Visualising Bluetooth Interactions: Combining the Arc Diagram and DocuBurst Techniques

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ABSTRACT
Within the Bluetooth mobile space, overwhelmingly large sets of interaction and encounter data can very quickly be accumulated. This presents a challenge to gaining an understanding and overview of the dataset as a whole. In order to overcome this problem, we have designed a visualisation which provides an informative overview of the dataset. The visualisation combines existing Arc Diagram and DocuBurst techniques into a radial space-filling layout capable of conveying a rich understanding of Bluetooth interaction data, and clearly represents social networks and relationships established among encountered devices. The end result enables a user to visually interpret the relative importance of individual devices encountered, the relationships established between them and the usage of Bluetooth 'friendly names' (or device labels) within the data.

Categories and Subject Descriptors
H.5.2 [Information Interfaces and Presentation (e.g., HCI)]: User Interfaces;

General Terms
Design, Human Factors

Keywords
Bluetooth, friendly name, mobile phones, mobile computing. visualisation, DocuBurst, Arc Diagrams.

1. INTRODUCTION
Bluetooth is a short-range wireless protocol by which enabled devices can exchange content. Each device is identified with a 12-digit hardware ID, unique to an individual device, and a user determined short string known as a '*friendly name.*' Bluetooth can be used with a wide variety of devices from home computers to portable laptops, PDAs, mobile phones, keyboards, mice and headphones. We can easily encounter hundreds of devices as we go about our daily routine: from traveling on the bus to sitting at a desk at work and being surrounded by colleagues' phones and laptops.

In our previous work, we observed that a mobile user may encounter several thousand devices within a month and that these encounters may include several hundred unique friendly names [7]. The amount of data that Bluetooth encounters yields in even a short period is also overwhelming, especially for large groups of people. For example, in previous study [7] we recorded Bluetooth device encounters at 10 second intervals and this yielded over 200,000 recorded encounters with devices across 6 participants in just 24 days.

Chen [2] states that information overload "*becomes a common problem in the exponential growth of widely accessible information in modern society.*" This is certainly the case, in our experience, with Bluetooth. The data can rapidly grow within the first few days to the point where gaining an overview of the dataset quickly and easily is virtually impossible. In this paper, we explore the combination of Arc Diagram techniques [15,6,8] and the DocuBurst space filling radial diagram [3,4] as a means by which we can explore the interactions recorded for a Bluetooth device by providing an at-a-glance overview to more effectively and intuitively visualise the wealth of Bluetooth data that can be garnered from just one device. Such a visualisation has practical applications for designers and developers working with Bluetooth as well as in the domains of social networking and human digital memory (or lifelogging).

2. RELATED WORK

2.1 Bluetooth and Familiarity
Nicolai [9,10] popularized the concept of familiarity of devices within the Bluetooth space. He suggests that there are 3 main types of devices that are encountered: those that are well known, regularly encountered and *familiar* to you; those that are somewhat known, encountered at semi-regular intervals (known as a *familiar stranger*) and those which are infrequently encountered and generally unknown (known as *strangers.*) His work demonstrated that social context could be drawn from general encounters with devices. In [7], we extended Nicolai's work and examined a more robust mechanism for calculating a measure of familiarity for an encountered device. Our mechanism provides a cumulative score based on a device's presence relative to the others by dividing each day into intervals at which presence and duration of presence is examined.

2.2 Arc Diagrams
The Arc Diagram is a concept developed by Wattenberg [15] for visualising complex repetition in string data. Documents such as DNA sequences, music, programming code or HTML pages contain sequences, and each sequence may have repeated subsequences. Arc diagrams are especially suited to conveying these complex patterns and we can see an example of how an Arc Diagram describes a document in Figure 1. Related

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sequences are simply represented using an arc which connects any two sequences, however, extra information can be conveyed based on the width and opacity of the arc. It is also important that all arcs are somewhat transparent to ensure that all crossings are clearly identifiable.

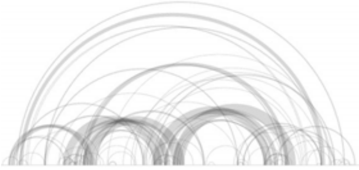


Figure 1. An Example Arc Diagram Showing String Repetition in a HTML Page

Alternative applications of the Arc Tree approach include ArcTrees [8] and Thread Arcs [6]. ArcTrees are used to visualise relationships within Hierarchical data such as structured documents. Thread Arcs are used to visualise relationships between threaded emails over time. The Arc representation of these threads was used to enhance a user's understanding of the chronology and relationships between email messages allowing them to interpret the type of conversation or discussion present within the thread.

