birth and was grouped into intervals of 10 years. Due to limitations of the visual variables used, in one of the versions of the glyph, presented later in Section IV-A, the age was divided into four groups: under 50 years old, 51 to 65 years old, 66 to 80 years old, and over 80 years old. Land longitude were used to encode the screening location, and data were grouped by regions in Portugal: North, Center, Lisbon, Alentejo, and Algarve. The hearing loss attribute encodes the average hearing loss for each ear and was converted to categorical data according to the BIAP 02/1: Audiometric Classification of Hearing Impairments [30].

IV. Design Study

For the development of the glyphs, we chose to make three versions of the design, going from a more figurative representation, using semantic resources for a natural mapping, to a more abstract version that uses only geometric shapes in its composition. The variations are the following: i) a metaphorical design, which we call *Emoji glyph*, ii) a figurative design, which we call *Flower glyph*, and iii) a purely geometric polygon glyph called *Geometric glyph*. A fourth version, the star-glyph, was used as a baseline in the evaluation phase.

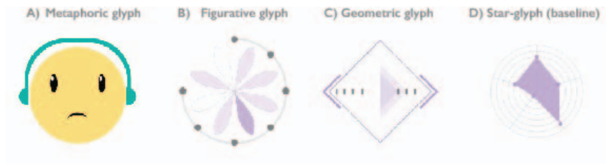

Fig. 1. The four glyph designs considered for this study: metaphoric (top left), figurative (top right), geometric (bottom left), and a star-glyph (bottom right).

A. Emoji Glyph

The first glyph utilises a face metaphor to visually represent hearing loss patients (see Figure 1). The design aims to create a visual metaphor expressing the emotions and face of a patient who experiences hearing loss. Inspired by the Chernoff [8] faces, the design presents emojis utilising semantic relationships to depict hearing loss. The facial expressions represent various statuses during the screening process.

The emojis' graphical elements incorporate headphones to indicate hearing loss, with the headphones' size encoding the magnitude of hearing loss in each ear. Sunglasses represent patients without hearing loss, while patients with partial hearing loss are depicted with a headset on the affected side (see Figure 2). Additionally, the headphones and glasses' colours represent the region in Portugal where the test was performed.

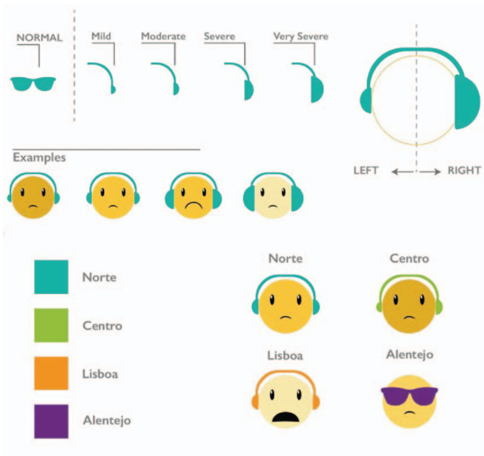

Fig. 2. Representation of "hearing loss" (top) and "region" (bottom) attributes in the emoji glyph.

The colours of the faces are used to represent age. In this case, different yellows are applied to indicate different age ranges: under 50 years old, 51 to 65 years old, 66 to 80 years old, and over 80 years old.

Finally, the glyph encodes status through facial expressions, primarily via the shape of the mouth (see Figure 3). The glyph represents the eight statuses by encoding "positive" statuses with variations of smiling (i.e. from slight smiling to open-mouth smile) and ”negative” statuses represented by variations of sad smileys. The longer the process of contacting patients, the more intense the expression becomes. For example, a user who had a successful first contact will have a slight smile, while a patient who completes all the service stages and makes a purchase will have a larger and happier smile.

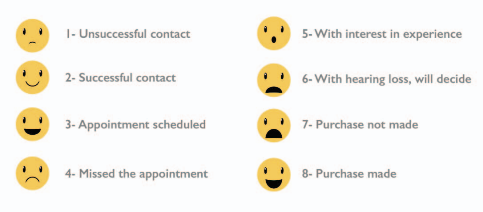

Fig. 3. Representation of the “status” attribute in the emoji glyph.

