TabularVis – A Circos-inspired Interactive Web Client based Tool for Improving the Clarity of Tabular Data Visualization

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Abstract: Table visualization is one of the earliest problems in the field of data visualization, and there are many applications which provide different solutions to this task. One of the most popular ones is Circos, a well-known genome visualization software package based on the so-called circular layout technique. In this work, we present an interactive web-based visualization tool inspired by Circos' table viewer web application, in which we provide new extensions and techniques beyond its existing main ideas, for improving the clarity of the generated visualization. One of them is making the links easier to follow by giving an automatic solution to reduce the number of intersections between the links. We also present different tools which could be particularly useful in such situations, in which the table's data induce extreme scatter, i.e., the difference between the data is significantly large or small. Our proposed visualization accepts tables with non-negative numbers, and the amount of efficiently displayable data depends on the number of zeros in the table. In the paper, besides describing our contributions in detail, we also compare the outputs of our method and Circos table viewer to confirm the legitimacy of our application and the implemented techniques it contains.

1 INTRODUCTION

Nowadays, it is difficult to find a scientific or industrial field, in which the relationships between data do not play an important role. Almost everything affects something else, and it is crucial to notice these dependencies and understand the relationships that they describe. The connections are often represented by values, and each one can indicate the related connection's type or property.

Tables have a long history in database management and computer science, and they suit well to store information about relationships. In this paper, we deal with connections which are represented by numbers. However, organizing these connections into a table does not make them easily readable or understandable by itself, because when a table is formed by many rows and columns, it becomes harder to work with it. There are a lot of various reasons and purposes why the users want to visualize tables, and what they want to see in the resulting image. By using tabular visualization, our goal is to display relationship information. There are a lot of different techniques to achieve this goal, but the circular layout is one of the most prominent ones. It is used in the field of graph drawing and many visualization applications, including the highly cited and popular *Circos* software package (Krzywinski et al., 2009). In this paper, we present an improved approach of how Circos visualizes connections based on tables, by giving new tools for displaying the value, the direction, and the pattern of the connections. Sometimes it is confusing to follow the links in a diagram, so we introduce a sorting method as well, to make the diagrams more transparent by reducing the number of intersections between the connections. Multiple search and optimization algorithms were implemented for this task, and we compare them with each other to find the one with the best performance.

In this work, first, we discuss the related works, then in Section 3.2, we introduce our visualization method in detail. Also, we briefly present Circos to make the comparison of the two visualization solutions easier. After this, we propose our solution for reducing the intersections of the connections. At the end of the paper, we introduce the features and the performance of our self-developed application, which was implemented to present our results.

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2 RELATED WORK

Circular layout is often used to visualize connections, especially for genomic data or graphs. However, its advantages, which come from its simplicity and symmetry, make it perfect to visualize other general data as well. The rotation invariant property, the ability to reduce the number of eye movements, and weakening the reading order implications are just three of these advantages, which are discussed in the work of Chuah and Eick (Chuah and Eick, 1998).

In these referenced works we can see examples of genome (Katapadi et al., 2012; Burkart-Waco et al., 2012; Schmutz et al., 2014; Tine et al., 2014), network (Lin et al., 2014; Dang et al., 2015; Irimia and Horn, 2013; Irimia and Van Horn, 2014), and general (Blasco-Soplón et al., 2015; Pan et al., 2013; Fujiwara, 2015; Nicholas et al., 2014) data visualization by researchers from different disciplines. There are a lot of studies which show good use cases for how the circular layout can easily visualize the connections; here we would like to mention some of them. Circos is an open-source and free application licensed under GPL. Also, it is widely used in the field of genome research, because of its success in displaying variation in genome structure and positional relationship between genomic intervals. Besides, it can show different plot types inside the tracks of the diagram, to provide more information about genomes. However, despite the fact that Circos is a powerful visualization tool, unfortunately, it is not user-friendly at all. It is a command line application written in Perl, and it uses configuration files to create the diagrams. Moreover, learning how to use the software can be hard and time consuming for researchers with basic IT skills. There are numerous applications, for example, *ggbio* (Yin et al., 2012), *Rcircos* (Zhang et al., 2013), or *OmicCircos* (Hu et al., 2014), which aim to provide a more user-friendly and improved circular genome visualization. These mentioned applications are packages which have been developed for the R statistical software environment. By using them, it is ensured that the users can take the advantages of R while they are creating visualizations. However, only static images can be generated with all the applications that we mentioned so far, and this makes it significantly harder to customize the diagrams after they were created. The possibly used third party software or any framework assumes the knowledge of them, and they can make the installation of the application more complex and time-consuming. The circular layout combined with interactive data visualization techniques (e.g. in *Mizbee* (Meyer et al., 2009) or *J-Circos* (An et al., 2015)) can help the users to understand their data better and faster. Unfortunately, the possibility of customizing the diagram in the way of removing or changing its elements is missing in these two mentioned applications. In turn, this functionality could help to make the diagram more personalized. Additionally, these software still operate with one or more configuration files, which is still not the most user-friendly solution. However, both applications have inspired us to extend the possibilities of visualizing the connections' values in a diagram.

