Uncovering Moving Off-View Objects on Large Interactive Displays

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Declaration

I hereby declare and confirm that this thesis is entirely the result of my own original work. Where other sources of information have been used, they have been indicated as such and properly acknowledged. I further declare that this or similar work has not been submitted for credit elsewhere.

Hagenberg, October 8, 2012

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Kurzfassung

Große Displays bieten eine umfangreiche Arbeitsfläche und werden daher oft zum Explorieren von großen Datenstrukturen wie Karten verwendet. Die große Fläche erlaubt auch die zeitgleiche Verwendung des Displays durch mehrere Anwender. Um ungestörtes Arbeiten von mehreren Benutzern zu ermöglichen wird jedem Benutzer ein eigenes Fenster als Arbeitsfläche zur Verfügung gestellt. Sind allerdings bewegte Objekte involviert, können diese das Fenster und das Sichtfeld des Anwenders verlassen. Obwohl das Objekt womöglich noch auf dem großen Display sichtbar ist, ist es außerhalb des Sichtfelds des Anwenders. In dieser Arbeit wird eine neue Visualisierungstechnik „Canyon“ vorgestellt um dieses Problem zu behandeln. Canyon hängt kleine Fenster mit dem nicht sichtbaren Objekt und dessen Umgebung an die Außenkanten des Anwenderfensters an. Uninteressante Bereiche zwischen dem Objekt und dem Anwenderfenster werden wie Papier gefaltet um den Platzverbrauch zu minimieren. Eine empirische Anwender-Studie wurde durchgeführt um die Vor- und Nachteile von Canyon zu evaluieren. Canyon wurde mit einer bekannten Technik namens „Wedge“ verglichen. Resultate der Studie zeigen, dass Canyon besonders in komplexen Situationen genauere Ergebnisse erzielt und vergleichbar schnell ist.

Abstract

Wall-sized displays provide great space and thus are often used for exploring large data sets, such as maps. The large space also allows simultaneous work by multiple users. To support simultaneous work without interference, functionality of creating individual workspaces has to be provided. However, moving targets may exit these workspaces and an individual's field of view, and thus become "off-view". Although the object may still be visible somewhere on the surface of a large display, not being able to see the object presents a problem. This work presents a novel information visualization technique, "Canyon", to address the off-view problem. Canyon attaches a small view of an off-view object including its surroundings to the external boundary of the detail view. Uninteresting space between the detail view and the off-view object is reduced to conserve space by employing a paper folding metaphor. An empirical study was conducted to assess the benefits and limitations of Canyon, in comparison to an established technique, called "Wedge". Canyon was found to be more accurate across a number of task conditions, especially in more complex situations, and was comparably efficient to Wedge.

Chapter 1

Introduction

Every person can get involved in emergency situations at any time. It is vital for victims to receive help in time, especially from first responders like police, ambulance and fire fighters. In 2011, 6.9 million emergency calls were placed from mobile networks[1] in Austria. This number shows that first responders have to take care of multiple cases simultaneously.

To ensure fast and adequate help for people involved in emergency incidents, it is crucial for the coordinators to have a good overview over all incidents and their action forces. In order to make grounded decisions, every group member needs to be aware of what happened, what is planned, which steps were already taken, etc. For example at a police command center, not all coordinators work in the same room, but there are persons constantly coming, passing or gathering information and leaving. Therefore it is important to present the situational overview in a manner, that can be apprehended at a glance.

The need for having a quickly understandable situation overview does not only exist in unforeseen emergency situations, but also in planned large scale operations like providing security for major sport events. These large scale operations involve a lot of people for coordination and execution, in addition to civilians. Furthermore, many smaller events have to be coordinated, like arrivals of foreign chiefs of state and other public figures.

1.1 Case Study: Police

To help understand how emergency responders work, the police of Upper Austria gave insights into their work. In meetings and discussion rounds, preliminary information about their work and expectations for a new situation overview system were discussed. To raise awareness about spatial limitations and a better understanding of their workflow, the police command center was visited. Furthermore, observing a district command group training was

[1]Data retrieved from http://www.fmk.at/Notrufstatistik.aspx, September 3, 2012

possible, to see and understand what types of incidents occur and how the police responds to them.

Provided with these insights by police officers, it was possible to find out where they needed support and how digital systems could help them. Currently, they use two different map displays for depicting the current situation. Either physical media, such as paper or metal-based maps, or a computer with a projector is used. Paper maps, hung on walls, are usually foiled to be able to make annotations with non-permanent markers. Maps, printed on magnetic boards are also hung on walls. They are used in combination with magnets to mark positions of units.

When a case escalates to a higher level a special command and control room is used containing a projector. Since there is no support for their special use case, the digital situation display is also limited in flexibility. The most used symbols, like different cars, traffic signs and other symbols describing the situation are saved as templates in a screen presentation. Digital map systems like Google Maps™ are used to retrieve map images. Usually a simple screenshot is made of the target area. It is pasted into a screen presentation. The necessary symbols describing the situation are pasted onto the map image. This is projected on a central spot in the command and control room and serves as a situation display. This is a very rigid workflow. When the area of interest widens, all symbols and annotations have to be placed again. Quickly exploring the map area by panning and zooming to clarify eventual questions is not possible while seeing the situation describing symbols.

In guidelines for leading disaster operations of the Austrian police [45] the cycle of managing large-scale operations is described. It starts with situation assessment. After an overview of the situation is gained, decisions are made and the execution is planned. All necessary missions are assigned and the execution has to be controlled. Then the cycle starts over with assessment of the situation, after the first missions were executed. Situation assessment involves assessing the initial situation and controlling, whether the executed orders were effective, whether the orders led to the desired result, whether the orders have to be corrected or new decisions have to be made.

Situation assessment includes displaying the current situation. According to the guidelines, a situation display should be clearly arranged and whenever possible be graphical. Furthermore, it should be placed centrally in the command center. It represents the current state and must always be kept up to date. A proper situation display is very important for the situation awareness of every team member. A lack of situation awareness can lead to imperfect assessment of the situation. Since crucial decisions are made based on the mental model of the situation, it becomes evident how important the situation display is.

1.2 Interactive Situation Display

The police case study shows, that there is a need for supporting emergency responders in creating and keeping their situation display up to date. A digital system can add flexibility to situation overview creation and maintenance by enabling fast transitions between or changes of viewed areas. Since a lot of geographical data, like locations of incidents and units, is involved for understanding the current situation, a digital map application was designed to support situation overview.

1.2.1 Digital Whiteboard System

Designing an appropriate system for situation displays in emergency response context requires making design decisions regarding hardware and software. A vertically orientated wall-sized display provides overview for the command group. Pen input supports quickly annotating the overview by drawing. To support simultaneous work on the large display, individual workspaces can be created. These decisions were made considering the police context.

Fast Overview: Vertical Orientation

It is crucial that everyone has the same mental model about the situation, since important decisions are made based on the emergency responders' understanding of the situation. A vertical display can be viewed by every member of the command group and provides peripheral information. It shows the same picture, independent of the angle of view. A vertical display provides a faster overview, since it does not have to be approached actively, unlike a horizontal tabletop display. Despite these advantages, face-to-face communication is not supported by a vertical display. However, when someone enters the room, he or she can get an overview about the situation with a vertical display at a glance.

Making Annotations: Pen Input

Besides placing symbols on maps to describe the current situation, adding various information by annotating is important. Traffic conditions like construction sites, which should be avoided, are annotated. Incidents may require road blockades or areas to be closed off. This information can be visualized quickly by drawing it on the map. Since such annotations are traditionally done with a pen, the digital whiteboard system is operated by pen input.

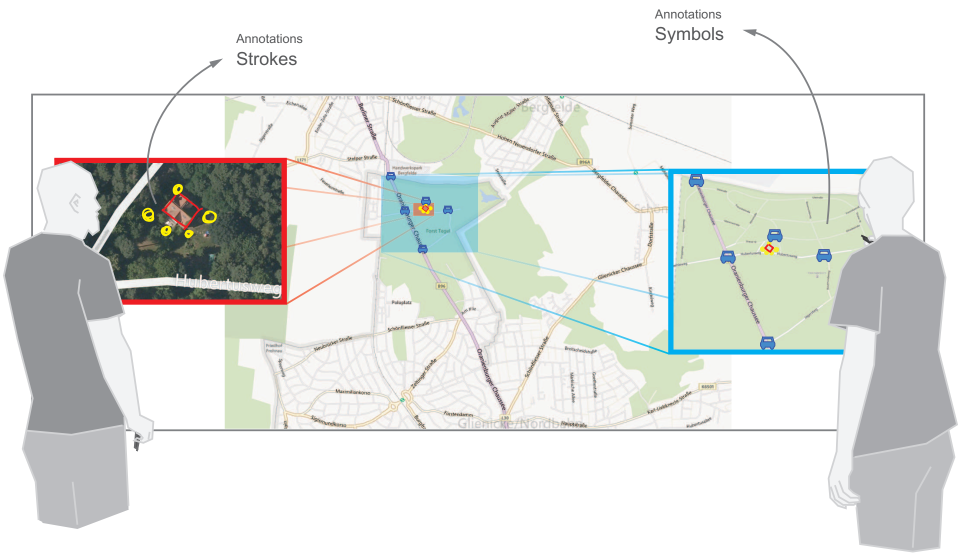


Figure 1.1: Interactive situation display operated by two persons. The map in the middle is the overview map, two detail maps are currently opened. The focus areas overlap in this case.

Flexible and Simultaneous Work

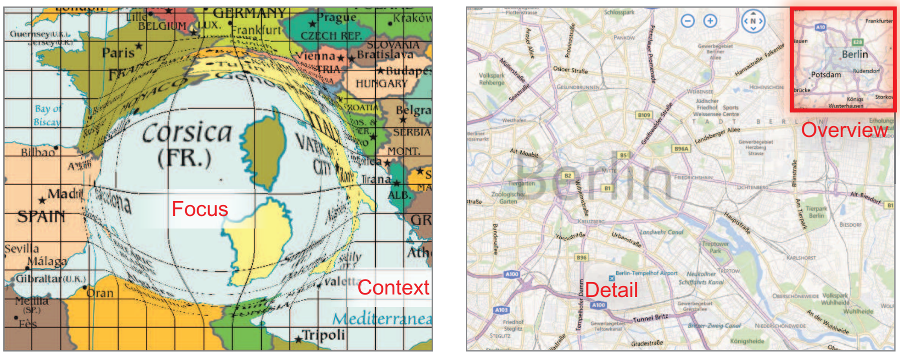
A digital map system already offers a lot of flexibility. Map areas can be explored easily by zooming and panning. Also, different map modes like street views or satellite views can be used, for example to explore insufficiently mapped areas like forests.

Consider, for example, the situation of a kidnapping suspect hiding in a barn. While a special force of the police would be in charge of securing the near region around the barn and catching the suspect, another team would be securing the far region. The team securing the far region has to prevent both the onlookers and other unauthorized persons from entering the dangerous area and the suspect from escaping. Using this example, multiple zoom levels and eventually map modes could be used to support the situation display. Figure 1.1 illustrates a possible situation display for this case. While the near region requires a high zoom level and perhaps a satellite view, the far region needs to overlook a greater area, and therefore requires a lower zoom level. Since both teams are working simultaneously, multi-user input must be supported by the interactive situation display.

Different people need to operate map areas independently at the same time. The literature suggests two main techniques for showing multiple levels of detail simultaneously [12]:

- **Focus+Context** techniques show focus region(s) of higher detail embedded in their surrounding area of lower detail level. The gap between the two levels of detail is typically bridged using distortion (using the metaphor of a magnifying lens). Figure 1.2 (a) shows an example of a lens interface. There are multiple variations including showing focus regions as translucent overlays or applying fisheye or rubber sheet metaphors.
- **Overview+Detail** techniques show focus region(s) in extra views while marking the focused area on the overview region, typically with a simple rectangle. Usually the detail area is shown in big and the overview as a small context-provider, as shown in Figure 1.2 (b). However, the reverse is also possible.

Since in Focus+Context techniques focus areas are embedded within their surroundings, it is not possible to have overlapping foci or place them flexibly to provide overview for the whole command group without introducing a lot of distortion. A person standing in front of the whiteboard and working on the focus area would block a large part of the overview map. As the above mentioned example shows, areas of interest can overlap and need to be viewed at the same time. With Overview+Detail techniques multiple independent detail views of the same focus area can be opened. Detail views can be flexibly placed wherever desired. Therefore, the interactive situation display in this work is implemented as a multi-user map application based on an Overview+Detail interface providing a large overview map. Figure 1.1 pictures a possible situation display of the above discussed example with an Overview+Detail interface.



(a) Focus+Context (b) Overview+Detail

Figure 1.2: Examples for techniques showing different zoom levels. (a) shows a magnifying lens from [39] as an example for Focus+Context interfaces. (b) shows Overview+Detail used in Bing Maps.

Summarizing, a large, wall-sized interactive whiteboard offers space for displaying the current situation for the whole team. Its vertical orientation, supports providing the same picture for everyone. A multi-user map application lets multiple people annotate the situation display simultaneously with pen input. An Overview+Detail interface enables free positioning of detail views while providing overview for the whole team.

1.2.2 Enhancing Situation Awareness

A multi-user map application on a large display can improve the situation display and therefore increase situation awareness. To support simultaneous work, the functionality of creating individual custom workspaces is provided. However, since moving targets may exit these workspaces, the targets become off-view objects.

Moving Off-View Objects

Having a comprehensive understanding of the situation is crucial to the decision making quality, and thus enabling the person to stay aware of objects outside the current workspace is an important design criterion. The limited focal area of a human, standing close to a large screen with direct input, restricts his or her field of view. Although the object may still be visible somewhere on the screen of a large whiteboard, not being able to see the object presents a problem (see Figure 1.3). These objects, outside of the users

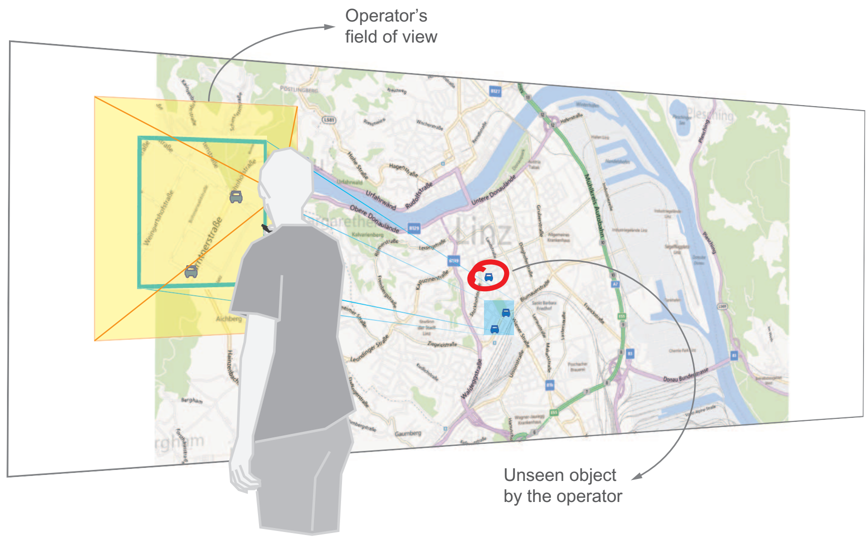


Figure 1.3: Restricted field of view of a person standing close to a large display. Although the red encircled object is visible on the screen, it is not seen by the person.

view, are considered off-view objects. This problem exists not only on small devices, as the current literature has focused on, but also on large displays with individual workspaces.

The problem of not being able to see an object strongly relates to the "off-screen" problem, where objects of interest are located outside a given window view [6, 12, 22]. Given a large display where the object might still be visible somewhere, therefore on-screen, the term "off-screen" is not appropriate. However, when the object is unseen by the user, it presents the same problem. Therefore, the more appropriate term "off-view" is introduced.

Since the interactive situation display is based on an Overview+Detail interface and potentially shows multiple maps, all edits done in one map are synchronized across all maps. While a person works on a detail map, he or she might miss occurrences outside of this workspace. These occurrences can include edits done by other persons or self-edited cars moving outside the workspace. Missing occurrences might lead to an incomplete picture of the situation for the person. It is likely that he or she will stay out of the decision process or make imperfect decisions. To overcome this problem, an off-view visualization technique named "Canyon" was developed in this work. It attaches orthogonal strips of map material including the off-view object to the detail view. As shown in Figure 1.4, uninteresting space between the detail view and the off-view object is folded to bring the object closer to the operator's workspace. The idea of folding unused parts of the screen, therefore reducing space while still providing context, was inspired by the technique "Mélange" [14]. To enhance distance awareness, a shadow was added to the folded part to enforce the metaphor of a folded paper strip. Distance is conveyed by the depth of the fold implied by the shadow's degree of darkness. By showing off-view objects, persons operating the situation display can stay aware of objects, that would otherwise be out of their view.

Figure 1.4: Moving targets may exit an individual's workspace and field of view (left). Canyon visualizes off-view objects by using a paper folding metaphor (right).

Focus of this work

The goal of this work is to enhance situation awareness for emergency incidents by providing information of moving targets outside of the operator's screen. While current literature has concentrated on rather abstract pointing methods for visualizing off-screen objects, this work concentrates on the design and evaluation of Canyon. Canyon provides a higher level of detail than usual pointing methods that use abstract cues pointing towards the off-screen objects. Canyon shows the off-view object and the area surrounding it. It is compared to an existing abstract pointing technique called "Wedge" [22]. This work evaluates whether a higher level of detail improves accuracy in off-view object awareness.

1.3 Contributions

Known literature explores the off-screen problem, which considers small displays and objects that are actually not on screen. This thesis investigates the field of unseen, although visible, objects on large displays. The off-view problem is defined and investigated. Canyon, a visualization technique standing out by providing a high detail level was designed to uncover unseen off-view objects. Canyon was compared to Wedge, an existing abstract visualization technique, in order to investigate whether a higher level of detail improves accuracy in off-view object awareness. Results indicate that Canyon is more accurate at recognizing movement, distance and location at similar speed. Furthermore, participants preferred Canyon over Wedge.

1.4 Outline

A short overview about the structure of this work is given here. First, the background knowledge gathered to have a better understanding about this topic is presented in Chapter 2. Related work regarding off-screen visualization techniques, investigated and published by other researchers is presented. For a better understanding of emergency responders' work, an informal background study has been conducted and is presented in the same chapter.

Based on this background knowledge, the design of the interactive situation display and the off-view visualization technique Canyon is presented in Chapter 3. The interactive situation display is described briefly, since it is not the focus of this work. The design of Canyon is described in detail. Furthermore, other off-screen visualization techniquess were implemented to be compared with Canyon. Two existing techniques, EdgeRadar [24] and Wedge [22], and two novel techniques, Bubble Window and Spring Mélange were developed. These techniques are described at the end of Chapter 3. The implementation of Canyon is presented in Chapter 4. This chapter covers the calculation and realization of the folding metaphor.

To evaluate if Canyon fulfills initial expectations, a user study with 16 participants was conducted and is presented in Chapter 5. Results show that Canyon was in many cases significantly less error-prone than Wedge, while the difference in trial completion time was not statistically significant. Furthermore, 14 out of 16 participants preferred Canyon. All results of the study are presented and discussed in Chapter 6. Finally, Chapter 7 covers conclusion of this work and presents future work.

Chapter 2

Background

This chapter presents collected background knowledge for designing an off-view visualization technique. The first section presents related work. Since the off-view problem on large interactive displays with direct input has not been investigated yet, related work in the field of off-screen visualizations was researched. The second section of this chapter presents a background study conducted to gather a better understanding of the emergency response context. An observation of a police command center training is reported.

2.1 Related Work

As previously explained, we distinguish the off-view problem from the off-screen problem. Objects become off-screen any time the screen is too small to represent the area of interest, often caused by the need of higher level of detail. However, off-screen objects are also off-view, and we can leverage existing off-screen visualizations to understand and approach the off-view problem. This section presents existing techniques on large visual spaces and visualizing off-screen objects. A comprehensive review on Overview+Detail, Focus+Context and Zooming interfaces was published by Cockburn et al. [12] in 2009.

2.1.1 Navigation-based Techniques

Scrolling

Pan, zoom or scroll are the simplest techniques for exploring large visual spaces. Different techniques have been developed to support navigation with scrolling or pan and zoom. 'Speed-dependent automatic zooming' [27] reduces the zoom level of documents when scrolling with high speed. This provides an overview during fast scrolling actions, rather than a blurry document.

Pan and Zoom

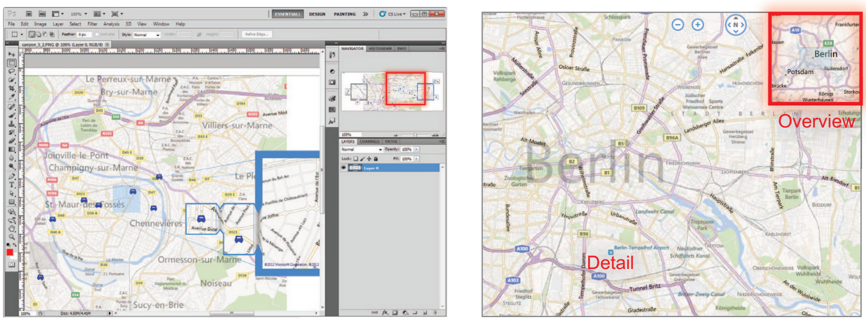
Navigation tasks can also be performed using zoomable interfaces. Zooming implies that only one view at a time is visible. This means that views are temporarily separated [12], and therefore users have to remember previous views and connect them mentally. Pad [38] was the first zoomable desktop environment, using zooming actions to browse the computer system. It introduced “semantic zooming”, which varies the level of detail of item presentation depending on the current zoom level. To recognize design issues with pan and zoom interfaces early, Furnas and Bederson introduced ’Space-scale diagrams’ [18].

Plumlee and Ware [43] evaluated cognitive costs of visual comparisons on large information spaces. They compared zooming user interfaces to multiple windows. Their results suggest that only one graphical object can be held in memory, and therefore they propose using extra windows for making visual comparisons of greater complexity. Overview+Detail interfaces provide multiple windows, as described in the next section.

2.1.2 View-based Techniques

Overview+Detail

Overview+Detail interfaces provide an overview and detail view simultaneously, but spatially separated. These interfaces are used in many common computer applications, examples are the navigator in Adobe Photoshop (see Figure 2.1 (a)) or the slide thumbnails in Microsoft PowerPoint. Digital map systems like Google Maps or Microsoft Bing Maps use Overview+Detail interfaces. As shown in Figure 2.1 (b)), the detail view is using most of the screen space, while the overview is given as an inset in a corner.



(a) (b)

Figure 2.1: Two applications of Overview+Detail interfaces. The Navigator in Adobe Photoshop (a) gives an overview over the image (top right). (b) shows Overview+Detail used in Bing Maps.

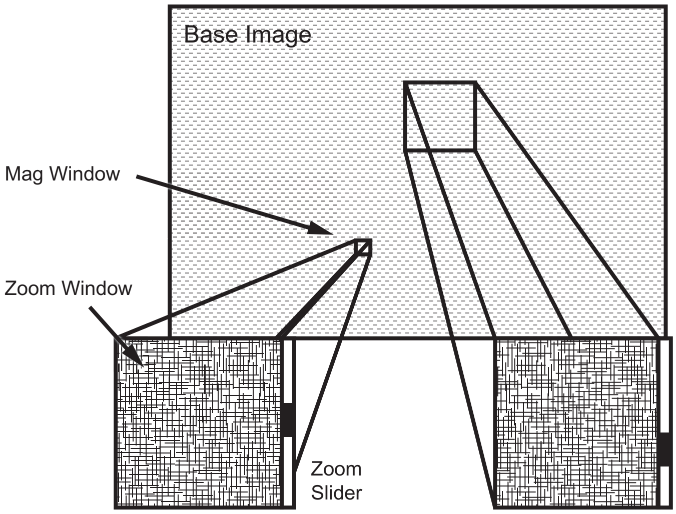


Figure 2.2: DragMag Image magnifier. Redrawn after [52].

In contrast, the DragMag image magnifier [52] grants the most screen space to the overview area and enables the creation of multiple smaller detail views. Translucent rectangles mark the detail views on the overview and lines connect them (see Figure 2.2). DragMag is of particular interest in this work, since the situation display is based on this interface technique. DragMag was also used as the base interface for PolyZoom [30]. PolyZoom adds the functionality of building focus hierarchies with an Overview+Detail interface. It is a successor of Stack Zooming [29], which was limited to 1D data. Plaisant et al. [41] already found in 1992 that intermediate windows are useful when the detail-to-overview ratio is over 20:1. In 1995 they included multi-level map browser in their design guidelines [42].

Different studies show that Overview+Detail interfaces have a high acceptance rate, even when the performance is worse. Hornbæk et al. [26] compared a traditional scrollbar interface, a fisheye interface and an Overview+Detail interface for reading electronic documents. Fisheye was faster, but Overview+Detail more accurate ("effective") and 19 out of 20 participants preferred it. Furthermore, Hornbæk et al. [25] studied whether an overview enhances performance of map navigation tasks. Although participants were faster without an overview, 26 of 32 preferred having the overview. Kaptelinin [32] compared scrolling, dragging and an overview interaction technique for file browsing and found that participants were faster in the overview conditions. Again, having an overview was preferred. Pietriga et al. [40] compared classical Pan & Zoom, Overview+Detail, magnification lens and DragMag. They found that Overview+Detail works better for exploring dense regions and Focus+Context is also efficient for sparse regions. This is a well studied field with many more results.

It has been shown that Overview+Detail interfaces expose good performance in various user studies. However, they divide attention to at least two views and leave it to the user to build the connection between them. Focus+Context techniques try to overcome these issues by combining focus regions and the surrounding area and provide some transition between them.

Focus+Context

In contrast to Overview+Detail, Focus+Context interfaces combine both—focus and context—in one view, aiming to decrease short term memory load. The connection between the focus and the context is mostly established using distortion. Cockburn et al. [12] state that, while standard Overview+Detail interfaces are separated on the x- and y-axis, a separation on the z-axis is also possible. The magnification lens in the document previewer 'Yap' is used as an example. However, the lens can also be seen as Focus+Context with no transition between focus and context area. Focus+Context is a very well explored field of research with plenty of proposed techniques.

The first interface considered a Focus+Context interface was 'Bifocal Display' by Spence and Apperley in 1982 [49]. The analogy was a paper strip. By bending the left and right sides to the back, the area of interest was focused, while still preserving some context. The folding back resulted in visual distortion. 'Perspective Wall' [35] followed Spence and Apperley's idea. Furnas established in 1986 the term "fisheye views" [17]. It grants most space to the area with the highest degree of interest, and decreases the size of other areas depending on the distance.

Since Furnas, a lot of metaphors, shapes and applications have been researched. Metaphors include (magnifying) lenses [1, 15, 39, 46, 48], rubber sheet [47], hyperbolic geometry [33, 34] and fisheye [17]. Focus regions can have different shapes, most often they are either circular [1, 39, 48] or rectangular [15, 46]. Research was done in application contexts, like map and large image exploration [15], document reading [46], tables [44], menus [7], large hierarchies in general [33], and many more.