B. Flower Glyph

The second glyph design (see Figure 1) is inspired by flowers. The shape of the petals represents different regions in Portugal, with the shape being narrower and double ends towards the North and more rounded towards the Alentejo (see Figure 4). Each petal corresponds to a frequency in the right and left ears, with the opacity of the filling colour encoding the gravity of hearing loss. Normal hearing is represented without filling colour. The color of the petals represents the status, with green and blue indicating positive statuses, and warmer tones indicating negative statuses (see Figure 5). The circle with the dots around the flowers represents the age group, each dot represents 10 years.

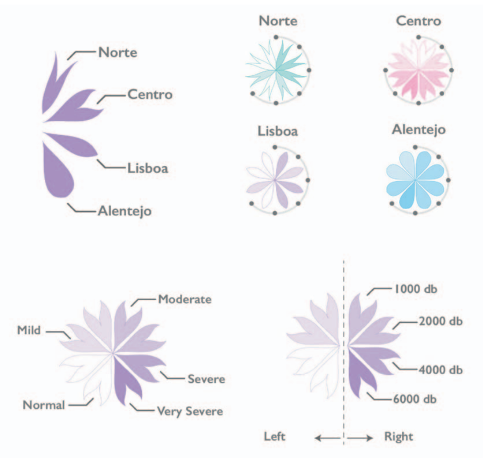

Fig. 4. Representation of “region” (top) and “hearing loss” (bottom) attributes in the flowers glyph.

C. Geometric glyph

The third glyph design consists of geometric polygonal shapes with diamonds at the centre representing the average

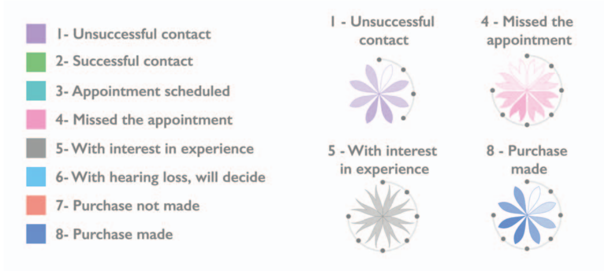

Fig. 5. Representation of “status” attribute in the flowers glyph.

hearing loss in both ears (see Figure 6). The size of the area and intensity of colour represent the degree of hearing loss. The age of the patient is represented by 8 vertical lines in the centre of the glyph. The region is represented through external strokes on the outline of the diamond area, this representation is made with the aim of making a semantic relationship with the highest stroke representing the north and the lower strokes representing the south. The status is represented through colour, following the same schema as the Flower glyph.

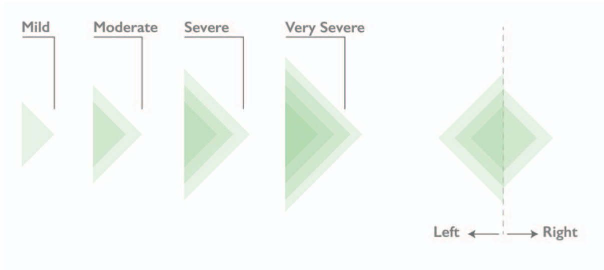

Fig. 6. Representation of the hearing loss in the geometric design.

Fig. 7. Representation of “region” attribute in the geometric glyph.

D. Star Glyph - baseline

To enable comparison of the glyphs, a fourth glyph was produced to be used as a baseline in the evaluations—a star-glyph representation. The glyph is divided into five axes, figure 8, where the first axis represents the regions, starting from the highest point that represents the North. The upper side axes represent the hearing loss values of the left and right ears; the higher the value, the greater the loss. The right inner axis represents age; each ring of the graph has a value of 10 years. The lower left axis represents status, with a total of 8. Each round of the graph represents a status reinforced through the colour representation, which uses the same colour schema as the Flower glyph and Geometric glyph.

