Mobile Visualisation Techniques for Large Datasets

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Abstract

Visualisations are a quick and powerful tool for data analysis and information acquisition. The aim of this literature review is to investigate visualisation and techniques that exist in the desktop and mobile platforms. The mobile platform is investigated in detail, focusing on various factors that affect visualisations for limitedly resourced mobile devices.

1 Introduction

The human sense of sight accounts for more information acquisition than the rest of the senses put together (Ware, 2013). Advances in the computing field and mobile platform, combined with the power of visualisation and interaction techniques for mobile phones, provide mobile users with an opportunity to access and acquire information and manipulate data, at a glance. In order to take advantage of this opportunity, research is required to explore measures that can be taken to design visualisations for limited resourced mobile devices. The design of a visualisation needs to be effective in providing users with relevant information. The next section discusses visualisations in general, followed by a discussion that is specific to the mobile platform in Section 3.

Data demands from various disciplines are amongst key drivers of the technological advances in the computing field. Visualisations are useful for gaining insight from the available data, as they help users derive more knowledge from large datasets by making complex patterns discoverable to the users (Card, Mackinlay, & Shneiderman, 1999). More discussion on data types and visualisations associated with the various data types is provided in Section 4.

Mobile devices are becoming ubiquitous (Mouton, Sons, & Grimstead, 2011). While there may be other factors contributing to this ubiquity, developments in computing resources of mobile devices feature amongst those factors. These developments together with interaction techniques, enable visualisations to be rendered on mobile devices (Rukzio, Broll, Leichtenstern, & Schmidt, 2007). In spite of the advancements, mobile devices still lag behind desktop devices due to comparatively limited capabilities (Van Tonder & Wesson, 2008). Visualisation techniques are therefore limited on the mobile platform as opposed to the desktop platform. Consequently, visualisations are often less powerful and complex on the mobile platform compared to the desktop platform. However, complexity does not necessarily imply effectiveness for a visualisation. Interaction techniques are explored in Section 5 of this literature review.

An effective visualisation supports user tasks in a seamless manner. A user should be able to focus on the intended goal during the interaction with a visualisation. In order to achieve the goal, a visualisation should be designed such that the user focuses more on the goal and less on the tasks. A discussion of user tasks commonly supported in visualisations is given in Section 6. The literature review concludes in Section 7, summarising the important aspects discussed throughout the literature review.

2 Computer visualisation

Computer visualisation is concerned with "computer-based, interactive visual representations of data to amplify cognition" (Card et al., 1999, pp. 7). The desktop platform has more powerful computer resources than the mobile platform. As a result, a visualisation design process targeted for the desktop environment becomes less challenging than designing for the mobile platform (Van Tonder & Wesson, 2008). Furthermore, processing of a visualisation is faster due to the processing speed delivered by the memory and other performance enhancing factors such as advanced graphical application programming interfaces (APIs) (Van Tonder & Wesson, 2008).

Data is a backbone to a visualisation. It is therefore important for visualisation designers to understand data, together with various aspects surrounding it. In addition, other important factors to consider are devices for displaying visualisations, interactions styles on devices and users of visualisations. Considerable attention to these factors would produce designs that achieve the desired goals which enhance acquisition of information knowledge and aid cognition. Some studies have proposed approaches to classifying data (Chittaro, 2006; Ware, 2013). Classes from these studies were based on the types of data used (e.g., text and map-based) by Chittaro (2006) while Ware (2013) gives classes of data as categorical, real-number and integer data based on wide usage of these classes of data in the computing field. Having a clear understanding of various types of data used assists designers and developers to create more intuitive visualisations that represent the underlying data as closely as possible.

Interactivity in visualisations is a major factor that designers have to cater for in order to enhance user experience. It helps a user to focus on the task at hand rather than get frustrated by interaction styles that require an effort for the user to learn. Ideally, a designer should have an image of a typical user of the visualisation being developed, including a user's context in order to incorporate appropriate interaction techniques (Chittaro, 2006; Dix, Finley, Abowd, & Beale, 2004). The interaction styles are supported by the type of hardware and software available on the device. The next subsection discusses hardware and software that is useful in visualisations.

2.1 Hardware and software specifications

Presentation plays an important role in a visualisation. Visualisations on the desktop environment benefit from large screen sizes and high resolutions available in this environment (Callegaro, 2013). The powerful computing resources on the desktop platform (Yoo & Cheon, 2006) make it arguably easier for developers to create visualisation in this environment. Designers are not confined by limitations that challenge designs in the mobile platform.

Random access memory (RAM) plays a significant role for performance of a visualisation. Depending on how data is represented in a visualisation, RAM becomes useful in determining how much of the representation can be cached for fast access. This aspect improves the responsiveness of a visualisation. Desktop devices enjoy relatively unlimited speed compared to their mobile counterparts. Processing speeds from central processing units (CPUs) and graphics processing units (GPUs), like RAM, enhance performance of visualisations by improving the speed at which a visualisation operates. GPUs also improve the quality of the graphics rendered on the screens (Kutter, Shams, & Navab, 2009). These factors contribute towards the effectiveness of a visualisation, which in turn enhances user satisfaction. Software also impacts the type of visualisations that can run on a device. Environments such OpenGL, Direct3D, Compute Unified Device Architecture (CUDA), Close to Metal (CTM) and GeoTools-Lite give developers access to powerful graphics enhancing APIs that benefit visualisations (Kutter et al., 2009; Rhyne & MacEachren, 2004).

General advances in computing areas such as grid and cloud computing and networking (Mouton et al., 2011) provide more computing resources to less powerful workstations. This enables more data to be accessed and processed, and in turn enabling more visualisations to be developed and rendered, both locally and remotely. The resources available on devices impact the visualisation design since designer need to match the capabilities of the devices to the features of a visualisation. The next subsection explores factors important for the design of visualisations in the computing field.