Carpendale et al. presented 'Graph folding' [10], which brings focus regions closer together by shearing the extruded surface. Furthermore, advanced calculation of distortion was subject to research [51]. Due to the great amount of proposed approaches, Carpendale and Montagnese researched a framework for unifying them [11]. Baudisch et al. [4, 5] presented a different approach to Focus+Context. They embedded a smaller high resolution display into a big low resolution display. The higher resolution display presented the focus, while the context was presented in lower resolution.

Multi-scale and Multi-focus

Multi-scale interfaces are essentially zoomable interfaces, and were discussed previously. However, the term multi-scale interfaces or navigation is also used in recent literature. Multi-scale interfaces are defined by providing different presentations of the content depending on the scale. Maps or Pad [38] are examples for this kind of interface. Multi-focus interfaces are defined by providing multiple foci at the same time. Many Overview+Detail and Focus+Context interfaces allow having multiple foci, examples are [15, 48, 52].

There are also techniques that support both, multi-scale and multi-focus interaction. For instance, PolyZoom [30] and Stack Zooming [29] allow having multiple foci at multiple zoom levels at the same time. Mélange [14] supports multiple foci by folding space inbetween points of interest. The points of interest can also be viewed at different levels of detail. Mélange is of particular interest, since it inspired the off-view technique presented in this work.

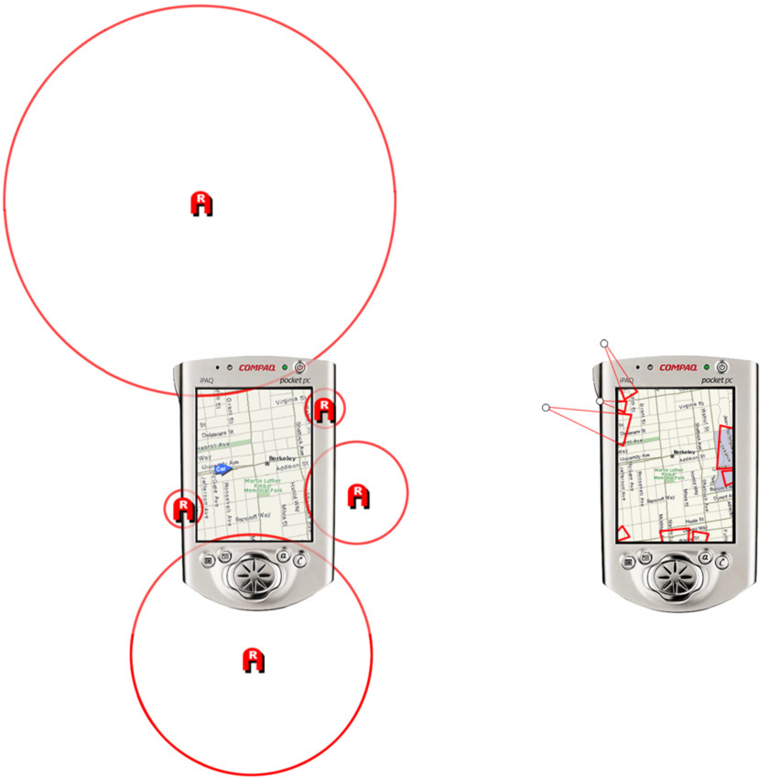
2.1.3 Cue-based Techniques

Cue-based techniques are mainly developed in a small display context, e.g. for mobile phones. They do not offer enough space to use view-based techniques and navigation-based techniques show poor performance. Therefore, techniques that convey information about off-screen objects and can be shown on small displays were developed. Often the information is presented using abstract representations of objects (proxies), in order to fit on small displays. The known techniques can be categorized as pointing techniques or contextual views, as discussed in the following sections.

However, not only small displays, but also large displays provide use cases for this kind of off-screen visualizations. To minimize user's effort when moving objects on a large display, Baudisch et al. developed 'Drag-and-Pop' [3] bringing potential drop targets closer to the user. In [13], different techniques for moving objects were evaluated, including one technique presenting a small overview of the screen elements at the user's position when a drag operation started.

Pointing Techniques

One approach to provide information about off-screen objects is to point in their direction. Typically, graphical elements are overlaid onto the border region of the screen. Direction of the off-screen object is conveyed by pointing in the respective direction, distance is conveyed by different properties of the visual cues, e.g. size. Putting this information together gives the location of the object. Simple graphical visualization are arrows [8, 9] and rays [2]. Rays are lines pointing outward the screen. These convey direction. For conveying distance, different properties of the shapes, like opacity, size, length, line



(a) (b)

Figure 2.3: Showing pointing techniques (a) Halo and (b) Wedge. Images from [23].

thickness, etc. are manipulated.

Baudisch and Rosenholtz [6] proposed a technique called Halo, which draws a circle around the off-screen object's location that intrudes into the screen (see Figure 2.3 (a)). The result of Halo are arcs overlaid on the screen borders. Therefore, the size of the arcs provide information about the distance of the off-screen object. Halo suffers from two limitations, one is that overlapping arcs are hard to separate and the second is that arcs in corners are heavily cropped and provide therefore too little information. To overcome Halo's limitations, Gustafson et al. developed Wedge [22], shown in Figure 2.3 (b). Wedge uses partly visible isosceles triangles to point towards the off-screen object. It is based on the principle of amodal completion. The less space demanding shape of wedges themselves as well as its degrees of freedom and the layout algorithm help reduce overlap. A comparison to Halo shows higher accuracy.

Burgiat et al. published two comparative evaluations involving Halo and Wedge. They compared two arrow-based visualizations to Halo and found

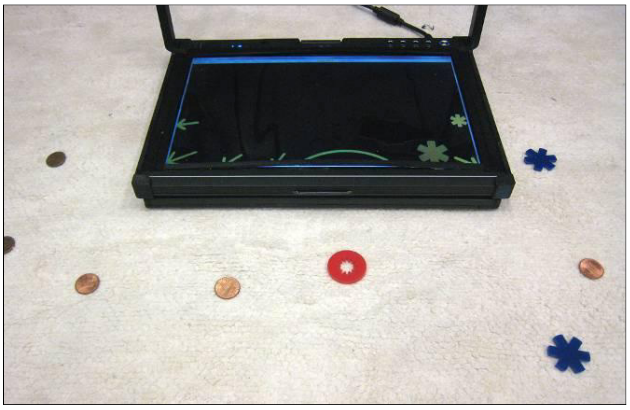


Figure 2.4: Some off-screen visualizations implemented in Portico. Arrows, Halo and icons. Image from [2].

that arrows were more accurate at distance tasks, while Halo performed better for location tasks [9]. In their second evaluation [8], they compared arrows, Overview+Detail and Wedge. The results showed that Wedge performed better for distance tasks and Overview+Detail is useful for recognizing the spatial configuration of off-screen objects. Wedge was used as the comparative technique for the technique presented in this work and evaluated in the user study described in Chapter 5.

Portico [2], a recently published portable system, consisting of a tablet and two cameras, implemented several off-screen visualizations. Since the cameras' field of view exceeds the tablet, objects placed near the tablet are recognized and considered off-screen. The implemented visualizations of off-screen objects include lines (rays), arrows, callouts (speech bubbles) with the tail pointing in the object's direction and Halo. These are considered pointing techniques. Furthermore, it represents off-screen objects as icons on the screen border, which is considered a contextual view. Figure 2.4 shows some off-screen visualizations implemented in Portico. Distance information is provided by varying the representation's alpha blend, size, length and line thickness.

Contextual Views

Contextual information about objects outside the current view is shown along window borders. Usually, the area used for information display is very small or compressed. Contextual views are derived from fisheye views, by providing a focus area and context surrounding the focus. City Ligths [53] describes itself as "space-efficient fisheye techniques". It builds on the metaphor of showing shadows of unseen object along the view border. Used visualizations are lines, points or halos. EdgeRadar [24] overlays all objects within the off-screen area onto a compressed border area of the view. While objects orthogonal to the view edges are only compressed in one direction, objects in corner regions are compressed in both directions. Furthermore, EdgeRadar can only show a finite off-screen area. A version of EdgeRadar was used in a 3D environment in Aroundplot [31]. A more recent example of contextual views was published by Frisch and Dachselt [16] in 2010. They presented node-link diagrams with off-screen object representations in the border region.

Interactive Off-Screen Techniques

While this work focuses solely on the visualization of off-screen targets, interaction with off-screen representations is also a field of research. The previously cited class diagram by Frisch and Dachselt [16] automatically focuses the associated node after clicking a proxy. Irani et al. [28] proposed a technique called 'Hopping'. As soon as a laser beam, originated at the mouse-down position, intersects with a Halo, proxies near the mouse position are created. Clicking on a proxy teleports the user to the object's location. Moscovich et. al [37] published two interaction techniques to node-link diagrams: Link Sliding and Bring & Go. Link Sliding let users travel along a link by providing snapping to links and speed-dependent zooming. Bring & Go foreshortens the links and brings nodes close to the mouse location. Clicking a proxy node moves the view to the specific node.

2.2 Background Study

The background study aimed to get insights on how emergency responders work. It was conducted in the context of the Austrian police. It was an ongoing process with multiple sources of input. The control center of the police of Upper Austria was visited. Police officers presented their equipment and its utilization was recorded. Relevant documents were searched and included in the background study. Furthermore, the police provided the opportunity to observe a training for district command centers, which gave a better understanding of work in emergency response situations.

2.2.1 Police Command Center

The Upper Austrian police command center was visited to find out, what utilities police officers were using and how they worked with them. They had several wall-mounted maps, which were either paper-based and often laminated, or maps printed on metal. Therefore, pins, non-permanent markers or sticky notes were used to annotate paper-based maps. For metal-based maps, magnets were used for annotations, as shown in Figure 2.5. Using these items, typically locations of different types of forces were marked. These in-

Figure 2.5: A wall-mounted metal-based map in the Upper Austrian police command center. Magnets are used for annotation locations.

clude patrol cars, forces of other departments or dogs. Furthermore, drawings representing taken decisions, like road closures, were applied onto the maps.

The visited command center also provided a separate command room for special operations. The room was equipped with multiple traditional white-boards and flip charts. There was a centrally located projection space which was used for displaying the current situation. They described the process of updating the situation display as making a screen shot from a digital map system, like Google Maps, and pasting it into a slide show. They prepared template symbols which were pasted onto the map image.

2.2.2 Observation of Police Training

The police offered the possibility of observing a training of a district command group. The training took place on the last day of a four days seminar. In sum there were 18 police men and women participating, divided in two groups. One group of nine participants was observed. The group included participants with many years of experience as well as police officers in training. Previously prepared realistic cases were worked during the training. Higher degree police officers held the seminar and scripted the cases. We were provided with the script in advance for our preparation.

A realistic command center was augmented, equipped with one regular telephone, one emergency telephone, a radio communication device, 4 laptop computers, one projector, a flip chart, a pinboard, different laminated maps, pins, pens and paper. Telephone calls came in as scripted and were

Figure 2.6: The setup of the observed district police command group training. Several laptops were used, an overview of patrol cars was projected onto the wall and a paper-based map was used.

processed by the group. Before the training started, the group was granted approximately one hour to set up their command center. They were free to use any of the provided equipment as they wished. They used almost all of the provided equipment, however, they did not use the flip chart and used only one paper-based map showing the whole district, which was mounted on the pinboard. The setup of the command center for the training is shown in Figure 2.6. The participants organized themselves by taking in the following roles:

- *Minutes keeper.* Kept minutes of all operations, did not make decisions.
- *Communication.* Handled all phone communication, including answering inquiries from the media, called necessary action forces like ambulance, communicated with other police departments, for example to get additional forces or equipment, etc.
- *Emergency phone.* Answered all emergency calls and induced steps for operating these incidents.
- *Radio communication.* Handled all radio communication by channeling information between the command group and action forces.
- *E-Mail communication.* This was a special role. The person was in charge of all e-mail communication.
- *Research.* This was also a special role and the person searched for additional information in the interned when needed.
- *Situation display.* Always kept the situational overview up to date.

Two people were not found to have distinct roles, but rather helped out where needed. In a real district command center, the size of the group is approximately three to 4 persons. Therefore, e-mail communication would be integrated in communication, research would not be a distinct role and emergency calls would be taken by the same person handling radio communication. Although the group size was not realistic, the observation can still be considered valid, since there were also more cases to handle than in reality. They handled 11 incidents within three hours, while two incidents would be realistic on a busy day. The leader of the seminar said that "if you would have a day like this, you would get the next day off".

Incidents

During the police training, a total of 11 incidents were observed. A range from one to over 30 force units were involved in an incident. The incidents included a bomb found in the center of a village, a burglary at a car dealership, a suicide attempt announced by the husband, a fatal accident at a train station and an armed kidnapping involving violence.

Three patrol cars were sent to the accident at the train station. In addition to the patrol cars a cadaver-sniffing dog, a doctor and a undertaker were called in, making a total of 6 units handling the incident. In sum, 10 cars were sent to the bomb found site. The incident required numerous action forces for shutting off and securing a circular area of 300 m around the bomb. The police was informed about the possible suicide of a woman with an emergency call placed by her husband. The group reacted immediately and sent three patrol cars to search the indicated area. Since it was at a lake, they also requested a boat to assist the search, making a sum of 4 action forces to save the woman.

The police was announced about the kidnapping incident with an emergency call from a woman informing the police that her former husband was violent and threatened to kidnap the child, which was at school. The police immediately sent two cars to the school and one car to the woman's house. They found that the child was already taken and the kidnapper might be armed. In order to find the child, a search was initiated. All cars of the district were sent to designated predefined coded points describing a geographical location. This was a total of 29 cars. Furthermore, they received hints that the kidnapper was moving towards the adjacent district, which made them coordinate with the other district. The command group of the other district also started a search with about the same number of cars.

All other missions involved only one or two action forces. These missions provided the scenarios for the study described in Chapter 5 and the number of involved units per mission provided the base for choosing the numbers of moving objects.

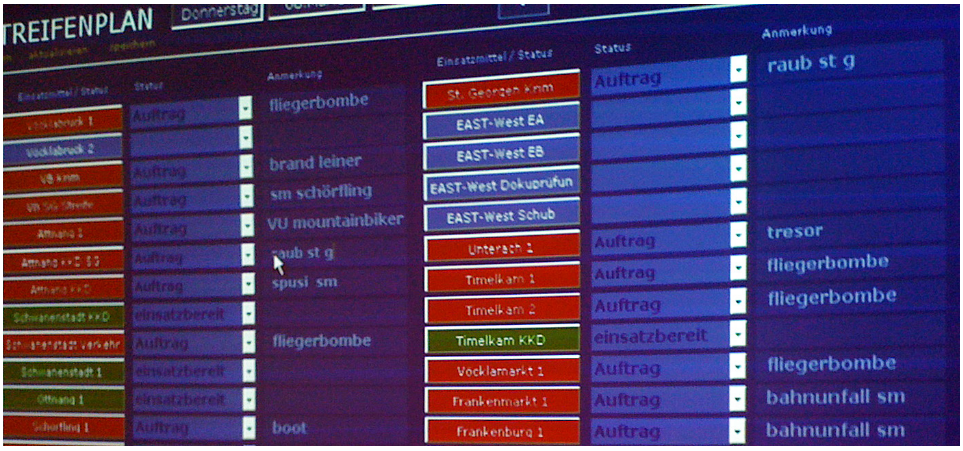


Figure 2.7: The list of action forces displaying the name, code and status of a car. This was projected onto the wall and used as main situation display during the police training observation.

Situation Display

The group was provided with the common application for action force overview, which is a list of all available vehicles displaying the name, the status of a car as a dropdown menu and a text field for comments. Figure 2.7 shows a close up of this action force overview. They used this overview as the situation display by providing information about the unit's assigned mission in the comment field. This overview list was projected onto the wall. However, they switched to using the paper map for the complex kidnapping case described before.

The information contained in the comments field and the frequency of querying updates about a unit's status gave insights about the importance of specific properties. These are ranked as following:

1. *Status.* Whether a car was available to be assigned to an incident, was already assigned to an incident or was not available.
2. *Name and code.* Provided information about the car. The name was usually the name of the town, where the police station was located, and the type provided information about the intended use of the car, for example forensics. However, if no other units were available, a forensics car was also used for other purposes during the police training observation.
3. *Occupation.* Described the incident the unit was currently assigned to.
4. *Location and destination.* Information on location was requested to know, which car could arrive fastest at an emergency site. Information about whether a car arrived at its destination was also requested frequently.

Information Flow

In general, all information was shared verbally. No other forms of sharing information, like in written form, was observed or mentioned. During the observation, new information or decisions were broadcasted to the group, rather than directed to a particular person. However, specific requests were directed to the person being responsible for that area of work.

As police officers described during the visit of the command center, the information usually represented on maps are locations of action forces or other incident-related objects and persons. They were usually marked with pins or magnets—depending on the map's subsurface—or were drawn with pens. In the observation, occupied search points were marked with pins during the kidnapping mission. Information was most often withdrawn from the map by simply looking at it. Another form was an explicit request by asking someone where a town, car or address was located on the map. Digital map systems on laptops were also used to retrieve location information.

The type of information that was usually requested included finding the closest available car to a specific location. Also, finding the location of a town, street name or address was requested. The other way around, namely finding the address to a location or verifying whether a given address existed, was also required. Furthermore, giving directions to a certain address was a use case. Digital map systems were often used in these cases.

Map Types

Both, analogue and digital map systems were used for different purposes. Analogue maps were used for getting an overview or for quick reference, since these kind of maps were mounted on walls in the command center, were constantly present and police officers were used to them. Analogue maps were used for retrieving rough distances. Digital maps were used for quick search of addresses or locations, for getting detailed information about an area or for directions. The digital map system used in the observed police training also provided the functionality of drawing a circle of a specified size, which was used for the bomb found incident. Information about street names and house number within that circle was retrieved from the digital map system. It took the police officer a long time to find that functionality, showing how important simple interaction techniques are. Furthermore, the satellite view was used for retrieving information about surrounding area of a location, for example whether there are houses or a river.

2.2.3 Summary

The background study provided a better understanding of how the police responds to emergency incidents. The police used analogue maps as well as digital map systems. Digital maps were often used for searching addresses, giving directions or exploring an area using the satellite view. During the observation of the police training 11 cases were worked. Concerning the number of units per incident, the results of the observation can be generalized to:

- One or two units are involved in small and not urgent incidents.
- Approximately 5 units are sent in urgent cases.
- About 10 units are necessary for incidents covering a larger area and many people.
- 60 units or more are used for an extensive search in emergency cases.

Important properties about units, that are crucial for situation awareness, were revealed. These properties were the status of a car, its name and code providing information about the car, the currently assigned incident, its current location and its destination. Information flow among group members was verbal and informal.

Although maps may not be used for displaying the situation for small-scale incidents, for large and urgent emergency cases the situation display is changed to a map-based situation display. Furthermore, the guidelines for leading disaster operations of the Austrian police [45] requires a situation display to be graphical, whenever possible.

Chapter 3

Application Design

This work includes design and implementation of an interactive situation display prototype. Its purpose is to provide strong context for investigating situation awareness with respect to off-view objects in an emergency response context. The functionalities and design decisions are described briefly, since it is not the main focus of this work, in the first section of this chapter. In the second section, the off-view visualization technique Canyon is described, which presents the main focus of this work.

3.1 Interactive Situation Display Design

The interactive situation display is realized on a large (3 $\times$ 1.125 m) interactive whiteboard with pen input. It is a multi-user map application based on an Overview+Detail interface.

3.1.1 Basic Conditions

Vertical Orientation

Decisions in emergency situations are critical. It is therefore crucial that everyone involved in the decision process has a good overview about the situation and the same picture in mind. A situation overview must be understandable in a glance. A vertical display provides the same picture for everyone. Unlike a horizontal display, it does not have to be approached actively, but a quick look is sufficient.

Pen Input

The situation should be described graphically with symbols and annotations on maps. For example, guidelines for leading disaster operations of the Austrian police [45] propose a graphical representation of the situation, whenever possible. Symbols can represent action forces of emergency responders, like their emergency vehicles, or information about an incident (e.g. a car crash or fire). Annotations are used to show information in a flexible and fast way. For example closing off an area around an incident site can be quickly indicated by drawing it on the map. The traditional tool for drawing or writing is a pen. Therefore, the input method for the interactive situation display is pen input. Anoto™ digital pens are used. Each pen has an integrated camera that sends position information by recognizing a dot-pattern[1].

Multi-user Interaction

A large display provides space for simultaneous multi-user interaction. Keeping the situation display up to date is faster when multiple persons can work simultaneously. This is crucial in time-critical emergency situations. Simultaneous multi-user interaction requires individual workspaces, where an action of one person does not interfere with another person's work. Focus areas can overlap, when for example a large incident occurs and requires securing off the near and far regions around the site. This would be handled by different people, but at the same time. Since focus regions might overlap, the ability to create and position detail views freely is provided. Overview+Detail interfaces provide these features, therefore the application includes this type of interface. This application provides a large overview map to provide context for the whole team while creation of multiple detail views to support individual work is possible.

Tools

The application provides different tools for describing the situation. All tools described below provide the same manipulation abilities on both, overview and detail maps:

- *Pen:* Colored strokes can be added to any map for individual annotations.
- *Navigate:* All maps can be panned or zoomed.
- *Focus area:* By encircling a map area, a detail view of the corresponding area can be opened.
- *Vehicle:* A vehicle symbol can be added to a map by tapping the desired location.
- *Route:* A route can be assigned to a vehicle by first, selecting the vehicle, and second, tapping on a location on the map. The vehicle will then follow a street route between the specified points, retrieved by using the Google Directions API[2].
- *Eraser:* All strokes and symbols can be removed by crossing them.

[1] More information is available at http://www.anoto.com/the-technology-1.aspx
[2] https://developers.google.com/maps/documentation/directions/

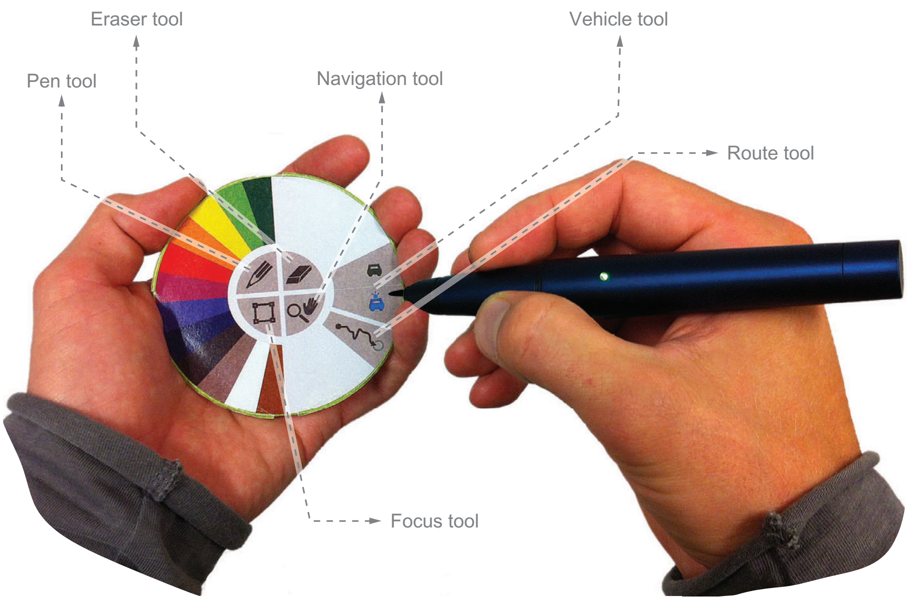


Figure 3.1: The hand-held physical palette used to operated the interactive situation display. Tools are switched by tapping with the pen on a symbol.

Since map images are only given for discrete zoom levels, continuous zoom has been implemented with the navigation tool. Continuous zoom is achieved by scaling the map image until the next zoom level is reached. Applying one of the above tools can done by using a hand-held paper tool palette, as shown in Figure 3.1. The tool is selected by tapping on the corresponding tool icon with the digital pen.

3.1.2 Creating Detail Views

Detail views are created by marking the desired focus area on the overview map. Marking can be done by drawing a circle, rectangle or some other shape. The bounding box of the drawn shape determines the bounding box of the focus area and, therefore, of the detail view. The maximum height or width of the detail view is 300 pixels in this implementation, which is 15% of the whiteboard width. However, the detail view size can be adapted as required. The aspect ratio of the selected focus area is preserved. The longest edge length (width or height) of the focus area is mapped to the maximum edge length of the detail view. Then, the next integer zoom level containing the drawn focus area is calculated, to have a crisp map image when opening a detail view. Therefore the bounds of the calculated and presented detail view are larger than the drawn focus area. It is ensured that the marked focus area is always fully visible within the opened detail view.

The focus area is marked on the overview map with a semi-transparent colored rectangle. Similar to the DragMag Image magnifier Prototype 1 [52], lines connect the detail window with the marked focus area on the overview for better association. After creation, the detail views can be freely repositioned by dragging the colored border. Their connection lines to the associated focus areas are updated in real time.

3.1.3 Independent Navigation

All detail maps as well as the overview map can be zoomed and panned independently. Navigation on the overview map gives flexibility to adjust the viewed area according to the current situation. Also, all map modes can be switched independently. As one detail map is viewed as a road map, another can be viewed in satellite mode.

3.1.4 Synchronizing Annotations

All annotations (vehicles and strokes) are synchronized among all maps. While a detail map is annotated, the annotations are visible on the overview map and all other detail maps in real time. When a detail map is opened, all existing annotations within that area are contained in the detail view.

3.2 Design of Canyon

The previous section described the base framework for the interactive situation display, which is based on an Overview+Detail interface. However, moving targets can exit a detail view and therefore become off-view objects. Although the objects may still be visible somewhere on the large whiteboard, it exits the field of view of a person standing close to the whiteboard. This is due to the restricted focal area of a human. Therefore, the object is off-view and unseen by the person using the detail view.

This section describes the novel off-view visualization technique called "Canyon". It was designed to overcome the off-view problem on large vertical surfaces. The idea of Mélange [14]—folding unused space like paper—is followed. The metaphor behind Canyon is to stitch strips of maps containing the off-view object to the detail view and fold the space in between. Figure 3.2 shows Canyon. Design, implementation and evaluation of Canyon presents the main focus of this work.

3.2.1 Design Goals

To enhance situation awareness with the interactive situation display, an off-view visualization technique must have certain features. These features were defined as design goals and are described as follows:

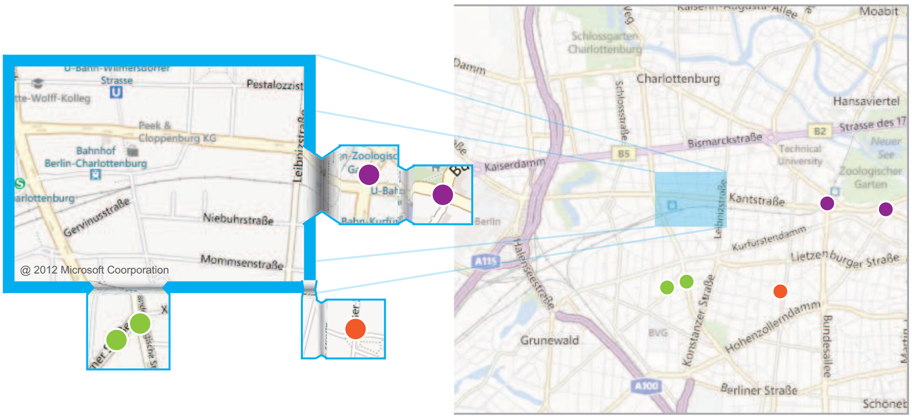


Figure 3.2: Canyon brings off-view objects close to the detail view and reduces uninteresting space by folding.

