Does the Orientation of an Euler Diagram Affect User Comprehension?

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***Abstract*—Euler diagrams, which form the basis of numerous visual languages, can be an effective representation of information when they are both *well-matched* and *well-formed*. However, being well-matched and well-formed alone does not imply effectiveness. Other diagrammatical properties need to be considered. Information visualization theorists have known for some time that orientation has the potential to affect our interpretation of diagrams. This paper begins by explaining why well-matched and well-formed drawing principles are insufficient and discusses why we should study the orientation of Euler diagrams. To this end an empirical study is presented, designed to observe the effect of orientation upon the comprehension of Euler diagrams. The paper concludes that the orientation of Euler diagrams does not significantly affect comprehension.**

I. Introduction

Euler diagrams represent set theoretic relationships using interconnected closed curves often drawn using circles or ovals. Curves are labelled, so affording context to the information or data therein. Figure 1 contains three Euler diagrams all representing the same information and illustrates that there are syntactic choices to be made when visualizing data. Each diagram tells us that Course Leaders are a subset of Lecturers, Lecturers are a subset of Academics and these staff could be Managers. Later in this section we will discuss the syntactic differences between the diagrams in figure 1.

Euler diagrams are regarded as a natural and effective way to depict sets and their relationships. They form the basis of numerous visual languages, including Swoboda and Allwein's Euler/Venn logic [1], Gil et al.'s spider diagrams [2], Kent's constraint diagrams [3], and Oliver et al.'s concept diagrams [4]. In the latter two cases, the visual languages are expressive enough to model complex properties of software. In addition, Euler diagrams are applied in a wide variety of other contexts including architecture [5], arts [6] and social media [7]. Wilkinson [8] presents a survey of natural science journals and online affiliated content from 2009 observing 72 occurrences of Euler diagrams. All of these uses of Euler diagrams demonstrate the importance of providing an account of how best to draw them in terms of user comprehension.

We already have some insight into how best to draw Euler diagrams. In particular, we focus on two categories of so-called well-matched and well-formed drawing principles. These are designed to yield effective diagrams, where effective means reducing comprehension errors. Gurr, theorising well-matched diagrams, postulates that the most effective diagram is one with structure and property that matches, or closely matches, that which it strives to represent [9]. Well-formedness describes relationships between curves and regions in a diagram. There has been some work on empirically testing these well-formedness properties, observing the extent to which they impact comprehension [10], [11]. Gurr's theory tells us to select well-matched diagrams and the empirical work guides us to select well-formed diagrams in order to maximize effectiveness.

In figure 1, the diagram d1 is neither well-matched or well-formed. It is not well-matched as its shaded region denotes that there are no Course Leaders that are not Lecturers: the set of Course Leaders is contained by the set of Lecturers but CL is not contained by L. It is not wellformed as it has a disconnected zone: the region inside A and L but outside CL comprises two disconnected pieces. The diagram d2 is well-matched but not well-formed. It is not well-formed as it has a disconnected zone, as described earlier, and a brushing point where CL meets L. The diagram d3 is both well-matched and well-formed. It does not exhibit any extraneous properties and the relationship between its curves and regions are neither disconnected or brushing and, therefore, it is regarded the most effective at conveying this information pertaining to staff hierarchy. There are a number of other well-formedness conditions that a diagram can exhibit. One example, concurrency, exists when two or more curve segments follow the same path [11].

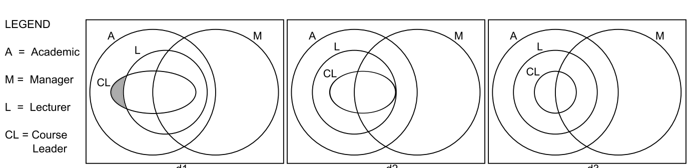

Fig. 1. Visualizations of a staff hierarchy.

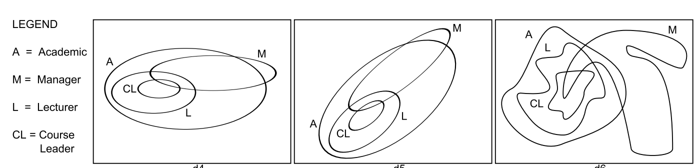

Fig. 2. Further illustrations of the staff hierarchy.