2.2 Design considerations

In human-computer interaction, the golden rule of design is 'understanding your materials' (Dix et al., 2004, p. 193). This refers to both humans and computers. The rule can be applied to the visualisation design process. Understanding the user needs, capabilities and user influences can produce successful visualisations that meet users' expectations. Similarly, understanding the computer limitations and capabilities helps in a design of a visualisation that also contributes towards meeting the user's expectations.

Shneiderman (2004) discusses three goals that designs should address for successful user interfaces. The goals can be adopted in designing visualisations as a user interface is a predominant feature of a visualisation. The goals are described below:

1. provide the right functions that will allow users to accomplish their goals
2. offer usability and reliability to prevent frustration (from undermining fun)
3. engage users (with fun-features)

The first two goals require a visualisation designer to provide users with adequate functionality to perform various user tasks related to a visualisation, e.g. providing a user with an overview of data in a visualisation (Shneiderman, 1996, more user tasks are discussed in Section 6). The functionality should also be usable and reliable and not put mental burden on a user during interaction with a visualisation. For the last goal, the aspect of fun could as well be brought in the visualisation domain as a way to provide more user satisfaction. This goal is more suited to mobile visualisation since the mobile platform is dominated by users operating in non-professional settings than the desktop platform (Shneiderman, 2004), though mobile users can still engage in professional settings. Combining goals by Shneiderman (2004) and Dix et al. (2004) gives a broader perspective for the designer, as the designer will have an understanding of user needs, system capabilities and user interface goals to base a visualisation on. This approach can result in positive reception of a visualisation by users as they would have contributed to its design.

Another study (Carr, 1999) proposes seven guidelines which can be followed in the design of visualisations. The guidelines are described below:

1. visualisation is not always the best solution - if there are other ways of meeting user goals, a design should explore those alternatives.

2. user tasks must be supported - refers to providing more interaction with a visualisation than the basic tasks provided in Shneiderman (1996, discussed in 6). This point compares with a point on interactivity in Chittaro (2006) as it addresses interaction styles that a design should allow during the visualisation process.

3. the graphic method should depend on the data - a visualisation should represent data in a dataset as closely as possible to the concept the data represents.

4. three dimensions are not necessarily better than two - a visualisation should use few dimensions to represent data, but should ensure that a meaning derived from such a visualisation is not reduced or distorted (Peng, Ward, & Rundensteiner, 2004)

5. navigation and zooming do not replace filtering - a visualisation should enable users to not only navigate the visualisation, but also filter out data to gain more perspective of items of interest.

6. multiple views should be coordinated - if a visualisation provides multiple views (e.g., Overview+Detail as described below), the views should be managed so that they do not frustrate the user while switching between the views.

7. test your designs with users - testing a visualisation with users helps discover usability problems. This is an important guideline in any design, as highlighted under the guidelines by Shneiderman (2004) on usability and reliability, discussed earlier in this section.

Effective visualisation designs have to capture the attention of a user and deliver information within a reasonable period of time. A user-centred approach helps to achieve this, as it places the user at the forefront of the design process, instead of relegating the user's role to the periphery of the entire process. For this to occur, a communication channel has to be established as early as possible in order to inform the design process (Chittaro, 2006; Dix et al., 2004), in an effort to understand the user.

Another advantage of engaging the user early during the design process is to help designers identify usability problems associated with the initial design early on (Rhyne & MacEachren, 2004). This helps to manage the design costs and minimise redesign costs. Such costs include time spent on the (initial) design, financial resources incurred and human labour deployed to the design process. Through the established communication, the developer can learn what the user's needs are and the user can in turn be aware of what the developer can and cannot offer. This approach leads to a better understanding of both players involved and hence a

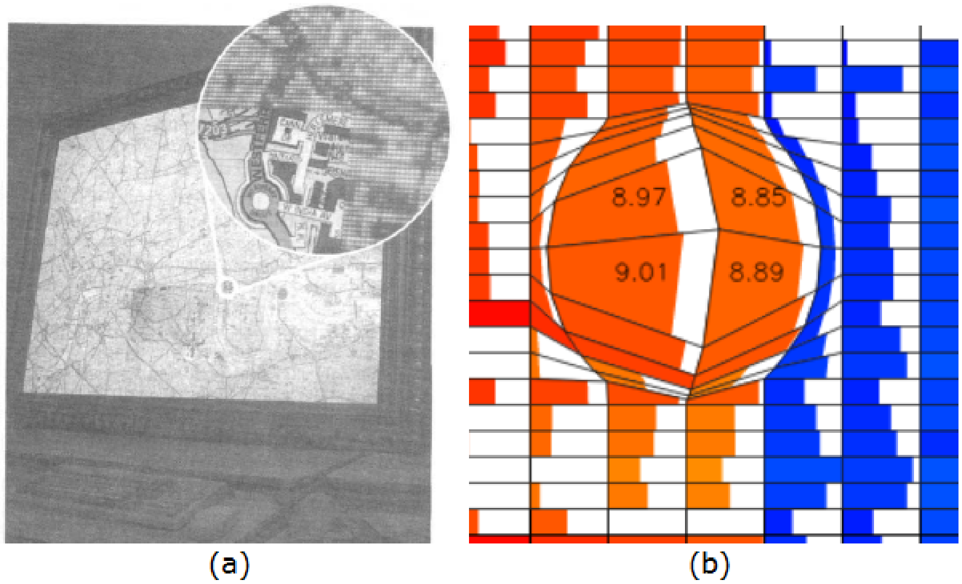


Figure 1: (a) The zoomed part gives a detailed information (Baudisch et al., 2001) (b) Fisheye view shows more detail at the centre - the focus (Ross, 2008)

more successful visualisation.

