Canyon: Providing Location Awareness of Multiple Moving Objects in a Detail View on Large Displays

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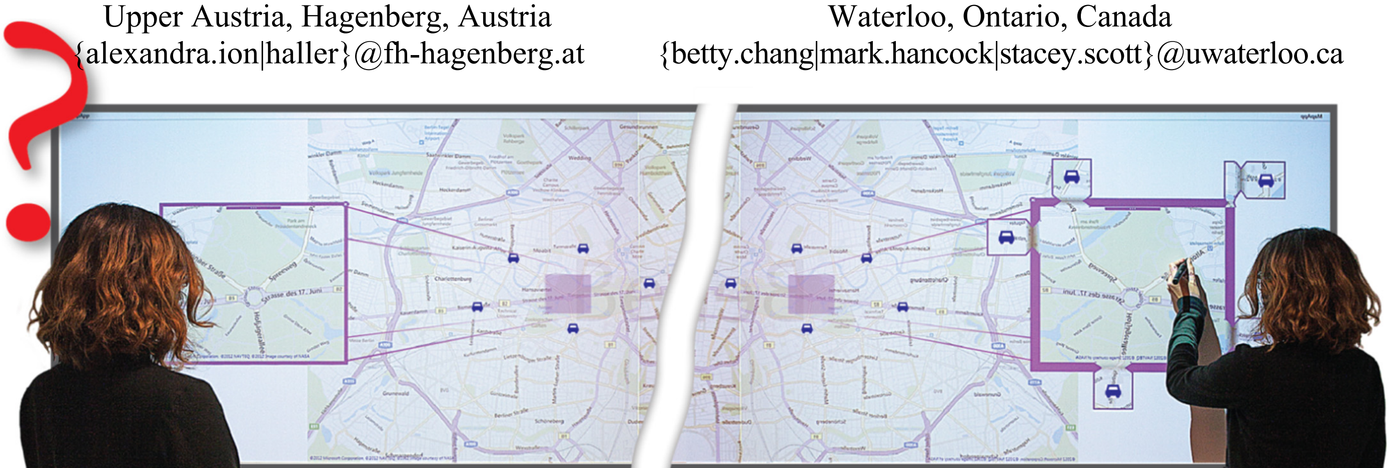

Figure 1: Moving targets may exit an individual's workspace and field of view (left). Canyon visualizes off-view objects by using a paper folding metaphor (right).

ABSTRACT
Overview+Detail interfaces can be used to examine the details of complex data while retaining the data's overall context. Dynamic data introduce challenges for these interfaces, however, as moving objects may exit the detail view, as well as a person's field of view if they are working at a large interactive surface. To address this "off-view" problem, we propose a new information visualization technique, called Canyon. This technique attaches a small view of an off-view object, including some surrounding context, to the external boundary of the detail view. The area between the detail view and the region containing the off-view object is virtually "folded" to conserve space. A comparison study was conducted contrasting the benefits and limitations of Canyon to an established technique, called Wedge. Canyon was more accurate across a number of tasks, especially more complex tasks, and was comparably efficient.

Author Keywords
Information Visualization; Overview+Detail; Dynamic Data; Large Display; Map Data

ACM Classification Keywords
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INTRODUCTION
Large, interactive displays are increasingly being used to support collaborative data analysis and decision-making involving large, complex datasets [24,26]. Yet, their large, shareable surface introduces navigation issues for collaborators, as people may wish to examine different aspects of the dataset. Offering multiple, independent views of the data can address this issue; however, data relationships can become unclear as the views diverge or are being explored at different zoom levels. Instead, Overview+Detail interfaces [8] can be used to provide an overview of the entire dataset along with multiple detail views. The bounds of the detail views are shown on the overview to provide context. When the dataset contains dynamic data this approach is insufficient for providing a consistent view of the data of interest within the detail views. Consider the following scenario in a police command centre, based on an early version of our prototype system developed for police officers.

A group of police officers stand at an interactive wall monitoring a large city map. The map is augmented with GPS-tracked police vehicles. An officer wishes to check on a particular incident. She selects the incident location on the map (overview) to open a view showing a zoomed portion of the incident area (detail view). She sees that three police vehicles have arrived at the scene. While she monitors the incident, one vehicle moves away from the scene, and its associated icon disappears as its location moves outside the bounds of the detail view. She receives a report that the vehicle is in pursuit of a fleeing suspect. Now, she needs to maintain awareness of this vehicle and the incident scene.