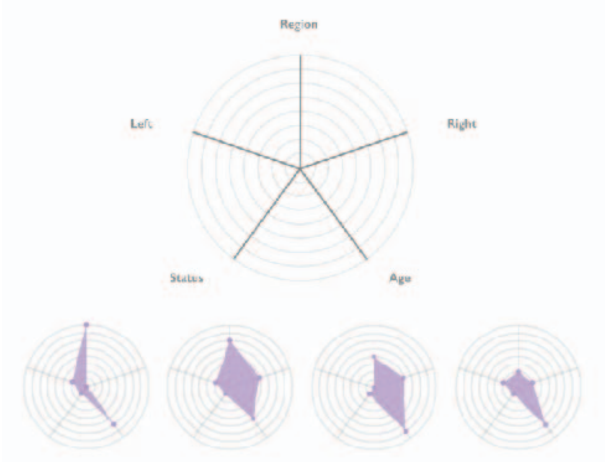

Fig. 8. Representation of the different attributes present in each axis of the star-glyph.

V. Evaluation

To identify the effectiveness of each glyph and to compare how each design behaves in the same context, two evaluation methods were applied. One was in-person evaluation through controlled semi-structured experiments; and another one was performed remotely through the crowdsourcing platform, Amazon Mechanical Turk (further referred to as MTurk). In in-person and remote experiments we collected 48 and 1455 answers, respectively. The main objectives were: to compare the performance of the different glyphs, to compare the four designs quantitatively, to collect improvement requirements for the respective glyphs, and to compare the results of the two applied evaluation methods.

A. Setup

To compare different evaluation methods, surveys were kept as similar as possible. However, some changes were made to the evaluation processes due to the limitations and requirements of the MTurk platform.

For the laboratory evaluation, a semi-structured experiment was conducted in a quiet, closed room at the university. Each participant evaluated two glyph designs that were randomly distributed among them. The evaluation consisted of five sections: intuition, encodings, memorability, perception, and subjectivity. A Google form contained the presentation of each glyph, ensuring uniformity throughout the procedure. A total of 48 responses were collected, with each glyph being evaluated 24 times.

For the Mechanical Turk evaluation, the same Google form was used, but with some adaptations because of the inability to control glyph exposure time. An input text field was added for participants to submit their MTurk WorkerID. Participants received a SurveyCode upon completion of the task, which was required to collect their reward. A total of 370, 367, 357, and 361 answers were accepted for the emoji glyph, flower glyph, geometric glyph, and baseline glyph designs, respectively. The process for rejecting or approving HITs was based solely on matching the worker ID and submitting the correct survey code.

B. Results

In our semi-structured experiments, we obtained significant results, with all glyphs displaying an assertiveness rate above 60% in the quantitative analysis. Moreover, all our glyph designs surpassed the star glyph, which served as a baseline for the study. Among the assessed glyphs, the geometric glyph stood out, with a value of 76.8% in assertiveness. Similarly, the emoji glyph obtained comparable results, with only a 0.40% difference between the two, as shown in Table I.

When the test results were grouped according to the questions related to each designed encoding, some glyphs showed better results in representing certain attributes than others, as seen in Table I. For instance, the emoji glyph, through the use of facial expressions and mouth shape, demonstrated a high assertiveness rate in representing status. Meanwhile, the flower glyph, despite having a lower overall score than the other glyphs, had a significantly higher assertiveness rate in representing age. Additionally, in the representation of hearing loss levels, the geometric glyph performed best.

The results obtained through evaluations on Mechanical Turk had a lower percentage of assertiveness compared to those in a controlled environment, with a difference of 20.11% in the geometric glyph, which performed best. However, this was expected since the number of participants was relatively larger. Analysis of the results showed that the geometric glyph still had the highest assertiveness rate, followed by the flower glyph, as seen in Table II.