2.3 DocuBurst

Figure 2. An Example DocuBurst Diagram

The DocuBurst visualisation [3,4] is used to explore the lexical content of documents and is designed to provide a rich overview of the concepts contained within the document. It leverages the relationships between the individual words in a document to higher-level concepts through a semantic lexicon, WordNet. It uses a radial space filling layout technique based on the previous work of [14]. The centre of the diagram contains a circle which represents the root node. Spanning out from the centre are a series of child nodes. Children are represented as a wedge connected to its parent. The size of the wedge is determined by the child's overall importance within the document and is proportional to the size of its parent. Figure 2. demonstrates how children are displayed within concentric rings spanning out from the root node. This visualisation technique, like Arc Diagrams, makes use of opacity displaying frequently occurring items as opaque with infrequent items appearing transparent.

3. DATA COLLECTION & PROCESSING

Bluetooth activity data can be recorded from a range of applications. In our laboratory, we have developed a Java ME based mobile application specifically designed to record Bluetooth interactions, at a high sampling frequency (every 10 seconds) than other available tools. This tool runs on a mobile phone and saves recorded data to an online database [7,1]. Alternative solutions to recording Bluetooth activity include the ContextLogger application developed by the University of Helsinki [11]. The ContextLogger is designed to record a wide range of mobile phone activity data including incoming and outgoing calls, contact information and Bluetooth. It is in use in a wide range of projects including those of the Reality Mining Project [5].

After collection, the data is automatically processed to extract information on each Bluetooth enabled device encountered by the logger. First, a measure of the encountered device's relative familiarity to the logger is calculated using methods described in [7]. This yields a score of an encountered device's overall presence within the dataset and allows a determination of how well they are known to the owner to be made. A list of periods at which each device was encountered is also extracted. As a device can move in and out of range thereby missing an individual poll, a small window for reappearance was allowed. This lets a device be re-encountered within a 5-minute window without considering it to be a new period of encounter for the device. This is based on Nicolai's [9] approach to dividing Bluetooth activity into individual periods of encounter. For each period of encounter, a list of collocated devices is also gathered. Finally all friendly names found for the given device are located and used to aggregate the devices.

4. VISUALISATION

Shneiderman [12] states that every information-seeking visualisation should seek to provide "overview first, zoom and filter, then details-on-demand." This statement has become the principle tenet and base design requirements for any information visualisation. At the core of this concept is the need to provide a visualisation which is effective in providing a high level overview of the data set as well as allowing detailed exploration of a specific area of interest within the data. Spense [13] also believes that an important aspect of the visualisation is to provide insight and understanding through engagement and that the person must be informed by the visualisation. Below we outline a means by which a user can gain a detailed understanding and an at–a-glance overview of the complex relationships contained within day-to-day Bluetooth interactions. We integrate the Arc Diagram concepts into a radial space-filling layout, which was designed with these concepts very much in mind. The size of the diagram also provides an immediate visual cue to the amount of the data and the number of devices that it represents.

4.1 Displaying Familiarity

Figure 3. Visualising familiarity by transparency.

In our visualisation, we represent each device as a node within a concentric radial layout. As the hardware ID of the device is unique, we use this to identify it within the visualisation, despite the fact is it not designed to be human readable. It is however chosen instead of a friendly name as if the encounters are too low for a given device, there may be no recorded friendly name, or as friendly names may be changed at any point, there may be more than one to choose from. As such, employing the friendly name to label and identify a device within the visualisation could present problems in selecting the a representative name for that device.

Familiarity represents a device's overall presence within mobile interactions and gives a measure of how important it is relative to the other devices. This is an extremely significant item of information to convey within the visualisation and to express it we use opacity and shading. The most familiar devices appear as solid black nodes, while those, which are determined to be unfamiliar, are displayed highly transparent and faded (see Fig. 3.). This allows familiar, unfamiliar, and familiar strangers to be visually determined and clearly distinguished.

4.2 Displaying Collocation

Typically devices are not encountered in isolation. For example, if you attend a meeting with John and Mary, you will encounter both John and Mary's Bluetooth devices. As their devices have been encountered at the same time we can infer a relationship between them. If you attend regular meetings with John and Mary, and hence regularly encounter both of their devices, they will form a strong "bond". We may then expect that if I encounter John, I will also encounter Mary. From the familiarity scoring of devices, we understand the strength of the relationship I have individually with John and with Mary, but there is a need to present the relationships within the encounters to give a more complete understanding of the data.

In a similar approach to Kerr [6], we extended Arc Diagrams to visualise presence of devices relative to one another allowing users to visually interpret the social relationships between the individual devices they have encountered. Within the inner area of our radial diagram an arc will connect an encountered device to another if they have been encountered at some point at the same time, i.e. they were encountered proximal to one another. The more collocated encounters, the stronger the weight of the line and the less transparent the arc. Conversely if a device has only been collocated infrequently with another, it will be represented as a thin transparent line. The inner area in Figure 4 illustrates this concept.