Beside genomic data, there is a demand for software solutions and tools for visualizing relationships and connections based on more general data. The R package called *circlize* (Gu et al., 2014) can create diagrams based on non-genomic data. The main purpose of circlize is still the genomic analysis, but thanks to its low-level graphic functions, the user can use it for displaying other kinds of data. Circos can visualize general data as well, but they have to be given in one of the required formats. The *InfoVis* library (Li, 2012) has a visualization tool called *Smith-Graph* which uses bars on the circle's circumference. A similar visualization method is Jen Lowe's solution (Bayer, 2011), with which she has won the WikiViz 2011 challenge.

There is a trend to bring the visualization right into the browser and make it as interactive as much as possible. Probably the most used tools for this kind of purpose are the *D3.js* (Bostock et al., 2011) and the *WebGL* libraries. There are many examples in the Chrome Experiments website (creative coding community, 2009), and WebGL also has been used in different scientific visualization projects (Mwalongo et al., 2015; Andrews and Wright, 2014; Bornelöv et al., 2014; Cui et al., 2016). Circos also has an online application for tabular data visualization, but it has less much less functionality than the desktop version of the software.

As we have pointed out above, the circular layout has proven its ability to visualize both genomic and general data. Also, few examples have been shown how the lack of interactive functionality can negatively affect the usability of an application. Besides, we have seen that there is a need for an easily accessible and user-friendly web-based application.

It is easy to imagine that a diagram can quickly become crowded if there are too many connections in it, and this may prevent the user from understanding the data. Decreasing the number of intersections between graph edges during a circular graph drawing is a well-known problem in the field of graph theory. In the work of Baur et al. (Baur and Brandes, 2005) we can see an example to construct a graph using a two-phase heuristic algorithm. The first phase minimizes the total length of the edges of the graph, and the second one uses the shifting heuristic to optimize the result of the previous step locally. Another example is the work of Gansner et al. (Gansner and Koren, 2007), which tries to find the best node placement by minimizing the length of the edges separately using a heuristic algorithm as well. Edge bundling (Lhuillier et al., 2017) is an efficient alternative to reduce the number of intersections in a diagram. Another way of avoiding crowded diagrams is the exterior routing and in the work of Gansner et al. (Gansner and Koren, 2007) we can see an example for that. However, we do not use the edge bundling because we want to keep the connections thickness in the diagram. We also want to make the diagram more transparent by performing a sort on any predefined order and preserving the relative position of selected elements.

3 TABLE VISUALIZATION

In this section, we introduce how Circos creates diagrams based on tabular data, and we compare it with our proposed technique because our improvements were inspired by Circos. We also point out a few shortcomings of its visualization method (which uses circular layout and Bézier curves), and we suggest solutions to them.

3.1 Circos' Visualization

Circos can visualize connections between the columns and the rows of a given table. A connection is represented by a cell and its value. Therefore, the cell's position determines which row and column are affected, and the value describes the relationship between them. The software visualizes these connections as we can see in Figure 1. The main concept in Circos is that a cell can only contain a non-negative value, and zero means no connection.
There are smaller angular segments (so-called ribbon caps) located at the end of the connections (see Figure 2). These indicate which segment is the other participant in the relationship, using the color of the connected segment. We can see in Figure 1 that the ribbon caps do not always appear in the diagram. The contribution tracks can be placed above each segment to show the relative values of its contained row and column and the sum of them.

3.2 Our Visualization Method

In this paper, our goal is to improve the previously introduced visualization in Subsection 3.1, by increasing its clarity in common situations, depending on the intentions of the user. Therefore, we specified the following criteria to create our visualization technique based on them. The first one was to construct a connection between two objects that helps the user to track and identify the visualized relationship. The second was about to give the ability to determine and compare the value of the connections easily and quickly. Lastly to provide more space for the labels and to give the possibility of grouping the table's rows and columns. We use circular layout in our solution as well, because of the advantages that it provides; and similarly to Circos we also use Bézier curves for constructing the connections. Circos can effectively display the relationships in many cases. However, there are many situations where its visualization makes im-

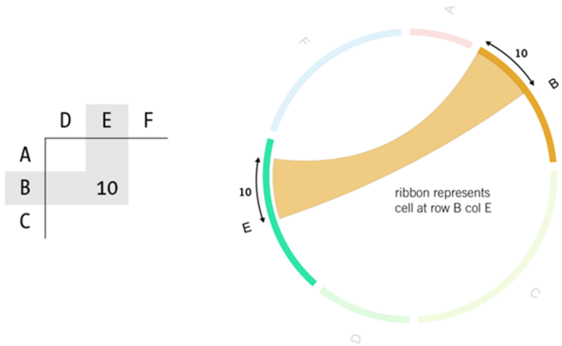
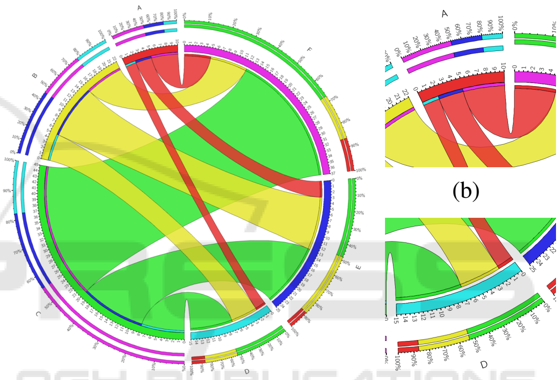


Figure 1: Circos' way to visualize connections (Krzywinski, 2008). The ribbon represents the value 10 of the cell at row B and column E. Rows and columns are represented by circular arranged segments, and their angular size is based on the summarized values of the corresponding one. The thickness of the ribbon is defined by the cell's value.