While the vehicle was no longer visible in the detail view, it may still be visible on the large overview map. It might be outside her focal view due to the size of the display. We define this problem as the "off-view" problem, where we wish to maintain awareness of objects within the detail view and of dynamically moving objects that begin in the view and leave the view over time.

We distinguish this problem from the previously identified "off-screen" problem, where objects of interest are located outside a given window view [4,8,13]. In our situation, objects located beyond the bounds of the detail view hold some relationship to objects in the overview (and may even be visible there). Moreover, the large display context provides additional screen real-estate around the detail view(s), unlike "off-screen" situations which are often limited to indicating the location of a non-visible object within the constraints of a small interface window (e.g., on a handheld device [4,13]). Thus, large displays provide a different design context with opportunities for different design solutions to provide location awareness of an off-view object.

To address this design space, we propose a new information visualization technique, called Canyon (Figure 1), developed for map-based datasets. In Canyon, orthogonal strips of map data that include the off-view object are attached to the detail view. To conserve screen space, the area between the detail view and the region containing the off-view object is "folded". This folding metaphor was inspired by the "Mélange" multi-focus interaction technique [9]. Canyon is designed to provide a high level of location detail by showing the off-view object as well as its surrounding map area.

To explore the potential of this design in facilitating location awareness of off-view objects, we conducted a controlled laboratory experiment comparing Canyon to an existing off-screen visualization technique, Wedge [13]. To set the context for this study we first present the related work. Next, we present the design of Canyon, the study method, and results. Finally, we discuss the overall study and provide design recommendations for future off-view object interfaces.

RELATED WORK

As previously mentioned, 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.

Navigation-based Techniques

Large visual spaces can be explored using pan, zoom or scroll. "Speed-dependent automatic zooming" [15] reduces the zoom level depending on scrolling speed. Zooming interfaces like Pad [19] separate views temporally, and require users to mentally connect the views [8]. Plumlee and Ware [21] report that only one graphical object can be held in memory, and recommend the use of multiple views to enable visual comparisons of complex data.

View-based Techniques

Overview+Detail interfaces provide overview and detail views simultaneously, but spatially separated, and leave the user to build the connection.

These interfaces are used in many common computer applications, like Microsoft PowerPoint's slide thumbnails. Digital map systems like Google Maps show a large detail view and give an overview as an inset. In contrast, the DragMag image magnifier [25] grants the most screen space to the overview area and provides multiple smaller detail views. PolyZoom [17] additionally supports construction of focus hierarchies. Plaisant et al. [20] found intermediate windows useful for detail-to-overview ratios exceeding 20:1.

Focus+Context interfaces combine focus and context areas in one view, aiming to decrease short term memory load. These areas are typically connected using distortion.

The first Focus+Context interface was 'Bifocal Display' [23], which used the metaphor of bending sides of a paper strip backward to create a focus area while preserving context. 'Fisheye views' [11] delegate a large portion of the view to the area of greatest interest and less space to other areas depending on their distance from this area. Baudisch et al. [3] embedded a small high resolution display (focus) into a large, low resolution display (context). A unifying framework, incorporating this wide range of approaches was presented by Carpendale and Montagnese [7].

Multi-scale interfaces, also known as semantic zooming [19], present content differently depending on scale.

Multi-focus interfaces provide multiple foci at the same time.

Many Overview+Detail and Focus+Context interfaces allow multiple foci [22,25]. Techniques supporting both, multi-scale and multi-focus interaction, include PolyZoom [17] and Mélange [9]. Mélange supports multiple foci and folds space in between points of interest, and allows viewing points of interest at different levels of detail. Mélange inspired the off-view technique presented in this work.

Cue-based Techniques

Pointing techniques provide information about off-screen objects by pointing in their direction. Typically, graphical elements are overlaid onto the screen border region.