To illustrate further differences in Euler diagram layout, the diagrams in figure 2 represent the same information as those in figure 1. Diagrams d3 to d6 are all well-matched and well-formed and are, by these properties, regarded as equally effective. However, there are clear visual differences between them. These differences can largely be attributed to the shape of their curves. Diagram d3 uses circles, diagrams d4 and d5 use ellipses and diagram d6 uses irregular shapes. Diagrams d4 and d5 are basically identical except that diagram d4 has been rotated by 150 degrees to yield d5. Diagrams d3 to d6 visually illustrate that well-matched and well-formed drawing principles alone are too naive in yielding effective Euler diagrams. Given the current state of knowledge, we are unable to determine which of these diagrams is most effective.

Thus, in addition to well-matched and well-formed, there are other diagrammatical properties to consider when ascertaining the effectiveness of a visual representation. Perceptual theorists know that we are sensitive to the diagrammatical properties of orientation, shape and colour [12]. Aware of this phenomena, information visualisation theorists manipulate these properties, affecting our interpretation and, thus, comprehension of diagrams [13].

Conscious that other diagrammatical properties affect our interpretation of diagrams, this research aims to ascertain the whether orientation impacts user comprehension of Euler diagrams. This is a key question as studies of Euler diagram comprehension (such as [11]) have assumed that users' understanding of a diagram is not impacted by orientation. If this turns out to be a false assumption then such studies have additional confounding variances, not taken into account by the investigators. The remainder of this paper focuses on the question of orientation and, in doing so, presents an empirical study addressing the general question: does the orientation of an Euler diagram affect our comprehension?

The remainder of this paper is structured as follows. In section II we present the design of the experiment. Section III describes our research vehicle and section IV presents our experiment execution and results. Finally, section V discuses our conclusions and future work.

II. Experiment Design

We are aiming to establish whether the orientation of an Euler diagram affects user comprehension. In order to investigate this, we designed an empirical study which requires participants to answer questions concerning the information conveyed by Euler diagrams. In particular, the study uses a parallel group design with repeated measures within each of the two groups; we call these groups *participant group A* and *participant group B*. We chose a set of Euler diagrams which were displayed to the two groups of participants, with group A being shown the diagrams with one orientation and group B being shown the same diagrams in a different orientation. In each case, participants were asked a question concerning the information within the diagram.

Consistent with other researchers who have investigated user comprehension [14], [15], [16], we recorded the time taken

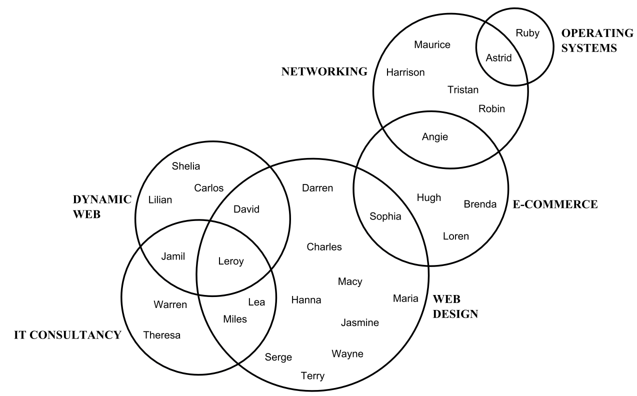

Fig. 3. An Euler diagram with 6 curves.

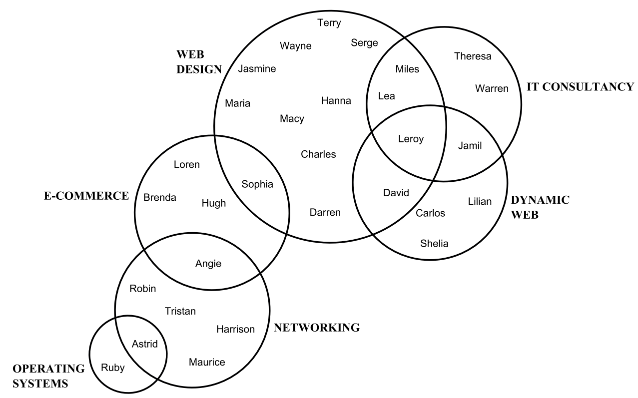

Fig. 4. Figure 3 rotated 180 °.

to answer the questions as the primary dependent variable. The independent variables were diagrams and rotation. If orientation impacts on comprehension then we would expect to see, for some diagram, a significant difference between the mean time taken to answer the posed question by participant group A to the mean time taken by participant group B.

In designing the study, we have considered the following factors. First, we identified the types of information conveyed by Euler diagrams, to enable the construction of a range of questions for the study. Second, we carefully considered choices in diagram layout, in order to ensure that we minimize unwanted variation across diagrams. The subsections that now follow expand upon the considerations just described.