(a) (b) (c)

Figure 2: Circos' visualization in detail: (a) shows the contribution tracks outside the circle, the so-called tick marks and tick labels on the segments, and the track. While (b) shows that the links start from a row segment, (c) displays that they end at the column segments. (b) and (c) also provide a closer look at the ribbon caps.

portant details harder to perceive. Also, it works well when the differences between the matrix's values are significant because in this case the relationships represented by thick ribbons are easily and quickly noticeable. However, it is harder to decide which relationships have larger values in the case of minor differences. Furthermore, the comparison of the values is not an easy task, especially if the segments are placed far from each other. The so-called *tick marks* and *tick labels* help this comparison by showing the row or column values at the top of the segments (see Figure 2).

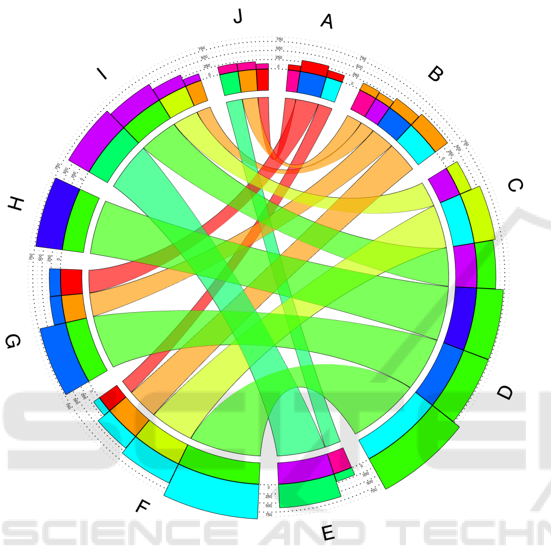
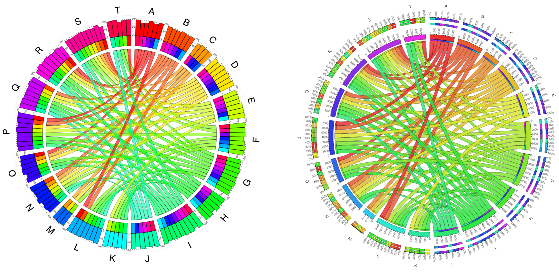


Figure 3: The extensions of the connections and the bars together form a block, and they can be arranged into groups like *block C* and *block D*. The height and the angular length of a bar have the same meaning, and they are both used for representing the value of a link. There are concentric circles behind the bars to make their values easier to read and compare, even if they are far from each other.

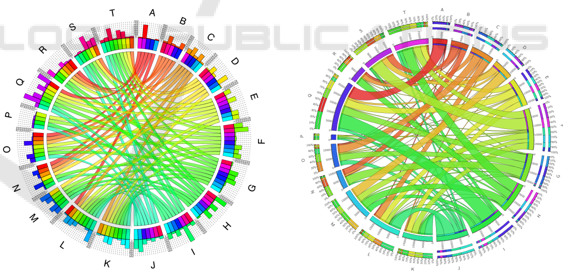
One of our main ideas is to remove Circos' segments – which represent the rows and the columns – and replace them with angular segments. These are created as an extension of the connections in both directions, and we call them bars in the rest of the paper. We use them to make the values easy to read and compare, and this is one of our mentioned criteria in Section 3.2. The newly defined bars have the same thickness as the links themselves, but they have different height based on the connections' value. They are positioned a little bit farther from connections' ends. Figure 3 shows that the bars are used together with the concentric circles to make the values easier to read and compare (see Figure 4). The blocks represent the row and the column from the table. It is created by placing the bars belong to the same row or column next to each other and marking them with the same color. Additionally, these blocks can be arranged into groups to represent rows and columns close to each other (see Figure 3).



(a) (b)

Figure 4: The left image (a) shows how the bars can easily indicate the values with concentric circles, while in Circos (b) it is harder to read and compare the values of the connections.

In Circos, wider ribbons represent larger values in the table, and they can grab our attention immediately, which is very useful in some cases. But if the scatter in the table's values is significant, then thick connections may cover other ones and make them hardly visible. This situation is perfect for finding out which row and column have the largest or smallest value, but it makes the patterns – formed by the connections or the direction of the ribbons – hard to recognize.



(a) (b)

Figure 5: The left image (a) shows our visualization with unified connection sizes, while in (b) we can see the result using Circos. We can recognize that the pattern of the connections is much more visible in the case of (a) than (b).

As a solution to this problem, we decided to make it possible to create all relationships equally visible by unifying the thickness of the links and the bars in the diagram. This way the links represent only the existence of a relationship between two bars (see Figure 5(a)), and as a result, thinner connections become more visible in the diagram, than before. Furthermore, the links with unified length make the pattern formed by the connections easier to perceive, instead of drawing our attention to a particular part of the diagram, while the bars' height still represents the relationships' values (see Figure 5). Moreover, the equal thickness of the bars increases the visibility and the comparability of them. With this feature, the redundancy mentioned at Figure 3 can be eliminated.

