

# Interaction Techniques for Chord Diagrams

Dylan Rees  
Department of Computer Science  
Swansea University  
Swansea, UK  
0000-0002-7129-5825

Robert S. Laramee  
School of Computer Science  
University of Nottingham  
Nottingham, UK  
0000-0002-3874-6145

Paul Brookes  
QPC Ltd.  
Birmingham, UK

Tony D’Cruze  
QPC Ltd.  
Mold, UK

**Abstract**—Chord diagrams are a popular high-dimensional method for showing connections between nodes, however they have scalability limitations and lack advanced methods for interaction and multivariate links. In this paper we introduce a novel interaction and layout method for improving the scalability of chord diagrams, explore sketch-based methods for showing multiple links and direction, and introduce a sketch-based brushing technique for filtering. We demonstrate the interaction techniques on a real-world call-center dataset and report feedback from domain experts in the call center industry.

**Index Terms**—chord diagrams; interaction; call-center data;

## I. INTRODUCTION

Chord diagrams are a popular high-dimensional visualization for representing relations. Their simplicity and the intuitive design results in common use in mainstream media to visualize affiliation [2]. The design and layout of chord diagrams are necessitated to be radial as all nodes can be directly connected to all other nodes, without crossing a third node.

Chord diagrams are often used to convey hierarchical data, where axis nodes along the circumference are placed into groups. Holten utilizes a hierarchical dataset to address another limitation of chord diagrams, namely scalability [1]. This solution offers user adjustable bundling to reduce clutter. This solution does not however, fully address the scalability problem as the addition of more nodes will increase the difficulty of identifying individual nodes.

Other interaction techniques used with chord diagrams include filtering and axis ordering for optimizations and data reasons [3], [4]. From an interaction point of view, chord diagrams generally lag behind other multi-variate visual designs such as parallel coordinates which offer many advanced interaction techniques [5].

In this paper we explore novel interaction techniques for chord diagrams. We introduce a novel interactive deformation that enables screen-focus to be placed on a given segment, offering more observable detail as is shown in Figure 1 (right). We introduce a novel sketch-based brushing technique for chord diagrams that enables multi-variate filtering of connections. We also introduce approaches for tracking multi-variate connections across multiple links.

The contributions of this paper are:

- The introduction of a novel interactive layout technique to support detailed views of a particular segment

- Support for joining multiple edge connections in a chord diagram
- An interactive sketch-based filtering method for tracking connections across multiple chord segments
- The application of the techniques to a real-world telecommunication dataset [6]

The rest of this paper is set out as follows: Section II outlines other work related to chord diagrams while Section IV outlines a deformation technique. Multiple linked chord diagrams are presented in Section IV-C and we present an evaluation and domain expert feedback in Section V. A conclusion and future work are discussed in Section VII.

## II. RELATED WORK

As with any information visualization project, two primary resources provide an overview of the field to find related work. These are provided by McNabb and Laramee [7], and Rees and Laramee [8] which survey data visualization surveys and books respectively. From these two surveys we identified a survey of radial visualization methods by Draper *et al.* [9] and a book by Lima, which depicts many radial visualization designs [10]. Lima’s book provides a history of radial visualizations and an aesthetically appealing collection, however, these images are static examples only and do not feature interaction.

For a historical look of research featuring chord diagrams we refer readers to the survey by Draper *et al.* Significant work since the publication of the survey are discussed here.

### A. Edge-Centered Optimization

Older research not included in the survey by Draper *et al.* is the work of Gansner and Koren [3]. They present methods that improve circular graph layouts (chord-diagrams) such as enhancing edge order for minimizing maximum edge lengths, bundling of edges, and routing some edges externally to reduce clutter. Many methods to reduce edge crossings in a circular layout have been long established [11]–[13]. Other methods seek to increase crossing angles for increased legibility [14]. Papp and Kunkli present a web-based circular layout for table visualization [15]. Nodes can be sorted to minimize crossings and thus minimize clutter. Other interactions apart from sort are only aesthetic such as color changes and arc sizes.

We utilize the external routing method introduced by Gansner and Koren, however we do not implement any edge