Approaches specific to map-based visualisations have been discussed in various studies (Baudisch et al., 2001; Chittaro, 2006). These are Overview+Detail (O+D) and Focus+Context (F+C). They are meant to overcome the presentation issue on desktop visualisations. O+D has one part of the screen displaying the overview of the entire visualisation while another part of screen displays a detailed part of the visualisation. F+C provides one view that shows both the context or overview together with content which is the detailed part of visualisation (Chittaro, 2006). Examples of O+D and F+C are shown in Figure 1 (a) and (b) respectively. The next subsection discusses categories of visualisations in the computing field.

2.3 Categories of visualisations

According to Card et al. (1999), computer visualisation in the early days focused on scientific computing with the aim of helping scientists work with large amounts of scientific data. Scientific visualisation therefore tended to be based on the nature of data scientists worked with, which mostly constituted physical objects (Card et al., 1999). Visualising data that was not based on physical objects but rather on abstract concepts (such as financial data) became apparent. Visualisation from the abstract concepts was coined information visualisation (Card et al., 1999). Other forms of visualisations exist. These include volume, flow, surface and geographical visualisation (Card et al., 1999; Rhyne & MacEachren, 2004). These visualisations either work with physical data or abstract concepts and can therefore be categorised as information or scientific visualisation. Volume visualisation deals with representation of 3D volumes and interaction techniques for working with those volumes. Flow visualisation deals works on visualising flows (of liquids or gases). Visualisation of data from geographical or location based disciplines is called geographical visualisation. Categorisation by Card et al. (1999) essentially gives two categories of visualisation.

The next section discusses visualisations in the mobile platform, followed by hardware and software specifications, design considerations that affect design in mobile visualisations and categories of visualisation in the mobile platform.

3 Visualisations in the mobile environment

The limited resources in mobile devices pose a challenge for visualisations, especially in comparison to the desktop devices. The challenge lies developing new visualisation techniques, since the traditional desktop visualisations cannot simply be transferred to the mobile platform given the limited resources such as small screen sizes and processors (Chittaro, 2006; Van Tonder & Wesson, 2008). Despite this challenge, technological advances in the computing field offer some opportunities to the mobile platform. For example, wireless networking technologies provide a platform for development of cloud-based applications which are unique to the mobile platform (e.g., navigation services) (Chittaro, 2006; Mouton et al., 2011).

The mobility factor also adds a new dimension of complexity. Mobile application developers have to consider factors such as multitasking, short attention spans and changing lighting conditions on a device screen (other factors are discussed in other sections, e.g., interactions styles are discussed in Section 5). These factors give rise for the need to design applications that give as much information as possible, and in arguably a shorter time than on a desktop device (Chittaro, 2006). Visualisations could achieve this short time requirement since they enhance acquisition of more information in a relatively shorter time than if presented otherwise (Card et al., 1999). The next subsection discusses hardware and software specifications that are useful in visualisations, followed by factors that affect the design of mobile visualisation and a description of categories of visualisations that are available in the mobile platform.

3.1 Hardware and software specifications

The ability of a mobile device to render visualisations depends on the hardware and software available on the device. The hardware and software on a mobile device consequently impact the design of a visualisation. The design of visualisations on the mobile platform therefore becomes a challenge due to limited resources (Van Tonder & Wesson, 2008). Below is a description of hardware and software that play various significant roles in mobile visualisation.

1. Screen - this is perhaps the most important resource for a visualisation since it affects the layout of visualisation (Chittaro, 2006). Screen size determines the amount of information a visualisation can display, while resolution specifies the quality of a graphics used for a visualisation. Higher resolution such as retina display on Apple devices of-

fer higher quality displays (Apple, 2013). Touchscreens are a dominant screen type in mobile devices.

2. Processor and RAM - these are responsible for performance of a visualisation since they determine how much and how fast data can be cached and accessed during a visualisation process.

3. Connectivity - mobile phones, especially smartphones, typically have several connectivity types such as WI-FI, mobile telecommunication technologies (e.g., 2G, 3G, 4G), Bluetooth, near field communication (NFC) (Samsung, 2013). These can be used in connecting with other devices that provide data for visualisation, or cloud-based visualisations (Mouton et al., 2011). Various connectivity capacities determine the speed of a visualisation process and are key especially if cloud-based visualisations are involved.

4. Storage - this is only useful to the extent a user needs to perform such tasks as extracting parts of data from a visualisation on a mobile phone.

5. Input/output devices - examples include microphones and speakers, which provide new ways of interaction, such as speech recognition (e.g. Siri by Apple) and many types of sensors (e.g. proximity sensors, GPS, temperature and humidity sensor) available in smart phones like Apple iPhone 5s and Samsung Galaxy S4 (Apple, 2013; Samsung, 2013). The io devices impact the design of visualisations as designers need to know which mobile devices to target in order to exploit as many io devices as possible and support as many interactions as possible on mobile devices (Wang, Huynh, & Williamson, 2013).

From the software perspective, libraries and APIs exist that enhance visualisations. Examples include Google Maps API, GeoTools-Lite and OpenGL ES (Rhyne & MacEachren, 2004; Van Tonder & Wesson, 2008; Wang et al., 2013). These tools help in designing visualisations that optimise hardware resources, hence improve the overall performance of visualisation. The knowledge and understanding of various hardware and software available on mobile devices can help in the design of new applications that take advantage of some of the unique features (e.g., GPS) of mobile devices. The next subsection explores factors that affect visualisation designs in the mobile platform.