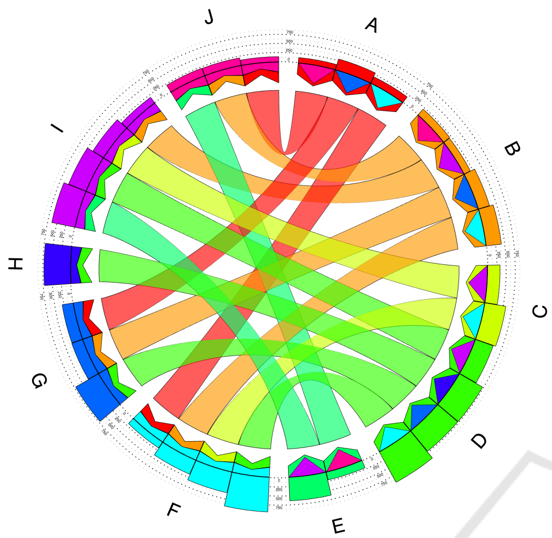


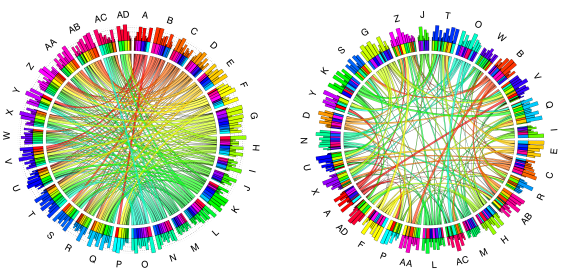
Figure 6: Shows the connections with unified length and our arrow-style shapes to indicate the directions. The shapes below *block e* indicate the connections' source, and the ones below *block h* show its target.

In some situations, it could come in handy to be able to determine the connections' direction and to decide which row or column is the start or the end of a relationship. Circos indicates the direction of a relationship by distinguishing a ribbon's starting and ending position. However, this way of representing the directions may not clear enough for somebody who does not have any preconception about the visualization method to find out the direction. We intended to offer a different and more informative way to display the connections' direction. Therefore we added a shape between the block and the link in a way that Figure 6 shows us to indicate the link's direction and the other block of the link. This solution works best when the connections have equal width since in this case the mentioned new shape does not deform and keeps the original arrow-style form without losing its meaning. This shape is always attached to the bar, and it has three different forms. Two of them are shown in Figure 6, and the third one, which is used for representing an undirected relationship, has a similar shape like Circos' ribbon cap with a different height. Our previously mentioned improvements are suffered from the problem of barely perceptible bars when the value of the represented relationship is too small. Because in this case, the height of the bar could be so small that it appears only as a circular arc. The proposed arrow-like shapes can increase the visibility of the bars in this case as well.

Our application provides these modifications as optional features since they are suitable for different situation, so the users can decide which one is the most appropriate for their purpose.

4 SORTING THE CONNECTIONS

One of the most important aspects of a visualization is that it should be easily understood. In our case, the position of the blocks and groups controls where the connections are placed, so any change in their order affects on the number of the intersections in the diagram. Because the intersections of the connections make the diagram less transparent and make the links harder to follow, the blocks' and groups' order has a huge influence on the clarity of the diagram. Therefore, it may be important to find an easy and fast way for modifying their order. In the rest of the paper, we reference the process of changing the blocks' and groups' order as sorting the connections. Figure 7 shows an example where sorting can help to avoid the clutter in the diagram. However, Circos do not provide an automatic solution to perform a sorting of the connections, which means that the user has to do it manually. This sorting problem is known as the circular crossing minimization problem in the field of graph drawing. it is an NP-hard problem, and researchers often use heuristic ways to deal with it (e.g. (Baur and Brandes, 2005; Gansner and Koren, 2007)). Because of the problem's complexity, our goal is to automatically find one of the sequences of the blocks and the groups, which can remove a large number of intersections from the diagram by using a heuristic approach as well.



(a) (b)

Figure 7: Example of how the sorting of the connections makes the diagram more transparent. The left image (a) shows the diagram without sorting, and the right image (b) shows the result that we get after applying it.

4.1 Used Algorithms

To get the desired order of the blocks and the groups, we tried and used two local search algorithms (hill climbing and max-conflicts) and three optimization methods (cross-entropy, simulated annealing, and bees algorithm), which are all discussed in more detail in (Brownlee, 2011) and (Russell and Norvig, 2010). These algorithms try to search the best possible position of the groups and the blocks to minimize the number of the intersections in the diagram. However, as we mentioned earlier, this is an NP-hard problem, and these methods only can give an approximation of the best "theoretical" solution. But in most cases, their results are good enough to remarkably increase the clarity of the visualization (see Figure 7).

However, not all parts of the diagram are controlled by the search, because the position of the bars is determined by the order of the blocks and the groups. This is done by creating a temporary list from the result of the search, starting with the block which contains the bar we want to set, then adding the blocks followed by it from the result. By reversing this newly created order, we can set the bars' position in the block.

The used algorithms produce a result within seconds or in the case of tables (20×20) approximately in ≈ 17 seconds. More detailed information about the run time of the algorithms can be found in Table 1. In the next subsections, we briefly introduce the methods and their time complexity.

Table 1: The running times in seconds for all algorithms and table sizes.