- *No change of the defined view.* The view, that a person defined, should not be altered.
- *Keep off-view object in context.* A person should always be aware of how an off-view object is related to his or her current view.
- *Provide distance awareness.* The distance to the context-providing view should be indicated.
- *Support fast comparison.* Fast comparison of off-view objects relatively to each other should be enabled.
- *Easy understanding of cues.* Provided cues of context relation and distance should be easy to understand.
- *Support expert knowledge.* When a user has expert knowledge about an area, he or she should be able to benefit from it. However, understanding the technique must also be possible with no expert knowledge.

3.2.2 Folding Paper

Elmqvist et al. [14] presented Mélange, a technique for exploring large visual spaces. It brings points of interest, which do not fit on the screen, closer together by folding unused space in between. This is illustrated in Figure 3.3. While Mélange fits multiple focus points into one viewport, the idea of folding space is followed to extend a workspace by showing off-view objects.

The idea of Canyon is to cut out a strip of a paper map containing the off-view object and attach it to the edge of the detail view. Since this strip of map can be long, depending on the distance of the object to the view, some reduction has to be performed. Elmqvist et al. [14] used a paper fold metaphor and discussed it as follows:

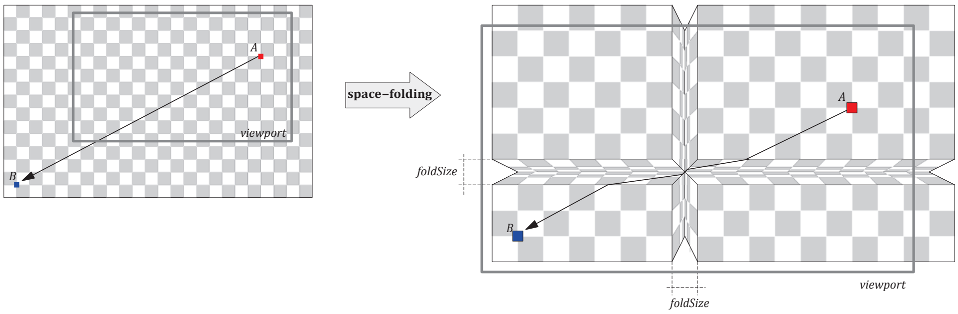


Figure 3.3: Mélange: Folding 2D space to bring focus points A and B into the viewport. Figure from [14].

> "Most often, the space closer to a focus region is more important than the space halfway between regions. Therefore, in our realization, the folds are sharp and angular (more like paper origami than fabric folding) [...]"

We believe that the authors of Mélange presented a reasonable argument for sharp folding. Furthermore, a paper fold metaphor is easy to understand since humans are familiar with paper manipulation. This achieves the design goal *Easy understanding of cues*. Therefore, the map strips in Canyon are sharply folded like paper to reduce uninteresting space.

3.2.3 A Deep Canyon

Once an object exits the detail view and becomes an off-view object, Canyon brings it and a predefined portion of its surroundings close to the detail view. The size of the cut-out view is defined as 80 × 80 pixels. Considering the size (297.0 × 111.375 cm) and resolution (2048 × 768 pixels) of the whiteboard, the cut-out view size results in an area of 11.6 × 11.6 cm. An orthogonal strip of map material from the off-view object to the detail view edge is attached to the detail view (see Figures 3.4 (a) and 3.4 (b)).

Folding Unused Space

Since there is no object of interest between the detail view edge and the edge of the cut-out view, this space is considered as uninteresting space. Therefore, it is sharply folded like paper, in order to bring the object of interest close to the detail view (shown in Figure 3.4 (c)). Since the cut-out view and the folded map are attached to the outside of the detail view, the defined detail view never changes. This fulfills the design goal *No change of the defined view*. Furthermore, by connecting the detail view and the off-view object, context is provided which fulfills the design goal *Keep off-view object in context*.

(a)

The red object is not visible on the detail map.

(b)

A strip of map from the off-view object to the view edge.

(c)

Folding the space in between brings the object closer.

(d)

A shadow added to the fold emphasizing the depth.

Figure 3.4: The basic design on Canyon shown step by step.

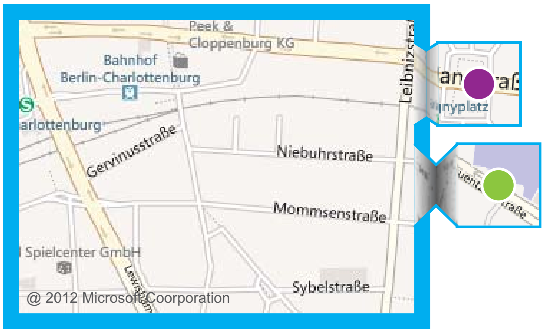


Figure 3.5: The size of the fold and the shadow is dependent on the off-view object's distance to the view enabling relative comparison.

Relative Comparison

The width of the folded map connecting the detail view with the cut-out view is dependent on the distance of the detail view edge to the off-view object. It is calculated by applying a logarithmic function, which results in different widths of the folded areas depending on the distance of the off-view object. The exact calculation is discussed in Chapter 4. Since the folded map's width varies, the location of a particular cut-out view of a closer object is closer to the detail view than the cut-out view of a farther off-view object. In other words, the folded width reflects the distance of the off-view object and influences the positioning of the cut-out view (illustrated in Figure 3.5). This makes the distances comparable relative to each other and fulfills the design goal *Support fast comparison* and partly *Provide distance awareness*.

Shadow: Showing Distance

It is not believed that the distortion alone, given by the perspective transformation of the folded map, provides proper distance awareness. While a difference in distance conveyed by distortion between a near and a far object is noticeable, the difference between two far objects is not. As the depth of the fold can no longer be estimated, distance awareness shrinks and the paper fold metaphor suffers. To overcome these issues, a shadow is added on the fold. As shown in Figure 3.4 (d), it intensifies the depth illusion of the paper fold metaphor and serves therefore as an additional cue for distance awareness. Given this additional cue for distance awareness, the design goal *Provide distance awareness* is met. As the calculation of the folded map width, the shadow is also dependent on the distance of the off-view object. The shadow is also calculated with a logarithmic function, since no maximum distance can be estimated. The calculation and implementation is discussed in Chapter 4.

3.2.4 Merging and Chaining

When two or more off-view objects are so close, that no individual cut-out view can be created for each of them, their cut-out views are merged. This happens, when the distance between the objects on the x- or y-axis is smaller than the defined cut-out view size. Based on the locations of the objects that are being merged, a bounding box is built and then enlarged by the cut-out view size in x- and y-directions. The objects are then centered within the merged cut-out view. This is illustrated in Figure 3.6.

Since an cut-out view cannot be attached to the detail view edge when another cut-out view is in between, the cut-out view that is farther away is attached to the closer one. The bounds of a closer off-view object are extended to incorporate all following intersecting cut-out views that are farther

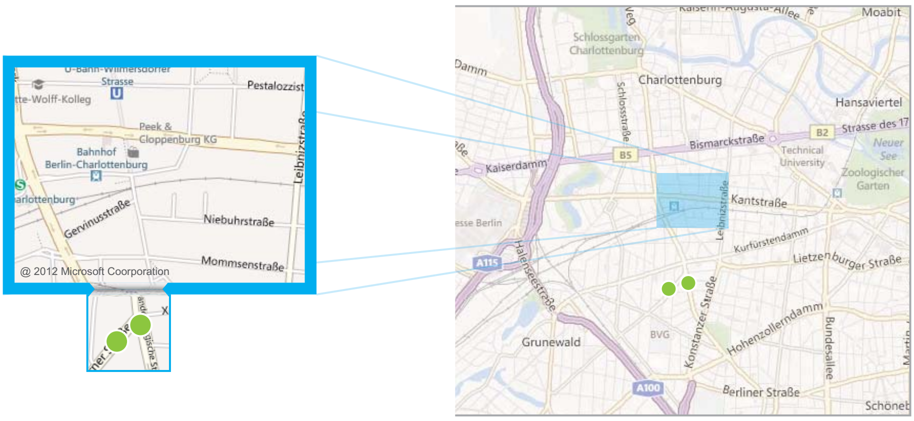


Figure 3.6: Merging. Close objects are represented in one Canyon.

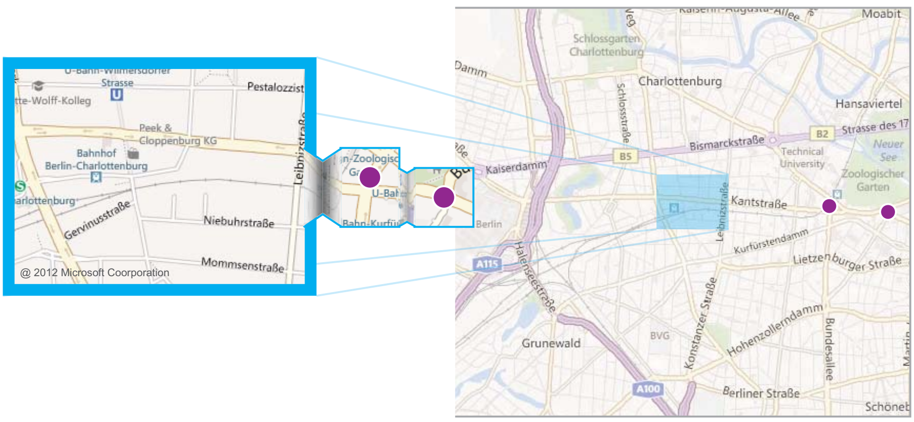


Figure 3.7: Chaining. Canyons visualizing objects moving in the same direction are chained.

away. Folded maps between cut-out views only depend on the distance between these views. Both the folded map width and the shadow are calculated based on this distance. This procedure describes chaining Folds and is shown in Figure 3.7.

3.2.5 Folding around a Corner

Representing off-view objects in corner regions has been a problem for many off-view or off-screen visualization techniques to some extent. As off-view objects are mostly visualized orthogonal to the view edges of a rectangular screen, corners provide a big area to cover but less space to visualize objects (see Figure 3.8). Gustafson [21] provided a good discussion on the extent to which different techniques are affected by the corner problem. His discussion is summarized here:

- Overview+Detail interfaces (see Section 2.1.2) are not affected by corner problems.
- Fisheye views (see Section 2.1.2) mostly spread targets evenly from the focal point and are mostly not affected.
- Arrows [8, 9] are often laid-out radially from the center and therefore not affected.
- CityLights [53] is seriously affected.
- EdgeRadar [24] is less affected than CityLights, but still compresses the corner region into a small rectangle.
- Halo's arcs [6] are severely cropped in corners which presents a problem.

Figure 3.8: The corner problem: Corner regions (red areas) provide big areas to cover but no space to visualize the objects. The blue bordered area in the middle represents the visible area within the detail view.

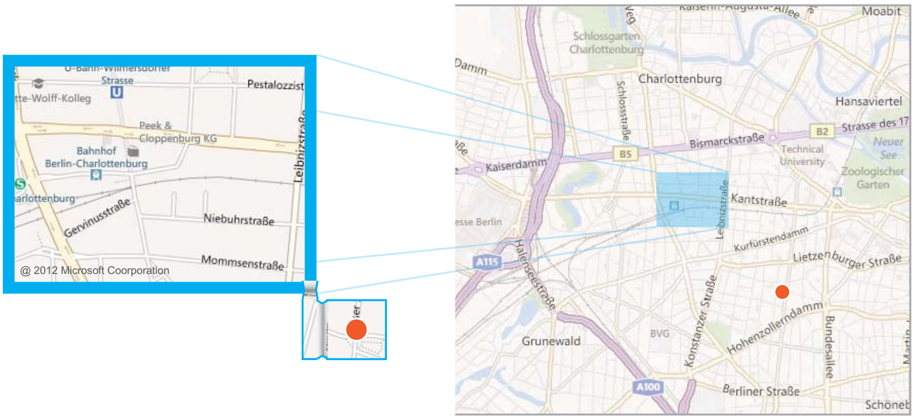


Figure 3.9: Objects in corner regions require folding twice to preserve paper folding metaphor.

Gustafson's Wedge technique [21, 22] is an improvement on Halo and is less affected by corner problems. Due to its shape, it uses less space and fits more easily into corners. Also Wedge's degrees of freedom (Rotation, Aperture and Intrusion) helps find a layout to reduce the corner issue. However, for distant objects the shape does not fit into the corner of the screen and the aperture must be reduced. This makes the technique inconsistent in this particular case and sometimes misleading.

Canyon visualizes off-view objects in corners by extending the vertical view edges and folding the objects orthogonally to these extended edges. This means that two folds are needed to show a corner object (see Figure 3.9). Since an object can be so close to a horizontal or vertical edge that its focus area would overlap, the focus area is shifted accordingly to avoid interference with other objects. Folding twice means that additional cognitive load is added, which is a drawback. On the other hand, the paper fold metaphor is preserved which should assist understanding.

3.2.6 Support Expert Knowledge

The main difference between Canyon and pointing techniques like Wedge [22] is the level of detail. Although both techniques show the location of an off-view object, Canyon also shows the surrounding area of an object. This feature aims to support expert knowledge about the area, as defined in the design goal *Support expert knowledge*. The development of Canyon mainly targeted emergency responders. They usually have comprehensive knowledge of the geographical area they are in charge of. This means that they are likely to know the exact location of the off-view object by seeing the surroundings provided by Canyon and the relation to the detail window, without having to interpret the distance or search it on the overview map. This expert knowledge should be supported, even though no expert knowledge is required to understand where the object is. Therefore, the evaluation of Canyon in Chapter 5 avoids expert knowledge to ensure that the technique also works without it.

3.2.7 Benefits and Limitations

Canyon provides a high level of detail by showing the surroundings of off-view objects, which can provide spatial hints about their precise location. This additional information can improve one's ability to locate an object. In order to avoid occlusion and maintain this location awareness, and as suggested by previous work [13], cut-out views are also designed to not overlap. In addition, the distance of the cut-out from the view is conveyed using a paper folding metaphor, already familiar in the physical world, which was successfully employed in Mélange [9]. The size of the cut-outs remains consistent and does not depend on the target distance. However, unlike other cue-based off-screen visualization techniques, each cut-out view uses additional space, and thus the technique may not generalize to situations where screen real estate is at a premium.

3.3 Off-Screen Techniques for Comparison

To evaluate the design of Canyon, an off-screen visualization technique for comparison is required, since the off-view problem has not been researched yet and the off-screen problem strongly relates. Based on literature research, two published off-screen approaches were implemented: EdgeRadar [24] and Wedge [22]. During the brainstorming process for finding new off-view visualization techniques to fulfill the above listed design goals, two other techniques ("Bubble Window" and "Spring Mélange") were developed and implemented. These techniques are each described below and shown in Figure 3.10.

Wedge, developed by Gustafson et al. [22], uses isosceles triangles, which are partly visible on the screen and point to the off-screen object. Its design is based on amodal completion, suggesting that the human visual system is able to complete a partly visible object by using the simplest known and fitting shape. In this case, the triangle. Figure 3.10 (a) shows this work's implementation of Wedge.

EdgeRadar, developed Gustafson and Irani [24], is a fisheye-based visualization technique that compresses all off-screen objects into a border around the screen. It is simple and therefore easy to understand. Implementation of EdgeRadar is shown in Figure 3.10 (b).

Bubble Window was an early idea during the brainstorming process for this work and is inspired by the window management technique published by Waldner et al. [50]. Their work created the idea that windows do not necessarily need to be rectangular. Bubble Window simply extends the detail view once an object exits. Therefore the route taken by the off-view object can be seen. However, with many moving objects and a high zoom level the screen becomes cluttered very fast, making this technique unusable, as shown in Figure 3.10 (c).

Spring Mélange was an earlier idea leading to the design of Canyon. Therefore it is also based on Mélange [14]. The design is similar to Canyon, but a spring was used as a distance cue. The metaphor was a spring holding a fold together. The more tense the spring is, the deeper the fold and therefore the greater the distance (see Figure 3.10 (d)). However, Canyon was preferred over Spring Mélange, because the paper fold metaphor was better understood. This lead to the decision to pursue the design of Canyon.

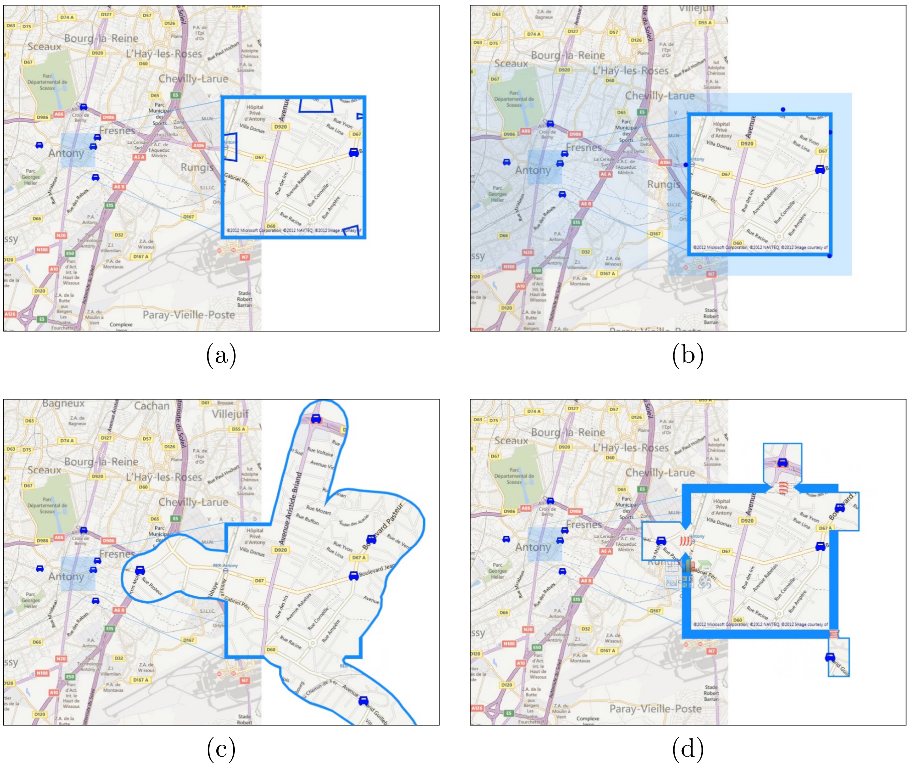


Figure 3.10: Considered and implemented off-screen and off-view visualization techniques to compare Canyon to. (a) Wedge, (b) EdgeRadar, (c) Bubble Window and (d) Spring Mélange.

An informal evaluation revealed Wedge as being the most preferred technique of the 4 described techniques. Therefore, Wedge was included in the user study and compared to Canyon. This user study is described in detail in Chapter 5.

Chapter 4

Implementation

The first section of this chapter describes the implementation of the off-view visualization technique Canyon. The design decisions for Canyon were discussed in Section 3.2. The second section covers used frameworks and basic functionalities implemented to embed Canyon.

4.1 Digging a Canyon

First, folding of objects orthogonal to view edges is described. The basic mechanisms of Canyon's implementation are covered within this explanation. The second part describes Canyon in corner regions. Corners are a special case since they provide little space for visualization but large areas to cover. To preserve the paper folding metaphor, Canyon visualizations representing objects in corner regions involve folding twice. Therefore additional fold parts are appended to provide connection to the view.

The general data model is explained, as all properties are calculated and stored into the model, before the actual visual representation is added to the view. A Canyon visualization is represented in code in the *CanyonModel*. The essential fields are listed as follows and shown in Figure 4.1.

- *Targets*. A list of off-view objects to be represented in one Canyon.
- *DetailView*. The reference to the view, to which a Canyon is attached.
- *ViewDistance*. The distance between cut-out view and the detail view.
- *FoldDistance*. The distance of the map area that is actually folded.
- *FoldSize*. The size (width or height) of the folded map.
- *MapBounds*. The bounding box[1] defining the cut-out view.
- *Bounds*. The bounding box[1] of the whole Canyon, including the cut-out view and the folded map.

[1]The bounding box includes size and position.

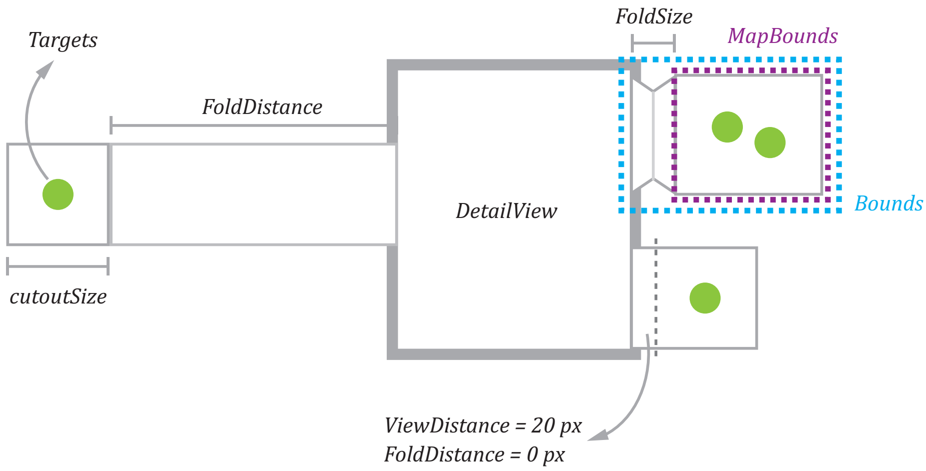


Figure 4.1: Illustration of the fields stored in the *CanyonModel* for calculating a Canyon visualization.

4.1.1 Orthogonal Fold

To provide a proper understanding of how the *folding* process works, the simpler condition, considering objects that are orthogonal to the view edges, is described. The layout of a Canyon is depending on the distance between the off-view target and the view edge in pixel. The distance is defined by

$$viewDistance = \left(target + \frac{cutoutSize}{2}\right) - viewEdge, \tag{4.1}$$

where *target* is the current off-view object location and *cutoutSize* is the predefined size of the visible area around the off-view object, which is defined here with 80 pixels. For both, *target* and *viewEdge*, the appropriate x- or y-coordinates are used for calculation, depending on the octant where the object is located. While for objects in the left or right octant the x-coordinate is used for calculation, for top and bottom octants, the y-coordinate is used.

The *viewDistance* defines, whether or not folding is necessary. It determines the *foldDistance*, which is the actual amount of map material, that is folded. The definition is given by

$$foldDistance = \begin{cases} viewDistance & \text{if } viewDistance > \frac{cutoutSize}{2}, \\ 0 & \text{otherwise.} \end{cases} \tag{4.2}$$

If the object is too close to the view, that no folding is necessary, the cut-out view is attached to the detail view. The *foldDistance* defines the *foldSize*,

$$foldSize = \text{round}\left(\ln\left(foldDistance^5\right)\right), \tag{4.3}$$

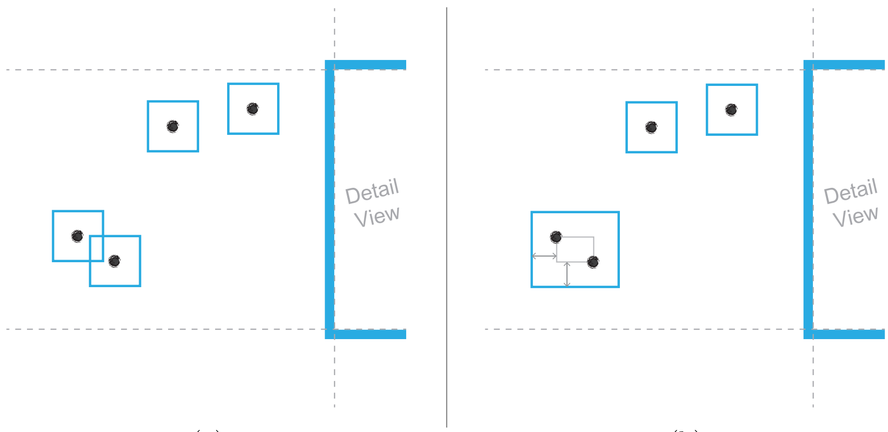
which determines the dimension—width or height depending on the current octant—of the folded map. This means, that the folded maps do not have the same size, but for farther objects the folded map is wider. This provides relative distance awareness among the Canyons. A logarithmic function was chosen for being able to represent both close and distant objects. It prevents the *foldSize* from growing extensively as objects increase their distance to the view.

Merging Canyons

Targets are merged into one cut-out view when

$$\Delta height < cutoutSize \text{ or } \Delta width < cutoutSize \tag{4.4}$$

depending on the current octant. To put it in other words, targets are merged into one cut-out view, when their cut-out views overlap. The procedure of *merging* starts with sorting the Canyons ascending by their distance to the view. Again, this is done for each octant. The list of Canyons is iterated to find groups of targets, that are represented in one Canyon. One *CanyonModel* receives the group of targets to represent. The cut-out view of the Canyon is recalculated by increasing the bounding box of the targets by $cutoutSize/2$ on each side (see Figure 4.2).



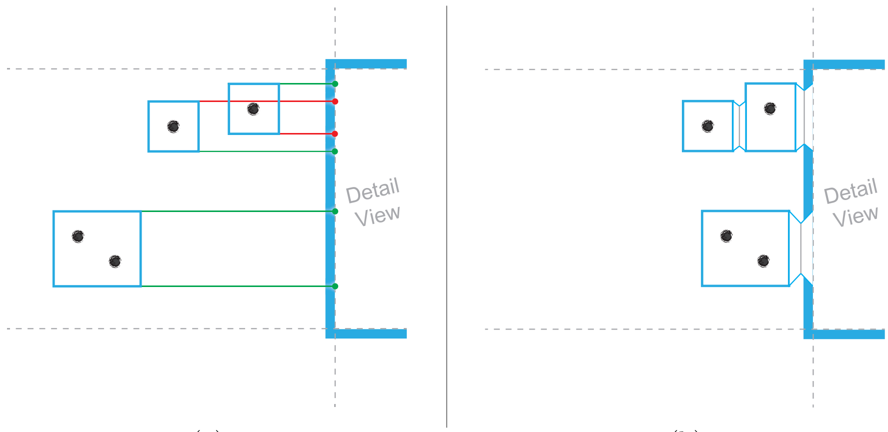
(a) (b)

Figure 4.2: Merging Canyons. When cut-out views overlap (a) targets are represented in one cut-out view (b). One *CanyonModel* holds a list of targets. For obtaining the new cut-out view, $cutoutSize/2$ is added to the bounding box of the targets.

Chaining Canyons

Canyons can only be attached to the detail view, when there is no other, closer Canyon in between. In this case, the Canyon is attached to its predecessor. To detect an intersection, the respective bounds are checked, whether one bound lies within the bounds of another Canyon. The coordinates used are dependent on the current octant. For left and right octants, Canyon's bounds in y-direction are compared, for top and bottom octants, the x-coordinates are compared. Figure 4.3 (a) shows the detection of intersecting bounds of objects in the left octant. How Canyons are chained is illustrated in Figure 4.3 (b).