A. Euler Diagram Specification

To execute the study, we had to produce a range of Euler diagrams of which to ask questions. As in [11], we placed data items within the curves in order to enable meaningful questions to be asked. For instance, figure 3 tells us that the set of students studying the module OPERATING SYSTEMS is disjoint from the set of students studying E-COMMERCE. Figure 5 expresses that DATA STRUCTURES is being studied by the student Victor. Scaled versions of these diagrams were used in the study.

When drawing Euler diagrams, even those which are both well-matched and well-formed, there are numerous choices to be made, such as curve thickness or the relative positioning of labels. In order to minimize confounding variables, we adopted the following drawing conventions:

1) all diagrams were monochrome, drawn in an area of 765×765 pixels,
2) the curves used all had a 2 pixel stroke width and were circles,
3) the curve labels were written using upper case letters in Times New Roman, 14 point size, font in bold,
4) data items were written using lowercase letters, except that the first letter was capitalised, and with Ariel 12 point size font,
5) each curve label was positioned closest to its corresponding curve, and
6) data items were evenly distributed within the regions (called *zones*).

Each diagram used in the study contained curves of three sizes, as seen in figure 5. Moreover, conforming to previous observations concerning user comprehension, all diagrams were well-matched and well-formed.

While striving to minimize confounding variables, it was deemed important there was some diversity in the diagrams, so that participants had to read and understand each diagram before being able to answer the posed question. The diagrams were chosen to have the following characteristics:

1) type 1: 4 curves, 9 zones and 20 data items,
2) type 2: 6 curves, 13 zones and 30 data items, and
3) type 3: 8 curves, 17 zones and 40 data items.

The premise for these choices is it allows diagrams to exhibit the range of basic set theoretic concepts, namely set inclusion, disjointness, and set intersection. Moreover, the diagrams needed to exhibit a reasonable level of complexity in order to demand cognitive effort on the part of the participant; having only a few curves, zones, or data items was deemed insufficient.

Our study used 6 diagrams for each of the three characteristic types, giving 18 diagrams in total for each set of participants. Each of the drawn diagrams was randomly rotated by an angle between 45 ° and 315 ° in order to remove possible bias arising from the manner in which the facilitator had drawn the diagram. These (rotated) diagrams were allocated to participant group A. Figures 3 and 5 are examples of two diagrams allocated to participant group A. These diagrams were copied and each randomly rotated a second time. These diagrams were allocated to participant group B. Figures 4 and 6 are examples of two diagrams allocated to participant group B which are the rotated copies of figures 3 and 5 respectively. The second random rotations were designed so that no diagram was within $\pm 45^\circ$ of either the original diagram or that obtained under the first rotation.

B. Data and Questions

We had to choose a context for the information displayed in our Euler diagrams. Our aim was that participants should be familiar with the context of the information, so that they did not need to learn anything except for how to interpret the Euler diagrams. Moreover, it was also considered important that the participants did not have any pre-exposure to the actual information represented. Since we anticipated that our participants would be university students, we decided to visualize information about fictional university modules and the students studying those modules. The module names were based on those commonly found in British undergraduate computing courses. Student names were taken to be first names only, a mixture of both male and female names, and reflected a variety of ethnicities.

Three styles of question were specified: 'Which', 'Who' and 'How'. Example questions are:

1) Which module is being taken by 5 students?
2) Who is taking INTERACTION DESIGN, HCI and OBJECT-ORIENTED DESIGN but not UML?
3) How many students are taking both MOBILE COMPUTING and FORMAL METHODS but not ARTIFICIAL INTELLIGENCE?

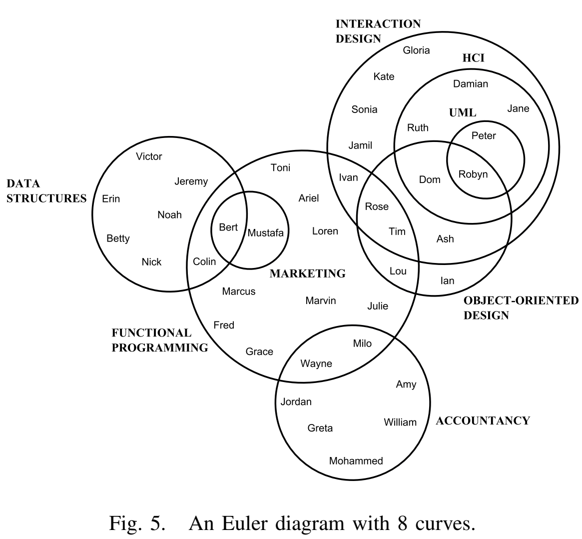

Fig. 5. An Euler diagram with 8 curves.