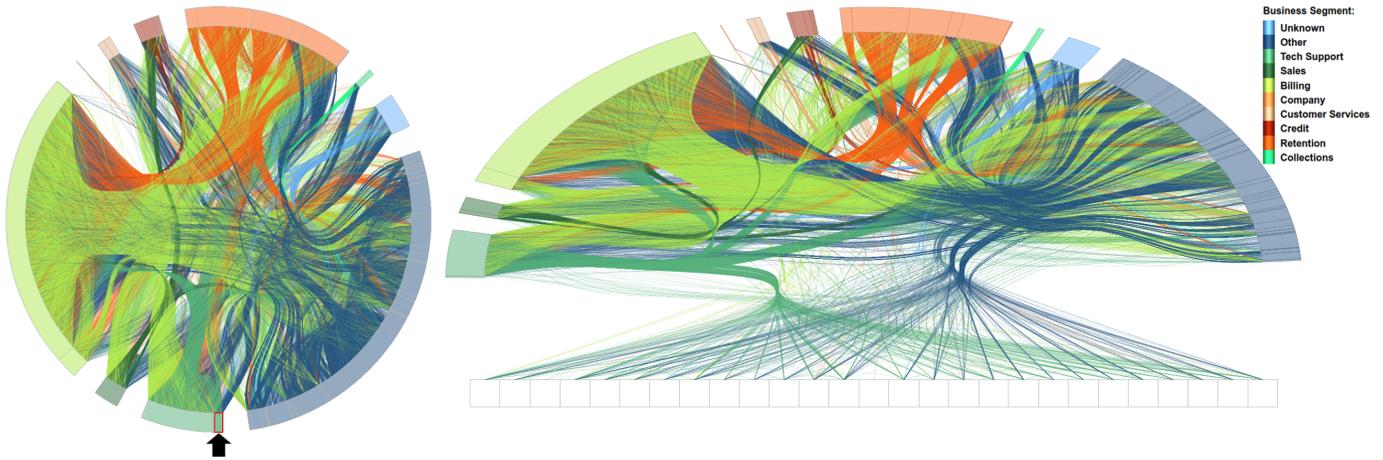


Fig. 1. (Left) A chord diagram of calls transferred between agents categorized by department of a call center. An edge bundling technique is utilized to reduce clutter [1]. A department within the Tech Support business segment is highlighted at the six o'clock position of the chart. (Right) A deformed chord diagram, with the user-chosen Tech Support department from the left image expanded to 98 times its original length, enabling the visualization of calls transferred between individual agents.

optimizations. We focus on a deformation technique for a detailed view of individual nodes and multi-variate brushing for filtering.

### B. Data-Centered Optimization

While the previous work cited in this sub-section utilizes sorting to reduce clutter or edge crossing angles of the chords, the work of Cava *et al.* utilizes sorting based on the data. Cava *et al.* present a radial design featuring a number of concentric rings with each ring representing an attribute and instances distributed radially [16]. Categorical values are represented by a colored circle with the color indicating the category, while numerical values are represented by rectangles with the height of the rectangle mapped to the value. The center of the circular design features a chord-diagram indicating connections between instances. Interactions supported include sorting, bundling, and highlighting of nodes.

We also implement a sorting method based on data attributes and a bundling technique, however, this is not the focus of our work. Our work features multi-edge connections, connecting to multiple nodes in a user-specified order, as well as a method for brushing these connections, and an interactive ellipse warping method for screen-focus on a particular segment.

### C. Edge Bundling

A popular paper discussed in the survey by Draper *et al.* [9] is from Holten, who demonstrates an edge bundling technique for use with a hierarchical chord diagram through the use of b-splines [1]. Users are able to adjust the level of bundling for a balance between clutter reduction and individual chord identification. Interaction for filtering is also demonstrated, chords are filtered with the mouse by drawing a line, with all chords not crossing this line being removed. This bundling technique presented by Holten is used in many other methods including our own. A number of papers present edge bundling techniques

for chord-diagrams [17]–[19]. Lhuillier *et al.* provide a state of the art report of edge and trail bundling techniques [20].

Crnovrsanin *et al.* [21] utilize Holten’s edge bundling technique [1] in their visualization of social networks. They present a technique of chords representing intra-group connections being rendered on the outside of the traditional circular layout similar to the technique presented by Gansner and Koren [3].

Zeng *et al.* introduce a radial based design for visualizing commuter interchanges across a city [22]. Unique features presented include statistics on flow volume at each node, the bundling of bidirectional bundles and placing one segment as a ‘flyover ring’.

Although not strictly edge bundling, Nicholas *et al.* demonstrate a multi-chord diagram [23], an extension of chord diagrams enabling for connections between more than a single pair of categories, e.g. three-way connections. Chord thickness to represent a weighted value is utilized by Etemad *et al.* [24]. The chord diagram has thorn shaped chords inspired by Spirograph for visualizing ecological networks.

Our work focuses on other novel interaction techniques for chord diagrams although we do implement the hierarchical edge bundling technique introduced by Holten [1] to help reduce clutter.

### D. Segment-Centered

Chord diagrams are often used to visualize large amounts of data. As such, segments are often cluttered and require a technique to drill down into individual data points. Borkin *et al.* use a radial-based chord diagram for visualizing file system provenance [32]. Segments of the circle represent a time-based hierarchy which can be interacted with by clicking to expand that segment and its hierarchy.

Wang *et al.* visualize software calls with the use of a chord-diagram [34]. Users are able to drill-down into the segments to reveal the sub segments and their connections, as well as filter out other segments.

Works	Edge Optimization	Edge Bundling	Data Centered	Segment Centered	Animation	Filtering	Hierarchical
Holten [1]		✓				✓	✓
Gansner and Koren [3]	✓	✓					
Meyer <i>et al.</i> [25]		✓		✓		✓	
Krzywinski <i>et al.</i> [26]						✓	
Bae and Lee [27]						✓	
Bostock <i>et al.</i> [4]		✓	✓		✓	✓	✓
Zhao <i>et al.</i> [28]		✓	✓	✓	✓	✓	✓
Gou and Zhang [29]		✓		✓		✓	✓
Kuhar and Podgorelec [30]		✓				✓	✓
Alsallakh <i>et al.</i> [31]						✓	
Borkin <i>et al.</i> [32]			✓	✓			✓
Zeng <i>et al.</i> [22]		✓				✓	
Peixoto [33]		✓					✓
Crnovrsanin <i>et al.</i> [21]		✓				✓	✓
Nicholas <i>et al.</i> [23]		✓				✓	
Etemad <i>et al.</i> [24]		✓				✓	
Wang <i>et al.</i> [34]			✓	✓		✓	✓
Cava <i>et al.</i> [16]		✓	✓		✓	✓	✓
Papp and Kunkli [15]	✓						
Ren <i>et al.</i> [35]							

TABLE I

A TABLE SUMMARIZING RELATED WORK. THE EDGE OPTIMIZATION COLUMN INDICATES WORK THAT FEATURE TECHNIQUES FOR IMPROVING CHORD DIAGRAM LAYOUTS BY ENHANCING EDGE POSITIONS, WHILE THE EDGE BUNDLING COLUMN SHOWS WORK FEATURING CLUSTERS OF EDGES. THE DATA CENTERED COLUMN MARK WORK THAT SORT EDGES ACCORDING TO THE DATA BEING DISPLAYED. THE COLUMN LABELED SEGMENT CENTERED INDICATES WORKS THAT FEATURES A METHOD OF INTERACTING WITH SEGMENTS FOR DISPLAYING MORE DETAIL. WORK FEATURING ANIMATION, FILTERING, AND HIERARCHICAL DATA ARE INDICATED IN THE FINAL COLUMNS.