First, *intersectionGroups* are detected, by iterating over the sorted list of merged *CanyonModels*. The list is sorted by the relevant coordinate for detecting intersections of Canyons. For an object in the left octant, as illustrated in Figure 4.3, the *intersectionDistance* is the distance between the top side of the detail view and the top side of the object's cut-out view. Groups of intersecting Canyons are built. The bounds of all Canyons—except the farthest one—within an *intersectionGroup* are adjusted, that the bounds of the closer Canyon contain the bounds of its succeeding Canyon (see Figure 4.3 (b)). Since bounds of Canyons are altered in this pass, it is checked again if the Canyons can be merged. If so, they are merged by recalculating the Canyon bounds. After the *intersectionGroups* are found and all adjustments are applied, the bounds are recalculated to reflect the new position of the Canyon, which attaches the Canyon to its predecessor.



(a) (b)

Figure 4.3: Chaining Canyons. The upper two Canyons in (a) are chained, since their bounds overlap in y direction. The end result after merging and chaining is shown in (b).

4.1.2 Corner Fold

Since corner objects are not orthogonal to the view, Canyons representing these object are folded twice. An additional non-distorted piece of map is used to virtually prolong the view edges and therefore provide space to attach Canyons. This map piece is as wide as the border of the detail view. A small folded map is added to the corner of the detail view connecting the detail map with the virtual fold border. To ensure that there is always enough space for folding corner objects as shown in Figure 4.4 (d), cut-out views must always be kept within distinct octants. When a cut-out view exceeds the octant bounds, it is shifted into the octant were the off-view target is located, as shown in Figure 4.4 (c). This corner handling is performed only on the vertical edges of the view. The previously described mechanisms, merging and chaining, apply for corner objects the same way as described for off-view objects located orthogonal to the detail view edges.

4.1.3 Let there be Shadow!

For adding the shadow to the folded map, the maximum darkness applied to the middle of the folded map is calculated. The maximum darkness of the shadow is calculated depending on the ratio of visible map in the fold and invisible map material that is folded away, giving

$$darkness = \left(1 - \frac{foldSize}{foldDistance}\right)^5. \tag{4.5}$$

A linear gradient from the calculated maximum darkness in the middle to transparent on the outsides of the fold is drawn.

4.1.4 Pixel Shader

Folding and adding the shadow onto the map image is implemented in a Windows Presentation Foundation (WPF) pixel shader for fast computation on the Graphical Processing Unit (GPU). The shader language HLSL[2] and the shader editor Shazzam[3] were used for implementing and testing the paper folding shader. Shazzam provided example shaders including code for a shader for horizontal paper folding distortion. This example shader was extended to add a linear gradient for the shadow and functionality for vertical paper folding was added. Both, distorting the map using linear interpolation and adding the shadow is performed in the same shader and is therefore done in one pass. The shader code for horizontal folding is included in Appendix C.2.

[2]High Level Shading Language for DirectX http://msdn.microsoft.com/en-us/library/windows/desktop/bb509561%28v=vs.85%29.aspx

[3]http://shazzam-tool.com/

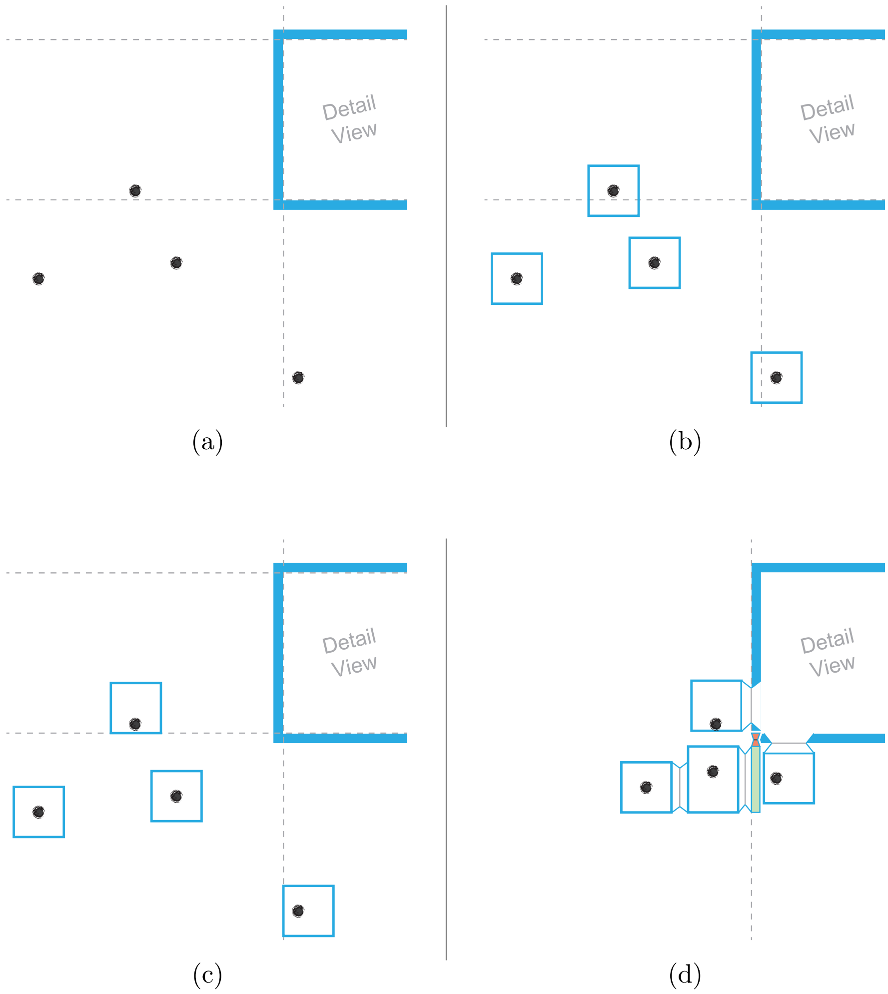


Figure 4.4: Corner Handling. Off-view target locations are shown in (a). In (b) the original cut-out views around the targets are shown. These are shifted into the octants, where the target is located (c). Finally, (d) shows how objects in corner regions are folded twice. The red small folded map connects the corner Canyon to the detail view. The green map is the *virtual fold border*. Notice that it is not distorted. Chaining and merging are applied when necessary, as in this case chaining is applied.

4.2 Underlying Framework

The application is written in the programming language C# using Windows Presentation Foundation (WPF) 4[4]. For map retrieval and display, the open source framework GMap.NET[5] was used. It provides functionalities like downloading map images, tiling of map images, adding makers onto the map, conversion between geographic coordinates (Latitude and Longitude) and screen coordinates and many more. Furthermore, the framework encapsulates most of the functionalities into one Map Control[6]. For opening detail views, a new Map Control is instantiated and placed on the screen. An open detail view is marked on the overview map by using the bounds of the detail map in geographic coordinates and placing a translucent rectangle with the same bounds on the overview map. This focus area marker is kept up to date. For better identification, lines connecting the corners of the detail view with the corresponding corners of its marker on the overview map are drawn. These connecting lines are updated on moving the detail view or any zoom and pan operations on either map.

The pen, vehicle and focus area tools, described in Section 3.1.1, add items onto the map. These tools extend the *MapMarker* class provided by GMap.NET, which handles moving and scaling the marker objects when the map is panned or zoomed. The eraser tool collects a list of all touched markers during a erase operation and removes these markers from all maps. The navigation tool is a custom implementation, which pans and zooms the map by setting the appropriate position or zoom level properties. Since map images are only available for discrete zoom levels, GMap.NET does not provide continuous zoom. This was added by applying a scale transformation on the map images between two zoom levels.

[4] http://msdn.microsoft.com/en-us/library/ms754130(v=vs.100)

[5] http://greatmaps.codeplex.com/

[6] Information about WPF controls is available at http://msdn.microsoft.com/en-us/library/bb613551(v=vs.100)

Chapter 5

Evaluation

This chapter presents the methodology used to evaluate a novel off-view visualization technique called Canyon. The design of Canyon is described in Section 3.2. As a baseline for comparison, Wedge [22] was chosen out of multiple techniques, as described in Section 3.3. In this chapter, the comparative user study design is explained. The results of this study are presented and discussed in the next chapter.

The goal of this work is to determine whether off-view visualization techniques with high level of detail can outperform techniques with low level of detail. Canyon was designed to show off-view objects with high level of detail. Wedge is considered a pointing technique, which is a sub-group of cue-based approaches. These two techniques are compared in a controlled laboratory-based experiment. A higher level of detail is expected to provide higher accuracy in determining off-view objects' locations.

Strong context is provided in order to investigate, if the results can be applied in an emergency response context. However, this study aims for precise measurement of users' performance. Therefore external factors, that are not being studied, are eliminated as much as possible. The provided context is strongly based on an observed police command group training, described in the background study in Section 2.2. Police incidents, which occurred in the background study, were used to provide context to the tasks. These incidents include a bomb found, burglary, shoplifting, suicide attempt, etc. Due to this police context, cars were chosen as the geo-referenced objects to study.

Important features for an emergency response scenario were revealed in the background study. In particular, it was determined important to know

- where the cars are currently located,
- which car is closest to an emergency site,
- which car has arrived at an emergency site,
- which car is not assigned to a mission and is therefore free to be sent to a new emergency site.

These features were the basis for designing the tasks of this study. Estimating location and distance was tested directly by individual tasks. Since no emergency sites were visualized, testing arrival at an emergency site was not measured directly. However, it was tested how well movement was conveyed. Mission assignment to a car was not tested, since no status of objects was visualized. Since the map application was based on an Overview+Detail interface, an additional task was added, measuring if cognitive association of objects between the overview and detail maps was possible. Users must be able to recognize, that two visualizations (one on the overview map, one on the detail map) represent the same object.

A mixed design was used for this study, as later discussed in more detail. Two visualizations were tested across two densities with 16 participants. The main focus of this study was to find out which technique proves to be more effective at supporting the tasks discussed above. Furthermore, measuring participants' preference and therefore acceptance of the tested visualization techniques was vital to the study.

5.1 Participants

16 unpaid students from an university computer science undergraduate program (6 females, 10 males) participated in the study. Their age ranged from 21 to 31 years ($M = 23.19$, $SD = 2.92$). Participants were divided in groups of two, resulting in 8 groups. Since the studied tasks were not collaborative, participants were free to sign up as they liked, regardless of how well they knew the other participant. The native language of all participants was German, yet the instructions were given in English. Thus, on a background questionnaire completed by participants at the beginning of the study, they were asked to rank how comfortable they felt with English on a 7-point Likert scale, with 1 being not familiar with English and 7 being very comfortable with English. Overall, they felt fairly comfortable with the English language ($M = 5.06, SD = 1.03$). Participants reported using a computer on average 7.08 hours a day ($SD = 2.37$).

Participants were also questioned about their experience and usage of direct input computational devices (including tablets and smartphones) and digital map systems. 25% of the participants reported having no experience with pen-based devices, 31.25% reported having 1 to 5 years experience (see Figure 5.1). 50% of the participants reported using direct input devices frequently throughout the day and 31.25% reported using such devices daily. Digital map systems were reported to be used by 43.75% of participants several times a month and by 37.5% of participants several times a week. These data are visualised in Figure 5.2. Finally, no participant reported any previous experience with interactive whiteboards.

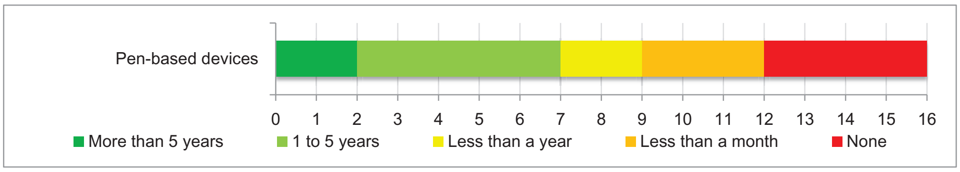


Figure 5.1: Participants' experience with pen-based computational devices.

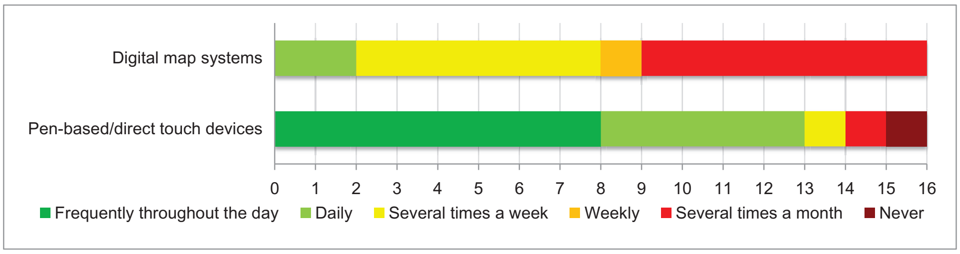


Figure 5.2: Participants' usage of pen-based or direct touch computational devices and digital map systems.

5.2 Apparatus

The study was conducted on a large interactive whiteboard, measuring 3×1.125 m, with a total resolution of 2048×768 pixels. The whiteboard was operated by two Hitachi CP-A100 projectors and input was given by Anoto digital pens (ADP-301), as shown in Figure 5.3. The experiment was conducted using the Overview+Detail map application, described in Chapter 3. Both, zooming and panning, were disabled to prevent participants from changing the given map area. However, they were able to move the location of the detail window, since due to the visual expansion of the Canyon view, the objects of interest could exceed the visible area. Microsoft Bing™ was chosen as the map provider due to its minimal visual clutter as compared to Google Maps™ and comparable loading times.

5.3 Experimental Design

Two visualization techniques were tested with two densities in 4 different tasks, resulting in

	16	participants
×	2	*Techniques* (Canyon, Wedge)
×	2	*Densities* (5 cars, 10 cars)
×	2	repetitions in condition
×	7	task trials
	896	total trials

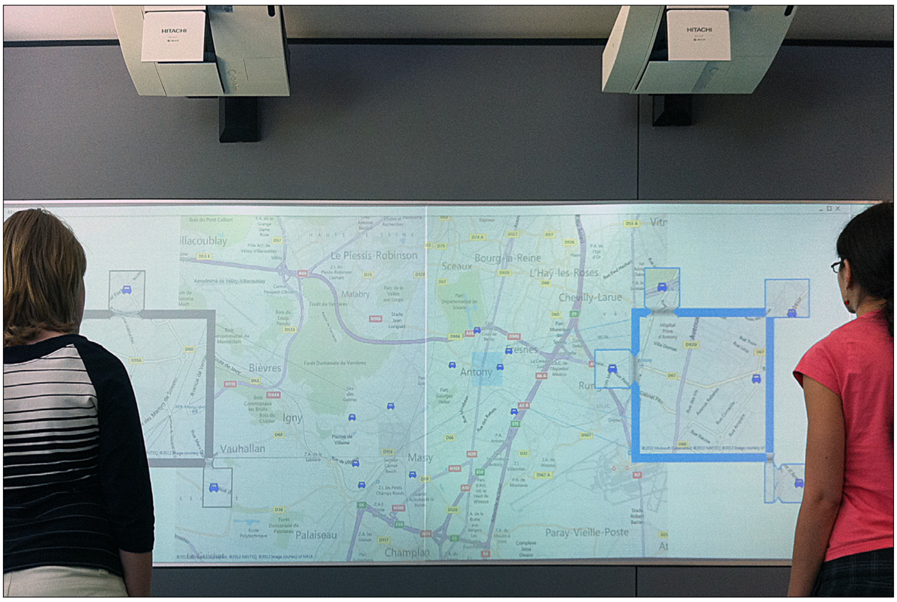


Figure 5.3: The study was conducted on a large interactive whiteboard with groups of two participants.

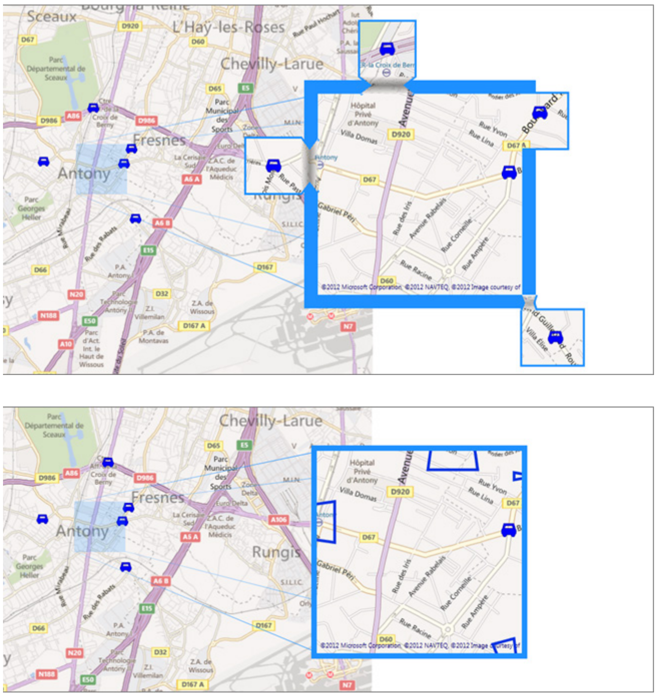
For three of the 4 tasks, participants completed two trials within the task. One task had only one trial, resulting in 7 task trials per condition. Technique and density were counterbalanced, as shown in Table 5.1. Due to their different natures, tasks were not counterbalanced and appeared in the order as described below.

Group	*Technique Block I*		*Technique Block II*	
1 & 5	Wedge 5	Wedge 10	Canyon 5	Canyon 10
2 & 6	Canyon 5	Canyon 10	Wedge 5	Wedge 10
3 & 7	Wedge 10	Wedge 5	Canyon 10	Canyon 5
4 & 8	Canyon 10	Canyon 5	Wedge 10	Wedge 5

Table 5.1: Counterbalancing of the independent variables Technique and density.

5.3.1 Visualization Technique

Two visualization techniques were compared: Canyon and Wedge. Wedge was implemented as described in [22] and [21], but with a straight base connecting the two legs of the triangle. Since the detail windows where sized 300×300 pixels, the maximum length of the base was determined to be 150



(a)

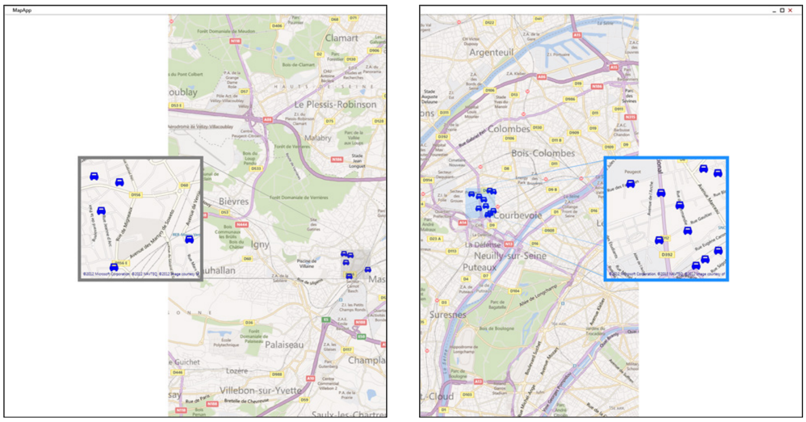
(b)

Figure 5.4: The compared off-view visualization techniques Canyon (a) and Wedge (b).

pixels. While with Wedge off-view objects are visualized within the detail window, Canyon places the off-view objects on the outer border of the detail window. Wedge shows the location of the off-view object with an abstract shape, namely a partly visible, isosceles triangle. In contrast and as described in detail in Chapters 3 and 4, Canyon shows the actual object plus its surroundings and uses distortion to fold parts that are not of interest. Figure 5.4 shows both techniques.

5.3.2 Density

The techniques were tested with two different densities, 5 and 10 cars, assigned to each detail window (see Figure 5.5). The numbers were chosen based on the findings from the background study. For smaller emergencies, one to 5 units were sent to the site, while for larger emergencies approximately 10 units were sent. In the largest emergency that was observed, a kidnapping case, more than 30 cars were involved. However, in such emergencies it would not make sense to use detail maps, but rather to use the entire overview map.



(a) (b)

Figure 5.5: The tested densities, 5 cars (a) and 10 cars (b).

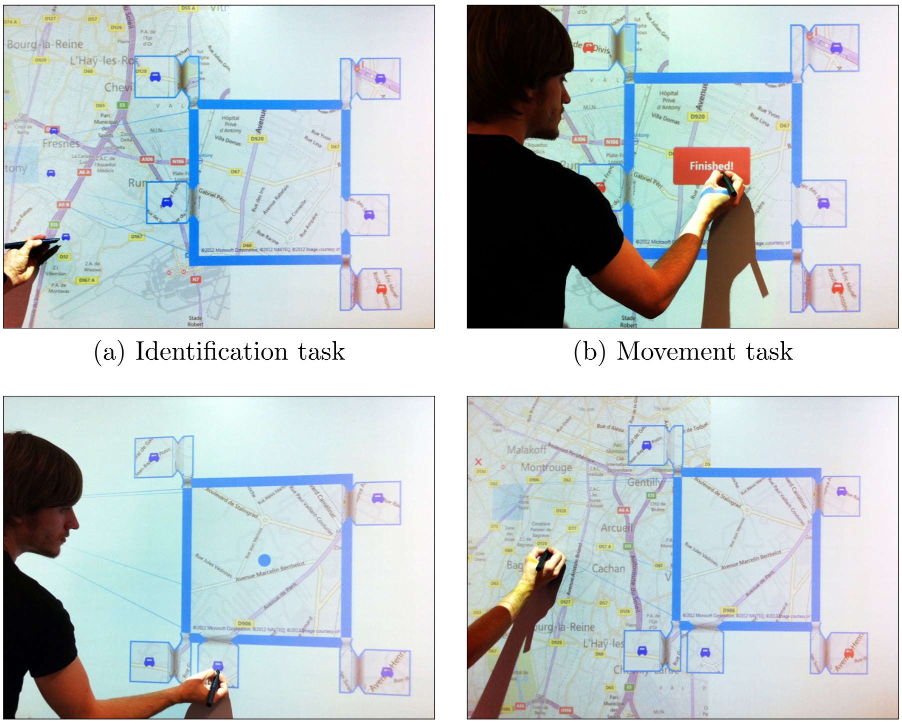
5.3.3 Tasks

Suburban areas of Paris were used so that participants would be unlikely to have in-depth knowledge of the map data, and thus have similar expertise. For every task, visually comparable map areas were selected and car locations were randomly generated. Each car had a route assigned, determining its movement. The routes were randomly determined prior to the study and used across groups. The starting positions were randomly generated within the area of the detail view. The route destinations were randomly generated in two different distances to represent near and far off-view objects. The near area corresponded to the detail view area enlarged to 300%. The far area was the detail view area enlarge to 600%. 60% of the cars of the target density were generated in the near area, the remaining 40% were generated in the far area.

The cars moved with realistic speed[1] $\times$ 10. This speed was chosen as a trade-off between representing realistic driving conditions and keeping study time short. All cars were paused at each task. Four tasks were used to test location, distance, movement estimation and cognitive mapping of objects between overview and detail map. Images of all tasks are given in Figure 5.6.

Task 1 - Identification: A car on the detail map was highlighted and the participant had to select the car on the overview map that corresponded to the highlighted car (see Figure 5.6 (a)). The trial ended on selection of a car on the overview map. The overview map and all cars on the overview map were visible.

[1]Routes and speed were obtained from Google Directions API (https://developers.google.com/maps/documentation/directions/)



(a) Identification task (b) Movement task

(c) Distance task (d) Location task

Figure 5.6: Tasks performed in the experiment: (a) identify a car on the overview map, (b) select all stationary cars, (c) select the closest car and (d) mark the location on the overview map.

Task 2 - Movement: All cars were paused and the participant had to select all cars, that were already stationary prior to pausing all cars. After selecting all stationary cars, the participant ended the trial by hitting the "Finished" button located in the center of the participant's detail map, as shown in Figure 5.6 (b). Again, the overview map and all cars on the overview map were visible.

Task 3 - Distance: Participants were asked to rank the closest cars to the middle of the detail map (see Figure 5.6 (c)). In the first trial, they were asked to select the closest car. In the second trial, they were asked to select the second closest car. By selecting a car, the trial was ended. The center of the map was marked by a colored circle. The overview map, including the cars, was hidden to ensure that participants estimated distances only from the off-view visualizations.

Task 4 - Location: A car was highlighted on the detail map and the participant marked the location of that car on the overview map by tapping once. The trial ended when the participant tapped on the overview map. The overview map was visible, but the cars on the overview map were not (see Figure 5.6 (d)).

Trials per Task

For every task, participants had to complete multiple trials depending on the density:

$$repetitions = \left\lceil \frac{density}{3} \right\rceil .$$

This means, two repetitions were completed in the 5 car condition and three repetitions in the 10 car condition. With different levels of repetition, the design was unbalanced. Therefore repetition three was omitted for the analysis.

5.4 Procedure

The study consisted of 4 main blocks: the introductory block, two technique blocks and the finishing block.

First, in the *introductory block*, the participants were welcomed and given a brief overview about the project. After signing the consent form, they filled out the background questionnaire. To get familiar with the digital pen, the participants drew on a sketching application for approximately 5 min. Then, the procedure and all tasks were explained and shown. They were instructed to complete the tasks as accurately and fast as possible.

A *technique block* started with a visual explanation of the technique. To get familiar with the technique, one training block with all 4 tasks tested with two cars per detail view were completed. Then four *condition blocks* were performed. For each density (5 and 10 cars), two blocks were performed. First, the participants were instructed to monitor the cars. The cars started within the detail window and moved outwards. After a few seconds, the movement was paused and the participants were asked to perform the Identification task. Then the cars resumed their movement and the participants were instructed to monitor the movement of the cars. Again, after a few seconds, the movement was paused and the Movement task began. Since the participants already gained knowledge about the car positions at that point, the map was changed. The overview map was hidden and the Distance task started. Afterwards, the overview map was made visible and the participants performed the Location task. For every condition block different but comparable map areas were chosen in the suburban area of Paris. After all condition blocks were done, the technique block ended with filling out questionnaires for the technique and each level of density. The technique block took approximately 17 min to complete.

After having completed both technique blocks, the participants were asked to fill out the exit questionnaire and were interviewed about their overall preference concerning the two techniques. This was the *finishing block*. The study was completed in one session lasting approximately 60 minutes.

5.5 Hypotheses

The main difference between the two tested techniques is their level of detail. While Wedge is a cue based abstract visualization, Canyon shows the actual object plus its surroundings. Considering the specific features of Canyon and Wedge, the hypotheses in the study were as following.

Identification Task

Hypothesis 1: For finding the corresponding car on the overview map, both techniques will be accurate. Participants are expected to search the car relative to the detail area, rather than actually estimating the location, resulting in no difference between the techniques.

Hypothesis 2: The trial completion time is expected to take longer with Canyon. This is due to the higher level of detail, therefore requiring higher cognitive load.

Hypothesis 3: With high density and therefore more cars on the overview map to choose from, participants will produce more errors and consume more time than with low density.