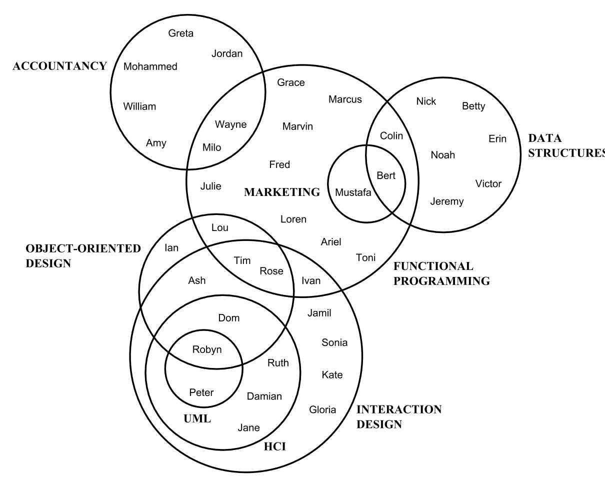

Fig. 6. Figure 5 rotated 148 °.

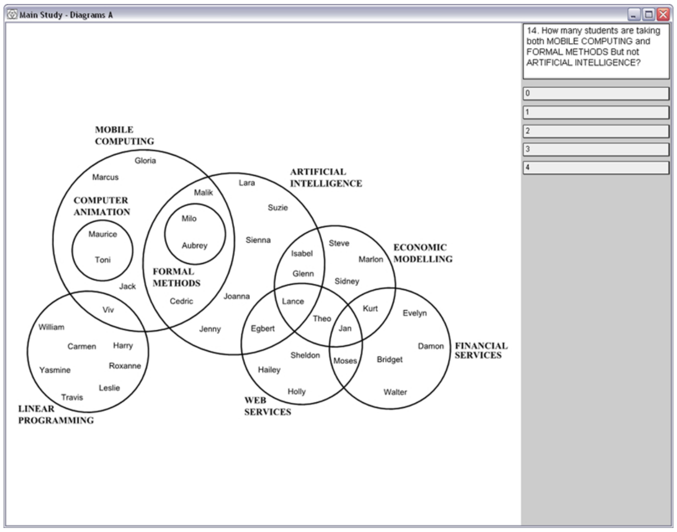

Fig. 7. Research Vehicle

Here, the first question was that asked of the diagram in figure 3 and of the rotation of it in figure 4. The second question was that asked of the diagram in figure 5 and of the rotation of it in figure 6.

There were 18 different questions in total, one for each of the 18 diagrams used in the study. The six diagrams of each characteristic type were allocated, between them, two of each style of question. All questions were multiple choice and had either 4 or 5 choices of answers; the correct answer was always unique.

III. Research Vehicle

To collect data during the study, we used a software tool (which we call the research vehicle) to present the questions to participants, gather the answers given to the questions and the time taken to reach each answer. Each time the participant answered a question, the research vehicle would ask the participant to indicate when they were ready to proceed to the next question, thus allowing them to pause between questions. Further, there was a maximum time limit of two minutes for each question. This was to ensure that each experiment did not continue indefinitely. Figure 7 is a screen shot of the research vehicle. It presents the third style of question, 'How', as specified in section II-B. The research vehicle was used for two phases of the experiment, a *training phase* and a *data collection phase*.

The training phase was designed to give participants the opportunity to practise interpreting Euler diagrams and using the software, to avoid any learning effect during the actual data collection stage. In the training phase, each participant was presented with 6 Euler diagrams and their questions, one after the other, in a fixed order; these 6 diagrams were distinct from those used in the actual study. They were exposed to two examples of each question type and examples of 4, 6 and 8 curve diagrams.

The data collection phase presented the 18 chosen diagrams to each participant in a random order. The randomizing of the order of questions was an attempt to negate potential learning effects had the diagrams been presented in the same order throughout the study. It is the data from this phase that we analyze in order to test our hypothesis.

IV. Experiment Execution and Results

We are aiming to establish whether the orientation of Euler diagrams affects user comprehension. Specifically we want to test the null hypothesis that there does not exist an Euler diagram where the mean time taken to interpret the diagram is different when the diagram is oriented differently versus the alternative hypothesis that there exists at least one Euler diagram where the mean time taken to interpret the diagram is different when the diagram is oriented differently.