Zhao *et al.* present a radial design for the display of long, time oriented data [28]. Their application features chord connections at the center of the design to show connections between time series. The work features many interaction techniques although these are predominantly focused on the time series segments, including zooming.

Our work also features a method for interacting with a chosen segment for more detail. Our implementation differs from previous work as we implement a deformation technique to maximize the focus screen space to provide more room for a user-chosen segment.

### E. Hierarchical Data

Chord diagrams can be used to represent hierarchical data. A patent application by Burtner *et al.* demonstrates a hierarchical chord diagram including plurality of visual nodes [36]. Stasko and Zhang provide a flexible method for visualizing hierarchical data in a radial format [37]. They utilize a deformation method to zoom in on smaller hierarchies, creating a larger version of the focused section. This differs from our work as the hierarchies do not connect to one another in a chord diagram. Another technique for the same type of data is presented by Yang *et al.* [38].

Gou and Zhang demonstrate a hierarchical chord diagram that offer views of different levels of the hierarchy [29]. Kuhar and Podgorelec utilize a hierarchical chord diagram as part of an application for visualizing ontologies featuring edge bundling and mouse-over interaction [30]. Peixoto demonstrates a nested generative model for describing the structure of large networks by utilizing chord-diagrams with hierarchical edge bundling [33]. Our work features a deformation method for zooming on a particular hierarchy, different from these works.

### F. Genomics Visualization

Krzywinski *et al.* present a tool called Circos for the visualization of genomics data [26]. The tool offers clickable figures that can be selected for the display of features or annotations. Meyer *et al.* utilize a chord-diagram for genome visualization and the connections between chromosomes [25]. Users are able to select an individual chromosome from an overview to see the connections from that specific chromosome.

Our implementation features novel interaction techniques not included in these works.

### G. Applications

Chord diagrams are used to represent a number of different types of data-sets across many domains such as information technology [39]–[41]. Alsallakh *et al.* present Contingency Wheel for the visualization of contingency tables [42]. Nodes are represented in multiple category segments arranged radially, with their radial placement within the segments representing the association strength. Chord links between segments indicate the frequency of connections between categories. Alsallakh *et al.* [31] further expand on the Contingency Wheel to visualize larger datasets and to address limitations of scalability and understanding. Alsallakh *et al.* expand on the Contingency Wheel, using different aggregation and additional visual elements for visualizing overlapping sets and their connections [43]. Bae and Lee use a chord-diagram to visualize tag relations with interactions including selection and focus+context [27]. Our implementation utilizes call connections through departments of a call center to demonstrate novel interaction techniques.

### H. Visualization Tools

The JavaScript D3 visualization library by Bostock *et al.* [4] utilizes the Circos [26] style for their chord layout. D3 enables

users to create their own interaction techniques however these options require programming knowledge. A particular D3 example features hierarchical edge bundling as proposed by Holten [1]. Interaction techniques supported within the D3 environment include zooming and panning, and mouse-over interaction.

Charticulator is a tool presented by Ren *et al.* for creating bespoke visualizations including chord diagrams [35]. The tool enables the creation of visualizations without the need for any programming knowledge. However, the visualizations created do not feature advanced interaction mechanisms.

These tools feature means of creating chord diagrams whereas our implementation is designed to showcase some novel interaction techniques.

### I. Radial Layouts

Diehl *et al.* compare the use of radial based visualizations to Cartesian layouts, concluding that Cartesian layouts outperform their radial equivalents [44]. However, they did not analyze layouts for the use of displaying connections between nodes. Burch *et al.* perform an eye tracking study to compare tree diagram layouts, including radial based designs [45]. They conclude that a traditional tree layout significantly outperforms other designs. However, the radial hierarchical design used did not have a fixed structural layout. A chapter titled ‘On the benefits and drawbacks of radial diagrams’ in *The Handbook of Human Centric Visualization* by Burch and Weiskopf further discusses the benefits and drawbacks of radial diagrams [46]. Chord diagrams are not discussed in their chapter however, although they do note that curved links are more difficult to follow, that rendering performance of radial diagrams is decreased due to increased computation of polar coordinates, and that radial diagrams can generally be more aesthetic. These researchers study the use of circular designs and their perceptibility whereas our work starts with a traditional circular layout chord diagram, however we deform this to maximize screen space use for focus on a particular segment.

## III. DATA DESCRIPTION AND USER REQUIREMENTS

The data used to demonstrate the techniques in this paper is a real-world dataset of call transfers between departments of a telecommunications provider. The dataset has a hierarchical structure with each department belonging to a particular business segment and having a number of its own agents. In total the data set consists of 10 business segments, 92 departments, and 3,174 call center agents. The dataset comprises of one day of calls totaling 225,256 calls, of which the majority feature no agents or are dealt with by a single agent and therefore do not feature a transfer connection. The remaining 17,914 calls feature 80,361 transfers, with a maximum of 17 transfers in one call.