Movement Task

Hypothesis 4: Participants are expected to produce fewer errors for recognizing movement with Wedge than with Canyon. First, they have a smaller area to monitor. And second, for Wedge the foreground object moves, meaning the colored wedge shape. Since the off-view cars are always centered in the Canyon cut-out view, they don't move, but the map in the background does. This is expected to be more difficult to see.

Hypothesis 5: No difference is expected in trial completion time, since it will mainly represent the selection time, rather than the contemplation time.

Distance Task

Hypothesis 6: Canyon is expected to result in fewer errors than Wedge, since the distance that has to be interpreted is only the folded distance, which is smaller than the total distance to the object. Furthermore, for clustered objects, the distance has only to be interpreted once, unlike Wedge, which requires the distance to be interpreted for every object individually.

Hypothesis 7: Due to the before mentioned features, Canyon is expected to be faster than Wedge.

Location Task

Hypothesis 8: Finding the exact location is expected be more accurate with Canyon, due to the fact that Canyon shows the surroundings of the object. Participants are expected to perform template matching on the map material, rather than estimate the location.

Hypothesis 9: Since there is a higher level of detail of the object's location with Canyon, participants are expected to strive for finding the exact spot and spend therefore more time. Wedge is expected to be faster than Canyon.

5.6 Data Collection

5.6.1 Error Rates

Error rates were defined for every task individually to best represent accuracy with respect to the task. The error measures are described in detail for every task individually in the Results Section 6.1. The Identification task used a binary error measure. For the Movement task, two different types of errors—omission error and the false-positive error—and a combined error were analyzed. For the Distance task, the error was measured by normalizing the distance of the selected object to the distance of the target object. Finally, for the Location task, the Euclidean distance between selected and correct location denoted the error.

5.6.2 Trial completion time

The time spent on a trial was recorded in milliseconds. The timer started on closing the instructional pop up and ended on performing the required action. For the Corresponding task, selecting a car on the overview map ended the time measuring for one trial. Hitting the "Finished" button completed the Movement task. The Distance task ended on selecting a car and the Location task ended on tapping on the overview map.

5.7 Statistical Analysis

Since car locations and routes were pre-generated based on the chosen map areas, the density factor was not separable from the map. Therefore, two separate analyses for each density were performed to avoid this confounding factor. Instead, *Density Order* was included as a between-subject factor, to account for learning effects and fatigue, as some of the participants would have performed comparable trials at different times throughout the study session. Error rates and trial completion times were thus analyzed using a 2 (*Technique*) × 2 (*Position*) × 2 (*Density Order*) full-factorial repeated-measures ANOVA ($\alpha = .05$), separately for each level of density. The factor *Technique* represented the tested off-view visualization techniques as within-subject factor and *Position* and *Density Order* were between-subject factors. *Position* refers to whether the participant used the left or right detail view. *Density Order* describes whether a group started with 5 cars or 10 cars. In other words, whether the analyzed density was first or second.

Chapter 6

Results and Discussion

The first part of this chapter presents the quantitative results of the user study evaluating Canyon. The methodology is described in Chapter 5 and Canyon's design is covered in Section 3.2. The feedback given by the study participants is described in the second part of this chapter. The third part discusses the results.

6.1 Study Results

This section gives error rates and trial completion time per task and density. A significance level of $\alpha = .05$ was used for all statistical tests. The trial completion time was recorded in milliseconds for precision, but is presented in seconds for better understanding. The error measure is specified for every task separately.

6.1.1 Identification Task

This task measured, whether participants were able to cognitively associate objects between overview and detail maps. Both techniques were expected to be accurate (*Hypothesis 1*), Canyon was expected to be slower than Wedge (*Hypothesis 2*) and participants were expected to be slower with 10 cars than with 5 (*Hypothesis 3*).

Measure

The error rate was measured as a binary error,

$$e = \begin{cases} 0 & \text{for selection of correct car,} \\ 1 & \text{for selection of incorrect car.} \end{cases}$$

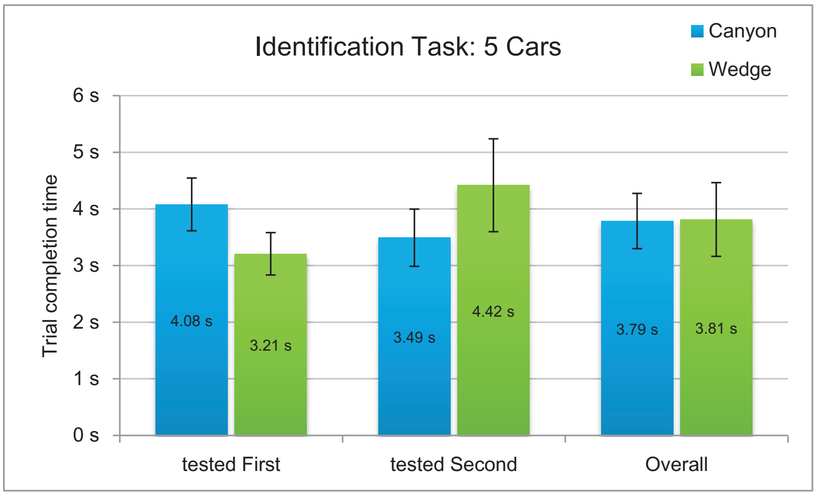


Figure 6.1: Trial completion time in seconds for the Identification task with 5 cars. The graph shows values, when 5 cars condition is tested first (left), when it is tested second (middle) and the overall trial completion time (right). Error bars show standard error.

Five Cars Condition

There was no error at all in both techniques when only 5 objects were used, therefore *Hypothesis 1* ("Both techniques are accurate") is supported for 5 cars. Trial completion time was not significantly different, $F(1, 13) = 0.006$, $p = .940$, with $M = 3.79$ s ($SD = 1.95$ s) for Canyon and $M = 3.81$ s ($SD = 2.60$ s) for Wedge. However, a significant Technique by Density Order interaction effect, $F(1, 13) = 6.570$, $p = .024$, was found for trial completion time. The trial completion times, presented in Figure 6.1, show that Canyon gets faster, when 5 cars is tested after 10 cars. This can be interpreted as a learning effect. In contrast, Wedge gets slower when 5 cars is presented as the second condition. Participants relied mainly on the base length of Wedges for distance indication during the first blocks. They learned over time that the base length is not consistent for corner objects and spent therefore more time to complete the Wedge shapes properly.

Ten Cars Condition

No significant effects were found for error rate on maps with 10 objects. Both techniques were accurate and *Hypothesis 1* is supported. While the error rate for Canyon was $M = 4.69\%$ ($SD = 21.30\%$), the error with Wedge was $M = 6.25\%$ ($SD = 24.40\%$). However, there was a significant main effect of Technique for trial completion time, $F(1, 13) = 6.037$, $p = .029$. Wedge was significantly faster with 10 objects ($M = 4.74$ s, $SD = 2.65$ s) than Canyon

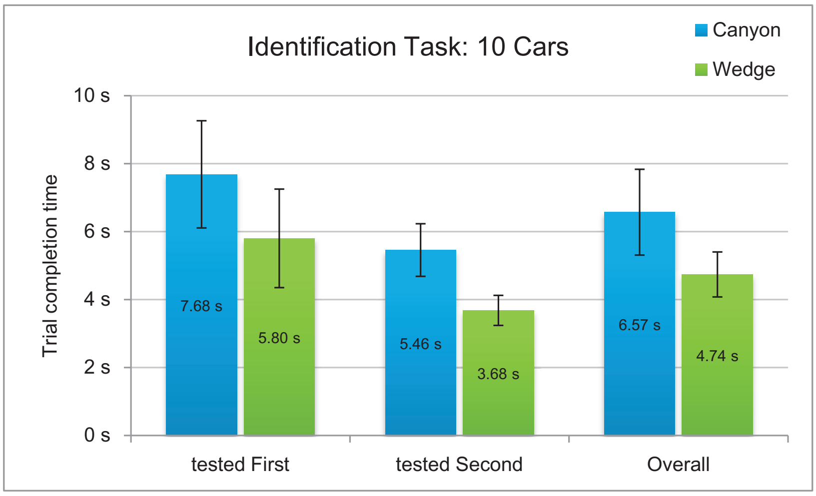


Figure 6.2: Trial completion time in seconds for Identification task with 10 cars. The graph shows values, when 10 cars condition is tested first (left), when it is tested second (middle) and the overall trial completion time (right). Error bars show standard error.

(M = 6.57 s, SD = 5.05 s). This is due to the growth of Canyon, sometimes even exceeding the screen borders. Highlighted targets were sometimes not visible and participants had to move the detail view to find them. This result supports *Hypothesis 3* ("Higher error rate and completion time with more cars") and *Hypothesis 2* ("Canyon is slower") with 10 cars.

Furthermore, a statistically significant main effect of Density Order was found, $F(1, 13) = 5.376$, $p = .037$. Participants were faster when the 10 cars condition was second (M = 4.57 s, SD = 2.66 s), than when it was first (M = 6.74 s, SD = 4.98 s). This can be interpreted as a learning effect. Trial completion time data are shown in Figure 6.2.

6.1.2 Movement Task

How well movement was conveyed was measured by asking participants to select all stationary cars. Wedge was expected to be less error-prone (*Hypothesis 4*) and as fast as Canyon (*Hypothesis 5*).

Measure

Participants could produce two different types of errors. First, an error could be made by not selecting a correct (stationary) object,

$$e_{omission} = \frac{c - s_c}{c}.$$

The other type of error was selecting an incorrect (moving) object,

$$e_{\textit{false-positive}} = \frac{s_i}{d - c}.$$

The overall error, which was a combination of both error rates, was analyzed as well,

$$e_{\textit{overall}} = \frac{c - s_c + s_i}{d}.$$

Term c denotes the number of correct objects, d is the tested density, s_c is the amount of correct cars selected and s_i is the amount of incorrect cars selected. Since for this task only one repetition was performed, trial completion time equals task completion time. How long it took participants to select all stationary objects was determined by measuring the time between closing the instructional pop up and pressing the “Finished” button located in the center of each detail map.

Five Cars Condition

None of the error measures, or the completion time, was significant for the 5 cars condition. Participants missed on average 16.77% ($SD = 29.34\%$) of the stationary cars with Canyon and 7.45% ($SD = 17.52\%$) with Wedge, $F(1, 13) = 3.563$, $p = .082$. With each of the two techniques $M = 7.03\%$ ($SD = 21.11\%$) moving and therefore incorrect cars were selected, $F(1, 13) = 0.000$, $p = 1.000$. The overall error rate amounts to $M = 13.13\%$ ($SD = 23.61\%$) using Canyon and $M = 10.00\%$ ($SD = 19.67\%$) with Wedge, $F(1, 13) = 0.326$, $p = .578$. It took $M = 5.82$ s ($SD = 4.10$ s) to complete the task using Canyon and $M = 5.69$ s ($SD = 3.30$ s) using Wedge, $F(1, 13) = 0.050$, $p = .826$.

Ten Cars Condition

No significant difference between techniques regarding the omission-error $e_{\textit{omission}}$ was found in the 10 cars condition, $F(1, 13) = 3.270$, $p = .094$. The difference in Technique was found to be very significant at incorrectly selected cars $e_{\textit{false-positive}}$, $F(1, 13) = 10.687$, $p = .006$. Participants selected significantly fewer moving cars with Canyon ($M = 3.13\%$, $SD = 7.56\%$) than with Wedge ($M = 10.19\%$, $SD = 15.28\%$). There was a significant main effect of Technique for the overall error $e_{\textit{overall}}$, $F(1, 13) = 5.957$, $p = .030$, showing that Canyon was overall less error-prone ($M = 16.25\%$, $SD = 14.97\%$) than Wedge ($M = 25.63\%$, $SD = 16.64\%$) for recognizing movement. All error rates are shown in Figure 6.3.

Hypothesis 4 (“Wedge is less error-prone”) can be rejected, since there is no support from the data that Wedge was less error-prone than Canyon for observing movement. Contrary to expectations, Canyon produced overall fewer errors than Wedge. While it was expected that a smaller area is easier

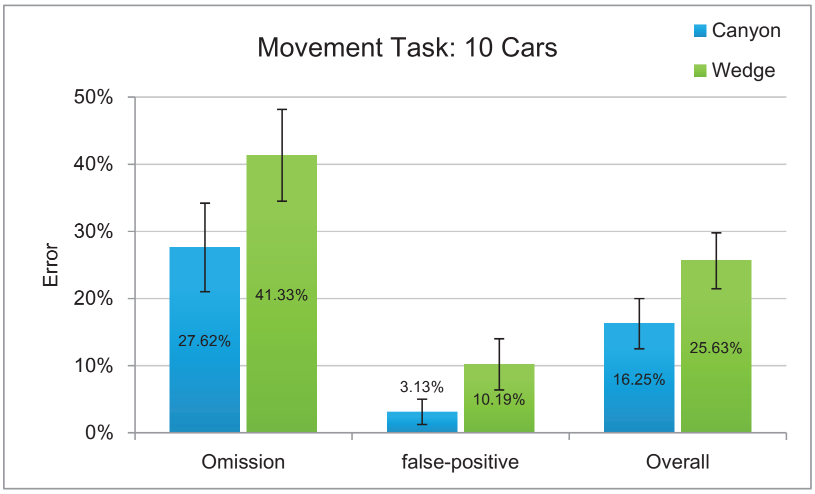


Figure 6.3: Error rates (%) for Movement task with 10 cars. Showing error rates for missed objects (left), for incorrectly selected objects (middle) and the overall error rate (right). Error bars show standard error.

to monitor, the fact that movement is primarily observed peripherally was not accounted for. This might explain why participants were more accurate with Canyon. The visual design of Wedge gets unclear with more objects on the screen, as it produces overlaps. Furthermore, the layout algorithm introduced even more movement to the visual cues, as Wedges representing objects located in the same direction competed about on-screen space.

There was a significant main effect of Position, $F(1, 13) = 15.051$, $p = .002$, regarding the false-positive error $e_{false\text{-}positive}$. This indicates that it made a difference whether a participant used the left or right detail window. The participant on the right side selected significantly less incorrect objects ($M = 2.34\%$) than the one on the left side ($M = 10.97\%$). However, this corresponds to an effect size of 8.63% and is therefore a difference of less than one object (0.86). Due to this small effect size, this main effect can be ignored. The reason for this effect is that there were significantly more correct (stationary) cars on the right detail window ($M = 6.09$, $SD = 1.924$) than on the left ($M = 4.56$, $SD = 1.076$), $F(1, 62) = 15.445$, $p < .001$. Since participants standing on the right side had less incorrect (moving) objects, they were more likely to select fewer incorrect objects and therfore commit fewer false-positive errors.

No significant difference in completion time between the two techniques was found, $F(1, 13) = 0.050$, $p = .827$. On average, it took 8.79 s ($SD = 5.09$ s) to select all presumed stationary cars with Canyon and 9.02 s ($SD = 4.51$ s) with Wedge in the 10 cars condition. Since there were no significant differences in completion time with both densities, *Hypothesis 5* is supported.

6.1.3 Distance Task

Participants were asked to select the closest object in the first trial, and the second closest in the second trial. Canyon was expected to be less error-prone (*Hypothesis 6*) and faster (*Hypothesis 7*) than Wedge.

Measure

The error rate for finding the closest object to the center of the map was measured relative to the target,

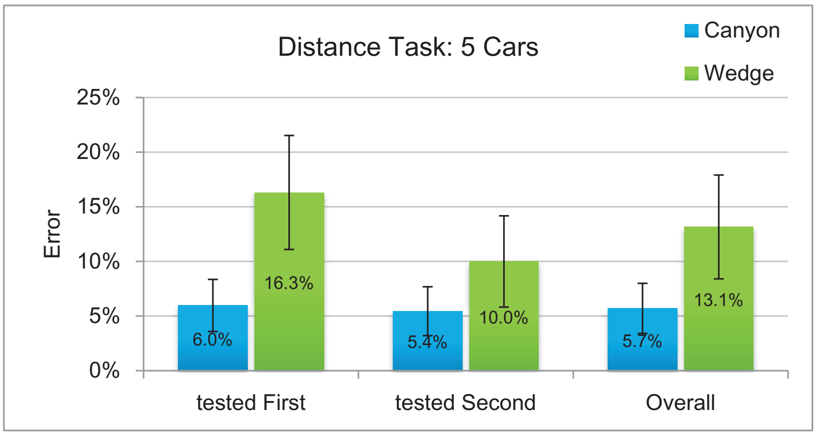
$$e = \frac{d_s - d_t}{d_t},$$

where d_t describes the distance from the map center to the closest off-view object—the target object—and d_s is the distance from the map center to the selected object. The object chosen in the first trial remained highlighted and could not be selected again in the second trial. Therefore, the target object was defined as the closest object among unselected objects.

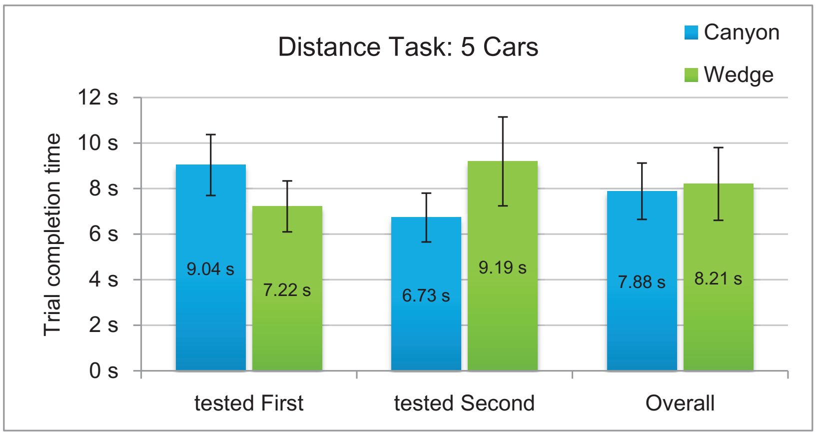
Five Cars Condition

A significant main effect of Technique, $F(1, 13) = 5.489$, $p = .036$, for error rate and 5 objects can be reported. While the error rate with Canyon was $M = 5.70\%$ ($SD = 9.17\%$), it was significantly higher with Wedge ($M = 13.15\%$, $SD = 19.01\%$). This result supports *Hypothesis 6* ("Canyon is less error-prone"). The error with Canyon remained constantly low, indepented if the 5 cars condition was tested first or second. Wedge improved slightly when the condition was tested second (Effect size = 6.31%, n.s.). Since there was no significant difference in trial completion time across Techniques, $F(1, 13) = 0.123$, $p = .731$, *Hypothesis 7* ("Canyon is faster") must be rejected. The trial completion time was $M = 7.88s$ ($SD = 4.95s$) for Canyon and $M = 8.21s$ ($SD = 6.39s$) for Wedge.

Trial completion time increased with Wedge, when the 5 cars condition was tested second (Mean difference = 1.96 s), while it decreased with Canyon (Mean difference = 2.31 s). This was a statistically significant interaction effect of Technique by Density Order, $F(1, 13) = 5.423$, $p = .037$. In fact, this is the same pattern that occurred in the Identification task in the 5 cars condition. Therefore, this interaction effect can also be explained by participants rethinking their strategy for Wedge and spending therefore more time on trial completion as the 5 cars condition was tested second. Participants might have relied on Wedge's base length as the primary cue for distance and found out over time and multiple trials, that this cue is not consistent, especially for objects in corner regions. The results shown in Figure 6.4 support this explanation, since the error rates decrease for Wedge when 5 cars are tested second. The trial completion time decreased for Canyon when 5 cars



(a)



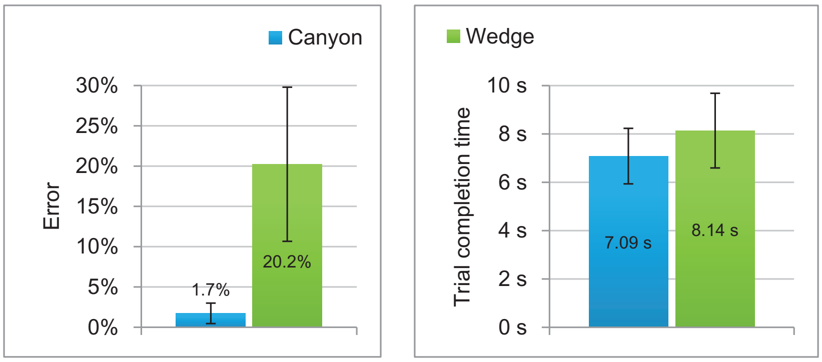
(b)

Figure 6.4: Measures for Distance task with 5 cars. (a) shows error rates, (b) shows trial completion time. Error bars show standard error.

were tested as the second condition, which can be interpreted as a learning effect.

Ten Cars Condition

A significant main effect for Technique was found, $F(1, 13) = 9.276$, $p = .009$, for the error rate of estimating distance with 10 cars. While the error amounted to $M = 1.72\%$ ($SD = 5.08\%$) for Canyon, the error was $M = 20.23\%$ ($SD = 38.27\%$) for Wedge. This finding supports *Hypothesis 6* ("Canyon is less error-prone"). Regarding trial completion time, there was no significant difference in Technique to report, $F(1, 13) = 0.822$, $p = .381$.



(a) (b)

Figure 6.5: Measures for Distance task with 10 cars. (a) shows overall error rate, (b) shows trial completion time. Error bars show standard error.

Therefore *Hypothesis 7* ("Canyon is faster") must be rejected. On average, it took 7.61 s ($SD = 5.45$ s) to estimate the distance for one object. Figure 6.5 (a) shows overall error and (b) shows overall trial completion time.

6.1.4 Location Task

Location estimation was tested by asking participants to find and mark the location of an off-view object on the overview map. All cars on the overview map were hidden. Canyon was expected to be more accurate than Wedge (*Hypothesis 8*), but slower (*Hypothesis 9*).

Measure

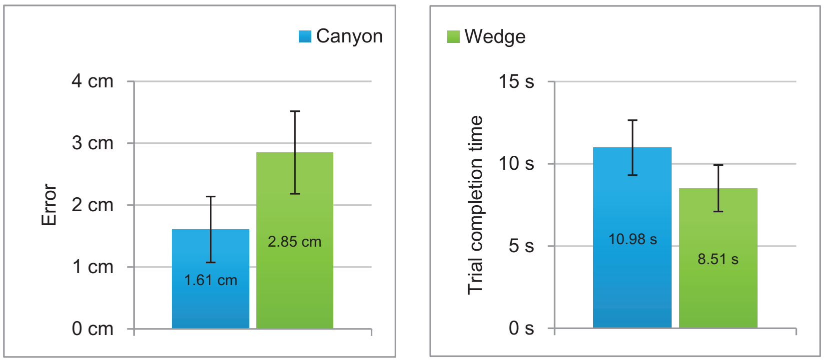
The error rate for finding the location of an off-view object was the distance between the actual object location and the selected location on the overview map, measured in cm on the whiteboard,

$$e = \|p_s - p_t\|,$$

where p_s is the selected location by the participant and p_t is the actual object location—the target location. Although the error rate was analyzed in cm, the differences in meters are given in addition for better understanding. One cm on the whiteboard corresponds to ≈ 87 m in real-world distances represented by the overview map.

Five Cars Condition

No significant difference in Technique was found for error rate and 5 cars, $F(1, 13) = 3.401$, $p = .088$. The average error using Canyon amounted to



(a) (b)

Figure 6.6: Measures for Location task with 10 cars. (a) shows overall error rate, (b) shows trial completion time. Error bars show standard error.

2.60 cm ($SD = 4.01$ cm) which corresponds to 226 m in real-world distance. Using Wedge, the average error was 3.58 cm ($SD = 2.52$ cm) which corresponds to 311 m. Regarding trial completion time, Technique was marginally significant, $F(1, 13) = 3.901$, $p = .070$. Canyon was slower ($M = 11.93$ s, $SD = 5.57$ s) than Wedge ($M = 9.32$ s, $SD = 4.41$ s). Also, a marginally significant main effect of Density Order, $F(1, 13) = 3.851$, $p = .071$, showing an increase in time when 5 cars were tested second ($M = 11.86$ s, $SD = 6.03$ s) compared to when it was tested first ($M = 9.39$ s, $SD = 3.81$ s). Since the Location task was always last, this may have been caused by a fatigue effect.

Ten Cars Condition

When estimating location was tested with 10 cars, Technique was very significant, $F(1, 13) = 9.405$, $p = .009$, for error rate. Canyon produced an error rate of $M = 1.61$ cm ($SD = 2.13$ cm), while the error was significantly higher with Wedge ($M = 2.85$ cm, $SD = 2.67$ cm). In meters, the error for Canyon amounted to 139 m and to 247 m for Wedge. This result supports *Hypothesis 8* ("Canyon is more accurate").

Difference in trial completion time was not significant, $F(1, 13) = 2.436$, $p = .143$, therefore *Hypothesis 9* ("Wedge is faster than Canyon") can be rejected. On average, estimating location of one object took $M = 10.98$ s ($SD = 6.67$ s) with Canyon and $M = 8.51$ s ($SD = 5.66$ s) with Wedge. See Figure 6.6 (a) for error rate and 6.6 (b) for trial completion time.

A significant main effect of Position (whether participant used left or right detail window), $F(1, 13) = 8.064$, $p = .014$, for error rate was found. Participants produced a higher error rate on the left side (Effect size = 1.1 cm). This was likely due to the lower position of the left detail area on the overview map. It was easier to estimate the location of the cars on the right side, since the detail area was at eye-level. However, Position did not significantly affect trial completion time.

There was a significant main effect of Density Order for trial completion time, $F(1, 13) = 8.124$, $p = .014$. Both techniques were faster when 10 cars was tested second (Mean difference = 3.80 s). This can be interpreted as a learning effect.

6.1.5 Summary

Quantitative data collected during the user study showed no statistically significant difference in techniques when tested with 5 cars. The only exception is a significant difference in Technique and error rate at the Distance task, $F(1, 13) = 5.489$, $p = .036$. Even in the 5 cars condition, Canyon was significantly less error-prone ($M = 5.70\%$, $SD = 9.17\%$) than Wedge ($M = 13.15\%$, $SD = 19.01\%$). However, in the 10 cars condition, Canyon was significantly more accurate than Wedge in all tasks, except for the Identification task. The error rates for the 10 cars conditions are summarized in Table 6.1. Trial completion times for 10 cars are summarized in Table 6.2.

Task	Canyon	Wedge	F	p
Identification	4.69% (21.30%)	6.25% (24.40%)	0.351	.564
Movement	16.25% (14.97%)	25.63% (16.64%)	5.957	.030
Distance	1.72% (5.08%)	20.23% (38.27%)	9.276	.009
Location	1.61 cm (2.13 cm)	2.85 cm (2.67 cm)	9.405	.009

Table 6.1: Error rates per task for 10 cars condition, showing mean (standard deviation).

Task	Canyon	Wedge	F	p
Identification	6.57 sec (5.05)	4.74 sec (2.65)	6.037	.029
Movement	8.79 sec (5.09)	9.02 sec (4.51)	0.050	.827
Distance	7.09 sec (4.59)	8.14 sec (6.18)	0.822	.381
Location	10.98 sec (6.67)	8.51 sec (5.66)	2.436	.143

Table 6.2: Trial completion times per task for 10 cars condition, showing mean (standard deviation).