3.2 Design considerations

In order to address some of the challenges and take advantage of new opportunities highlighted in the previous sections, design approaches have been proposed by several studies (Chittaro, 2006; Fling, 2009). Fling (2009) gives guidelines that are general for mobile design and development, but could be adapted for the mobile visualisation. Chittaro (2006) gives an approach that is specific to mobile visualisation. Descriptions of the approaches are given in the following paragraphs.

An approach by Chittaro (2006) proposes six area of focus when designing for mobile visualisation. These are:

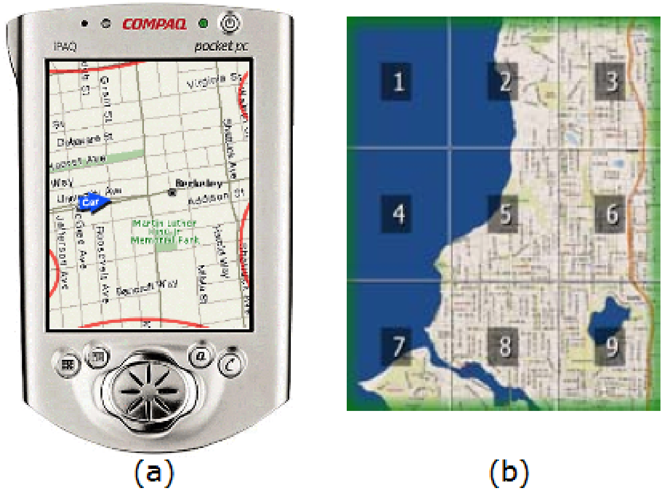


Figure 2: (a) Halo with arcs referencing off-screen places (Baudisch & Rosenholtz, 2003). (b) ZoneZoom segments a screen into nine views (Robbins et al., 2004).

1. mapping - designers should be able to graphically emphasise important aspects within the visualised data such that the user will effortlessly pick important patterns and relationships within the visualisation.

2. selection - the limited screen requires careful attention. Designers should be able to pick relevant data and discard undesired data. Selection should not only be determined by the designer, the user should also be able to filter for relevant data within the entire dataset, in order to suit their own needs (Fry, 2009).

3. presentation - this is a key area for visualisation as it is a final destination of information to the user in the visualisation. Approaches such as O+D and F+C (discussed in Subsection 2.2) often fail due to limited screen sizes (Chittaro, 2006). Different approaches specific to map-based visualisations have been proposed, namely i) visual references to off-screen points of interest, e.g. in Halo (Baudisch & Rosenholtz, 2003) and City Lights (Zellweger, Mackinlay, Good, Stefik, & Baudisch, 2003). Figure 2(a) shows a screenshot of Halo. The arcs along the edge of the screen direct the user to the off-screen points of interest in a map. However, these approaches tend to introduce some clutter of their own (Van Tonder & Wesson, 2008) and ii) intuitive ways of switching among the visualisation parts, e.g. in ZoneZoom (Robbins et al., 2004). ZoneZoom splits the view into nine sub-views which are mapped to number keypads on a phone. Figure 2(b) ZoneZoom view of a map. To zoom in to an area of interest, a user selects a number corresponding to the area of interest.

4. interactivity - this concentrates on how users interact with the visualisation. A visualisation should allow the user to interact with the dataset as much as possible as they explore the information for patterns.

5. human factors - it is crucial to understand target users of a visualisation - their literary and computer skills and cognitive abilities. The design should provide a visualisation that is highly usable even amongst a widespread potential user population in the mobile platform (Dix et al., 2004; Paelke, Reimann, & Rosenbach, 2003).

6. evaluation - the effectiveness of the visualisation should be determined. It is important to test the usability of a visualisation, based on what the user's experience is during the interaction (Dix et al., 2004).

Fling (2009) has seven areas for design focus for mobile platform, could be adapted for the design of visualisations. These are:

1. context - which is defined as:
   - the general understanding of the task a user is performing
   - the environment in which the task is performed:
     - physical context - the physical location of the user
     - modal context - the psychological state of the user

   A comparable study (Pombinho, Carmo, & Afonso, 2009) proposes five contexts to explore in visualisation, these are: personal, environment, temporal, social and spatial contexts. The first two are similar to the modal and physical contexts in Fling (2009). The last three offer additional context, and relate to a time when a user performs a task, other people around while a task is performed and orientation respectively. Some of the contexts tend to be neglected in many mobile applications, focusing interaction only between the user, the mobile device and services (Rukzio et al., 2007). All these allude to complexity involved in designing for mobility.

2. message - what the visualisation needs to tell a user.

3. look and feel - how the interface is designed and how will users interact with it.

4. colour - colour depths, posterisation, human perception, psychology of color and colour palettes should all be considered for an effective design.

5. layout - is the visualisation laid out such that a user will interact with it in a simple way, without mental overload. Other researchers present similar suggestions regarding presentation. Owing to small screens, clutter is a serious challenge in mobile devices compared with the desktop devices. It reduces the user's ability to perform a task effectively (Pombinho et al., 2009; Rosenholtz, Li, Mansfield, & Jin, 2005). As such, a considerable effort is required to minimize clutter when designing a visualisation.

6. typography - how a design addresses fonts, size, styles and readability and clutter is managed.

7. graphics - how a design aids a user's cognition with images - iconography.

Although Fling (2009) makes a distinction between the last four points, the points address the same issues related to layout and so can be put as one point - look and feel. The first three points can then be adopted for a visualisation design. Some aspects from Fling (2009) and Chittaro (2006) are comparable. For example, the message in Fling (2009) addresses some of the aspects of a visualisation similar to those addressed in presentation and mapping from Chittaro (2006). Human factors and interactivity in Chittaro (2006) address factors such as interaction styles available for a visualisation and these factors are covered by the context in Fling (2009).