As well as belonging to departments, agents also belong to specific teams within the departments. The agent’s physical site location is also archived along with a categorical skill level. Many call metrics are recorded for each call such as

the connection duration with each agent, and a measure of the customer effort made when talking to the agent known as CES (Customer Effort Score). A time stamp is also associated with each call.

The techniques introduced in this paper are a response to analyze call transfers between different agents in a range of call center departments. Due to the large number of call center agents, overplotting becomes a challenge. The methods presented attempt to address the following requirements:

- The ability to visualize transfers at the business, departmental and individual agent scale.
- Study multiple transfers within individual calls
- View call details

The visual design should inform analysis of the dataset and provide insight into agent and customer behavior.

While techniques such as edge bundling and node position optimization can reduce clutter and line crossings, they do not prevent overplotting of nodes on the circular axis. Consequently identifying individual nodes amid a large number becomes difficult. Previous work provides drill down methods for exploring segments of a chord diagram (see Section II-D), however, it does not allow for easy tracking of connections from one individual node to another. The ability to track connections between multiple nodes is generally absent from previous works.

## IV. INTERACTION TECHNIQUES FOR CHORD DIAGRAMS

We introduce an interactive method for expanding a user-chosen segment of a chord diagram, in this case, this represents a particular call center department. With over 3,000 agents represented, identifying individual agents within the available screen space can be very difficult. To remedy this problem we develop a deformation technique to expand the size of individual departments. The user is able to pick an individual segment of the radial visualization to expand it to maximize its size in screen-space to see more detail. An example of this can be seen in Figure 1. On the left image, a call center department within the Tech Support segment is chosen and highlighted with color on the axis segment that represents the department. The color of the axis segment indicates the business segment to which the department belongs and can be referenced in the legend.

### A. Dynamic Select + Rotate + Expand Layout for Segment Focus

The user is able to select any department by clicking on its representation on the chord diagram segment. On the selection of a department, the segment representing the department will be colored, and the whole diagram smoothly rotated to position the department at the lowest point at the six o’clock position. This is demonstrated in the first two scenes of Figure 3. The use of animation is incorporated to convey the rotation with visual continuity. Once a department has been chosen and highlighted, a second click on that department causes it to expand to form a long edge segment of agents, with other departments rotated to form an arc over this straightened

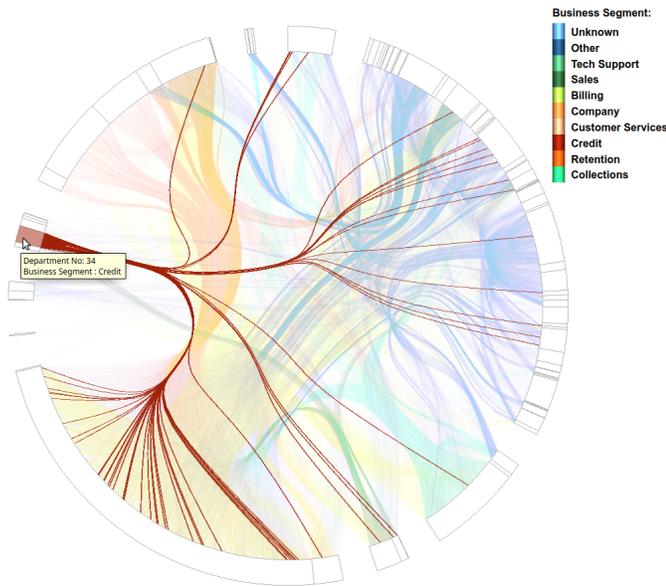


Fig. 2. A department belonging to the Credit business segment has been highlighted using the mouse-over feature, showing all connections from that department.

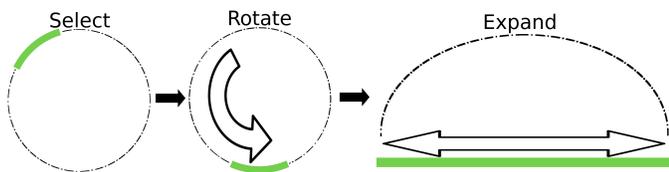


Fig. 3. A demonstration of the interaction for expanding a segments. A user chosen segment rotates to the bottom of the diagram to show that it has been selected, then expanding to fill the horizontal screen space.

segment as can be seen in Figure 1. Animation is again used for the expansion to convey visual continuity, this can be seen in the accompanying video [47]. Figure 3 illustrates the process of a chosen segment rotating to the six o'clock position, then expanding to fill the screen space.

Once expanded, the department is segregated into individual agents, enabling an interactive focus to be placed on individuals rather than whole departments as was only possible previously. As other departments are no longer the focus once the deformation has been made, connections within the same non-focus business segments are not rendered in order to reduce clutter.

The bundling technique first introduced by Holten [1] is demonstrated in both the traditional plot and the deformed plot introduced in this paper, as seen in Figure 1.