6.2 Subjective Feedback

To collect subjective feedback on the tested techniques, participants completed post-condition questionnaires and were interviewed. After having completed a technique block, participants rated the technique for each density separately in questionnaires. After the study, they were interviewed about their overall preference regarding technique.

6.2.1 Participants' Ratings

After each technique block, participants were asked to rate how much knowledge they felt they had for each task and both levels of density. The rating was based on a 7-point Likert scale, where 1 means they had no knowledge, but rather guessed. And 7 means they knew exactly where the objects were, if they were moving, etc. All questionnaires are included in Appendix A. Figure 6.7 shows all ratings.

A Wilcoxon Signed-Rank Test comparing both techniques for each density indicated that participants felt having more knowledge with Canyon ($Median = 5$) than with Wedge ($Median = 3$) at the Distance task with 5 cars, $z = 2.208$, $p = .027$. For the same task, but with 10 cars, participants felt again more confident with Canyon, $z = 2.248$, $p = .025$. For finding the exact location of an off-view object, participants ranked Canyon higher than Wedge both, for 5 cars, $z = 2.015$, $p = .044$, and 10 cars, $z = 2.133$, $p = .033$. The ranking of the remaining conditions were not found to be significantly different.

However, it is interesting that participants rated Wedge ($Median = 5$) slightly higher than Canyon ($Median = 4.5$) for the Movement task and 10 cars. The above presented results show, that they performed significantly better in terms of error rate with Canyon than with Wedge. This indicates that participants felt overwhelmed by the amount of objects and Canyon's growth and thought they would lose overview. They did not realize that since movement is perceived well on the periphery, they were often correct. Furthermore they were not explicitly given feedback, whether they were wrong or right. The cars just resumed their movement, which showed implicitly the correct (stationary) objects. The difference in ratings of this condition was not significant and further studies are necessary to properly understand this effect.

After the experiment, participants were also asked about their preferences. They were asked for their preferred technique by task and overall in the exit questionnaire. Figure 6.8 shows that they strongly preferred Canyon. Wedge got the highest rating for observing movement with 6 participants (37.5%) preferring it. Overall, 14 out of 16 participants (87.5%) preferred Canyon over Wedge.

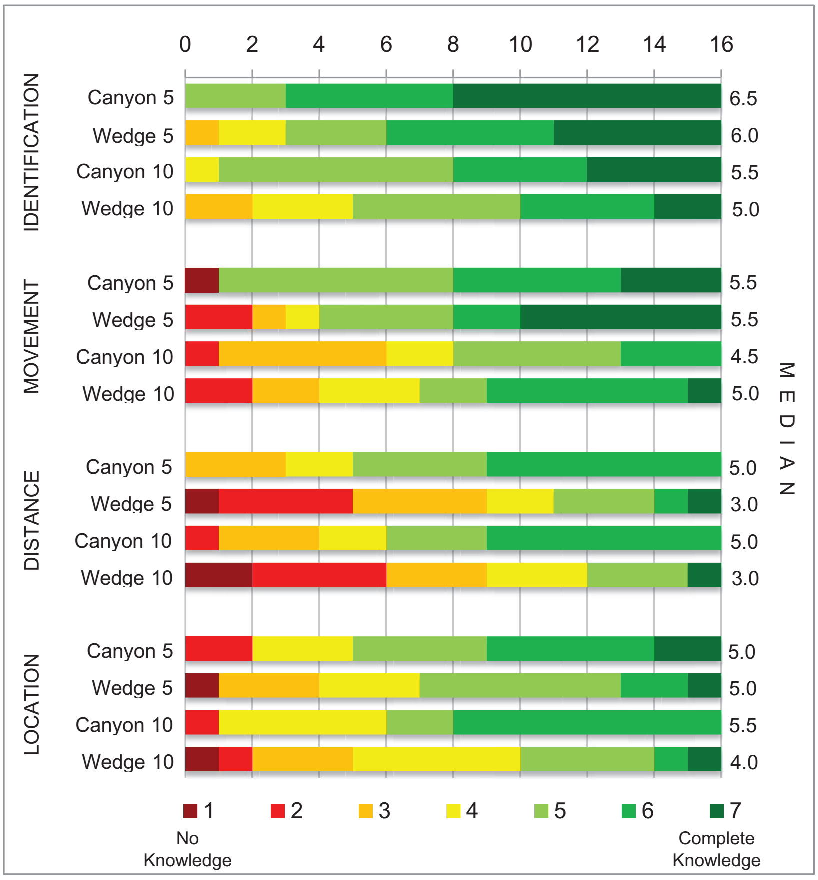


Figure 6.7: Subjective ratings of how much knowledge participants had about off-view objects. Per task and condition.

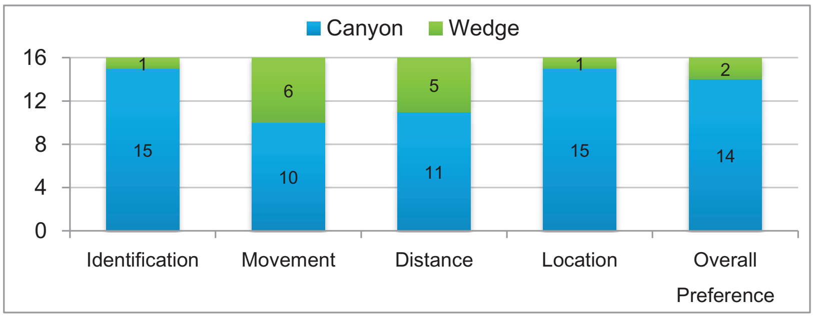


Figure 6.8: Overall preference of participants. Per task and overall.

6.2.2 Participants' Feedback

Participants were also interviewed about their overall preference after having completed the exit questionnaire. The interview was informal and both participants of a group were in the room during the interviews. Each of them was asked for a statement, which technique he or she preferred overall and for a short explanation why.

As previously shown, 14 participants stated in the exit questionnaire, that Canyon was the preferred technique. Twelve participants stated that they found Canyon "clearer" or "easier" because they were confident about the off-view objects locations. According to these participants, Canyon also provided good orientation by giving reference points within the cut-out view. Two participants gave the example of a roundabout, that is shown in both, the cut-out view as well as on the overview map and made finding the object's location easy. Another participant explained the same effect with seeing the green of a park within the object view.

> "I liked it [Canyon] better because it was easier to orientate with the small [cut-out] map and one can associate the object better. For example, if it is near a park, you see the green on the small [cut-out] map." – Participant 5B

Eight participants stated explicitly that they liked having the additional piece of map around the off-view object with the Canyon technique giving additional details. Two participants remarked negatively that Canyon uses much space, one also said that it can get confusing due to the growth.

Five participants said that estimating distance was difficult with Canyon.

> "It [Canyon] was more difficult for [estimating] distances because it was difficult to convert the shadow into distance information" – Participant 6A

This is interesting, since the Distance task was ranked significantly higher for Canyon compared to Wedge, as described earlier. In the interviews, participants referred to reading the exact distance from the shadow, rather than compare distances of objects to each other as done during the Distance task. Two participants stated explicitly that they felt, distance was better conveyed with Wedge. One participant suggested specifying the actual distance instead of folding. Another participant found the inconsistent base length of Wedges difficult to understand and proposed an interesting solution: using a circular detail view instead of a rectangular one. This idea will be discussed in the Future Work Section 7. Two participants felt that the fold and shadow metaphor of Canyon gave a good understanding of distance. However, improving distance awareness with Canyon should be subject of future work.

Participants gave more feedback about Canyon than Wedge. The Wedge technique was described by 9 participants as "confusing", especially with overlapping Wedges, “overcharging”, difficult to keep overview and imagine, where the cars are located.

> “I found it really difficult [with Wedge] to imagine where the legs intersect” – Participant 8B

> “You could locate the cars easier [with Canyon] because you did not have to imagine how big the triangles are once they are complete” – Participant 7B

One participant described Wedge as being “too abstract for people lacking imagination or spatial sense”. He personally liked Wedge, but slightly tended to Canyon. Another participant preferred Wedge over Canyon, because Wedge was clearer to him.

In summary, participants appreciated the high level of detail provided by Canyon and preferred it over the abstract cues of Wedge. They stated that estimating absolute distance was difficult with Canyon. The biggest weakness of Wedge were overlapping cues, which often confused the participants. Two participants used the term “intuitive” for describing Canyon. One participant described Canyon as being “somehow funnier”, showing that she enjoyed using the technique.

6.2.3 Study Observations

It was observed during the study, that participants used their hands in order to interpret Wedge properly. Some participants used small hand gestures as an aid to compare Wedges. Figure 6.9 shows how one participant traced the legs of a Wedge carefully with both hands at the Location task. After she

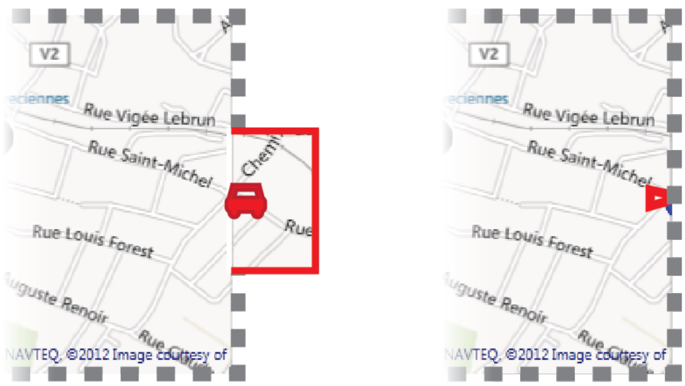
Figure 6.9: One strategy for interpreting Wedge. The participant traces the legs of Wedge with her fingers until they intersect. Then she measures the distance relative to the detail view.

found an intersection point, she measured the distance to the border of the detail view. Then she shifted this distance into the detail view to get the distance relatively to the detail view size. She used this relative distance for obtaining the proportions on the overview map. Participants did not use this tracing strategy from the start, but developed it during the first condition blocks.

Participants tended to step backwards to observe the movement of the cars. Increasing the distance to the display increased their focal range and conveyed a feeling of having better overview. Participants also stepped back in order to complete Wedges. In contrast, they looked very closely at Canyon's cut-out view. For both techniques participants looked repeatedly to the detail map and overview map. However, they compared detail and overview map more extensively with Canyon. This is due to their strategy of finding object's locations by matching the corresponding map areas.

One configuration of the Distance task contained an off-view object, which was very close to the detail view. Figure 6.10 shows this configuration with both off-view techniques. The Wedge representing this object is very small, which lead to overlooking it. Four out of 8 participants missed to select it as the closest object. In contrast, none of the participants facing this configuration with Canyon missed it.

In conclusion, participants appreciated the additional detail provided by Canyon and preferred it over the abstract cues in Wedge. For them, estimating absolute distance was difficult with Canyon, and the main drawback of Wedge were the overlapping cues, which often confused the participants.



(a) (b)

Figure 6.10: A very close off-view object visualized with Canyon (a) and with Wedge (b).

6.3 Discussion

The results of this study indicate that Canyon and Wedge perform similar with low density. There were no statistically significant differences in Technique in the 5 car conditions. However, the differences become significant with higher density, which was tested in this study with 10 cars. Therefore, the mentioned quantitative results in this discussion refer to results in the 10 cars condition. Results from the 5 cars conditions are explicitly identified as such.

The quantitative results suggest some positive results for accuracy in favor of Canyon over Wedge in the 10 cars condition, with no corresponding differences in trial completion time, suggesting that this benefit does not come at the cost of speed. Furthermore, participants preferred Canyon over Wedge. While this study was framed in a police emergency response context with moving cars as targets, the results will likely generalize to other situations involving large screen setups with moving targets and the need for detailed views. The tasks were designed to reflect strengths and weaknesses of the techniques regarding general off-view object features like location, distance and movement.

Specifically, the results indicate that Canyon more accurately conveyed movement in the Movement task. Even though the amount of objects on the screen and the growth of Canyon may overwhelm participants, they still performed better using Canyon. This improved movement awareness may be due to Canyon placing off-view objects outside of the workspace, where movement can be perceived in the periphery.

While there was no error at all at the Identification task with 5 cars, with none of the two techniques and the error was very little (5.5%, n.s.) with 10 cars, the trial completion time with 10 cars was significantly different. Participants were faster with Wedge. Although participants used the same strategy to solve the task—namely search the object relative to the marked detail area—Canyon was slower. As dicussed in the results, this is due to the growth of Canyon, even exceeding the screen borders. Participants did not see some targets and had to move the window to find them and complete the task.

The results also suggest that Canyon allows participants to be more accurate at measuring distance, which corresponds well with participants' stated preferences. However, five participants stated during interviews that they could not determine the target distance by observing the shadow. A distinction between *relative* and *absolute* distance conveyed by Canyon may help to explain this discrepancy. In the Distance task, participants were required to estimate the relative distance (i.e., first and second closest cars). We suspect that participants are instead referring to an inability to precisely measure the absolute distance, rather than an inability to describe the next closest target. Unlike in Wedge, where the closest target may result in a very small triangle, off-view targets in Canyon have more consistent sizes. Even though the corners require more effort to interpret, the Canyon visualization, namely the distortion and shadow, is consistent for both corner and regular cases.

These same comments also seem to contradict the quantitative results about absolute location awareness in the Location task. Using Canyon, participants measured 1.24 cm more accurately than with Wedge, despite the comment that the shadows were insufficient. Interviews with the participants revealed a potential explanation. Participants commented that even though it was difficult to estimate the exact distance with Canyon, the cut-out views provided cues to the exact location of the targets, such as landmarks and features of the landscape. Moreover, participants were able to compare the cut-out views with the overview map to match the location in Canyon. In contrast, Wedge does not provide extra clues to the surrounding and participants had to rely only on their estimation of the intersection of wedge legs.

Although the minimum values were not statistically significant, we believe the minimum values for estimating location indicate the potential of Canyon. For better imagination, how accurate the actual location location was estimated, the values are given in meters. While the minimum error with Canyon was 8 m in the 5 car condition, the minimum error with Wedge amounted to 52 m. With 10 cars, the minimum error with Canyon was 4 m, while with Wedge it was 13 m. Although 13 m are already very accurate, 4 m is even higher than current GPS accuracy[1].

6.3.1 Design Recommendations

Based on the results of this study, designers of applications running on large scale displays involving individual workspaces and moving off-view objects should consider the following design recommendations:

Provide context of the off-view targets. The results showed that providing the surrounding area of off-view objects provided clues and awareness of their location. This information was especially helpful on top of the distance cues conveyed by distortion and shadow. Participants also rated Canyon higher and preferred the provided context more than the abstract cues in Wedge.

Make distance cues consistent. The findings revealed the importance of providing a consistent visualization and the fact that people may first interpret a visualization based on the most salient features, such as the base length in Wedge. Moreover, the results indicated that Canyon's paper folding metaphor provided a more understandable method to interpret relative distance for the participants than Wedge did. It also

[1] GPS Standard Positioning Service Performance Standard (SPS PS) accuracy is 7.8 meters (95% confidence) [19].

enabled higher accuracy while maintaining comparable speed. However, special attention is needed for objects at extreme distance, such as very close or distant. One approach may be to adjust the parameters of the shadow in a consistent manner based on the specific situations to increase its expressiveness.

Avoid clutter and pay attention to dynamic movement. Despite the success of Wedge on mobile devices and its compact design, the results revealed that the interface was too cluttered and confusing for the participants in the large display environment. Thus, the design should avoid clutter and overlapping of cues. The jiggling of the cues in the high-density condition was another factor that confused participants in Wedge. Designers should consider both static and dynamic aspects of the visualization.

Stem growth and ensure visibility. Uncontrolled growth of Canyon was intentionally allowed in the study to investigate trade-offs in Canyon's design. However, the results revealed that this growth significantly increased the time to perform tasks. Therefore, off-view objects should always remain visible and not exceeding the screen border so the awareness of the objects is preserved.

6.3.2 Categorizing the Study

As McGrath stated in [36], generalizability over populations, precision in control and measurement and realism of context cannot be maximized simultaneously. This study is considered a controlled laboratory experiment and the focus lied on precision in measurement. However, to validate whether the results can hold in a real world setup, the study was conducted in an police emergency response context. In fact, the study hardware had the same specifications as the whiteboard installed at the Upper Austrian police command center. Therefore a tendency towards realism is given. This study is classified between precision and realism on McGrath's Research Strategies chart, but closer to precision than realism (see Figure 6.11).

6.3.3 Generalizing Canyon

Canyon was evaluated within a map-based interactive large display that provided individual workspaces, for an emergency response context. However, the general "off-view object" context may be applicable to other task contexts.

Canyon may be useful for content management on a large display. In a multi-monitor desktop environment, people often have a primary task on the primary monitor and multiple types of content opened on the secondary monitor to support the primary task [20]. This also applies to large displays. Consider working on the layout of a large poster of size DIN A1 (841

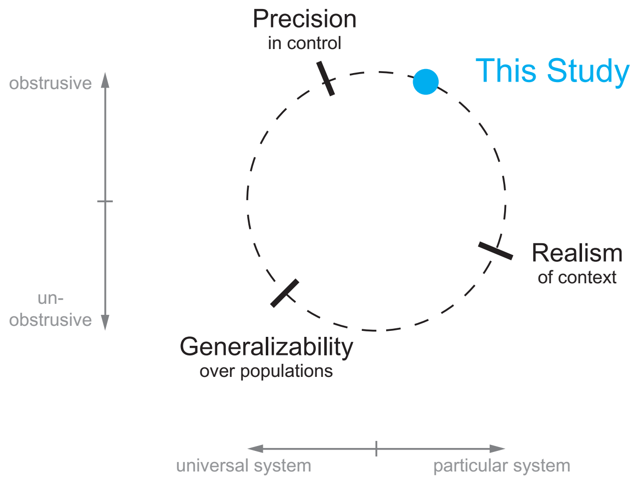


Figure 6.11: Categorization of this study according to McGrath's chart of research strategies [36].

× 594 mm) on a large whiteboard to edit it in its original scale. Multiple folder views might be opened and contain input for the poster, such as text, sponsors' logos and potential images. Often, a web browser view is needed to search for the appropriate fonts or images, and mail client for related email threads and attachments. In this case, the primary task is in the view containing the poster design, and folder, web browser and mail client views are secondary tasks, assisting the primary task. Opened views for secondary tasks could be removed from the screen to reduce clutter and be represented by Canyon around the primary-task-view. This reduces distance on a large display [3] and facilitates efficient retrieval of required views due to cognitively associated locations.

Canyon may also be used in a calendar view for visualizing future appointments or events. For example, the current time point plus 6 hours are presented in detail. The y-axis might represent hours and the x-axis might represent days. Future calendar items are laid out accordingly using Canyon to represent the connection to the current time point.

Canyon may also be used for exploring large node-link diagrams, like UML-diagrams or mind maps. Moreover, trees or node-link graphs are common structures for many interfaces' underlying data, such as Twitter tweets with conversation history. With many Twitter clients, views have to be changed to see the underlying conversation of a tweet. Canyon can show the headline of the underlying conversation within the same view, providing awareness if there is additional content and providing a preview of existing content.

Chapter 7

Conclusion

This work presented Canyon, a novel off-view visualization technique for large-display applications. It provided a high level of detail and employed a paper folding metaphor. Therefore, it used both distortion and shadow to convey distance information. The additional detail provided by showing the surrounding area of an off-view object gave additional cues for location awareness. An empirical laboratory-based user study was conducted to investigate the effectiveness and efficiency of Canyon compared with an established technique, Wedge. Results revealed that Canyon improved the accuracy in the high-density condition while maintaining comparable speed, across density conditions, to Wedge. Furthermore, participants acknowledged the additional detail provided with Canyon in interviews and questionnaires and 14 out of 16 participants reported preferring Canyon overall.

Contribution

This work addressed the largely unexplored issue of having visible on-screen objects but people not being able to see them due to their restricted field of view, when working with individual workspaces. We called this the "off-view" problem. Although it relates to the "off-screen" problem, this term is not appropriate due to objects might being visible somewhere on the screen of the large display. Furthermore, a technique for informing users about off-view objects by providing a high level of detail was developed and evaluated. Known related literature provides information about off-screen objects with abstract cues, providing a low level of detail. Results showed that a higher level of detail assisted accuracy at off-view objects' location awareness.

Future Work

This study was designed as an initial study to find out, if the idea of providing additional detail is beneficial for conveying movement, distance and location awareness. Furthermore, study results were expected to point out areas requiring further investigation.

The uncontrolled growth of Canyon visualizations does not guarantee visibility of off-view object visualizations. In order to stem Canyon's growth the visualizations' sizes should be reduced. However, the beneficial effects of providing additional detail must be preserved. Therefore, it is to be investigated *how much* detail is required to preserve benefits at enhancing off-view objects' location awareness. In other words, the break-even point of level of detail and visualization size has to be found.

In-depth knowledge of an area can be particularly beneficial when using Canyon for showing off-view objects on maps. Further research can investigate how much performance improvement can be gained with Canyon for people with knowledge of the local area.

Since corners are a well-known problem in off-screen visualization techniques and have not been explicitly tested in this study, further investigation with focus on corners should be considered. Individual views on a large display can be circular and therefore have no corner regions. The effects of having circular views but no corner issues can be investigated in future work.

Some study participants reported not being able to interpret the distance information conveyed by Canyon's shadow. An understandable scale of the shadow cue is necessary, in order to make distances readable. A similar approach like Mélange's [14] fold pages might be an interesting solution and should be studied.

Since this work only concentrated on visualizing off-view objects, interaction techniques for allowing people to determine *which* objects to visualize are to be researched. Finally, adding interaction functionalities like dynamically focusing an off-view object by tapping its representation should be added.

Appendix A

Study Material

A.1 Consent Form

Einverständniserklärung

Studie zur Effektivität von Off-Screen Visualisierungen von bewegten Objekten auf Karten auf einem interaktiven Whiteboard

Bitte lesen sie sich dieses Dokument sorgfältig durch und wenden Sie sich bei möglichen Fragen direkt an einen der Untersuchungsleiter Alexandra Ion oder Betty Chang.

Alle von Ihnen erhobenen Daten werden vertraulich behandelt. Nur die Mitglieder des Projektteams haben Zugang zu den von Ihnen erhobenen Daten. Die Darstellung der Untersuchungsergebnisse erfolgt ausschließlich in anonymisierter Form. Personenbezogene Informationen werden, falls erforderlich, so verändert, dass keine Rückschlüsse auf die Ursprungsperson möglich sind.

Ihre Teilnahme an der Untersuchung ist freiwillig. Sie können die Bereitschaft zur Teilnahme jederzeit widerrufen beziehungsweise die Teilnahme an der Untersuchung abbrechen.

Durch Ihre Unterschrift erklären Sie, dass Sie freiwillig an der Untersuchung teilnehmen und dass Sie den Inhalt der Einverständniserklärung gelesen und verstanden haben.

Bei Fragen zur Untersuchung und zu Ihren Rechten als Untersuchungsteilnehmer steht Ihnen die Untersuchungsleiterin Alexandra Ion (S1010629011@students.fh-hagenberg.at) sowie Dr. Michael Haller (michael.haller@fh-hagenberg.at) gerne zur Verfügung.

Name, Datum, Unterschrift

A.2 Questionnaires

A.2.1 Background Questionnaire

Background Questionnaire

* Required

Participant ID *

What is your age? *

What is your gender? *

- Male
- Female

What is your occupation or program? *
e.g. MTD, MC, etc

How many hours do you use a computer per day? *

What is your dominant hand? *

- Left hand
- Right hand

What is your native language? *

How comfortable are you with English *

	1	2	3	4	5	6	7	
Not comfortable with English	○	○	○	○	○	○	○	Very comfortable with English

How frequent do you use pen-based or direct touch computational devices? *
e.g. tablets and smartphones

- Frequently throughout the day
- Daily
- Several times a week
- Weekly
- Several times a month
- Never

How much experience do you have using pen-based computational devices? *

- None
- Less than a month
- Less than a year
- 1 to 5 years
- More than 5 years

How frequent do you use digital map systems? *
e.g. Google map, MapQuest, and GPS systems

- Frequently throughout the day
- Daily
- Several times a week
- Weekly
- Several times a month
- Never

How much experience do you have using interactive whiteboards? *

- None
- Less than a month
- Less than a year
- 1 to 5 years
- More than 5 years

How much experience do you have using interactive pen-based whiteboards? *

- None
- Less than a month
- Less than a year
- 1 to 5 years
- More than 5 years

Submit

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A.2.2 Condition Questionnaire

Participants completed 4 condition questionnaires, one for each combination of visualization technique and density. The questions were identical for all condition questionnaires.

Wedge Questionnaire - 5 Cars

* Required

Participant ID *

For finding the corresponding car on the overview map, how well could you find the car? *

	1	2	3	4	5	6	7	
I could not find them at all	○	○	○	○	○	○	○	I could always find them easily

For monitoring the cars, were you looking at the overview map or your detail map? *

- ○ Overview map
- ○ Detail map
- ○ Other:

For identifying stationary cars, how well could you identify stationary cars? *

	1	2	3	4	5	6	7	
I could not identify the stationary cars at all	○	○	○	○	○	○	○	I could always identify the stationary cars easily

For estimating the closest cars, how well could you estimate the closest cars? *
Including the 2nd and 3rd closest cars

	1	2	3	4	5	6	7	
I could not identify the closest cars	○	○	○	○	○	○	○	I could always find the closest cars easily

For marking the exact location of a highlighted car on overview map, how well did you know the exact location of the cars? *

	1	2	3	4	5	6	7	
I did not know the exact locations of cars	○	○	○	○	○	○	○	I always knew the exact locations of cars

How disturbing was the partner's detail map? *

	1	2	3	4	5	6	7	
Not disturbing at all	○	○	○	○	○	○	○	Too disturbing

Submit

A.2.3 Exit Questionnaire

Exit Questionnaire

* Required

Participant ID *

For finding the corresponding car on the overview map, which technique was more helpful? *

- Wedge
- Canyon Melange

For finding the corresponding car on the overview map, what strategy did you use in the Wedge technique? *

- I used the relative location of cars on the overview map to find the car
- I knew where the cars were located based on my detail map
- Other:

For finding the corresponding car on the overview map, what strategy did you use in the Canyon Melange technique? *

- I used the relative location of cars on the overview map to find the car
- I knew where the cars were located based on my detail map
- Other:

For identifying stationary cars, which technique was more helpful? *

- Wedge
- Canyon Melange

For estimating the closest cars, which technique was more helpful? *

- Wedge
- Canyon Melange

For marking the exact location of a highlighted car on overview map, which technique was more helpful? *

- Wedge
- Canyon Melange

Which technique produced the least amount of distractions from your partner's detail map? *

- Wedge
- Canyon Melange

Which technique did you like more? *

- Wedge
- Canyon Melange

Appendix B

Study Results

B.1 Interview Transcript

Interviews were given in German and translated for this thesis into English by the author.

Participant 1A: I preferred Canyon, because you could see the corresponding map area around the car on the overview map. I would give every car a different color. I suggest to take Canyon, give every car a different color and an outline, if they are stationary. With Wedge, you always have to approximate it in your mind. Most difficult with Canyon was estimating distance.