Our study recruited 32 participants, including six during a pilot phase. The participants were randomly allocated to either group A or group B; these groups were equal sizes. They were all undergraduate students from the University of Brighton's School of Computing, Engineering and Mathematics and they spanned all undergraduate years. The participants performed the experiment on campus within a usability laboratory which affords a quiet environment free from noise and interruption. Each participant was alone during the experiment, in order to avoid distractions, with the exception of an experimental facilitator who was present throughout. The same computer and monitor was used by each participant. The experiment took approximately 1 hour and participants were paid £6 to take part.

There were three phases to the experiment. Before participants entered the aforementioned training phase (which introduces the participants to the research vehicle), participants were introduced to the notion of Euler diagrams and the types of questions to be asked. This was achieved using hard copy printouts of three diagrams, with four, six and eight curves respectively, and with one question of each style. Participants were given a few minutes to study the diagrams and questions after which the experimental facilitator explained how to answer the questions. When the facilitator was happy that the participant clearly understood how each answer was derived, the participant was asked whether they were happy to proceed with the experiment.

The participants then entered the training phase, where they had the opportunity to use the research vehicle to answer questions. When all six questions were answered participants were shown data indicating questions answered correctly and how long each question took to answer. If a question was answered incorrectly the facilitator went through the question with the participant. The participants then entered the data collection phase of the study, where we collected the quantitative data.

Initially, a pilot study was undertaken involving six participants. The experimental design, method and research vehicle proved robust, with no changes required. Subsequently, the main study was instigated involving a further 26 participants. All questions were attempted and completed comfortably within the two minutes allowed. There were no differences between the execution of the pilot study and the main study so their data sets were combined, consistent with [17]. Consequently, the following results are based on 32 participants and $18 \times 32 = 576$ observations.

A. Results and Analysis

In order to explore whether orientation impacts user comprehension, it is insightful to examine the box and whisker plot in figure 8. This illustrates that, for each diagram, the times taken to answer the question by participants in group A are very similar to the times taken to answer the question by participants in group B. Considering diagram 1, for example, we see that the interquartile ranges are almost identical across participant groups. In fact, the interquartile ranges for each diagram, by participant group, overlap substantially except perhaps for diagram 16. Despite these substantial overlaps, we can see that there is variation between the different diagrams, indicating that the study design is robust and fit-for-purpose. In summary, this plot indicates that orientation is unlikely to impact comprehension.

Source	DF	SS	MS	F	P
group	1	1.1012	1.1012	0.83	0.369
diagram	17	65.4768	3.8516	46.36	0.000
group*diagram	17	1.4599	0.0859	1.03	0.419
subj(group)	30	39.7617	1.3254	15.95	0.000
Error	510	42.3739	0.0831		
Total	575	150.1735			

TABLE I
ANOVA FOR LOG TIME.

To verify this insight, we conducted an analysis of variance (ANOVA) test, taking into account the diagram and participant group. In order to conduct this test, we require the data to be normal. However, a normal probability plot (not included here) revealed that the data are not normally distributed, but applying a transformation (in this case taking the log of the time taken) resulted in a normal data set. Using this transformed data set, the statistical calculations are included in table I.

First, we consider the row for group, which concerns difference in time taken between the two groups. Here, a p-value of 0.369 indicates that there was no significant difference in the mean time taken to answer the questions by the participants group A with the mean time taken by participants in group B. By contrast, there were significant differences between the mean times taken to answer questions about each diagram (ignoring the breakdown by participant group), with a p-value of 0.000 seen in the row for diagram. This indicates that there was a significant amount of diversity in our selected diagrams. Thus, these two p-values mean that we can safely and rigorously use the data to compare the affect of orientation.

The pertinent row, with regard to our hypothesis, is that for the interaction of group and diagram there is a differential effect of rotation among diagrams. A p-value of 0.419 means that there is insufficient evidence to reject the null hypothesis and we conclude that orientation does not affect user comprehension.

B. Error Results

Of the 576 observations there were a total of 19 errors giving an error rate of 0.03 or 3%. Table II lists each diagram which incurred errors. For each diagram, errors are distributed between participant groups.