Off-screen object's direction is conveyed by pointing and distance is conveyed by altering the visual cues' properties, e.g. size. Combining this information gives the location of the object. Visualizations include arrows [5] and rays [1]. Halo [4] draws a circle around the off-screen object's location that intrudes into the screen. However, it suffers from overlap and corner issues. A comparison of arrows and Halo [5] shows arrows to be more accurate for distance tasks, and Halo performing better for location tasks. Instead of using circles, Wedge [13] uses partly visible isosceles triangles to point towards the off-screen object. Wedge was found to be more accurate than Halo. In a comparison of arrows, Overview+Detail, and Wedge [6], Wedge outperformed the other techniques for distance tasks. Wedge was included as the comparison technique in our study, due to its effectiveness.

Contextual views are derived from fisheye views and use abstract visual representations along the view border to point to the location of off-screen objects.

City Lights [27] and EdgeRadar [14] provide contextual information by displaying proxies of off-screen objects into a compressed border region within the view. Contextual views are also used for large node-link diagrams [10].

Interactive off-screen techniques allow interacting with proxies and auto-focus of the associated object [10,16,18]. Our work focuses on the visualization, rather than manipulation, of off-view objects. Current off-screen visualizations mainly target small displays and use abstract cues. To our knowledge, no research has investigated visualization of off-view objects on large displays featuring individual views. To address this usage context, we developed Canyon, a multi-focus approach to visualize off-view objects on large displays. The design and implementation of Canyon is described next.

DESIGN OF CANYON

Canyon was designed to provide location awareness of targets, outside of the focal area of a person, on large displays with direct input (see Figure 2 (d)). Targets can be static or dynamic, and they are visualized around the detail view.

Design Goals

For enhancing location awareness about off-view targets on large displays, we defined the following design goals:

G1. *No change of the defined view.* The view defined should not be altered (by another person or the system).

G2. *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.

G3. *Provide distance awareness.* The distance to the workspace should be indicated.

G4. *Support fast comparison.* Fast comparison of off-view objects relative to each other should be enabled.

Folding Paper

The idea of Canyon is to bring off-view objects close to the current workspace by using a paper folding metaphor. Canyon was inspired by Mélange [9], a technique for fitting multiple focus points into the viewport by folding unused space in between. In contrast, Canyon extends the view by adding cut-out views onto the user's view.

The design details can be explained using a map exploration context (see Figure 2). Consider having a workspace showing a user defined map area and multiple objects, which are outside of the user's focal range. Canyon extends the view by cutting out a strip of a paper map containing the off-view object and attaches it to the edge of the detail view. Since this strip of map can be long and the space in between is uninteresting, it is sharply folded like paper in order to bring the objects of interest close to the detail view. A paper folding metaphor is easy to understand since humans are familiar with paper manipulation. Since the cut-out view and the fold are attached to the outside of the map view, the defined view never changes, fulfilling G1. Moreover, by connecting the detail view and the cut-out view with the fold, context is provided, fulfilling G2.

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 target. It is calculated by

$$foldSize = \text{round}(\ln distance^5).$$

A logarithmic function is used to avoid overly large folds caused by very distant objects. Since the *foldSize* varies, G4 and partly G3 are fulfilled.

Adding Shadow

One design goal of Mélange was providing distance awareness. Elmqvist et al. [9] used an abstract environment in their study with a checkerboard-like background and additional black lines indicating screen units as an additional distance cue. Like the authors of Mélange, we think that distortion alone does not provide 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 folding metaphor suffers.

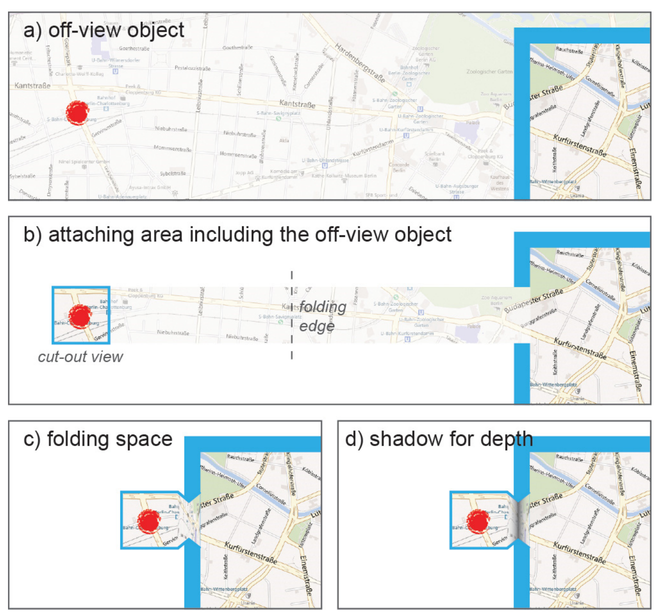


Figure 2: Canyon attaches a strip of map material containing the object to the view and folds uninteresting space away.