Regarding the results for different attributes, the geometric glyph performed best in representing age. The emoji glyph, as in the controlled environment evaluation, had the highest assertiveness rate in representing status. Unlike the controlled environment experiment, the emoji and flower glyphs performed best in questions related to region, as shown in Table II. Finally, as in the previous evaluation, the geometric glyph had the best results in representing hearing loss.

C. Discussion

When analyzing the different developed glyphs, it was noticed that a device that became extremely important in the perception of information was the use of semantic relationships. All the encodings that tried to provoke some type of natural mapping had superior performance compared to the abstract attributes. This can be seen in the results of the emoji glyphs that through the use of smiles to represent the status

	Emoji	Flowers	Geometric	Baseline
Age	73.33	91.03	76.00	68.00
Status	96.00	63.40	58.00	70.00
Region	68.00	57.60	78.00	70.00
Hearing Loss	72.00	69.20	81.33	62.67
Average	76.4	72.3	76.8	67.2

TABLE I
ASSERTIVENESS RESULT DIVIDED BY EVALUATED ATTRIBUTES PERFORMED AND THE AVERAGE IN A CONTROLLED SEMI-STRUCTURED EXPERIMENT.

	Emoji	Flowers	Geometric	Baseline
Age	46.75	59.36	64.98	60.01
Status	63.78	44.79	42.85	50.00
Region	55.27	55.47	54.20	47.78
Hearing Loss	56.30	57.16	59.29	51.52
Average	54.72	55.01	56.69	53.01

TABLE II
ASSERTIVENESS RESULT DIVIDED BY EVALUATED ATTRIBUTES PERFORMED AND THE AVERAGE IN MECHANICAL TURK.

obtained a 96% of assertiveness in the controlled evaluation, while the other glyphs had values below 70% for the same attribute. In the Mechanical Turk evaluation, the glyph emoji also presented better results for the representation of status, although with lower values.

The geometric glyph was found to be more effective in representing regions in the controlled evaluation than in the MTurk evaluation. Participants associated the position of the mark in the glyph with the geographical distribution of the regions in Portugal. However, the same test obtained lower results, compared to the controlled evaluations and the evaluations among other glyphs in the MTurk platform. This could be due to the context in which the glyphs were evaluated. The controlled evaluation was mainly conducted by Portuguese individuals, whereas the MTurk evaluation involved people from different parts of the world. It may be challenging for people outside of Portugal to make the connection between the vertical positioning of the regions of Portugal and the positioning of the mark on the glyph. Therefore, the evaluation process showed that the context of glyph application and evaluation directly affects its performance when making semantic relations.

In addition to the use of metaphor, another graphic device that proved to be fundamental for the glyph's effectiveness during the evaluation period was the use of redundancy. In the geometric glyph,the use of three visual elements reinforcing the information made it easier for the user to observe levels of hearing loss and compare both ears to other glyphs.

Briefly, the following improvement requirements were noticed in the different types of glyphs for future work:

- Emoji glyph: Improve colour-coding for regions – search for colours that are more distinguishable from each other. If possible, also use visual redundancies to reinforce the information. Changing the age coding – the use of different shades of yellow for age proved to be difficult to perceive.
- Flower glyph: Using another visual encoding to represent the region – the shape of the petals proved to be a difficult graphic device to decode. Reviewing the use of colours to represent the status – it has many variables and proved difficult to decode.
- Geometric glyph: As with the flower glyph, in reviewing the use of colours for the representation of status one strategy is to use redundancy with two other visual resources, aiming that it is one of the most performant.

VI. CONCLUSIONS

We propose three different approaches to glyph design: one metaphorical, one geometric, and one figurative without metaphorical relations. Two different approaches were also applied to evaluate the glyphs, a semi-structured experiment carried out in a controlled environment and another using crowdsourcing, through the Amazon Mechanical Turk platform. The different evaluation processes showed that the glyphs present different results for the different attributes.