	5×5	10×0	15×15	20×20
Hill climbing	0 s	6 s	106 s	724 s
Min-conflicts	0 s	1 s	5 s	19 s
Cross-entropy	0 s	1 s	5 s	18 s
Cross-entropy and Min-conflicts	0 s	11 s	111 s	475 s
Simulated annealing	0 s	1 s	4 s	14 s
Bees algorithm	0 s	4 s	37 s	154 s

4.2 Search Space

Before we could start to discuss the used algorithms, we have to define a search space for the methods. It consists of states that store all possible combinations of the positions of the groups and the blocks. Moreover, it contains the actions of how the search methods can modify the states. The sorting methods are operating in this search space to find better order for the groups and blocks. This is a simple definition of the problem, and it contains only the necessary information for the search, the position of the blocks and the groups and the relationships between the blocks. This information is enough for us to find a better order, which generates fewer intersections than the initial state. In the diagram, the position of the groups and the blocks determines the location of the connections, but during the sorting, instead of using the exact location of them, we just deal with their order. After the search, we can easily get back their position from this. Also, to be able to get information about the connected blocks, we store the position of a connection's start and end segments. Figure 8 shows information about the groups and blocks, which is stored in a state.

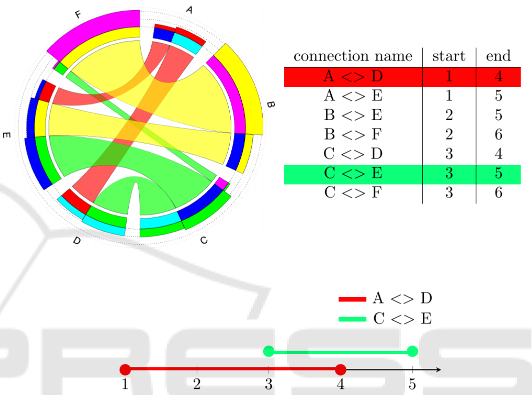


Figure 8: In the picture, we can see the information, which is stored in a state. At the bottom, it also displays that by testing the overlap of the ranges – created from the connections – we can determine whether they are intersecting or not.

The state has to know whether the given action can apply to it or not and if yes, the result also has to be known. We defined our actions to move the groups and the blocks to a new position in the order, and since we do not want to prioritize any of the actions, we have the same cost for all of them. Beside this, it is important to make a difference between two states, so they store the number of intersections to describe the goodness of their status and give the basis for the comparison of them. This number can be calculated by using the analogy of testing for overlapping ranges, which were created from the stored positions of the connection as Figure 8 shows. If two ranges overlap, then the two connections intersect each other. Otherwise, there is no intersection between them. To decide whether two ranges overlap each other or not, we have to define their midpoint. We have to use a distance function as well, and we used the following:

$$f(a,b) = \begin{cases} 2\pi - |a-b|, & |a-b| > \pi \\ |a-b|\pi, & \text{otherwise} \end{cases}$$

Also, we have to define a function, which normalize the given value to the range $[0, 2\pi]$

$$l(a) = a - \left(\left\lfloor \frac{a}{2\pi} \right\rfloor \cdot 2\pi\right)$$

The function $g(a,b)$, that finds the midpoint of two given points, is given in the following form:

$$g(a,b) = \begin{cases} l\left(\frac{a+b}{2} + \pi\right), & |a-b| > \pi \\ l\left(\frac{a+b}{2}\right), & \text{otherwise} \end{cases}$$

It is also important to know when a point is inside in the given range and we can find out this by using the $h(a,b,c)$ function.

$$h(a,b,c) = f(g(a,b),c) - \frac{f(a,b)}{2}.$$

The overlap of two ranges is tested by using the $sgn(h(a,b,c))$ function for both ranges and all of their points.

$$k(a,b,c,d) = sgn(h(a,b,c) \cdot h(a,b,d)) + sgn(h(c,d,a) \cdot h(c,d,b))$$

We denote the connections as $c_1, \ldots, c_n$ where n is the number of the links in the diagram. Our connections are defined with their start and end positions, which are denoted with two functions, $s(c_i)$ and $e(c_i)$ respectively $i \in [1,n]$. The existence of an intersection is calculated from the overlap function ($k(a,b,c,d)$) in the following way:

$$q(i,j) = 1 + sgn\left(-1 - \frac{k(s(c_i), e(c_i), s(c_j), e(c_j)))}{2}\right).$$

With testing all connections with each other we can calculate the number of the intersections in the diagram in the following way:

$$\sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} q(i,j).$$

The result of the sum is 1 if there is an intersection between the two given edges (e_i, e_j) and 0 otherwise. Therefore this function was used as an optimization criterion to minimize the intersections in the diagram.

4.3 Hill Climbing

Our first choice was the well-known hill climbing method because it visits all the neighbors of a state during the search, and thus it is more likely to get better results. Sometimes the search could trap in a local minimum, so to avoid this, we modified it to randomly choose another state if there is no better one around it. The algorithm has two parameters. The first one controls how many times it can jump to a random state (the value used by us 10), and the second one specifies how many iterations it can do (we used 100). This search algorithm does not use any knowledge or heuristic about the problem, it is just a brute force method to find a better state and therefore its running time is long.