4.3 Displaying Friendly Names

A device's friendly name can be changed by the user at any point in time, and potentially many times over short periods of time. We have previously observed that there is a large degree of overlap between the friendly names used where we recorded encounter data for 6,181 unique devices, while only 1566 unique friendly names were found [7]. This demonstrates that considerable overlap exists between friendly names in the Bluetooth space. This is mainly attributable to approximately 25% of users opting to use the devices default, manufacturer specified, name e.g. Nokia 6230i. We leverage this in our visualisation. Instead of representing individual device's friendly names as nodes we aggregate friendly names, which occur across multiple devices, and display them as a wedge in the radial diagram, in a style identical to that of DocuBurst. The device hardware IDs are ordered based on the occurrence and overlap of friendly names, and so align with the friendly name wedges appropriately. Any devices within this wedge which have further overlap are recursively subdivided until all friendly names have been displayed.

The display of friendly names adapts the DocuBurst technique to the domain, but preserves the visual richness of the technique (see Figure 4.) In our approach the depth of child nodes conveys the number of friendly names recorded for a given device. This provides visual insight into the frequency of change for friendly names, an infrequent but important occurrence. Additionally, the wedged radial approach provide an excellent means to rapidly gain an overview of friendly name usage within the dataset and the amount of overlap that exists between encountered devices' friendly names. Large friendly name wedges represent friendly names which are commonly found within the dataset and which span multiple devices. Overlapping friendly names can cause difficulty in identifying the intended device for interaction [7] and the visualisation allows the viewer to visually determine how problematic this may be within the dataset. Also, gaps in the radial burst will indicate where no friendly name has been

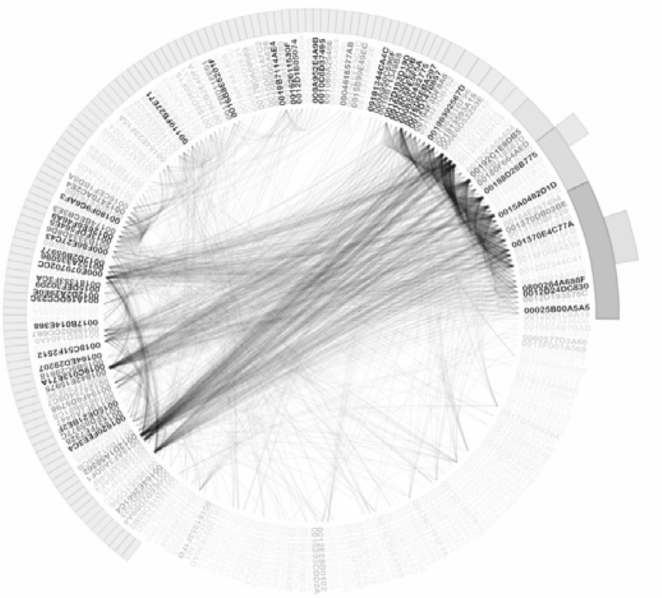


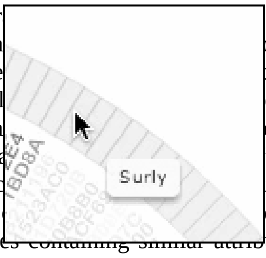
Figure 4. A Bluetooth Visualisation displaying 10 days data for one device. (Inset: tooltip to inquire on the friendly name)

encountered. Finally, we also make use of opacity to represent a friendly name's relative important within the dataset.

5. FUTURE WORK

Currently the visualisation is static in nature as it was designed to provide an at-a-glance overview of the dataset. We would like to extend the current visualisation to include some level of interaction. For example, selection of a particular device within the visualisation might highlight the arcs representing collocation for that device. It would also be useful to provide some focus+context techniques [13,14] for exploring the data set. This might include the ability to select a date range for the data being displayed, thereby allowing the viewer to focus the visualisation on periods of particular interest.

We also would like to examine extending this visualisation to provide more detailed information to a user on the Bluetooth inter devices. This could include expa o allow the representation of Blue ded on multiple devices and the resul en those devices. Additionally, enha echnique within the current visua ul. Employing some automatic lexic uld allow for the aggregation of not endly names but also friendly names utes or words. This may serve to provide a more effective overview of the friendly names contained within the dataset. It may also allow us to automatically classify the type of friendly name which has been encountered, e.g. use's a model name, a manufacturer name, a persons name etc.



Finally, colour and hues might be used within the visualisation to indicate and distinguish particular types of links between the encountered devices or perhaps the classification(s) or type(s) of friendly name(s) which has been encountered for a particular device.

6. CONCLUSIONS

In this paper we have presented a combination of the Arc Diagram and the DocuBurst visualisation techniques for visualising device encounters within the Bluetooth-enabled mobile space. Our visualisation technique allows the relationships between encountered devices to be quickly established by providing an understanding of the relative importance (or familiarity) of an encountered device as well as visually representing the relationships between and collocation for encountered devices. Finally our technique provides an understanding of the relative overlap and overall usage of Bluetooth '*friendly names*' for the encountered devices. The Bluetooth Visualisation is a unique tool for interpreting interactions within the mobile space. It provides a one-dimensional overview of the Bluetooth encounters and affords a user rapid cognition of an overwhelmingly large data set.

7. ACKNOWLEDGMENTS

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