To overcome these issues, a shadow is added onto the fold. It intensifies the depth illusion and serves as an additional cue for distance awareness, which fulfills G3. The maximum darkness of the shadow is calculated depending on the ratio of visible map in the fold,

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

It is applied as a linear gradient from the maximum darkness in the middle to transparent on the sides. The shadow and the distortion are applied in a pixel shader in one step using linear transformation. Mélange enhanced distance awareness by using fold pages, each representing the size of the screen. Although this linear translation of distance is well-understandable, we used non-linear distance representation for representing objects regardless of their distance.

Merging and Chaining

When the distance between off-view objects on the x or y-axis is smaller than the cut-out view size defined with 80 pixels in this implementation, the cut-out views are merged. The cut-out view is enlarged to accommodate these targets. When one cut-out view is in between another and the detail view, the farther away one is chained. The bounds of a closer cut-out view are extended to incorporate all following intersecting cut-out views that are farther 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 (see Figure 3).

Corners

Representing off-view objects in corner regions requires special attention in many off-screen visualization techniques. As off-screen objects are mostly visualized orthogonal to the view edges of a rectangular screen, corners present a bigger area to cover but less space for visualization. Canyon visualizes corner off-view objects by extending the vertical view edges and folds the cut-out views orthogonally to these extended edges. Thus, two folds are needed to show a corner object (see Figure 3), and may increase the cognitive load to understand it. Nevertheless, the paper folding metaphor is preserved which should assist understanding. Cut-out views are always kept in distinct octants around the view to prevent them from overlapping. When one cut-out view overlaps octant edges, it is shifted into the octant, where the centre of the represented object is.

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. We expect that 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 uses additional space, and thus the technique may not generalize to situations where screen real estate is at a premium.

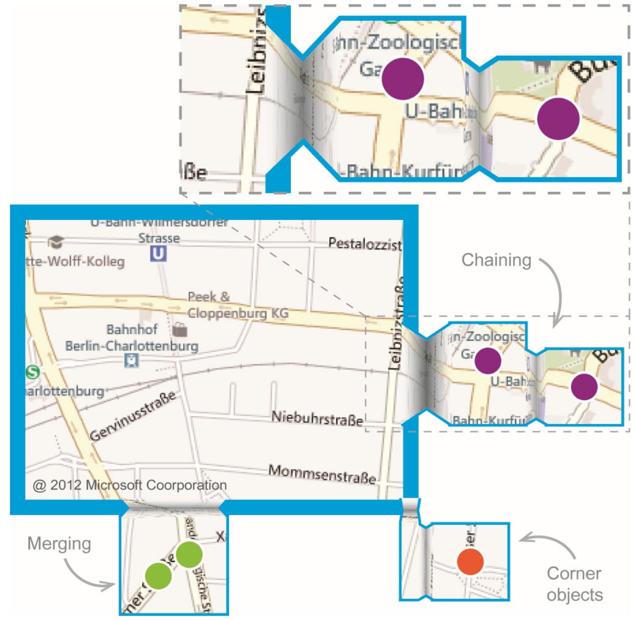


Figure 3: Close objects are merged in one Canyon (bottom). Objects located in the same direction are chained (right). Corner objects require folding twice (bottom right). The close up at the top shows the fold in detail.

We designed Canyon for the specific purpose of supporting awareness of multiple objects in a detailed view that may move out of the view. However, it is not clear to what degree our design improves location awareness, or whether the use of additional space and information will increase cognitive load. In addition, our paper-folding metaphor differs from other off-view visualization techniques, and we are interested in how effectively our technique conveys an object's distance from the cut-out.