The results in Mechanical Turk showed that the use of crowdsourcing for glyph evaluation is a viable alternative. When we compare the results of the laboratory evaluation with the evaluation of the Mechanical Turk, we find correspondence in the results confirming the requirements for improvements collected. The greater variation of the results in relation to the results obtained in a controlled environment can be compensated by the scalability of the platform. The results also demonstrate the utility of using Mechanical Turk to gain new insights into glyph design.

Finally, the result of the project showed that none of the glyph alternatives had an unanimous performance. Some glyphs were better at representing one set of attributes than others. With this in mind, we conclude that the choice of the glyph depends on its application context. As is the case with the representation of regions, where the geometric glyph performed better in the tests with Portuguese people. Further experiments are needed to analyse the possibility of a glyph design that works for all the represented attributes. This opens a niche for future research in contextual glyph design.

ACKNOWLEDGMENT

This work is partially founded by Project “Agenda Mobilizadora Sines Nexus”. ref. No. 7113, supported by the Recovery and Resilience Plan (PRR) and by the European Funds Next Generation EU, following Notice No. 02/C05-i01/2022, Component 5 - Capitalization and Business Innovation - Mobilizing Agendas for Business Innovation and by the FCT - Foundation for Science and Technology, I.P./MCTES through national funds (PIDDAC) and by the A4A: Audiology for All (CENTRO-01-0247-FEDER-047083) financed by the Operational Program for Competitiveness and Internationalisation of PORTUGAL 2020 through the European Regional Development Fund, within the scope of CISUC R&D Unit - UIDB/00326/2020 or project code UIDP/00326/2020.

The authors would like to thank to João Miguel Cunha for his willingness to review this document.

References

[1] M. O. Ward, "A taxonomy of glyph placement strategies for multidimensional data visualization," *Information Visualization*, vol. 1, no. 3-4, pp. 194–210, 2002.

[2] R. Borgo, J. Kehrer, D. H. Chung, E. Maguire, R. S. Laramee, H. Hauser, M. Ward, and M. Chen, "Glyph-based visualization: Foundations, design guidelines, techniques and applications." in *Eurographics (State of the Art Reports)*, 2013, pp. 39–63.

[3] C. M. Wittenbrink, A. T. Pang, and S. K. Lodha, "Glyphs for visualizing uncertainty in vector fields," *IEEE transactions on Visualization and Computer Graphics*, vol. 2, no. 3, pp. 266–279, 1996.

[4] S. J.H., F. E.J., G. R.M., and F. H.P., "The surgical implications of physiologic patterns in myocardial infarction shock." pp. 126–141, 1972.

[5] T. Munzner, "A nested model for visualization design and validation," *IEEE transactions on visualization and computer graphics*, vol. 15, no. 6, pp. 921–928, 2009.

[6] J. Fuchs, P. Isenberg, A. Bezerianos, and D. Keim, "A systematic review of experimental studies on data glyphs," *IEEE transactions on visualization and computer graphics*, vol. 23, no. 7, pp. 1863–1879, 2016.

[7] M. O. Ward, "Multivariate data glyphs: Principles and practice," in *Handbook of data visualization*. Springer, 2008, pp. 179–198.

[8] H. Chernoff, "The use of faces to represent points in k-dimensional space graphically," *Journal of the American statistical Association*, vol. 68, no. 342, pp. 361–368, 1973.

[9] C. Levit and T. Lasinski, "A tool for visualizing the topology of three-dimensional vector fields," in *Proc. Visualization'91*. Citeseer, 1991, pp. 33–40.

[10] J. Fuchs, F. Fischer, F. Mansmann, E. Bertini, and P. Isenberg, "Evaluation of alternative glyph designs for time series data in a small multiple setting," in *Proceedings of the SIGCHI conference on human factors in computing systems*, 2013, pp. 3237–3246.

[11] S. H. DuToit, A. G. W. Steyn, and R. H. Stumpf, *Graphical exploratory data analysis*. Springer Science & Business Media, 2012.

[12] P. Goffin, W. Willett, A. Bezerianos, and P. Isenberg, "Exploring the effect of word-scale visualizations on reading behavior," in *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, 2015, pp. 1827–1832.