There are other factors that affect the design of the visualisation. A wide variety of mobile devices that exist in the market is another challenge to designers of visualisations. Fragmentation features significantly, since designers have to worry about providing effective visualisations across many devices in a way that does not distort meaning from one device screen size, resolution and OS to another (Akbari et al., 2014; Callegaro, 2013).

Connectivity is also worth considering during the design of a visualisation. The cost (of short life batteries of mobile devices, telecommunication network charges and low-bandwidth connectivity speed) associated with rendering visualisation on a mobile phone require a structured approach to design. The challenge posed by low band-width connections can be overcome by designing visualisations that minimise operations on mobile devices, leaving presentation as the only task done on the mobile device.

The next subsection discusses categories of visualisation that exist for the mobile platform.

3.3 Categories of visualisation

A discussion on categories of visualisations was provided in Section 2.3, giving categories as scientific and information visualisations. This section discusses categories of visualisation that were found in related work to be more applicable to the mobile context as proposed by Chittaro (2006). Five categories have been proposed for mobile visualisation based on the following data types: text, abstract, maps, physical objects, and pictures data. The categories can also be put scientific or information visualisation. For example, visualisations of physical objects is scientific visualisation according to a classification given in Section 2.3. Depending on the context, some visualisation categories will be more popular than others. For example, information visualisation is arguably more popular in mobile platform than scientific visualisation due a wide population potentially dominated by non-professionals (Shneiderman, 2004). This is due to the ease of access and use by mobile devices without a need for formal training as it is a normal case with desktop computing (Chittaro, 2006; Shneiderman, 2004). The next section discusses data types that are typically used in visualisations, resulting in a broader domain for visualisations than provided by categorisation from this section and Section 2.3.

4 Visualisation data types

Data is key to visualisation. Many disciplines generate and use data from their own institutions for internal and external use. A discussion in previous sections (Section 2.3 and 3.3) essentially narrows visualisations down to two categories - scientific and information visualisations. In this section, visualisations are classified according to data types. This gives a broader domain of visualisations than just the scientific and information visualisations. Data types commonly used in visualisations were investigated from several studies (Chittaro, 2006; Shneiderman, 1996; Ware, 2013). Ware (2013) classifies data according to three types, namely categorical, integer and real-number data. Categorical data assigns labels to data within datasets and cannot be ordered in a sequence. For example, Figure 3(a) shows a screenshot of news24 elections app described later in this section, the different political votes represent categorical data. Categorical data type is one of two types which will be used in this research. Integer data involves data that can be ranked in a sequence. For example, ranking the political parties according to the total votes they got from the elections falls under this data type, as shown in Figure 3(a). Real-number data is data associated with intervals and ratios. For instance, the distances between the different points of interest in Figure 2(a) fall under the real-number data type.

Chittaro (2006) gives five classes of data which visualisation targets on mobile devices. These are pictures, text, physical objects, abstract data and maps. Data represented by visualisations under this classification is in the form of pictures, text, physical objects, abstract concepts and maps respectively. Map-based data type is the other type under the focus for this research.

Shneiderman (1996) proposes a taxonomy based on seven data types, namely: 1-dimensional (1D), 2-dimensional (2D), 3-dimensional (3D) and multi-dimensional, temporal data, tree data and network data. 1D type represents data that has one variable in a database, e.g. list of honours students for a particular year. 2D type represents data with two variables, visualisations include geographic data or surface areas, with x and y coordinates that represent a point on a surface. Figure 2 shows examples visualisations of 2D data type. 3D works with data that has three values or variables in a representation, e.g., an object has three x, y and z coordinates that represent a point in space. Figure 3(b) shows an example of a visualisation for 3D data. Multidimensional types represent data stored in statistical and relational databases, usually with more than three variables. Visualisations for this data type are usually expressed as scatter plots and parallel coordinates. Figure 4 shows parallel coordinates visualisation for automobile data as an example of multidimensional data type. Temporal type includes any of the above data types, plus an added time component. This time is used to explore behaviour of data as time changes. Figure 5 shows a temporal data visualisation for selected technology stock between the years 2000 and 2010. Tree data can be displayed with hierarchical relationships that show links between items in a dataset. Each item has one link above it - to a parent item, and can have other links below - to child items. An exception is the parent item, which has no parent link. A directory structure in a computer filing system is an example of such data type. An example of a tree visualisation is shown in Figure 6. Network type represents links between groups of items in a dataset. Nodes in this type cannot be represented in a tree-like format. An example of visualisation is shown in Figure 7.