METHOD

We conducted an empirical study in order to explore these benefits and limitations. Specifically, our study investigated how well people could understand the connection between the detail window and overview map, the effect of using additional space, and the degree to which Canyon provides awareness of a target's absolute location, relative location, and movement. As a baseline for comparison, we used Wedge [13], a well-designed off-screen technique (see Figure 4) due to little literature regarding the off-view problem.

Participants

Sixteen unpaid participants (6 female, 10 male), between 21 and 31 years of age, were recruited from a university computer science undergraduate program. Participants signed up as individuals, but were paired up to complete the study. 75% of participants reported being familiar with direct-input computational devices and all of the participants reported having used digital map systems.

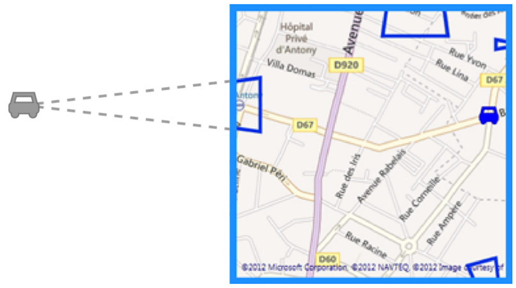


Figure 4: Wedge visualizes object locations with partly visible isosceles triangles overlaid on the view.

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, with input through Anoto digital pens (ADP-301). The context of the study was a map-based police emergency response situation with an Overview+Detail interface inspired by DragMag [25], which provided a large overview and allowed flexible placement of detail views to provide awareness of the current situation (see Figure 5).

Design

We used a 2 (*technique*) × 2 (*density*) × 2 (*position*) mixed design with the following factors:

- *Technique:* Canyon, Wedge; within-participants
- *Density*: 5 cars, 10 cars; within-participants
- *Position:* left, right; between-participants

For the technique factor, we compared our Canyon visualization, which provides details of the surroundings of a target, to Wedge, an established off-screen visualization technique that uses abstract cues (see Figure 4). Wedge was implemented as described in [13], including the overlap resolution algorithm. Since the map application itself included an Overview+Detail interface, Overview+Detail was not used as a comparative technique. For the density factor, each participant's detail view presented 5 or 10 moving cars as targets.

Figure 5: The study setup included a large shared overview map and one detail map for each participant.

Suburban areas of a large, foreign city 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 prior to the study. Since two participants completed a task simultaneously with the same overview map, each participant had a detail map and thus the detail map areas were not the same. To account for any variance caused by differences in map area, we included the position factor.

Tasks

Four tasks were used to explore spatial limitations, the degree of difficulty to relate detail view and overview, and how well movement, relative location, and absolute location of objects are conveyed. Since we opted for higher precision and realism, tasks were inspired by the previously studied police work context. Selections were achieved by tapping the corresponding object once with the pen.

- T1. *Identification.* A car was highlighted in red on the detail map, and the participant was asked to select the corresponding car on the overview map. This task tests how well objects can be correlated between maps.
- T2. *Movement.* All cars were paused. The participant was then asked to select all cars that were stationary prior to the pausing, and then select the "Finished" button. Knowledge about whether a car is moving improves a police officer's situation awareness and motivates this task. We test how well movement is conveyed.
- T3. *Distance.* While all cars are stationary and off-view, the participant was asked to select the closest car to the centre point of their detail view and then the second-closest car. Thereby, we test how well relative distance is interpreted. This task was motivated by having a new incident in the middle of the detail map and the need to send cars to that location. The closest cars are expected to arrive fastest.
- T4. *Location.* A car was highlighted in red on the detail map, the participant was then asked to mark its location by tapping once on the overview map. This tests how well absolute location information is conveyed and was motivated by a police officer's need to know the absolute position of a police car.

Procedure

Each pair of participants was welcomed and given an overview of the project and study procedure. After filling out a background questionnaire, they were given time to practice drawing with the digital pen until they felt comfortable with the whiteboard technology.

Participants were then introduced to the tasks and the first technique through a presentation, followed by a training session. Then, they performed two blocks of all four tasks in the same order (T1-T4) for the first density condition, then two blocks for the second density condition, and then filled out post-condition questionnaires. Participants then followed the same procedure for the second technique, then completed an exit questionnaire and were interviewed. The order of technique and density were counterbalanced, but the density was presented in the same order of both techniques. Each trial was repeated 7 times for a total of 56 trials per participant (2 techniques × 2 densities × 2 blocks of tasks × 7 repetitions).