Participant 1B: I preferred Canyon, it was more clear because of the map, but I rather had just a [detail] map, because when cars are marked on the detail map, why don't they stay marked on the big [overview] map, then I would automatically know the distance. When triangles overlap too much, you could not see anything. Usually in police or ambulance fields, the cars tell you when they arrived, and you don't need to look if car just moved or not.

Participant 2A: I preferred the first technique [Canyon], it seems more clear than the one with the triangles [Wedge].

Participant 2B: I like the first one [Canyon] a bit better, because you had the cars still within the detail view and did not lose overview as with the triangles. It would have been easier, if the detail map would have been circular for Wedge, because then you do not need to zoom in the corners, you do not need to change the triangles in the corners [refers to inconsistent base length in the corners]. But from the two techniques, the first one [Canyon] was easier.

Participant 3A: Both techniques have advantages and disadvantages. For Wedge, the map of the partner does not distract you so easily, because it stays smaller. It's easier to find the closest car fast, simply because smaller arrows mean closer objects. You see that faster than if you have to watch out for details like if it's folded and folded again and how dark the shadow is. That takes longer to associate [distance information]. With Canyon it was easier to assign cars because one had more detail, where they should approximately be. So you saw [on the cut-out map] that there is a roundabout or a ramp, which makes it easier to assign cars. Other than that, both techniques have advantages. It depends on the use. It gets harder with more cars, with 5 cars it was always easier than with 10 cars. From my gut feeling I liked Canyon better, it seemed more professional and you could not imagine enough with the triangles. [Wedge] might be too abstract for people lacking imagination or spatial sense. I suggest to replace the folding with giving concrete distance. I liked both, Wedge because I could imagine the locations, Canyon because of the level of detail. I would like to have a combination of both techniques. Both are lacking some details to make them usable. A slight tendency to Canyon is given, but I liked both.

Participant 3B: I definitely liked Canyon better, because you had a piece of map which made orientation easier. I was totally overcharged with Wedge.

Participant 4A: I liked Canyon way better, also for estimating distances. I felt that the folds were more clear than the Wedges. I could not find out about the object's location with the angles [between Wedged's base and legs].

Participant 4B: I preferred Canyon, simply because it was more clear, therefore I could imagine easier where the car was. That's why I am a fan of that technique, except for estimating distances. For that Wedge is easier, because you can't tell the exact distance from the folds. But other than that I clearly preferred the first technique [Canyon].

Participant 5A: Both have advantages and disadvantages. I liked that you saw the streets with Canyon, because the triangle was confusing. I had no idea where it pointed [referred to Location task]. On the other hand, it [Canyon] used more space and became confusing. And especially in the corners I had no clue about how far the cars were. And when the shadow got darker, I could not tell anymore if it is a farther distance or a closer. I did not like estimating distances with both techniques. Wedge was more clear.

Participant 5B: I liked the second technique [Canyon] better, because it was easier to orientate with the small [cut-out] map and one could associate the object better. For example, if it was near a park, you could see the green on the small [cut-out] map. The one with the triangles [Wedge], goes crazy, when multiple [triangles] overlap and you do not stand a chance anymore.

Participant 6A: I preferred the first technique [Canyon]. It was more difficult for distances because it was difficult to convert the shadow into distance information. But you still had a mini map which provided a point of orientation. For example, you could recognize a roundabout on the [cut-out] map as well as on the overview map, which gives a good point of reference. I think that overall Canyon is better. It is more intuitive, but you have to get used to it. It is more effective than estimating triangles. When you know how much shadow means what distance, it is definitely as good [as Wedge].

Participant 6B: I preferred Canyon, because you had a small detail map [cut-out map], and if you also have local knowledge like with the Linz map, it is easier to assign locations. I also had a hard time estimating the distances with the shadow, because often is was just fine gray gradations, but all in all I liked Canyon better.

Participant 7A: I also liked the second technique [Canyon] better. I found it more clear because the distance was easier to estimate, how far the cars were away. I did not find the triangles very intuitive, unlike the shadow.

Participant 7B: I liked the second technique [Canyon] better, because you could locate the cars easier. You did not have to image how big the triangles are once they are completed. The shadow seemed like it got one unit darker, when the car is one rectangle [detail view area] farther away.

Participant 8A: In the beginning, both took some getting used to, but I liked the first one [Canyon] better, because it was more useful for most tasks. But for some tasks, the other one [Wedge] was also not bad. The first one [Canyon] was better for identifying the cars, with the second one [Wedge], the triangles did overlap, making it difficult to find the corresponding car. You could identify the cars better with the first technique [Canyon], and you could see better, which car was closer.

Participant 8B: I liked the first one [Canyon] better, it was somehow funnier. With the second one [Wedge], you did not see the cars and you did not really know where the cars were. With the first technique [Canyon], you had a small [cut-out] map, and you could orientate yourself with the streets on that map. I found it really difficult [with Wedge] to imagine where the legs intersect.

B.2 ANOVA Results

B.2.1 Identification Task

Five Cars Analysis

Trial Completion Time

Tests of Within-Subjects Effects

Measure: Density5_CompletionTime_ms

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	23384.691	1	23384.691	.006	.940	.000
	Greenhouse-Geisser	23384.691	1.000	23384.691	.006	.940	.000
	Huynh-Feldt	23384.691	1.000	23384.691	.006	.940	.000
	Lower-bound	23384.691	1.000	23384.691	.006	.940	.000
Technique * Position	Sphericity Assumed	3774122.749	1	3774122.749	.958	.346	.069
	Greenhouse-Geisser	3774122.749	1.000	3774122.749	.958	.346	.069
	Huynh-Feldt	3774122.749	1.000	3774122.749	.958	.346	.069
	Lower-bound	3774122.749	1.000	3774122.749	.958	.346	.069
Technique * DensityOrder	Sphericity Assumed	25881576.870	1	25881576.870	6.570	.024	.336
	Greenhouse-Geisser	25881576.870	1.000	25881576.870	6.570	.024	.336
	Huynh-Feldt	25881576.870	1.000	25881576.870	6.570	.024	.336
	Lower-bound	25881576.870	1.000	25881576.870	6.570	.024	.336
Error(Technique)	Sphericity Assumed	51210051.830	13	3939234.756			
	Greenhouse-Geisser	51210051.830	13.000	3939234.756			
	Huynh-Feldt	51210051.830	13.000	3939234.756			
	Lower-bound	51210051.830	13.000	3939234.756			

Tests of Between-Subjects Effects

Measure: Density5_CompletionTime_ms

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1847832239.863	1	1847832239.863	181.116	.000	.933
Position	10733572.280	1	10733572.280	1.052	.324	.075
DensityOrder	3094182.044	1	3094182.044	.303	.591	.023
Error	132632398.317	13	10202492.178			

2. Technique

Estimates

Measure: Density5_CompletionTime_ms

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	3785.982	289.082	3161.459	4410.505
Wedge	3813.015	370.670	3012.231	4613.799

3. Position

Estimates

Measure: Density5_CompletionTime_ms

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	3509.920	399.267	2647.356	4372.483
Right	4089.078	399.267	3226.514	4951.641

4. DensityOrder

Estimates

Measure: Density5_CompletionTime_ms

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	3644.021	399.267	2781.458	4506.584
Ten_Five	3954.976	399.267	3092.413	4817.540

5. Technique * DensityOrder

Estimates

Measure: Density5_CompletionTime_ms

Technique		Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Canyon	Five_Ten	4080.171	408.823	3196.962	4963.380
	Ten_Five	3491.793	408.823	2608.585	4375.002
Wedge	Five_Ten	3207.871	524.207	2075.391	4340.351
	Ten_Five	4418.159	524.207	3285.679	5550.639

Pairwise Comparisons

Measure: Density5_CompletionTime_ms

DensityOrder			Mean Difference (I-J)	Std. Error	Sig.[a]	Difference[a] Lower Bound	Upper Bound
Five_Ten	Canyon	Wedge	872.300	496.188	.102	-199.648	1944.248
	Wedge	Canyon	-872.300	496.188	.102	-1944.248	199.648
Ten_Five	Canyon	Wedge	-926.365	496.188	.085	-1998.314	145.583
	Wedge	Canyon	926.365	496.188	.085	-145.583	1998.314

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Ten Cars Analysis

Error

Tests of Within-Subjects Effects

Measure: Density10_Error

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	.008	1	.008	.351	.564	.026
	Greenhouse-Geisser	.008	1.000	.008	.351	.564	.026
	Huynh-Feldt	.008	1.000	.008	.351	.564	.026
	Lower-bound	.008	1.000	.008	.351	.564	.026
Technique * Position	Sphericity Assumed	.070	1	.070	3.162	.099	.196
	Greenhouse-Geisser	.070	1.000	.070	3.162	.099	.196
	Huynh-Feldt	.070	1.000	.070	3.162	.099	.196
	Lower-bound	.070	1.000	.070	3.162	.099	.196
Technique * DensityOrder	Sphericity Assumed	.008	1	.008	.351	.564	.026
	Greenhouse-Geisser	.008	1.000	.008	.351	.564	.026
	Huynh-Feldt	.008	1.000	.008	.351	.564	.026
	Lower-bound	.008	1.000	.008	.351	.564	.026
Error(Technique)	Sphericity Assumed	.289	13	.022			
	Greenhouse-Geisser	.289	13.000	.022			
	Huynh-Feldt	.289	13.000	.022			
	Lower-bound	.289	13.000	.022			

Tests of Between-Subjects Effects

Measure: Density10_Error

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	.383	1	.383	3.861	.071	.229
Position	.008	1	.008	.079	.783	.006
DensityOrder	.195	1	.195	1.970	.184	.132
Error	1.289	13	.099			

2. Technique

Estimates

Measure: Density10_Error

Technique	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Canyon	.047	.023	-.004	.097
Wedge	.063	.037	-.017	.142

3. Position

Estimates

Measure: Density10_Error

Position	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Left	.063	.039	-.023	.148
Right	.047	.039	-.038	.132

4. DensityOrder

Estimates

Measure: Density10_Error

DensityOrder	Mean	Std. Error	95% Confidence Interval Lower Bound	Upper Bound
Five_Ten	.016	.039	-.069	.101
Ten_Five	.094	.039	.009	.179

Trial Completion Time

Tests of Within-Subjects Effects

Measure: Density10_CompletionTime_ms

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	107266758.534	1	107266758.534	6.037	.029	.317
	Greenhouse-Geisser	107266758.534	1.000	107266758.534	6.037	.029	.317
	Huynh-Feldt	107266758.534	1.000	107266758.534	6.037	.029	.317
	Lower-bound	107266758.534	1.000	107266758.534	6.037	.029	.317
Technique * Position	Sphericity Assumed	633869.907	1	633869.907	.036	.853	.003
	Greenhouse-Geisser	633869.907	1.000	633869.907	.036	.853	.003
	Huynh-Feldt	633869.907	1.000	633869.907	.036	.853	.003
	Lower-bound	633869.907	1.000	633869.907	.036	.853	.003
Technique * DensityOrder	Sphericity Assumed	86693.949	1	86693.949	.005	.945	.000
	Greenhouse-Geisser	86693.949	1.000	86693.949	.005	.945	.000
	Huynh-Feldt	86693.949	1.000	86693.949	.005	.945	.000
	Lower-bound	86693.949	1.000	86693.949	.005	.945	.000
Error(Technique)	Sphericity Assumed	230993473.886	13	17768728.760			
	Greenhouse-Geisser	230993473.886	13.000	17768728.760			
	Huynh-Feldt	230993473.886	13.000	17768728.760			
	Lower-bound	230993473.886	13.000	17768728.760			

Tests of Between-Subjects Effects

Measure: Density10_CompletionTime_ms

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	4094247264.913	1	4094247264.913	145.358	.000	.918
Position	23427125.785	1	23427125.785	.832	.378	.060
DensityOrder	151429948.209	1	151429948.209	5.376	.037	.293
Error	366166940.973	13	28166687.767			

2. Technique

Estimates

Measure: Density10_CompletionTime_ms

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	6571.079	809.473	4822.320	8319.838
Wedge	4740.209	249.990	4200.139	5280.278

3. Position

Estimates

Measure: Density10_CompletionTime_ms

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	6083.457	663.404	4650.261	7516.654
Right	5227.830	663.404	3794.634	6661.027

4. DensityOrder

Estimates

Measure: Density10_CompletionTime_ms

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	4567.964	663.404	3134.768	6001.161
Ten_Five	6743.323	663.404	5310.127	8176.520

B.2.2 Movement Task

Five Cars Analysis

Omission Error

Tests of Within-Subjects Effects

Measure: Density5_Error

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	.139	1	.139	3.563	.082	.215
	Greenhouse-Geisser	.139	1.000	.139	3.563	.082	.215
	Huynh-Feldt	.139	1.000	.139	3.563	.082	.215
	Lower-bound	.139	1.000	.139	3.563	.082	.215
Technique * Position	Sphericity Assumed	.084	1	.084	2.149	.166	.142
	Greenhouse-Geisser	.084	1.000	.084	2.149	.166	.142
	Huynh-Feldt	.084	1.000	.084	2.149	.166	.142
	Lower-bound	.084	1.000	.084	2.149	.166	.142
Technique * DensityOrder	Sphericity Assumed	.033	1	.033	.842	.376	.061
	Greenhouse-Geisser	.033	1.000	.033	.842	.376	.061
	Huynh-Feldt	.033	1.000	.033	.842	.376	.061
	Lower-bound	.033	1.000	.033	.842	.376	.061
Error(Technique)	Sphericity Assumed	.507	13	.039			
	Greenhouse-Geisser	.507	13.000	.039			
	Huynh-Feldt	.507	13.000	.039			
	Lower-bound	.507	13.000	.039			

Tests of Between-Subjects Effects

Measure: Density5_Error

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	.938	1	.938	12.051	.004	.481
Position	.149	1	.149	1.907	.191	.128
DensityOrder	.036	1	.036	.462	.509	.034
Error	1.012	13	.078			

2. Technique

Estimates

Measure: Density5_Error

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	.168	.053	.054	.282
Wedge	.074	.030	.011	.138

3. Position

Estimates

Measure: Density5_Error

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	.169	.049	.063	.276
Right	.073	.049	-.034	.179

4. DensityOrder

Estimates

Measure: Density5_Error

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	.145	.049	.038	.251
Ten_Five	.097	.049	-.009	.204

False-Positive Error

Tests of Within-Subjects Effects

Measure: Density5_Error

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	0.000	1	0.000	0.000	1.000	0.000
	Greenhouse-Geisser	0.000	1.000	0.000	0.000	1.000	0.000
	Huynh-Feldt	0.000	1.000	0.000	0.000	1.000	0.000
	Lower-bound	0.000	1.000	0.000	0.000	1.000	0.000
Technique * Position	Sphericity Assumed	.035	1	.035	.684	.423	.050
	Greenhouse-Geisser	.035	1.000	.035	.684	.423	.050
	Huynh-Feldt	.035	1.000	.035	.684	.423	.050
	Lower-bound	.035	1.000	.035	.684	.423	.050
Technique * DensityOrder	Sphericity Assumed	.016	1	.016	.304	.591	.023
	Greenhouse-Geisser	.016	1.000	.016	.304	.591	.023
	Huynh-Feldt	.016	1.000	.016	.304	.591	.023
	Lower-bound	.016	1.000	.016	.304	.591	.023
Error(Technique)	Sphericity Assumed	.668	13	.051			
	Greenhouse-Geisser	.668	13.000	.051			
	Huynh-Feldt	.668	13.000	.051			
	Lower-bound	.668	13.000	.051			

Tests of Between-Subjects Effects

Measure: Density5_Error

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	.316	1	.316	8.631	.012	.399
Position	.016	1	.016	.426	.525	.032
DensityOrder	.035	1	.035	.959	.345	.069
Error	.477	13	.037			

2. Technique

Estimates

Measure: Density5_Error

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	.070	.039	-.013	.154
Wedge	.070	.036	-.006	.147

3. Position

Estimates

Measure: Density5_Error

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	.055	.034	-.018	.128
Right	.086	.034	.013	.159

4. DensityOrder

Estimates

Measure: Density5_Error

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	.094	.034	.021	.167
Ten_Five	.047	.034	-.026	.120

Overall Error

Tests of Within-Subjects Effects

Measure: Density5_Error

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	.016	1	.016	.326	.578	.024
	Greenhouse-Geisser	.016	1.000	.016	.326	.578	.024
	Huynh-Feldt	.016	1.000	.016	.326	.578	.024
	Lower-bound	.016	1.000	.016	.326	.578	.024
Technique * Position	Sphericity Assumed	.076	1	.076	1.578	.231	.108
	Greenhouse-Geisser	.076	1.000	.076	1.578	.231	.108
	Huynh-Feldt	.076	1.000	.076	1.578	.231	.108
	Lower-bound	.076	1.000	.076	1.578	.231	.108
Technique * DensityOrder	Sphericity Assumed	.076	1	.076	1.578	.231	.108
	Greenhouse-Geisser	.076	1.000	.076	1.578	.231	.108
	Huynh-Feldt	.076	1.000	.076	1.578	.231	.108
	Lower-bound	.076	1.000	.076	1.578	.231	.108
Error(Technique)	Sphericity Assumed	.623	13	.048			
	Greenhouse-Geisser	.623	13.000	.048			
	Huynh-Feldt	.623	13.000	.048			
	Lower-bound	.623	13.000	.048			

Tests of Between-Subjects Effects

Measure: Density5_Error

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	.856	1	.856	16.048	.001	.552
Position	.031	1	.031	.574	.462	.042
DensityOrder	.051	1	.051	.950	.348	.068
Error	.693	13	.053			

2. Technique

Estimates

Measure: Density5_Error

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	.131	.046	.032	.231
Wedge	.100	.032	.031	.169

3. Position

Estimates

Measure: Density5_Error

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	.138	.041	.049	.226
Right	.094	.041	.006	.182

4. DensityOrder

Estimates

Measure: Density5_Error

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	.144	.041	.056	.232
Ten_Five	.088	.041	-.001	.176

Trial Completion Time

Tests of Within-Subjects Effects

Measure: Density5_CompletionTime_ms

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	674118.156	1	674118.156	.050	.826	.004
	Greenhouse-Geisser	674118.156	1.000	674118.156	.050	.826	.004
	Huynh-Feldt	674118.156	1.000	674118.156	.050	.826	.004
	Lower-bound	674118.156	1.000	674118.156	.050	.826	.004
Technique * Position	Sphericity Assumed	21958765.282	1	21958765.282	1.632	.224	.112
	Greenhouse-Geisser	21958765.282	1.000	21958765.282	1.632	.224	.112
	Huynh-Feldt	21958765.282	1.000	21958765.282	1.632	.224	.112
	Lower-bound	21958765.282	1.000	21958765.282	1.632	.224	.112
Technique * DensityOrder	Sphericity Assumed	7640569.933	1	7640569.933	.568	.465	.042
	Greenhouse-Geisser	7640569.933	1.000	7640569.933	.568	.465	.042
	Huynh-Feldt	7640569.933	1.000	7640569.933	.568	.465	.042
	Lower-bound	7640569.933	1.000	7640569.933	.568	.465	.042
Error(Technique)	Sphericity Assumed	174890935.543	13	13453148.888			
	Greenhouse-Geisser	174890935.543	13.000	13453148.888			
	Huynh-Feldt	174890935.543	13.000	13453148.888			
	Lower-bound	174890935.543	13.000	13453148.888			

Tests of Between-Subjects Effects

Measure: Density5_CompletionTime_ms

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1995771209.130	1	1995771209.130	162.171	.000	.926
Position	6194584.943	1	6194584.943	.503	.491	.037
DensityOrder	49180781.663	1	49180781.663	3.996	.067	.235
Error	159985676.318	13	12306590.486			

2. Technique

Estimates

Measure: Density5_CompletionTime_ms

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	5481.626	621.902	4138.089	6825.163
Wedge	5686.888	646.707	4289.762	7084.014

3. Position

Estimates

Measure: Density5_CompletionTime_ms

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	5895.368	620.146	4555.625	7235.112
Right	5273.145	620.146	3933.402	6612.889

4. DensityOrder

Estimates

Measure: Density5_CompletionTime_ms

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	6460.870	620.146	5121.126	7800.613
Ten_Five	4707.644	620.146	3367.900	6047.388

Ten Cars Analysis

Omission Error

Tests of Within-Subjects Effects

Measure: Density10_Error

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	.301	1	.301	3.270	.094	.201
	Greenhouse-Geisser	.301	1.000	.301	3.270	.094	.201
	Huynh-Feldt	.301	1.000	.301	3.270	.094	.201
	Lower-bound	.301	1.000	.301	3.270	.094	.201
Technique * Position	Sphericity Assumed	.048	1	.048	.517	.485	.038
	Greenhouse-Geisser	.048	1.000	.048	.517	.485	.038
	Huynh-Feldt	.048	1.000	.048	.517	.485	.038
	Lower-bound	.048	1.000	.048	.517	.485	.038
Technique * DensityOrder	Sphericity Assumed	.000	1	.000	.003	.961	.000
	Greenhouse-Geisser	.000	1.000	.000	.003	.961	.000
	Huynh-Feldt	.000	1.000	.000	.003	.961	.000
	Lower-bound	.000	1.000	.000	.003	.961	.000
Error(Technique)	Sphericity Assumed	1.196	13	.092			
	Greenhouse-Geisser	1.196	13.000	.092			
	Huynh-Feldt	1.196	13.000	.092			
	Lower-bound	1.196	13.000	.092			

Tests of Between-Subjects Effects

Measure: Density10_Error

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	7.607	1	7.607	167.933	.000	.928
Position	.195	1	.195	4.312	.058	.249
DensityOrder	.065	1	.065	1.430	.253	.099
Error	.589	13	.045			

2. Technique

Estimates

Measure: Density10_Error

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	.276	.041	.188	.364
Wedge	.413	.051	.302	.524

3. Position

Estimates

Measure: Density10_Error

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	.400	.038	.319	.481
Right	.290	.038	.208	.371

4. DensityOrder

Estimates

Measure: Density10_Error

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	.313	.038	.232	.394
Ten_Five	.377	.038	.295	.458

False-Positive Error

Tests of Within-Subjects Effects

Measure: Density10_Error

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	.080	1	.080	10.687	.006	.451
	Greenhouse-Geisser	.080	1.000	.080	10.687	.006	.451
	Huynh-Feldt	.080	1.000	.080	10.687	.006	.451
	Lower-bound	.080	1.000	.080	10.687	.006	.451
Technique * Position	Sphericity Assumed	.032	1	.032	4.263	.059	.247
	Greenhouse-Geisser	.032	1.000	.032	4.263	.059	.247
	Huynh-Feldt	.032	1.000	.032	4.263	.059	.247
	Lower-bound	.032	1.000	.032	4.263	.059	.247
Technique * DensityOrder	Sphericity Assumed	.003	1	.003	.401	.538	.030
	Greenhouse-Geisser	.003	1.000	.003	.401	.538	.030
	Huynh-Feldt	.003	1.000	.003	.401	.538	.030
	Lower-bound	.003	1.000	.003	.401	.538	.030
Error(Technique)	Sphericity Assumed	.097	13	.007			
	Greenhouse-Geisser	.097	13.000	.007			
	Huynh-Feldt	.097	13.000	.007			
	Lower-bound	.097	13.000	.007			

Tests of Between-Subjects Effects

Measure: Density10_Error

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	.284	1	.284	35.839	.000	.734
Position	.119	1	.119	15.051	.002	.537
DensityOrder	.005	1	.005	.623	.444	.046
Error	.103	13	.008			

2. Technique

Estimates

Measure: Density10_Error

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	.031	.011	.007	.055
Wedge	.102	.019	.061	.143

3. Position

Estimates

Measure: Density10_Error

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	.110	.016	.076	.144
Right	.023	.016	-.011	.057

4. DensityOrder

Estimates

Measure: Density10_Error

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	.058	.016	.024	.092
Ten_Five	.075	.016	.041	.109

Overall Error

Tests of Within-Subjects Effects

Measure: Density10_Error

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	.141	1	.141	5.957	.030	.314
	Greenhouse-Geisser	.141	1.000	.141	5.957	.030	.314
	Huynh-Feldt	.141	1.000	.141	5.957	.030	.314
	Lower-bound	.141	1.000	.141	5.957	.030	.314
Technique * Position	Sphericity Assumed	.040	1	.040	1.695	.216	.115
	Greenhouse-Geisser	.040	1.000	.040	1.695	.216	.115
	Huynh-Feldt	.040	1.000	.040	1.695	.216	.115
	Lower-bound	.040	1.000	.040	1.695	.216	.115
Technique * DensityOrder	Sphericity Assumed	.002	1	.002	.106	.750	.008
	Greenhouse-Geisser	.002	1.000	.002	.106	.750	.008
	Huynh-Feldt	.002	1.000	.002	.106	.750	.008
	Lower-bound	.002	1.000	.002	.106	.750	.008
Error(Technique)	Sphericity Assumed	.307	13	.024			
	Greenhouse-Geisser	.307	13.000	.024			
	Huynh-Feldt	.307	13.000	.024			
	Lower-bound	.307	13.000	.024			

Tests of Between-Subjects Effects

Measure: Density10_Error

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	2.806	1	2.806	150.793	.000	.921
Position	.040	1	.040	2.150	.166	.142
DensityOrder	.003	1	.003	.134	.720	.010
Error	.242	13	.019			

2. Technique

Estimates

Measure: Density10_Error

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	.163	.026	.105	.220
Wedge	.256	.025	.202	.310

3. Position

Estimates

Measure: Density10_Error

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	.234	.024	.182	.286
Right	.184	.024	.132	.236

4. DensityOrder

Estimates

Measure: Density10_Error

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	.203	.024	.151	.255
Ten_Five	.216	.024	.164	.268

Trial Completion Time

Tests of Within-Subjects Effects

Measure: Density10_CompletionTime_ms

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	879944.697	1	879944.697	.050	.827	.004
	Greenhouse-Geisser	879944.697	1.000	879944.697	.050	.827	.004
	Huynh-Feldt	879944.697	1.000	879944.697	.050	.827	.004
	Lower-bound	879944.697	1.000	879944.697	.050	.827	.004
Technique * Position	Sphericity Assumed	31697711.288	1	31697711.288	1.790	.204	.121
	Greenhouse-Geisser	31697711.288	1.000	31697711.288	1.790	.204	.121
	Huynh-Feldt	31697711.288	1.000	31697711.288	1.790	.204	.121
	Lower-bound	31697711.288	1.000	31697711.288	1.790	.204	.121
Technique * DensityOrder	Sphericity Assumed	1079124.762	1	1079124.762	.061	.809	.005
	Greenhouse-Geisser	1079124.762	1.000	1079124.762	.061	.809	.005
	Huynh-Feldt	1079124.762	1.000	1079124.762	.061	.809	.005
	Lower-bound	1079124.762	1.000	1079124.762	.061	.809	.005
Error(Technique)	Sphericity Assumed	230229495.592	13	17709961.199			
	Greenhouse-Geisser	230229495.592	13.000	17709961.199			
	Huynh-Feldt	230229495.592	13.000	17709961.199			
	Lower-bound	230229495.592	13.000	17709961.199			