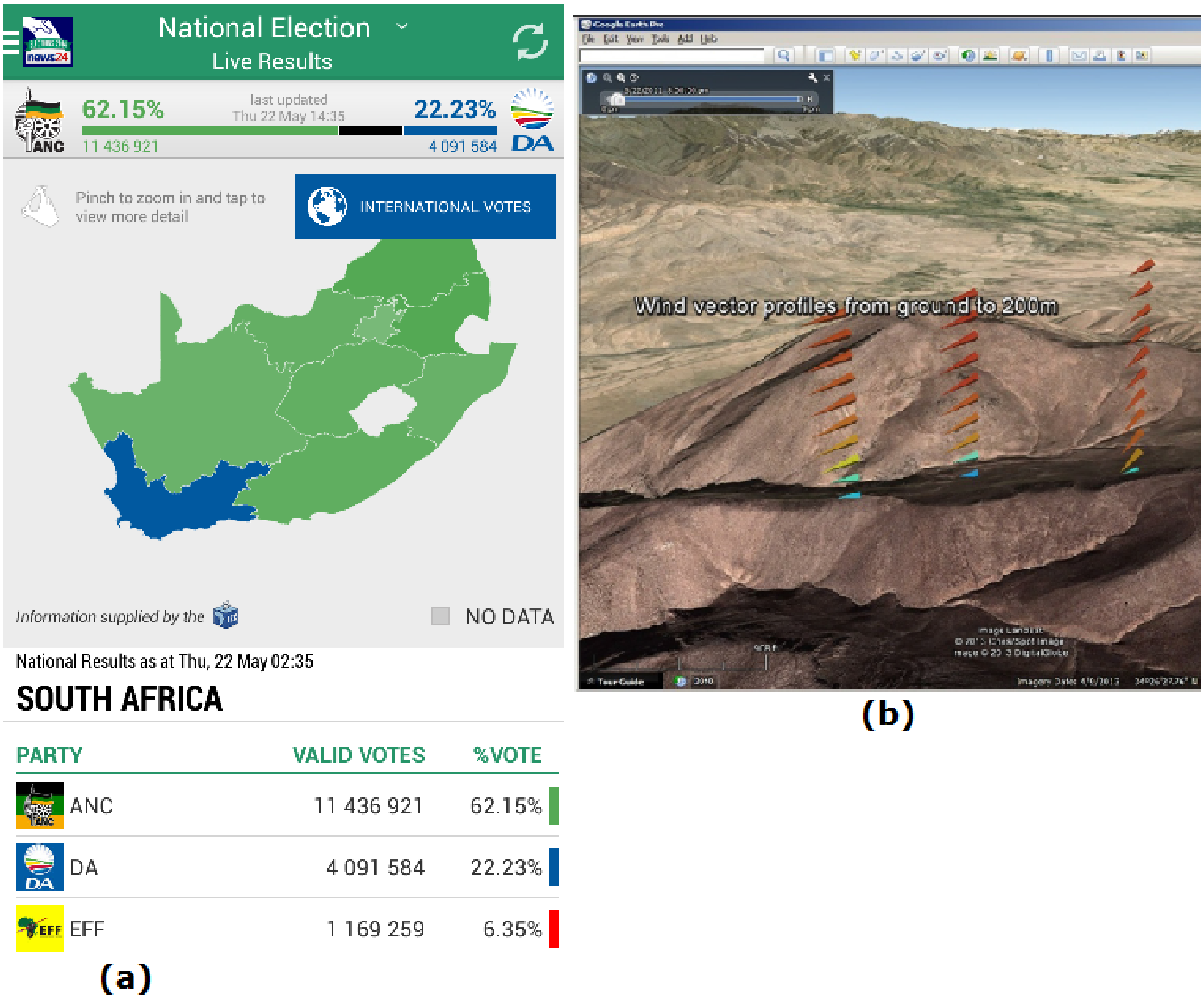


Figure 3: (a) News24 elections app displaying 2014 results by provinces (map-based) and total number of votes (integer data) political parties got (categorical data) (News24, 2014). (b) 3D land surface visualisation of wind vector profiles (Wang et al., 2013)

Data types provided Shneiderman (1996) encompasses classifications given by Chittaro (2006) and Ware (2013). For instance, all examples given in the classification by Ware (2013) can be represented in any of the type given by Shneiderman (1996). For a classification provided by Chittaro (2006), pictures, maps and physical objects can be represented in 2D or 3D, whereas text and abstract data can be represented in 1D.

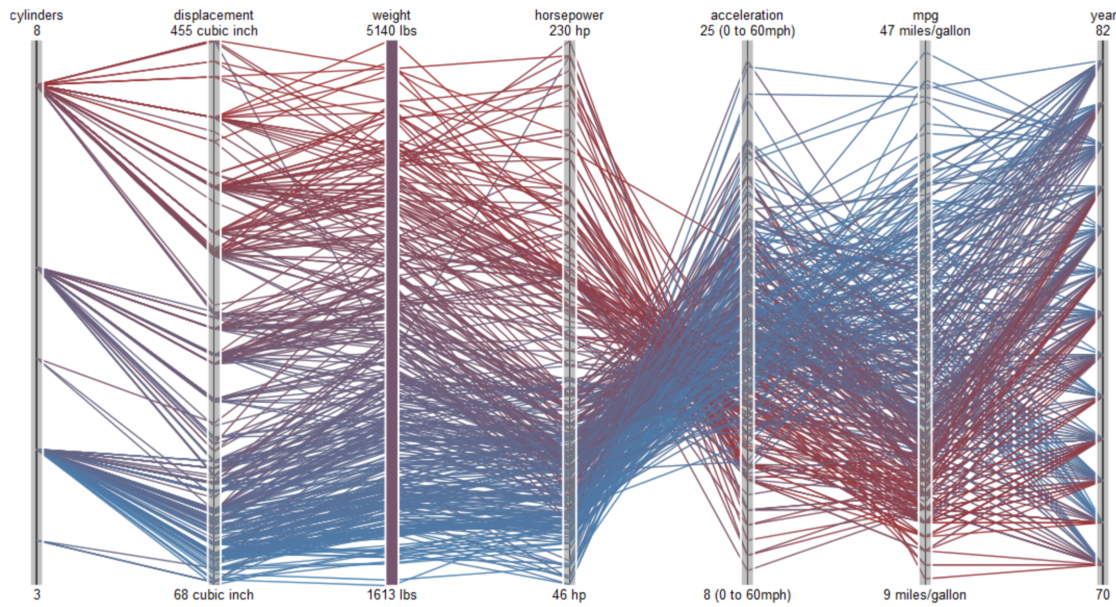


Figure 4: Parallel coordinates visualisation for automobile data (Heer et al., 2010).