4.4 Min-conflicts

This method is based on the idea, that the number of intersections can be significantly reduced by replacing the block, that causes the most intersections in the diagram. The algorithm searches for this block in every iteration, and then it tries to find a better position for the block. This method has only one parameter, which specifies the number of the iteration that it can do before it has to stop (we used 10). The min-conflicts algorithm is faster than the hill climbing because it visits less state during the search.

4.5 Cross-entropy

This algorithm uses the statistics of the blocks' position, which is updated from a specified number of generated states in every iteration. This statistical data is stored in a matrix, which contains the percentage of the blocks' occurrences for every position. The matrix's values will converge to the best position of the blocks which means that eventually, we will find a good solution. This algorithm has multiple parameters in order to fill and maintain the matrix, but the two most important are the number of the states generated by the algorithm in every iteration (which was 10 in our implementation) and the number of the used ones as elite states (the value used by us 2) to update the matrix.

4.6 Cross-entropy and Min-conflicts

We merged the cross-entropy and min-conflicts method to get better result. We implemented the min-conflicts methods' idea in the cross-entropy to increase the "goodness" of the elites. This means that in every iteration a min-conflicts search is performed on each newly generated state to get a state with fewer intersections.

4.7 Simulated Annealing

This global optimization algorithm is based on a probabilistic technique. It mimics the physical process of heating a material first and then slowly cooling it to improve its conditions. In our case, this means, that the method can accept worse orders of blocks and groups at the beginning, but as the temperature drops with each iteration, it accepts only the better orders with fewer intersections. The algorithm has three parameters, the acceptance ratio (we used 0.8), that we want to reach during the preheat process, the number of iterations per temperature (which was 10 in our application), and a maximum iteration number (we used 100 in our implementation).

4.8 Bees Algorithm

The last algorithm is also a global optimization method, and it tries to find the best state by simulating the movements of the bees searching for pollen. This means that in every iteration the method generates a specified number of random state, then it selects the best of them to perform further search on each of them. In our case, this means that we run the min-conflicts method on all of the best states. The algorithm's three important parameters are the number of the generated states, the number of the best states, and the number of min-conflicts runs per best state (we used the following values respectively: 20,2,10).

4.9 Algorithms Time Complexity

To present the time complexity of the proposed algorithms, we introduce the following notations.

- b : the number of the blocks in the diagram
- o : the number of the groups in the diagram
- m : the maximum number of iterations of the algorithm
- n : the number of the newly generated states
- w : the time complexity of quicksort
- u : the time complexity of updating all elements of a matrix with the size of $(b+o) \times (b+o)$
- p : the maximum number of iterations to find the best starting temperature for simulated annealing
- t : the number of iterations on each temperature
- r : the maximum number of iterations to find the best reheat temperature for simulated annealing
- z : the number of random searches per iteration to find new states in the bees algorithm
- j : the number of the best states through the whole search
- v : the number of min-conflicts runs per best state in the bees algorithm

The time complexity of the used algorithms can be seen in Table 2 to make the comparison between them easier.

Table 2: The time complexity of the used algorithms.

Algorithms	Time complexity
Hill climbing	$O(m \cdot (b^2 - b) \cdot (o^2 - o))$
Min-conflicts	$O(m \cdot (b-1) \cdot (o^2 - o))$
Cross-entropy	$O(m \cdot (n + w + u))$
Cross-entropy and Min-conflicts	$O(m \cdot ((n \cdot (b-1)) + u))$
Simulated annealing	$O(p + (m \cdot t) + r)$
Bees algorithm	$O(m \cdot (z + (j \cdot v)))$

4.10 The Result of the Algorithms

These methods were tested on randomly filled tables with four different sizes (5×5, 10×10, 15×15, and 20×20), and 100 tables were generated for each size to run the sorting on them. The overall result of the tests are shown in Figure 9, and it shows us that the algorithms effectively reduce the number of intersections in the diagram, and the average reduction of intersections was $\approx 55\%$.

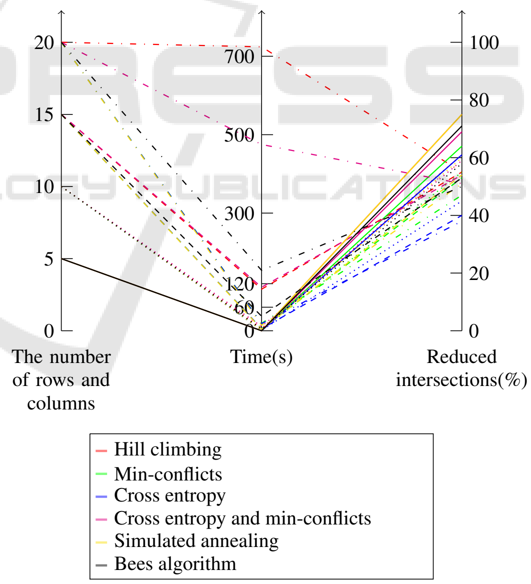


Figure 9: Parallel coordinates visualization of the algorithms' performance tested on different table sizes.

However, the comparison of the sorting algorithms' running time shows large differences when the number of the rows and columns increases in the table. The fastest ones (min-conflict, cross-entropy, and simulated annealing) need around 17 seconds in average to give results, while the rest of them require minutes to do the same for a table with the size of 20×20.