To support exploration of the focus segment, we implement an on-mouse-over feature that highlights the calls from a particular department, as seen in Figure 2. By hovering the mouse over the area of a particular department, the calls being transferred from that department are emphasized, while other transfers are de-emphasized. Emphasis is achieved by increasing the opacity of the transfers originating from the chosen department and decreasing the opacity of the other

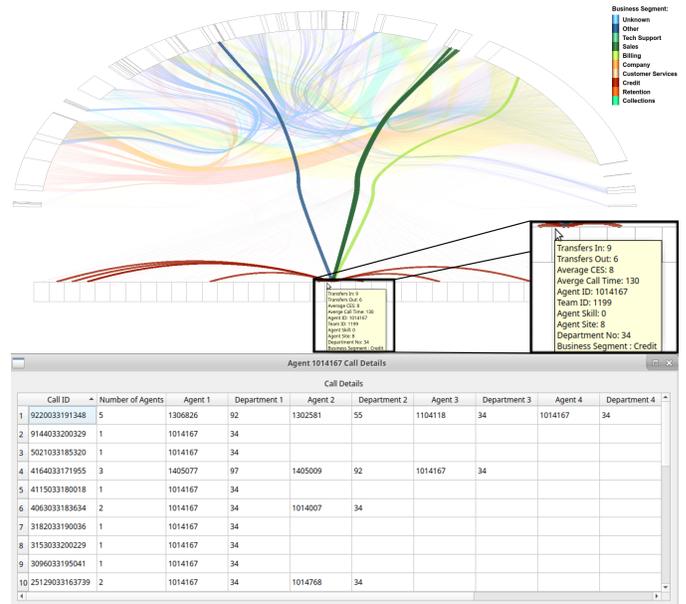


Fig. 4. (Top) The on-mouse-over feature for an individual agent. Call connections made to and from the agent are rendered over other connections. The information box provides agent details and metrics. Observable is that no calls are transferred by the agent to other departments, only received from other departments. A zoomed section in the bottom right of the figure shows the mouse-over detail. (Bottom) Agent detail dialog obtained by clicking an individual agent. The dialog lists all calls handled by the user-chosen agent, with details of other departments and agents involved in each call.

transfers. To further emphasize the highlighted connections, the rendering order is taken into account with user-chosen connections rendered in most recent order, to appear over the other connections. An on-mouse-over information dialogue also appears, providing details of the department number and to which business segment it belongs.

Once a department has been expanded using the select + rotate + expand layout outlined in Section IV, the on-mouse-over feature no longer highlights the department but highlights individual agents. This emphasizes all connections originating from a user-chosen agent, as well as all the connections received by the agent. Agent highlighting is achieved by the same opacity modifications as performed on departmental highlighting. For an individual agent, the on-mouse-over dialog provides data about the agent including the agent ID, site location, team and skill levels, the number of transfers in and out, and average call metrics (Figure 4 (top)). By clicking an individual agent, additional details of all calls handled by the chosen agent will be returned in a dialog box (bottom). These interactions are inspired by Shneiderman's Visual Information-Seeking Mantra of overview first, zoom and filter, then details-on-demand [48].

### B. Sketch-Based, Multi-variate Filtering

We introduce an interactive method for filtering chord diagrams based on multiple connections. Users are able to interactively sketch a filter by clicking on segments representing departments, mimicking a call with connections. These

departments are added to a list as the user sketches the filter. As departments are interactively selected, a dynamic edge is rendered between the departments in the list indicating a series of connections for filtering. Calls are then filtered to only those that feature agents in the compiled list. This can be seen in Figure 5. The dynamic nature of this sketch-based interaction is demonstrated in the accompanying video [47].

Different modes of filtering also apply to the selected list of departments. The first is calls that feature the listed departments, secondly calls that feature the listed departments in the same order specified by the filter, and thirdly only calls that feature direct links between the listed departments in listed order. Additional user options are to set the first listed department as the originating department of the call, and another option to make the last listed department to be the terminating department.

For user convenience, sketching options are available on a right mouse click. When a user is sketching, a right-click shows a menu with options to delete the last drawn point, clear the brush, or to terminate the current selection. This can be seen in the right image of Figure 5. This option allows the user to sketch the connections of a theoretical call to find calls that match the drawn profile.

### C. Representing Direction and Order

Traditionally chord diagrams are used to show connections between two nodes, however in the application of chord diagrams for call connections, one call may have multivariate or multiple edge connections. To accommodate this, we present methods for tracking a call across multiple connections, in our case, to multiple agents.

To achieve this we first need to establish a direction to the connections. For this we can use arrows as can be seen in Figure 6. An alternative method for this is to use color to code the direction, with start of a connection colored to an end of a colormap and the end of the connection colored to the opposite end of the colormap. A continuous colormap is best for this method. Indicators can also be used on the segments to indicate the start and end of a connection, however, overplotting is a problem with scaling. These techniques are not mutually exclusive and can be combined as in Figure 6.

Once one direction has been established, the color can be used to show call progress across multiple connections. Figure 7 shows an example of a single call with 12 transfers. A continuous colormap with multiple hues has been used to make it easier to distinguish between connections and to determine chronological agent order. Arrows indicate direction of individual connections.

*a) Animated Connection Order and Direction:* Another method to show direction and the order of the connections is by using animation. We demonstrate the use of a short black line that travels along the connections in call order. This is demonstrated in the supplementary video [47].

To give the user more control over the speed of the motion, we provide an interactive version of this using a time-window slider. When this is active, the two inputs of the slider control

the extent of how much of a call is rendered black. Having the lower slider input at the very lowest range and the high slider at the highest end of the range, the call edges are entirely black. By moving one of the sliders, the progress of the call can easily and intuitively be followed. This feature is inspired by the streamrunner feature [50] and is demonstrated in Figure 8 where the slider, seen at the top of the Figure, has been set to highlight the first seven transfers in black.