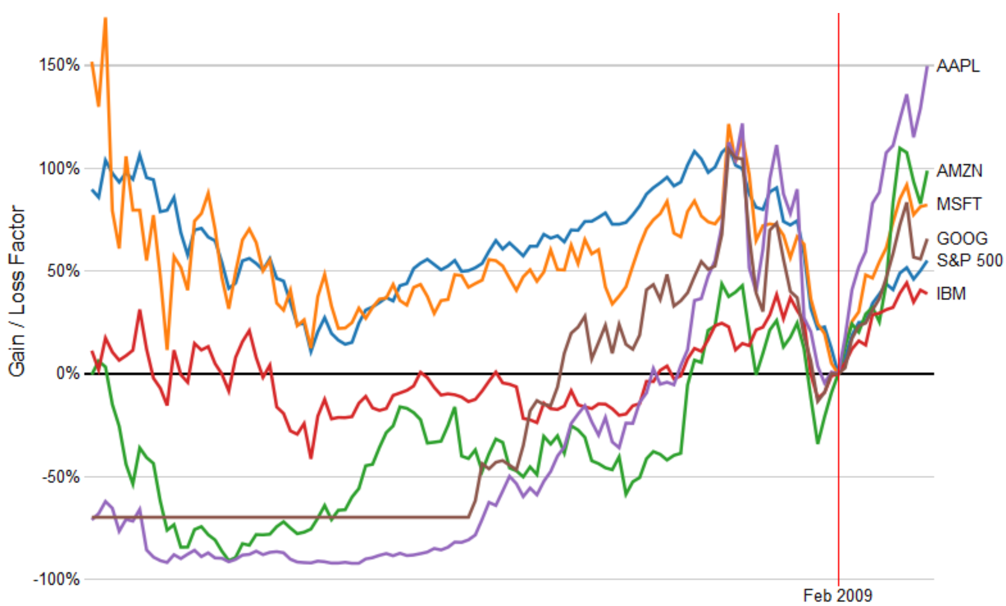


Figure 5: Visualisation of technology stocks representing temporal data (Heer et al., 2010).

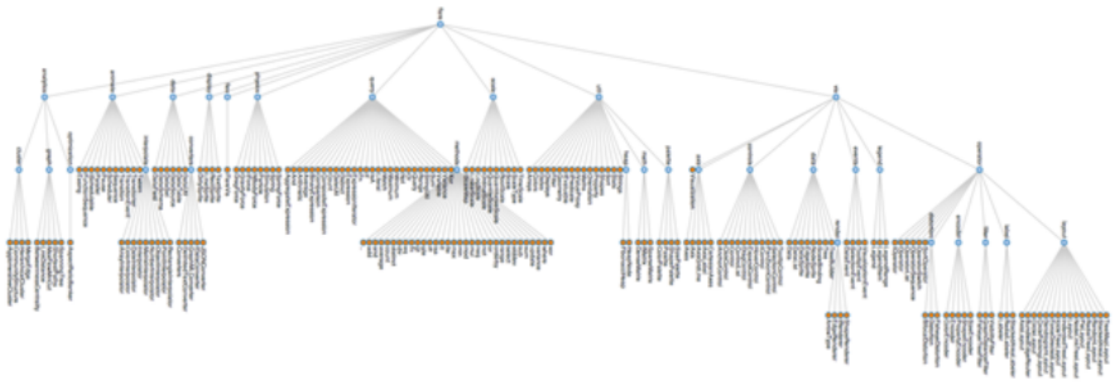


Figure 6: Tree visualisation (Heer et al., 2010).

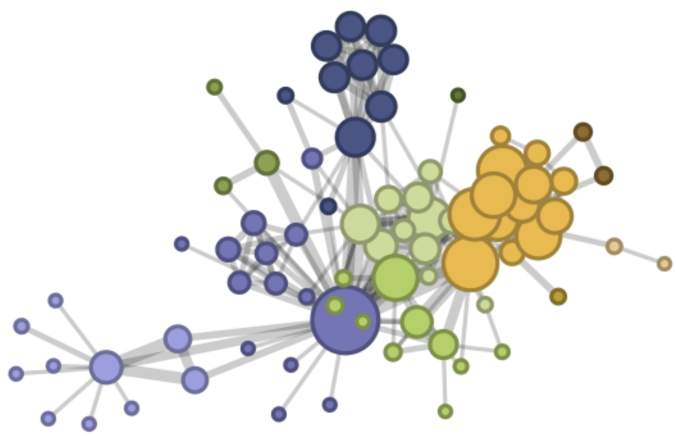


Figure 7: Network visualisation (Heer et al., 2010).

The data types to be visualised in this research are categorical and map-based data types. As such, a detailed investigation was conducted for an application that focused visualisations on these two data types. News24 Elections mobile application for visualising South African 2014 national election results and related news was explored. The application makes use of categorical data (e.g. different political parties participating in the elections) and map-based data (e.g., provinces, municipalities, etc.) to provide visualisations. Colours on various map divisions indicate the political party that had the most votes. For instance, Figure 3(a) shows national and international results. The international result shows an overall blue colour, while the national results show an overall green colour, except in one province. The underlying data used in this application is based on a large dataset of over 25 million registered voters. This application closely relates to the research topic, which focuses on visualisations of large datasets of map-based and categorical data types. Interaction styles such as pinching and tapping are provided by the visualisation to enable a user zoom in and view more details associated with geographical divisions of interest to the user. The next section discusses interaction techniques available in the mobile platform and how they support visualisation in the mobile devices.