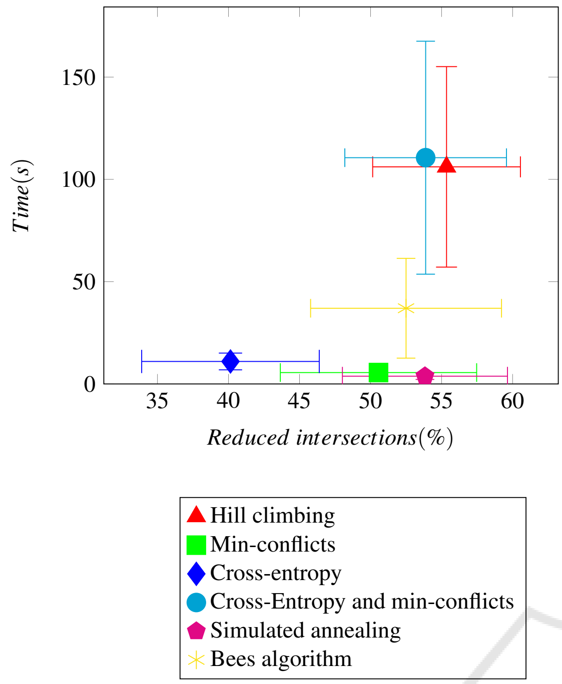
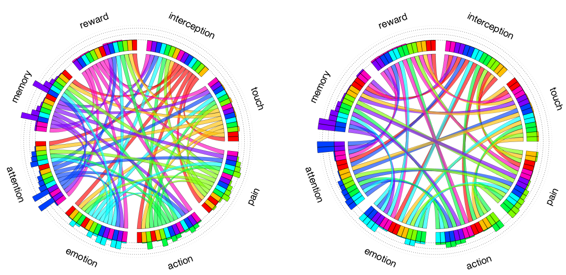


Figure 10: Comparison of the search algorithms' execution time and the resulting reduced intersections on 100 tables with 15 rows and columns.

When the results of the tests are grouped by sizes, the differences between the tested methods become clearer and more noticeable (see Figure 10). The cross-entropy method's performance is really poor compared to the others, and its running time is also not the best. However, its modified version has a better performance, but it requires way too much time to give a result. The hill climbing has the best performance, but the user has to wait too long for the algorithm to finish the sorting. The min-conflicts and the bees algorithms have a good performance, but there is a faster method with better performance, and this is the simulated annealing.



(a) (b)

Figure 11: These diagrams are created based on the heat maps from the work of Cauda et al. (Cauda et al., 2012). The left one shows the diagram (a) without sorting, and the right one (b) is created by applying the sorting feature.

Based on these results, it seems that the best possible choices for sorting are the hill climbing, the simulated annealing, the min-conflicts, and the bees algorithm. There are not big differences between the selected methods' performance ($\approx 5\%$), so when we choose an algorithm for our sorting process, we need to consider two important things, which are the following. How fast is the selected method and how much of the differences between the algorithms are visible in the current diagram. In the case of small table sizes, for example, tables with 5 rows and columns, the differences between the algorithms' results can be easily noticeable as Figure 12 shows us. But on the other hand, this small difference is almost negligible when the table's size is 20×20. Beside this, in Figure 12 we can also see in both cases, that even a bit worse result is way better than the original diagram without applying any sorting on it.

The selected algorithms have multiple parameters, and we focused on keeping the balance between the performance and the running time while we searched the best settings for them. All of the images in this paper are generated by using the previously mentioned parameters in the description of each method. Furthermore, we also used them in our application as default parameter values for the sorting algorithms.

5 APPLICATION

We have implemented a web application to present the proposed visualization method and the sorting of the connections. The software was written in the Dart programming language, and it uses WebGL for displaying the diagrams. These choices gave us the opportunity to make a fully interactive application, which lets the user modify (the data and the position of the segments and connections) and customize (change the visual appearance, like the color or the shape of the segments and the connections) the diagram. However, the sorting feature is not interactive, because the search methods need time to reduce the number of intersections. The position of the segments can be changed in real time, and the customization of its appearance is also possible. Our software supports to change the connections' shape by modifying the parameters of the Bézier curves. It offers different predefined coloring scheme for the blocks and the connections. The application can work with Circos' data files and Excel spreadsheets as well, in which the values are not limited to integers. Furthermore, our software has its own editor, with which the user can enter numbers in the table. These mentioned features allow easy data entry. The result of