### D. Other User Interaction Options

*1) Meta-data Filtering:* These filters are based on the meta-data of the call, for example a filter for the number of transfers in a call, or the time of day of the call. These filters can be adjusted by the user based on minimal and maximal values for each attribute, adjustable with user controls such as range sliders. Once the minimum and maximum values have been set, calls are iterated through to find the calls that fit into the indicated criteria.

*2) Agent Sorting:* Agent position about the circumference of the plot is determined by the business segment and department of the agent. Within the departments, a user option enables the sorting of the agents by data attributes increasing clockwise. These data attributes include the average call time, average agent effort score, and the number of transfers made. As well as this, agents have a categorical skill level, and a team designation which are also used for sorting. Agents are not necessarily exclusive to one department, therefore an agent will be repeated to be represented in each department that they belong to. An agent may also belong to more than one team or skill level, therefore they are also repeated for each skill or team if those categories are used as sort criteria.

*3) Intra-segment Connections:* To aid clutter reduction, we implement a user option that renders connections from the same business segment on the outside of the diagram. This exterior rendering is an imitation of that provided by Gansner and Koren [3]. An example of this can be seen in Figure 9 (top). This feature is disabled for non-focus departments when the deformation is used to expand a particular department; this reduces clutter. For the focus, deformed department, internal connections are routed underneath the department as in Figure 9 (bottom).

### E. Flight Data

We also demonstrate the techniques introduced in this paper on an alternative dataset [51]. Figure 10 shows completed flights recorded in a single 24 hour period. The edge connections represent flights between airport nodes grouped by their country and continent. The segment representing Germany has been expanded enabling individual airports to be seen. Observable with the expansion is that only one German airport in the dataset (Frankfurt) features flights to other continents, with other airports only featuring flights to other European countries or domestically.

Aircraft that feature more than one flight within the 24 hour time period have their flights connected, which can be explored by utilizing the techniques introduced for direction and order.

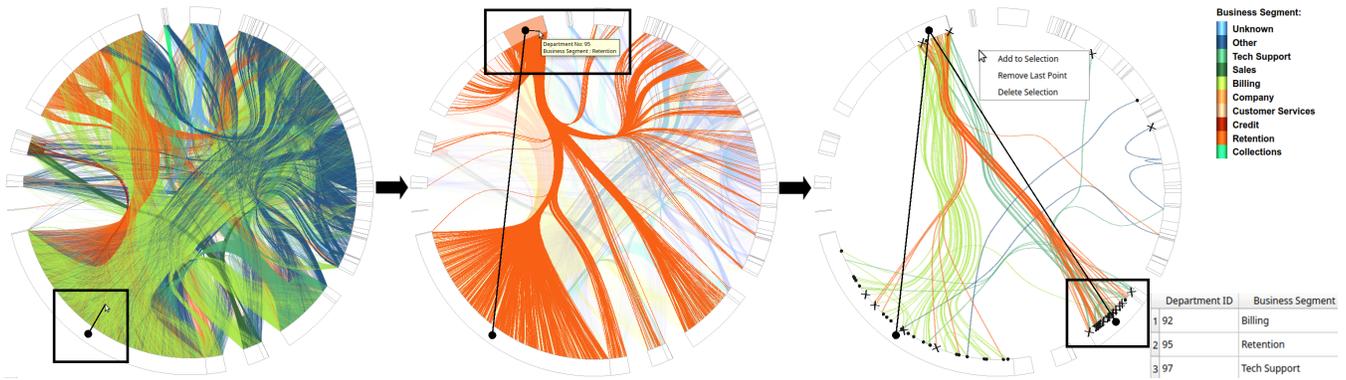


Fig. 5. A representation of the interactive sketch-based filtering of the the chord diagram. In the leftmost image, the user has clicked on department 92 in the Billing segment to begin the sketch-based filter. A point indicates this selection and a dynamic edge is rendered to the mouse cursor to show that the filter is being constructed. The middle image shows the next selection of department 97 in the Retention segment. Here the mouse-over feature can also be seen showing the connections from that department, providing information informing the construction of the filter. The final image shows a final selected department (97 in the Tech Support segment) with the filter applied. A list pictured in the bottom right provides details of the chosen segments. The filter has been selected to only show calls with these direct connections. The majority of the remaining calls start at department 92 and follow the departments in the filter and terminate at department 97 as indicated by the starting points and ending crosses. However, a minority of the calls start or end at other departments.

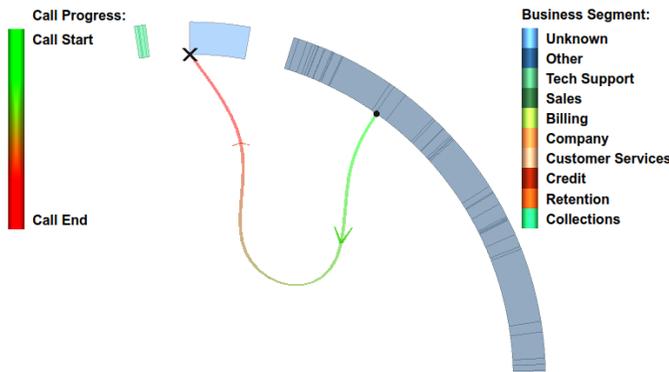


Fig. 6. A zoomed chord diagram showing a single connection between two departments. The direction of the connection is indicated by arrows and a green-to-red colormap, as indicated in the continuous legend. Business segment is indicated by the color of the axis. A point is also used to indicate the start of a call with a cross to indicate the end.