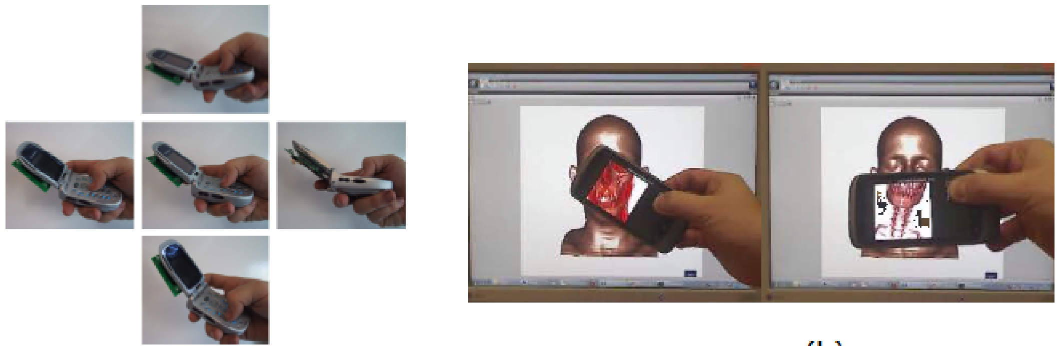
5 Interaction techniques for mobile devices

Interaction techniques provide a means for a user to actively engage in a visualisation process. A user is able to investigate, evaluate and drill down more on the data being visualised using some graphical user interface elements such as sliders and buttons or hardware buttons on mobile devices. The fragmentation problem from having many devices by different manufacturers brings a wide variety of interaction techniques which are an advantage and a disadvantage at the same time (Akbari et al., 2014). The advantages lie with users, since there is a wide variety of devices to choose from, whereas for the designer of a visualisation, incorporating a wide variety of devices is a challenging task (Akbari et al., 2014). These techniques can be exploited to enhance user experience.

As highlighted in Section 3.1, interaction techniques depend on the hardware and software available on a mobile phone. Often a combination of hardware resources achieves a single interaction technique, so interactions described under one resource are not exclusively realised by that resource. For instance, sensors detect device orientation when a user tilts a screen, and a screen display changes from horizontal to vertical layout or vice versa. Touchscreens support interaction techniques such as touch (e.g. swipe, slide, pinch, tap, multitap, etc. (Rukzio et al., 2007)). Some touchscreens also adapt to user context such as adjusting to lighting conditions.

Sensors enable techniques such as orientation (e.g. tilting and shaking) and motion detection (e.g. eye blink rate sensors in Google Glass) (Ishimaru et al., 2014; Rukzio et al., 2007). Some of the interactions allow for applications that are unique to this platform. For example, GPS allow mobile phones to interact with their geographical location, and provide services such as navigation. Applications that take advantage of these interactions techniques have been explored, such as TiltText (Wigdor & Balakrishnan, 2003) and TiltType (Partridge, Chatterjee, Sazawal, Borriello, & Want, 2002). For example, TiltText (Wigdor & Balakrishnan, 2003) uses an accelerometer and a tilt sensor to allow a user to select an alphanumeric option while texting a message on a mobile phone. Figure 8(a) shows how a user tilts a phone to input one of four options associated with a keypad.

Cameras enable users to use mobile devices as pointing device to other application (Ballagas, Borchers, Rohs, & Sheridan, 2006). An example is shown in Figure 8(b), where a camera is used in augmented visualisation to give a user a different visualisation from the one on a wall display (Sörös, Seichter, Rautek, & Gröller, 2011). Designing visualisations that exploit these techniques will enable a user of visualisation to have many options while interacting with the visualisation. The interaction techniques discussed in this section typically support tasks a user undertakes in order to achieve thier goal for using a visualisation. The next section discusses user tasks commonly used in visualisations.



(a) (b)

Figure 8: (a) User tilts a phone to select letters as he types text (Partridge et al., 2002). (b) Augmented visualisation (Sörös et al., 2011)

6 User tasks in visualisation

A user engages with a visualisation because they have a goal of gaining insight into the data being visualised. The goal aims to help a user make discovery of patterns within the dataset, make decisions or find explanations within the data (Card et al., 1999). To achieve the goal, often a series of tasks are undertaken. A visualisation should be designed such that a user's attention is focused more on the goal and less on the tasks involved in achieving the goal. Seven general visualisation user tasks that abstract the visualisation design process from any specific visualisation have been developed by Shneiderman (1996)(Carr, 1999). The seven tasks are described below according to Shneiderman (1996):

1. overview - a visualisation should allow a user to have an overview of the entire dataset, usually through zooming to the outermost level.

2. zoom - a user should be able to focus in detail on parts of interest in a visualisation.

3. filter - this complements zoom in that a user should be able to filter out items that are not of interest.

4. details-on-demand - a user should be able to get the details of an item or a group of times of interest when needed by selecting the item or the group.

5. relate - a visualisation should provide a way to explore relationships among items in a dataset.

6. history - this ensures that in a common but undesirable event when a user performed a certain action or got unexpected results from that action, they will be able to undo it.

7. extract - this allow for querying of data within datasets. Users should be able to extract parts of visualisation data if they so require.

A summary of literature review is provided in next section, highlighting important issues discussed throughout the literature review.

7 Summary

This paper explored literature related to visualisation and interaction techniques in the desktop and mobile environments. Specifically, the mobile platform as the focus of this research topic was investigated in detail. In addition, hardware and software that is useful for improving performance and quality of visualisations in the mobile platform was investigated. Design considerations on both platforms were discussed, looking into the guidelines that have been developed and are used in visualisations. Visualisation categories were also investigated for both environments. Emphasis was placed on managing clutter, especially in small displays of mobile devices. Data types common in visualisations were explored, highlighting categorical and map-based data types as key types to be visualised for this research. Examples were drawn from various applications to visualisations. Interactivity as an important factor in visualisation was discussed, highlighting its importance in assisting a user to achieve their tasks. The literature review concluded with a discussion on the user tasks commonly used in visualisation, emphasising the importance of having those fundamental tasks in all visualisations.

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