[13] C. Maçãs, E. Polisciuc, and P. Machado, "Glyphsome: Using SOM with data glyphs for customer profiling," in *Proceedings of the 15th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications, VISIGRAPP 2020, Volume 3: IVAPP, Valletta, Malta, February 27-29, 2020*, 2020, p. 301–308. [Online]. Available: https://doi.org/10.5220/0009178803010308

[14] D. H. Pilar and C. Ware, "Representing flow patterns by using streamlines with glyphs," *IEEE transactions on visualization and computer graphics*, vol. 19, no. 8, pp. 1331–1341, 2013.

[15] C. Dunne and B. Shneiderman, "Motif simplification: improving network visualization readability with fan, connector, and clique glyphs," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2013, pp. 3247–3256.

[16] C. Maçãs, E. Polisciuc, and P. Machado, "Vabank: visual analytics for banking transactions," in *2020 24th International Conference Information Visualisation (IV)*. IEEE, 2020, pp. 336–343.

[17] J. M. Cunha, E. Polisciuc, P. Martins, and P. Machado, "The many-faced plot: strategy for automatic glyph generation," in *2018 22nd International Conference Information Visualisation (IV)*. IEEE, 2018, pp. 71–77.

[18] L. Ying, X. Shu, D. Deng, Y. Yang, T. Tang, L. Yu, and Y. Wu, "Metaglyph: Automatic generation of metaphoric glyph-based visualization," *IEEE Transactions on Visualization and Computer Graphics*, 2022.

[19] E. Maguire, P. Rocca-Serra, S.-A. Sansone, J. Davies, and M. Chen, "Taxonomy-based glyph design—with a case study on visualizing workflows of biological experiments," *IEEE Transactions on Visualization and Computer Graphics*, vol. 18, no. 12, pp. 2603–2612, 2012.

[20] R. GROH, T. GÜNTHER, and T. GRÜNDER, "Towards visual exploration in glyph-based visualizations by using landscape metaphors," 2018.

[21] G. Lakoff and M. Johnson, *Metaphors we live by*. University of Chicago press, 2008.

[22] J. Fuchs, N. Weiler, and T. Schreck, "Leaf glyph visualizing multi-dimensional data with environmental cues," 2015.

[23] M. Chau, "Visualizing web search results using glyphs: Design and evaluation of a flower metaphor," *Acm transactions on management information systems (tmis)*, vol. 2, no. 1, pp. 1–27, 2011.

[24] A. Amirkhanov, B. Fröhler, J. Kastner, E. Gröller, and C. Heinzl, "Inspectr: Multi-modal exploration, visualization, and analysis of spectral data," in *Computer Graphics Forum*, vol. 33, no. 3. Wiley Online Library, 2014, pp. 91–100.

[25] H. Siirtola, "The effect of data-relatedness in interactive glyphs," in *Ninth International Conference on Information Visualisation (IV'05)*. IEEE, 2005, pp. 869–876.

[26] Y.-N. Li, D.-J. Li, and K. Zhang, "Metaphoric transfer effect in information visualization using glyphs," in *Proceedings of the 8th International Symposium on Visual Information Communication and Interaction*, 2015, pp. 121–130.

[27] A. M. A. Mendes, "Dispositivos médicos de reabilitação auditiva: caracterização do mercado em portugal," Ph.D. dissertation, Instituto Politécnico de Lisboa, Escola Superior de Tecnologia da Saúde de . . . , 2020.

[28] "Deafness and hearing loss," Apr 2021. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss

[29] S. R. Pratt, "Barriers to hearing health care: current status and a glimpse at the future," *American Journal of Audiology*, vol. 19, no. 1, pp. 1–3, 2010.

[30] "Biap recommendation 02/1: Audiometric classification of hearing impairments," 2017. [Online]. Available: https://www.biap.org/en/recommandations/recommendations/tc-02-classification/213-rec-02-1-en-audiometric-classification-of-hearing-impairments/file