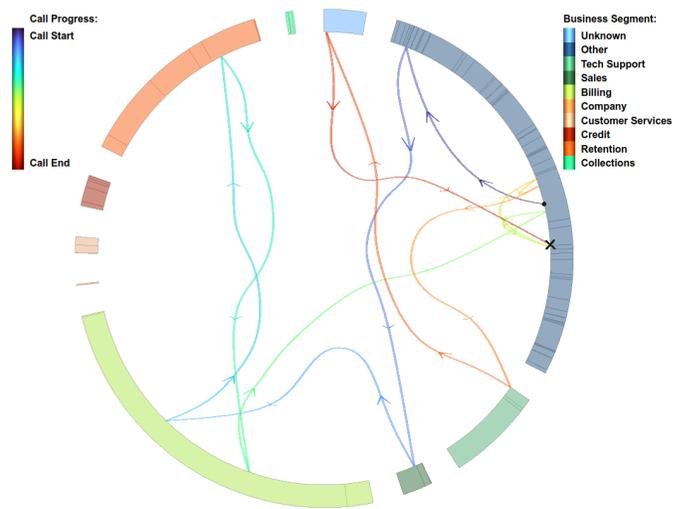


Fig. 7. An unusual call featuring 12 transfers between multiple departments. The edge direction representing each connection is indicated by arrows and a modified rainbow colormap [49], as indicated in the legend. Business segment is indicated by the color of the segment. A point is also used to indicate the start of a call with a cross to indicate the end.

In contrast to the call-center dataset, flights are shown to leave and return to the same airport whereas an agent is unable to transfer a call to themselves.

## V. DOMAIN EXPERT FEEDBACK

Because this application is customized for specialists in the call-center industry, we sought a domain expert feedback approach for evaluation. Feedback was garnered from two domain experts from the call center industry, familiar with the call-center dataset used in this paper. The two experts have over 50 years of experience between them in the call center industry. The experts were shown a demonstration of our implementation of the techniques introduced in the paper before being asked to provide feedback. We report this feedback here.

When asked how the demonstrated techniques might be useful, Expert 1 replied: *“The entire thing looks really easy to use, that’s a big component of making it useful to start off with.*

*The variety of different selection / filter options, and the ability to focus on areas of interest so quickly and dynamically are things that are particularly useful I think.”* Meanwhile, Expert 2 was most impressed with the clustering technique used: *“The hierarchical clustering technique and the adjustment of its strength does help reduce clutter.”* Expert 1 was asked how the techniques compare with how they currently explore the data; he was impressed with the ability to focus on an individual agent, and then being able to quickly switch to focus on another. *“What it does do though is make it much easier and quicker to navigate through and to switch perspectives and focus in specific areas.”*

Asked if the presented tool could help explore and present the data, Expert 1’s answer was: *“Definitely. To me the ease*

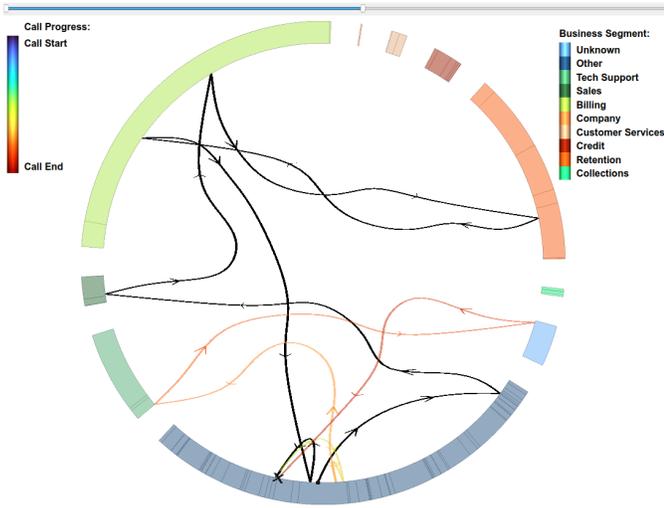


Fig. 8. The connections of a call with a black sliding edges interactively set by the user using the pictured range slider. The focus call features 12 transfers between multiple departments. The direction of the connection is indicated by arrows and a modified rainbow colormap [49], as indicated in the continuous legend. Business department is indicated by the color of each segment.

of use and it's general visual appeal, sickness is where the value is." Expert 2 was also positive about the visual appeal of the implementation: "The non-standard way of visualizing the data and the various animations would help make the visualization engaging for presentations." Asked if there were any improvements that could be made, Expert 1 replied: "To have the ability to compare different filtered groups, by having the entire main chord diagram duplicated, once for each group. That way you would use the tool to compare the experiences of say two different customer groups, side-by-side."

## VI. DISCUSSION AND FUTURE WORK

The techniques presented in this article aim to increase the number of nodes that can be used with a chord diagram through the use of interaction and deformation. To evaluate the effectiveness of the presented technique, a comparison of the visual space for each node is made. A number of factors influence the number of nodes that can be displayed including the physical size of the chord diagram, the distance which the diagram is being read at, and the medium of display. Since these variables are indeterminable and that the deformation is performed on the same canvas as the chord diagram, a common minimal perceptual size can be assumed  $s_{min}$ . Given the diameter of the chord diagram  $d$ , then the number of visible nodes  $n_{circ}$  is given by Equation 1.

$$n_{circ} = \pi * d / s_{min} \quad (1)$$

The deformation expands a single segment to the width of the available canvas, this can be assumed to be the same size as the diameter of the chord diagram  $d$ , although in reality screens are rarely square and have a larger side that can be used to maximize segment expansion. Desktop monitors vary