Data Collection

Each session was video and audio recorded. Timing data, car locations, and pen selections were captured through computer logs. Preference data were collected through post-condition and exit questionnaires.

RESULTS & DISCUSSION

This section presents the quantitative results, categorized by the tasks, as well as the overall study observation and participants' preference and feedback.

In our design, the density condition required a pre-determined task setup including map area and movement patterns of cars, and so our density factor was not separable from this setup. Our observations and preliminary analyses revealed that these different setups may have impacted participants' behavior, and so we performed two separate analyses for each density to avoid this confounding factor. We instead included *density order* as a between-participants factor, to separate learning effects and fatigue from the technique factor, as some of our participants would have performed comparable trials at different times throughout the study session. Error rates and trial completion time were thus analyzed using a 2 (*technique*) × 2 (*density order*) × 2 (*position*) repeated measures ANOVA ($\alpha = .05$) separately for each level of density.

We found little significant differences between the tested techniques in our 5-car analysis. However, the 10-car condition reveals a number of significant differences between Wedge and Canyon. Since the results of the 10-car analysis are more interesting we will report only these results in this paper. For a comprehensive report of all results, we refer the reader to our supplementary material.

T1 – Identification

The trial completion time was calculated from when the car was highlighted in the detail view to when the car was selected on the overview map. The error rate was measured as a binary value: whether the selection was correct or not. No main effects or interactions were found for error rate.

Trial Completion Time

A significant main effect of technique ($F_{1,13} = 6.037$, $p = .029$) was found. Wedge was significantly faster ($M = 4.74$ s, $SE = 0.66$ s) than Canyon ($M = 6.57$ s, $SE = 1.26$ s). We suspect that this was 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.

A significant main effect of density order was found ($F_{1,13} = 5.376$, $p = .037$). Participants were faster when the 10 cars condition was tested second ($M = 4.58$ s, $SE = 0.67$ s) than when it was first ($M = 6.74$ s, $SE = 1.25$ s), an expected learning effect. No other main effects or interactions were significant.

T2 – Movement

The trial completion time was calculated as the time from when the cars were frozen to when the "Finished" button was pressed. Three types of error were also calculated and compared: omissions, false-positives, and overall error. Omissions were calculated as the percentage of stationary cars participants missed. False-positives were calculated as the percentage of moving cars erroneously selected. The overall error was calculated as the sum of stationary cars missed and the number of moving targets selected divided by the total number of cars in the condition. There were no main effects or interactions for trial completion time or omissions.

False Positives

There was a significant main effect of technique ($F_{1,13} = 10.687$, $p = .006$). Participants selected significantly fewer moving cars with Canyon ($M = 3.13\%$, $SE = 1.89\%$) than with Wedge ($M = 10.19\%$, $SE = 3.82\%$). Participants may have been more accurate with Canyon as people can easily identify movement in their periphery, and in Canyon this movement remains outside the detail view, whereas with Wedge the movement is promoted to the focus. In addition, Wedge allows for overlapping objects and can become easily cluttered, making false movement detection more likely. No other main effects or interactions were significant.

T3 – Distance

Trial completion time was calculated as the time between dismissing the instructions and selecting a car. The error rate was calculated as the distance between the closest target and the selected target divided by the distance from the detail map centre to the selected target. For the second trial, the target was the closest object among the remaining objects. There were no main effects or interactions for trial completion time.

Error

A significant main effect of technique ($F_{1,13} = 9.276$, $p = .009$) was found. The error was far less for Canyon ($M = 1.72\%$, $SE = 1.27\%$) than for Wedge ($M = 20.23\%$, $SE = 9.57\%$). The main effect may be due to that Canyon provided a more consistent visualization at the corners and for objects at extreme distances. No other effects or interactions were significant.

T4 – Location

Trial completion time was calculated as the time from when the car was highlighted on the detail map to when the location was marked on the overview map. The error was calculated as the distance between the target location and the selected location on the overview map measured in centimeters on the whiteboard. The projected map's scale was approximately 1 cm : 87 m.