	Group A	Group B	Total Errors
diagram 2	1	2	3
diagram 4	1	0	1
diagram 6	2	2	4
diagram 8	2	1	3
diagram 12	1	0	1
diagram 13	2	1	3
diagram 14	2	2	4
	11	**8**	**19**

TABLE II
ERRORS FOR EACH DIAGRAM BY PARTICIPANT GROUP

As can be seen from table II, the maximum error for a diagram under a participant group is 2. Therefore, there is little useful information that can be derived from this error data regarding orientation of Euler diagrams affecting user comprehension. It was observed in the introduction of this paper that well-matched [9] and well-formed [11] drawing principles are designed to reduce comprehension errors of Euler diagrams. The very low error rate found here reinforces the premise of these principles.

With the exception of diagram 13, the remaining 6 diagrams listed in table II conveyed information about a subset relationship which accounted for 16 of the 19 total errors. Of these 16 errors, 12 errors were for questions that referenced a curve that was completely contained by another curve, thus conveying a subset relationship. These 12 errors occurred from 4 questions phrased either:

1) ‘Who is taking module A and module B but not module C?’ or,
2) ‘How many students are taking module A and module B but not module C?’

Of these 16 errors 4 other errors occurred from diagrams exhibiting subsets about which their questions did not reference. These questions required participants to count the number of students in a module and were phrased ‘Which module is being taken by n students?’ By contrast, of the 11 diagrams with no errors only three exhibited set inclusion. While well-matched and well-formed drawing principles appear to contribute to a very low error rate there is a notable bias in the nature of errors that do occur, specifically with diagrams exhibiting set inclusion.

V. CONCLUSIONS AND FURTHER WORK

In this paper we set out to establish whether the orientation of Euler diagrams affects user comprehension. To establish this we designed a parallel group study with repeated measures. We paid particular attention to the layout of the diagrams

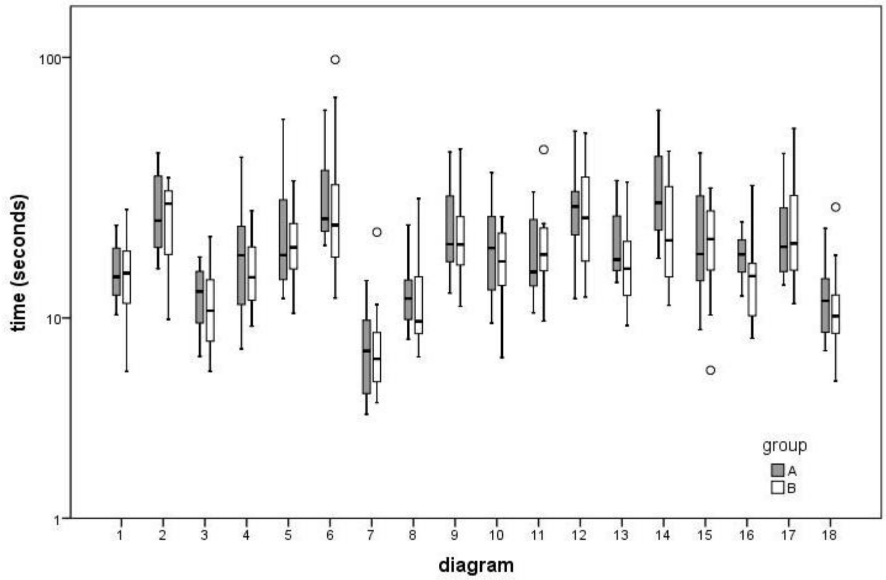

Fig. 8. Times taken (log scale) broken down by diagram and participant group.

used within the study as well as their complexity. To ensure a degree of difficulty to the questions in our study the diagrams had up to 8 curves present, 17 zones and 40 data items. To ensure the participants, who were undergraduate students, were familiar with the question domain the diagrams visualised information about modules and students enrolled for them. This was to avoid any bias in the data due to the avoided necessity of learning a new context; the emphasis of their learning was limited to the diagrams. Our analysis of the collected data demonstrated that orientation does not affect user comprehension. The next phase of this research will be to explore the effect of curve shape and colour upon the comprehension of users.

Our result has implications for Euler diagram layout as well as future usability studies. In particular, people who draw Euler diagrams need not worry about the orientation from an effectiveness perspective and can now focus on other diagrammatical properties. In addition, our work supports current techniques for automated Euler diagram layout methods, such as [8], [18], [19], [20], [21], which do not pay any regard to orientation.

In terms of usability studies, our work underpins that in [11], which assumed that Euler diagram orientation does not impact user comprehension. Furthermore, this gives flexibility to the design of future studies, whereby empiricists no longer need to concern themselves with this aspect of diagram layout.

Acknowledgment

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