Tests of Between-Subjects Effects

Measure: Density10_CompletionTime_ms

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	5072904311.451	1	5072904311.451	374.824	.000	.966
Position	6980962.699	1	6980962.699	.516	.485	.038
DensityOrder	56489202.262	1	56489202.262	4.174	.062	.243
Error	175943073.513	13	13534082.578			

2. Technique

Estimates

Measure: Density10_CompletionTime_ms

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	8785.784	754.202	7156.430	10415.138
Wedge	9020.297	638.401	7641.115	10399.479

3. Position

Estimates

Measure: Density10_CompletionTime_ms

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	8572.772	650.338	7167.801	9977.742
Right	9233.309	650.338	7828.339	10638.280

4. DensityOrder

Estimates

Measure: Density10_CompletionTime_ms

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	7963.549	650.338	6558.578	9368.520
Ten_Five	9842.532	650.338	8437.561	11247.502

B.2.3 Distance Task

Five Cars Analysis

Error

Tests of Within-Subjects Effects

Measure: Density5_Error_cm

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	30.642	1	30.642	3.401	.088	.207
	Greenhouse-Geisser	30.642	1.000	30.642	3.401	.088	.207
	Huynh-Feldt	30.642	1.000	30.642	3.401	.088	.207
	Lower-bound	30.642	1.000	30.642	3.401	.088	.207
Technique * Position	Sphericity Assumed	9.670	1	9.670	1.073	.319	.076
	Greenhouse-Geisser	9.670	1.000	9.670	1.073	.319	.076
	Huynh-Feldt	9.670	1.000	9.670	1.073	.319	.076
	Lower-bound	9.670	1.000	9.670	1.073	.319	.076
Technique * DensityOrder	Sphericity Assumed	17.292	1	17.292	1.919	.189	.129
	Greenhouse-Geisser	17.292	1.000	17.292	1.919	.189	.129
	Huynh-Feldt	17.292	1.000	17.292	1.919	.189	.129
	Lower-bound	17.292	1.000	17.292	1.919	.189	.129
Error(Technique)	Sphericity Assumed	117.129	13	9.010			
	Greenhouse-Geisser	117.129	13.000	9.010			
	Huynh-Feldt	117.129	13.000	9.010			
	Lower-bound	117.129	13.000	9.010			

Tests of Between-Subjects Effects

Measure: Density5_Error_cm

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1224.750	1	1224.750	52.047	.000	.800
Position	3.242	1	3.242	.138	.716	.010
DensityOrder	6.352	1	6.352	.270	.612	.020
Error	305.911	13	23.532			

2. Technique

Estimates

Measure: Density5_Error_cm

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	2.604	.570	1.374	3.834
Wedge	3.583	.429	2.656	4.509

3. Position

Estimates

Measure: Density5_Error_cm

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	3.252	.606	1.942	4.562
Right	2.934	.606	1.624	4.244

4. DensityOrder

Estimates

Measure: Density5_Error_cm

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	3.316	.606	2.006	4.626
Ten_Five	2.871	.606	1.561	4.180

Trial Completion Time

Tests of Within-Subjects Effects

Measure: Density5_CompletionTime_ms

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	218322872.028	1	218322872.028	3.901	.070	.231
	Greenhouse-Geisser	218322872.028	1.000	218322872.028	3.901	.070	.231
	Huynh-Feldt	218322872.028	1.000	218322872.028	3.901	.070	.231
	Lower-bound	218322872.028	1.000	218322872.028	3.901	.070	.231
Technique * Position	Sphericity Assumed	105825164.730	1	105825164.730	1.891	.192	.127
	Greenhouse-Geisser	105825164.730	1.000	105825164.730	1.891	.192	.127
	Huynh-Feldt	105825164.730	1.000	105825164.730	1.891	.192	.127
	Lower-bound	105825164.730	1.000	105825164.730	1.891	.192	.127
Technique * DensityOrder	Sphericity Assumed	25695738.919	1	25695738.919	.459	.510	.034
	Greenhouse-Geisser	25695738.919	1.000	25695738.919	.459	.510	.034
	Huynh-Feldt	25695738.919	1.000	25695738.919	.459	.510	.034
	Lower-bound	25695738.919	1.000	25695738.919	.459	.510	.034
Error(Technique)	Sphericity Assumed	727570935.665	13	55966995.051			
	Greenhouse-Geisser	727570935.665	13.000	55966995.051			
	Huynh-Feldt	727570935.665	13.000	55966995.051			
	Lower-bound	727570935.665	13.000	55966995.051			

Tests of Between-Subjects Effects

Measure: Density5_CompletionTime_ms

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	14449124179.646	1	14449124179.646	286.220	.000	.957
Position	54873018.112	1	54873018.112	1.087	.316	.077
DensityOrder	194385027.757	1	194385027.757	3.851	.071	.229
Error	656273603.671	13	50482584.898			

2. Technique

Estimates

Measure: Density5_CompletionTime_ms

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	11930.682	953.001	9871.848	13989.517
Wedge	9318.674	868.944	7441.435	11195.912

3. Position

Estimates

Measure: Density5_CompletionTime_ms

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	9969.930	888.139	8051.223	11888.637
Right	11279.426	888.139	9360.719	13198.133

4. DensityOrder

Estimates

Measure: Density5_CompletionTime_ms

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	9392.350	888.139	7473.643	11311.057
Ten_Five	11857.006	888.139	9938.299	13775.713

Ten Cars Analysis

Error

Tests of Within-Subjects Effects

Measure: Density10_Error_cm

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	49.495	1	49.495	9.405	.009	.420
	Greenhouse-Geisser	49.495	1.000	49.495	9.405	.009	.420
	Huynh-Feldt	49.495	1.000	49.495	9.405	.009	.420
	Lower-bound	49.495	1.000	49.495	9.405	.009	.420
Technique * Position	Sphericity Assumed	.671	1	.671	.127	.727	.010
	Greenhouse-Geisser	.671	1.000	.671	.127	.727	.010
	Huynh-Feldt	.671	1.000	.671	.127	.727	.010
	Lower-bound	.671	1.000	.671	.127	.727	.010
Technique * DensityOrder	Sphericity Assumed	11.142	1	11.142	2.117	.169	.140
	Greenhouse-Geisser	11.142	1.000	11.142	2.117	.169	.140
	Huynh-Feldt	11.142	1.000	11.142	2.117	.169	.140
	Lower-bound	11.142	1.000	11.142	2.117	.169	.140
Error(Technique)	Sphericity Assumed	68.415	13	5.263			
	Greenhouse-Geisser	68.415	13.000	5.263			
	Huynh-Feldt	68.415	13.000	5.263			
	Lower-bound	68.415	13.000	5.263			

Tests of Between-Subjects Effects

Measure: Density10_Error_cm

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	635.728	1	635.728	133.530	.000	.911
Position	38.392	1	38.392	8.064	.014	.383
DensityOrder	17.926	1	17.926	3.765	.074	.225
Error	61.892	13	4.761			

2. Technique

Estimates

Measure: Density10_Error_cm

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	1.607	.228	1.114	2.099
Wedge	2.850	.324	2.151	3.549

3. Position

Estimates

Measure: Density10_Error_cm

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	2.776	.273	2.187	3.365
Right	1.681	.273	1.092	2.270

4. DensityOrder

Estimates

Measure: Density10_Error_cm

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	1.854	.273	1.265	2.444
Ten_Five	2.603	.273	2.014	3.192

Trial Completion Time

Tests of Within-Subjects Effects

Measure: Density10_CompletionTime_ms

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	194883236.290	1	194883236.290	2.436	.143	.158
	Greenhouse-Geisser	194883236.290	1.000	194883236.290	2.436	.143	.158
	Huynh-Feldt	194883236.290	1.000	194883236.290	2.436	.143	.158
	Lower-bound	194883236.290	1.000	194883236.290	2.436	.143	.158
Technique * Position	Sphericity Assumed	11673635.388	1	11673635.388	.146	.709	.011
	Greenhouse-Geisser	11673635.388	1.000	11673635.388	.146	.709	.011
	Huynh-Feldt	11673635.388	1.000	11673635.388	.146	.709	.011
	Lower-bound	11673635.388	1.000	11673635.388	.146	.709	.011
Technique * DensityOrder	Sphericity Assumed	7774021.220	1	7774021.220	.097	.760	.007
	Greenhouse-Geisser	7774021.220	1.000	7774021.220	.097	.760	.007
	Huynh-Feldt	7774021.220	1.000	7774021.220	.097	.760	.007
	Lower-bound	7774021.220	1.000	7774021.220	.097	.760	.007
Error(Technique)	Sphericity Assumed	1039935604.260	13	79995046.482			
	Greenhouse-Geisser	1039935604.260	13.000	79995046.482			
	Huynh-Feldt	1039935604.260	13.000	79995046.482			
	Lower-bound	1039935604.260	13.000	79995046.482			

Tests of Between-Subjects Effects

Measure: Density10_CompletionTime_ms

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	12161027032.915	1	12161027032.915	213.482	.000	.943
Position	101933377.862	1	101933377.862	1.789	.204	.121
DensityOrder	462805784.192	1	462805784.192	8.124	.014	.385
Error	740545629.441	13	56965048.419			

2. Technique

Estimates

Measure: Density10_CompletionTime_ms

Technique	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Canyon	10981.112	1139.730	8518.876	13443.349
Wedge	8513.299	917.070	6532.090	10494.509

3. Position

Estimates

Measure: Density10_CompletionTime_ms

Position	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Left	8854.819	943.440	6816.641	10892.997
Right	10639.593	943.440	8601.415	12677.771

4. DensityOrder

Estimates

Measure: Density10_CompletionTime_ms

DensityOrder	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Five_Ten	7845.714	943.440	5807.536	9883.892
Ten_Five	11648.698	943.440	9610.519	13686.876

B.2.4 Location Task

Five Cars Analysis

Error

Tests of Within-Subjects Effects

Measure: Density5_Error_cm

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	30.642	1	30.642	3.401	.088	.207
	Greenhouse-Geisser	30.642	1.000	30.642	3.401	.088	.207
	Huynh-Feldt	30.642	1.000	30.642	3.401	.088	.207
	Lower-bound	30.642	1.000	30.642	3.401	.088	.207
Technique * Position	Sphericity Assumed	9.670	1	9.670	1.073	.319	.076
	Greenhouse-Geisser	9.670	1.000	9.670	1.073	.319	.076
	Huynh-Feldt	9.670	1.000	9.670	1.073	.319	.076
	Lower-bound	9.670	1.000	9.670	1.073	.319	.076
Technique * DensityOrder	Sphericity Assumed	17.292	1	17.292	1.919	.189	.129
	Greenhouse-Geisser	17.292	1.000	17.292	1.919	.189	.129
	Huynh-Feldt	17.292	1.000	17.292	1.919	.189	.129
	Lower-bound	17.292	1.000	17.292	1.919	.189	.129
Error(Technique)	Sphericity Assumed	117.129	13	9.010			
	Greenhouse-Geisser	117.129	13.000	9.010			
	Huynh-Feldt	117.129	13.000	9.010			
	Lower-bound	117.129	13.000	9.010			

Tests of Between-Subjects Effects

Measure: Density5_Error_cm

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	1224.750	1	1224.750	52.047	.000	.800
Position	3.242	1	3.242	.138	.716	.010
DensityOrder	6.352	1	6.352	.270	.612	.020
Error	305.911	13	23.532			

2. Technique

Estimates

Measure: Density5_Error_cm

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	2.604	.570	1.374	3.834
Wedge	3.583	.429	2.656	4.509

3. Position

Estimates

Measure: Density5_Error_cm

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	3.252	.606	1.942	4.562
Right	2.934	.606	1.624	4.244

4. DensityOrder

Estimates

Measure: Density5_Error_cm

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	3.316	.606	2.006	4.626
Ten_Five	2.871	.606	1.561	4.180

Trial Completion Time

Tests of Within-Subjects Effects

Measure: Density5_CompletionTime_ms

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	218322872.028	1	218322872.028	3.901	.070	.231
	Greenhouse-Geisser	218322872.028	1.000	218322872.028	3.901	.070	.231
	Huynh-Feldt	218322872.028	1.000	218322872.028	3.901	.070	.231
	Lower-bound	218322872.028	1.000	218322872.028	3.901	.070	.231
Technique * Position	Sphericity Assumed	105825164.730	1	105825164.730	1.891	.192	.127
	Greenhouse-Geisser	105825164.730	1.000	105825164.730	1.891	.192	.127
	Huynh-Feldt	105825164.730	1.000	105825164.730	1.891	.192	.127
	Lower-bound	105825164.730	1.000	105825164.730	1.891	.192	.127
Technique * DensityOrder	Sphericity Assumed	25695738.919	1	25695738.919	.459	.510	.034
	Greenhouse-Geisser	25695738.919	1.000	25695738.919	.459	.510	.034
	Huynh-Feldt	25695738.919	1.000	25695738.919	.459	.510	.034
	Lower-bound	25695738.919	1.000	25695738.919	.459	.510	.034
Error(Technique)	Sphericity Assumed	727570935.665	13	55966995.051			
	Greenhouse-Geisser	727570935.665	13.000	55966995.051			
	Huynh-Feldt	727570935.665	13.000	55966995.051			
	Lower-bound	727570935.665	13.000	55966995.051			

Tests of Between-Subjects Effects

Measure: Density5_CompletionTime_ms

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	14449124179.646	1	14449124179.646	286.220	.000	.957
Position	54873018.112	1	54873018.112	1.087	.316	.077
DensityOrder	194385027.757	1	194385027.757	3.851	.071	.229
Error	656273603.671	13	50482584.898			

2. Technique

Estimates

Measure: Density5_CompletionTime_ms

Technique	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Canyon	11930.682	953.001	9871.848	13989.517
Wedge	9318.674	868.944	7441.435	11195.912

3. Position

Estimates

Measure: Density5_CompletionTime_ms

Position	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Left	9969.930	888.139	8051.223	11888.637
Right	11279.426	888.139	9360.719	13198.133

4. DensityOrder

Estimates

Measure: Density5_CompletionTime_ms

DensityOrder	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Five_Ten	9392.350	888.139	7473.643	11311.057
Ten_Five	11857.006	888.139	9938.299	13775.713

Ten Cars Analysis

Error

Tests of Within-Subjects Effects

Measure: Density10_Error_cm

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	49.495	1	49.495	9.405	.009	.420
	Greenhouse-Geisser	49.495	1.000	49.495	9.405	.009	.420
	Huynh-Feldt	49.495	1.000	49.495	9.405	.009	.420
	Lower-bound	49.495	1.000	49.495	9.405	.009	.420
Technique * Position	Sphericity Assumed	.671	1	.671	.127	.727	.010
	Greenhouse-Geisser	.671	1.000	.671	.127	.727	.010
	Huynh-Feldt	.671	1.000	.671	.127	.727	.010
	Lower-bound	.671	1.000	.671	.127	.727	.010
Technique * DensityOrder	Sphericity Assumed	11.142	1	11.142	2.117	.169	.140
	Greenhouse-Geisser	11.142	1.000	11.142	2.117	.169	.140
	Huynh-Feldt	11.142	1.000	11.142	2.117	.169	.140
	Lower-bound	11.142	1.000	11.142	2.117	.169	.140
Error(Technique)	Sphericity Assumed	68.415	13	5.263			
	Greenhouse-Geisser	68.415	13.000	5.263			
	Huynh-Feldt	68.415	13.000	5.263			
	Lower-bound	68.415	13.000	5.263			

Tests of Between-Subjects Effects

Measure: Density10_Error_cm

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	635.728	1	635.728	133.530	.000	.911
Position	38.392	1	38.392	8.064	.014	.383
DensityOrder	17.926	1	17.926	3.765	.074	.225
Error	61.892	13	4.761			

2. Technique

Estimates

Measure: Density10_Error_cm

Technique	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Canyon	1.607	.228	1.114	2.099
Wedge	2.850	.324	2.151	3.549

3. Position

Estimates

Measure: Density10_Error_cm

Position	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Left	2.776	.273	2.187	3.365
Right	1.681	.273	1.092	2.270

4. DensityOrder

Estimates

Measure: Density10_Error_cm

DensityOrder	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Five_Ten	1.854	.273	1.265	2.444
Ten_Five	2.603	.273	2.014	3.192

Trial Completion Time

Tests of Within-Subjects Effects

Measure: Density10_CompletionTime_ms

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Technique	Sphericity Assumed	194883236.290	1	194883236.290	2.436	.143	.158
	Greenhouse-Geisser	194883236.290	1.000	194883236.290	2.436	.143	.158
	Huynh-Feldt	194883236.290	1.000	194883236.290	2.436	.143	.158
	Lower-bound	194883236.290	1.000	194883236.290	2.436	.143	.158
Technique * Position	Sphericity Assumed	11673635.388	1	11673635.388	.146	.709	.011
	Greenhouse-Geisser	11673635.388	1.000	11673635.388	.146	.709	.011
	Huynh-Feldt	11673635.388	1.000	11673635.388	.146	.709	.011
	Lower-bound	11673635.388	1.000	11673635.388	.146	.709	.011
Technique * DensityOrder	Sphericity Assumed	7774021.220	1	7774021.220	.097	.760	.007
	Greenhouse-Geisser	7774021.220	1.000	7774021.220	.097	.760	.007
	Huynh-Feldt	7774021.220	1.000	7774021.220	.097	.760	.007
	Lower-bound	7774021.220	1.000	7774021.220	.097	.760	.007
Error(Technique)	Sphericity Assumed	1039935604.260	13	79995046.482			
	Greenhouse-Geisser	1039935604.260	13.000	79995046.482			
	Huynh-Feldt	1039935604.260	13.000	79995046.482			
	Lower-bound	1039935604.260	13.000	79995046.482			

Tests of Between-Subjects Effects

Measure: Density10_CompletionTime_ms

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	12161027032.915	1	12161027032.915	213.482	.000	.943
Position	101933377.862	1	101933377.862	1.789	.204	.121
DensityOrder	462805784.192	1	462805784.192	8.124	.014	.385
Error	740545629.441	13	56965048.419			

2. Technique

Estimates

Measure: Density10_CompletionTime_ms

Technique	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Canyon	10981.112	1139.730	8518.876	13443.349
Wedge	8513.299	917.070	6532.090	10494.509

3. Position

Estimates

Measure: Density10_CompletionTime_ms

Position	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Left	8854.819	943.440	6816.641	10892.997
Right	10639.593	943.440	8601.415	12677.771

4. DensityOrder

Estimates

Measure: Density10_CompletionTime_ms

DensityOrder	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Five_Ten	7845.714	943.440	5807.536	9883.892
Ten_Five	11648.698	943.440	9610.519	13686.876

B.3 Condition Questionnaire Results

Wilcoxon Signed Ranks Test

Ranks

		N	Mean Rank	Sum of Ranks
Identification_Wedge_5 - Identification_Canyon_5	Negative Ranks	7[a]	6.00	42.00
	Positive Ranks	3[b]	4.33	13.00
	Ties	6[c]		
	Total	16		
Identification_Wedge_10 - Identification_Canyon_10	Negative Ranks	9[d]	6.44	58.00
	Positive Ranks	3[e]	6.67	20.00
	Ties	4[f]		
	Total	16		
Movement_Wedge_5 - Movement_Canyon_5	Negative Ranks	7[g]	7.21	50.50
	Positive Ranks	6[h]	6.75	40.50
	Ties	3[i]		
	Total	16		
Movement_Wedge_10 - Movement_Canyon_10	Negative Ranks	5[j]	7.10	35.50
	Positive Ranks	9[k]	7.72	69.50
	Ties	2[l]		
	Total	16		
Distance_Wedge_5 - Distance_Canyon_5	Negative Ranks	11[m]	8.95	98.50
	Positive Ranks	4[n]	5.38	21.50
	Ties	1[o]		
	Total	16		
Distance_Wedge_10 - Distance_Canyon_10	Negative Ranks	11[p]	8.00	88.00
	Positive Ranks	3[q]	5.67	17.00
	Ties	2[r]		
	Total	16		
Location_Wedge_5 - Location_Canyon_5	Negative Ranks	11[s]	6.68	73.50
	Positive Ranks	2[t]	8.75	17.50
	Ties	3[u]		
	Total	16		
Location_Wedge_10 - Location_Canyon_10	Negative Ranks	11[v]	6.86	75.50
	Positive Ranks	2[w]	7.75	15.50
	Ties	3[x]		
	Total	16		

a. Identification_Wedge_5 < Identification_Canyon_5
b. Identification_Wedge_5 > Identification_Canyon_5
c. Identification_Wedge_5 = Identification_Canyon_5
d. Identification_Wedge_10 < Identification_Canyon_10
e. Identification_Wedge_10 > Identification_Canyon_10
f. Identification_Wedge_10 = Identification_Canyon_10
g. Movement_Wedge_5 < Movement_Canyon_5
h. Movement_Wedge_5 > Movement_Canyon_5
i. Movement_Wedge_5 = Movement_Canyon_5
j. Movement_Wedge_10 < Movement_Canyon_10
k. Movement_Wedge_10 > Movement_Canyon_10
l. Movement_Wedge_10 = Movement_Canyon_10
m. Distance_Wedge_5 < Distance_Canyon_5
n. Distance_Wedge_5 > Distance_Canyon_5
o. Distance_Wedge_5 = Distance_Canyon_5
p. Distance_Wedge_10 < Distance_Canyon_10
q. Distance_Wedge_10 > Distance_Canyon_10
r. Distance_Wedge_10 = Distance_Canyon_10
s. Location_Wedge_5 < Location_Canyon_5
t. Location_Wedge_5 > Location_Canyon_5
u. Location_Wedge_5 = Location_Canyon_5
v. Location_Wedge_10 < Location_Canyon_10
w. Location_Wedge_10 > Location_Canyon_10
x. Location_Wedge_10 = Location_Canyon_10

Test Statistics[a]

	Identification_Wedge_5 - Identification_Canyon_5	Identification_Wedge_10 - Identification_Canyon_10	Movement_Wedge_5 - Movement_Canyon_5	Movement_Wedge_10 - Movement_Canyon_10
Z	-1.502[b]	-1.565[b]	-.359[b]	-1.088[c]
Asymp. Sig. (2-tailed)	.133	.118	.720	.277
Exact Sig. (2-tailed)	.178	.157	.746	.294
Exact Sig. (1-tailed)	.089	.079	.373	.147
Point Probability	.034	.040	.018	.021

	Distance_Wedge_5 - Distance_Canyon_5	Distance_Wedge_10 - Distance_Canyon_10	Location_Wedge_5 - Location_Canyon_5	Location_Wedge_10 - Location_Canyon_10
Z	-2.208[b]	-2.248[b]	-2.015[b]	-2.133[b]
Asymp. Sig. (2-tailed)	.027	.025	.044	.033
Exact Sig. (2-tailed)	.027	.023	.034	.034
Exact Sig. (1-tailed)	.014	.012	.017	.017
Point Probability	.003	.001	.001	.001

a. Wilcoxon Signed Ranks Test

b. Based on positive ranks.

c. Based on negative ranks.

Appendix C

Miscellaneous Material

C.1 Permissions to Use Co-Authored Work

September 25, 2012

I, Yu-Ling Chang, give Alexandra Ion permission to use co-authored work from our paper

> Ion, A., Chang, Y.-L., Haller, M., Hancock, M. and Scott, S. (2013). Canyon: Providing Location Awareness of Multiple Moving Objects in a Detail View on Large Displays. Submitted to *CHI '13: Proceedings of the 2013 annual conference on Human Factors in Computing Systems*.

for her master's thesis.

Sincerely,

Yu-Ling Chang

September 25, 2012

I, Michael Haller, give Alexandra Ion permission to use co-authored work from our paper

> Ion, A., Chang, Y.-L., Haller, M., Hancock, M. and Scott, S. (2013). Canyon: Providing Location Awareness of Multiple Moving Objects in a Detail View on Large Displays. Submitted to *CHI '13: Proceedings of the 2013 annual conference on Human Factors in Computing Systems.*

for her master's thesis.

Sincerely,

Michael Haller

September 25, 2012

I, Mark Hancock, give Alexandra Ion permission to use co-authored work from our paper

> Ion, A., Chang, Y.-L., Haller, M., Hancock, M. and Scott, S. (2013). Canyon: Providing Location Awareness of Multiple Moving Objects in a Detail View on Large Displays. Submitted to *CHI '13: Proceedings of the 2013 annual conference on Human Factors in Computing Systems.*

for her master's thesis.

Sincerely,

Mark Hancock

September 25, 2012

I, Stacey Scott, give Alexandra Ion permission to use co-authored work from our paper

> Ion, A., Chang, Y.-L., Haller, M., Hancock, M. and Scott, S. (2013). Canyon: Providing Location Awareness of Multiple Moving Objects in a Detail View on Large Displays. Submitted to *CHI '13: Proceedings of the 2013 annual conference on Human Factors in Computing Systems.*

for her master's thesis.

Sincerely,

Stacey Scott

C.2 Shader Code

The shader code for applying horizontal paper folding distortion and the shadow. The language of the code is HLSL.

```
// The input image
sampler2D input : register(s0);

// How much space on the left side is folded away,
// Ranging from 0 to 0.5
float left : register(c0);

// The darkness of the shadow in the middle of the fold,
// ranging from 0 to 1
float darkness : register(c2);

float4 main(float2 uv : TEXCOORD) : COLOR
{
  float right = 1 - left;

  if(uv.x > left && uv.x < right)
    return transform(uv);

  return 0;
}

```

```
float4 transform(float2 uv : TEXCOORD) : COLOR
{
  float right = 1 - left;
  // transforming the current point (uv) according to the new boundaries.
  float2 tuv = float2((uv.x - left) / (right - left), uv.y);

  float tx = tuv.x;
  if (tx > 0.5)
    tx = 1 - tx;

  float top = left * tx;
  float bottom = 1 - top;

  if (uv.y >= top && uv.y <= bottom)
  {
    // linear interpolation between 0 and 1 considering the angle of folding.
    float ty = lerp(0, 1, (tuv.y - top) / (bottom - top));
    // get the pixel from the transformed x and interpolated y.
    float4 color = tex2D(input, float2(tuv.x, ty));
    // apply shadow on interpolated color
    color = darkenColor(color, tuv);

    return color;
  }
  return 0;
}

float4 darkenColor(float4 color: COLOR, float2 uv : TEXCOORD) : COLOR
{
  float currentRatio = 0.0;

  if(uv.x > 0.5)
    currentRatio = (1 - uv.x) / 0.5;
  else
    currentRatio = uv.x / 0.5;

  currentRatio *= darkness;
  color.rgb = color.rgb - color.rgb * (currentRatio);

  return color;
}
```

Appendix D

CD Content

D.1 Thesis

Pfad: /

Thesis_Alexandra_Ion_2012.pdf Master's thesis as PDF file.

D.2 Study Results

Pfad: /study results

/log results . . . . Analysis of logged data during the study, SPSS output as Microsoft Excel files.

/questionnaire results . Results from questionnaires completed by study participants.

D.3 Online Literature

Pfad: /literature

2008-Gustafson-CHI08-Wedge.ppt PowerPoint slide show, referenced in Related Work.

2008-SPS-performance-standard.pdf Report "Global Positioning System Standard Positioning Service Performance Standard"

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