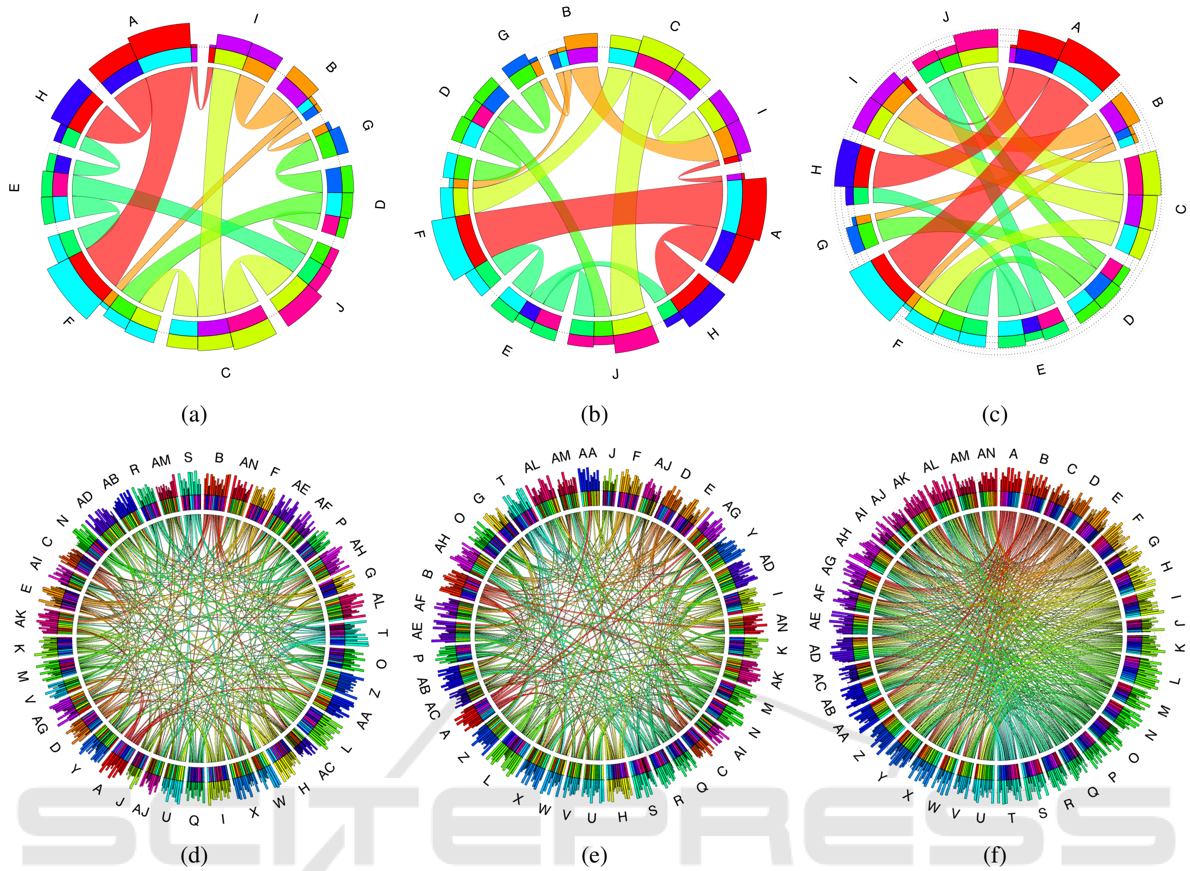


Figure 12: Comparison of search algorithms based on two different table sizes. A 5×5 table was used for the upper set of images ((a), (b), (c)) and one with 20 rows and columns was used for creating the lower diagrams ((d), (e), (f)). From the images above, (a) and (d) (sorted with simulated annealing) have the least number of intersections, (b) and (e) (sorted with bees algorithm) contain $\approx 5\%$ more intersections, and the last two, (c) and (f) have not been sorted.

the sorting can be downloaded as a PNG file, and it is also possible to download the input data in the format, which is used by Circos. The application is available at `https://arato.inf.unideb.hu/kunkli.roland/tabularvis/index.html` (at the current state of the development, our application works properly only with the latest stable version of Google's Chrome browser), and the source code is shared on GitHub (`https://github.com/pappgyorgy/TabularVis`).

6 CONCLUSION

We introduced some improvements to an existing tabular visualization technique, with which we can increase the clarity of the visualization in various cases. Replacing the segments with bars makes the values easy to read and compare, if the scatter in the values of the table is insignificant. The conception of concentric circles also serves this purpose. We used unified thickness for the connections to provide the ability to see the pattern more clearly, which are formed by the connections. This feature can provide more space for labeling in cases, when the differences between the tables' values are large. We also introduced a new way for representing the direction of the links with arrow-like shapes. Moreover, an efficient solution was provided to the problem of reducing the number of intersections between the links in the diagram, by modifying the order of the elements around the circle, based on different local search algorithms and global optimization methods. We also implemented our visualization and sorting method in a client-side web application which is available for public usage.

The proposed techniques have some limitations which give opportunities for further improvement. First of all, our method can only visualize tables filled with non-negative numbers, and it gives the best result in the case when there are elements, which are not connected with each other. This means that some of the table's cells contain zeros. Furthermore, dense tables with a large number of rows and columns can cause problems for our visualization method. Because in cases when the size of the tables is larger than 20×20 and it contains only a few zeros, then the middle part of the diagram becomes dense, and as a result, the connections will be hard to follow. Also, in this case, the sorting method is not effective because it may require minutes to complete the computations.

Based on these limitations, a possible future improvement can be to ensure that the visualization method works with tables filled with rational numbers. Because changing the position of a Bézier curve can cause intersections between the connections also in the case of when its end positions do not justify that, a modification of the sorting method to detect this kind of intersections can be a part of future work. The maximization of the used area inside the circle by modifying the parameters of the used Bézier curves individually is another potential way of improving our work. Besides these, we are planning to give detailed information about the connections or the segments (e.g., statistical information) by hovering the mouse over them. Because of the mentioned reason at the end of Section 2, we did not use edge bundling to avoid clutter in the diagram. However, it can be worth the effort to combine this technique with our proposed modification.

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