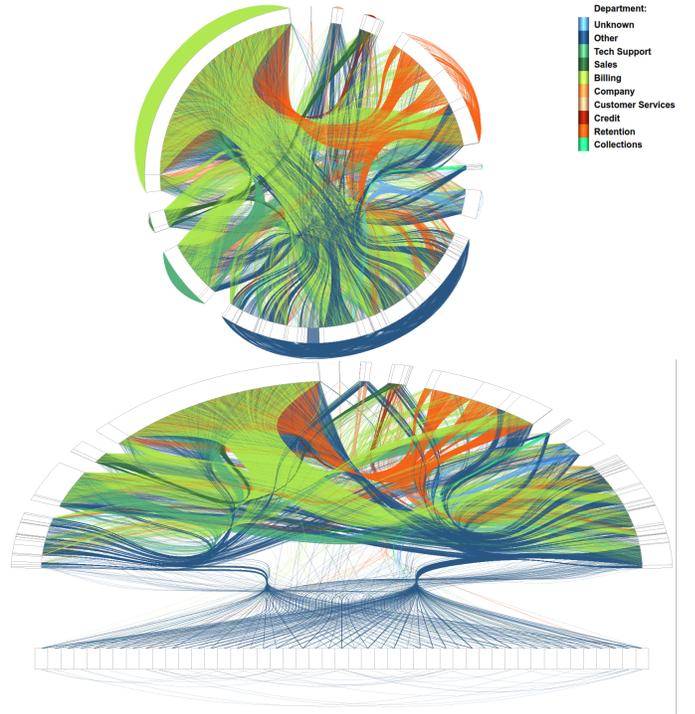


Fig. 9. (Top) Connections between agents in the same business segment are routed externally to reduce clutter. (Bottom) Connections between agents in the same business departments are not rendered when using the the deformation, however calls within the focus department are rendered underneath. The expanded section is 55 times larger than the original highlighted section, enabling individual agents to be seen.

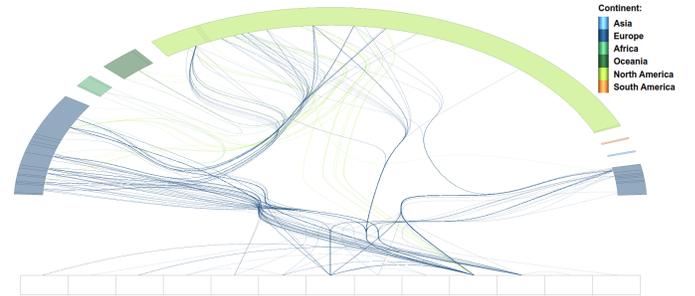


Fig. 10. Aircraft flights between airports in different countries and continents. The segment representing Germany has been expanded to 23 times its original size, enabling focus to be put on individual airports.

in aspect ratio from 4:3 up to 21:9 therefore the expansion will also increase by this factor. The number of visible nodes for an expanded segment  $n_{epnd}$  is given by Equation 2.

$$n_{epnd} = d / s_{min} \quad (2)$$

By substituting  $n_{epnd}$  for  $d / s_{min}$  in Equation 1, it becomes clear that the number of visible nodes in a chord diagram would be  $\pi$  times greater than an expanded segment. Therefore if more than three segments are available, the technique presented is beneficial.

In a dataset absent of categories to segment nodes, artificial segmentation may be used to enable the expansion deformation

technique.

A limitation exists with the maximum number of nodes that can ultimately be visualized. With the assumption that each visible node is an expandable segment the maximum number of nodes achievable with the deform expansion technique  $n_{circ+}$  is given by:

$$n_{circ+} = n_{circ} * n_{circ} / \pi \quad (3)$$

This shows that the potential increase in the number of nodes that can be displayed is proportional to the square of the number for an ordinary chord diagram.

The expansion demonstrated in Figure 1, generated from a real world dataset, provides a 98 times expansion in screen-space, revealing 27 agents which were previously indistinguishable and cluttered. Figures 8 and 10 show a 55 times and 23 times expansion in screen-space revealing 47 and 13 nodes respectively.

To further increase the number of possible nodes is future work for the project. Possible solutions to this are the use of lenses [52] or some further distortion.

Because the techniques presented in this article require interaction, this limits the techniques to an interactive medium, although expanded segments can be visualized statically and are, in our experience, intuitive. Animation techniques are again limited to an interactive medium.

Representing connection order in the case of connections through multiple nodes becomes less effective when overplotted, therefore it can be fairly ineffective without methods to filter connections. In the case we present, we apply meta-data filters to reduce clutter from overplotting, enabling for connections to be clearly seen. Addressing this challenge is future work. A potential problem exists with the use of color for tracking calls with multiple connections. Caution must be exercised as color-blind people may not be able to follow as intended. Other avenues for future work are to configure a linked multi-chord diagram for comparisons as recommended by the domain expert. A user study to determine how users comprehend the methods presented in this paper is another future work opportunity.

## VII. CONCLUSIONS

We present a novel deformation technique for interactive exploration of connection data in a chord diagram. This method enables a greater number of nodes to be represented in a chord diagram with interaction that facilitates individual nodes to be explored. We demonstrate this technique with a real-world call-center dataset, visualizing call connections to different agents in different departments. This technique maximizes the available screen-space to draw focus to a user chosen department. The technique is also demonstrated with an alternative dataset from a different domain. Additionally we introduce a method for tracking calls across multiple connections with multiple call-center agents. An interactive sketch-based filtering technique is introduced to filter calls based on the connections through different departments. We report domain expert feedback on our implementation of the novel techniques

presented in this paper, and discuss limitations of the presented techniques.

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