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 the 10 cars density was tested second (*Mean difference* = 3.80 s). This is likely caused by a learning effect. No other significant main effects or interaction were found.

Error

There was a significant main effect of technique ($F_{1,13}$ = 9.405, p = .009). Canyon was less error-prone (M = 1.61 cm, SE = 0.53 cm) compared to Wedge (M = 2.85 cm, SE = 0.67 cm). In meters, the average error for Canyon amounts to 139 m and to 247 m for Wedge. This main effect may be due to that the cut-out views provided participants more details surrounding targets so they can identify the absolute location based on the features of the landscape.

Questionnaires

After each technique block, participants were asked to rate how much knowledge they felt they had for each task at 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. The questionnaires used are included in the appendix accompanying this paper.

The post-condition questionnaire data were analyzed using two related samples Wilcoxon signed-rank tests. For the distance task (T3), the results showed that participants perceived themselves to have more knowledge of the targets with Canyon than with Wedge in both density conditions (5 cars: z = 2.208, p = .027; 10 cars: z = 2.248, p = .025). For the location task (T4), Canyon was also rated higher for both 5 cars (z = 2.015, p = .044) and 10 cars (z = 2.133, p = .033). The rating results for T3 and T4 are shown in Figure 6. No significant difference was found in technique for the remaining tasks.

After the experiment, participants were asked to rate their preferred technique by task and overall (see Figure 7). Canyon was more preferred per task and overall. Overall, 14 out of 16 participants (87.5%) preferred Canyon over Wedge. Wedge's highest rating was in the movement task (T2), with 6 participants (37.5%) preferring it to Canyon.

Interviews and Observations

At the end of the study, participants were asked to state their preferred technique and why. According to the participants, the major advantages of Canyon were the clear design and the additional detail provided in the cut-out views. Twelve participants stated that they found Canyon "clearer" or "easier" because they felt confident about the off-view object locations. Three participants pointed out that Canyon provided good orientation by giving reference points within

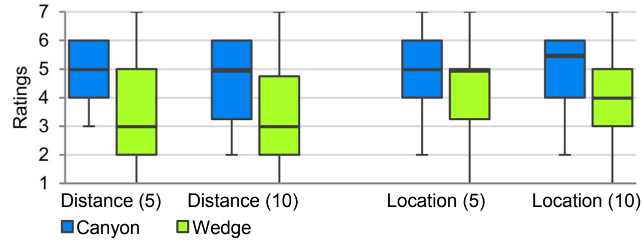


Figure 6: Significantly different Likert-scale ratings for Distance and Location task. 1 means having no knowledge about the object and 7 means having complete knowledge.

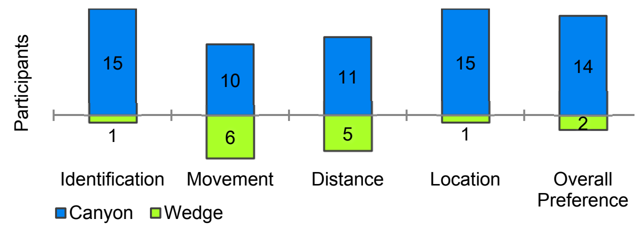


Figure 7: Preferences of technique per task and overall.

the cut-out view, such as roundabouts or parks, which helped locate the target.

> *"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*

One participant commented that with local knowledge, it would be even easier to assign locations with Canyon's cut-out view. However, the drawback of Canyon was estimating the exact distance as reported by 5 participants, and two participants stated explicitly that they felt, distance was better conveyed with Wedge.

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

Nevertheless, two participants felt that the paper folding metaphor of Canyon gave a good understanding of distance, and two participants described Canyon as "intuitive".

Wedge was described by 9 participants as "confusing", especially with overlapping Wedges. One participant commented that the inconsistent base length of Wedges at corners is difficult to understand, while one participant did not notice the inconsistency at all. Moreover, some participants commented that it can be difficult to complete the Wedges mentally.

> *"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 completed" – Participant 7B*

In fact, some participants used their hands in order to interpret Wedge properly and estimate location or distance. Figure 8 shows an example of one participant tracing the legs

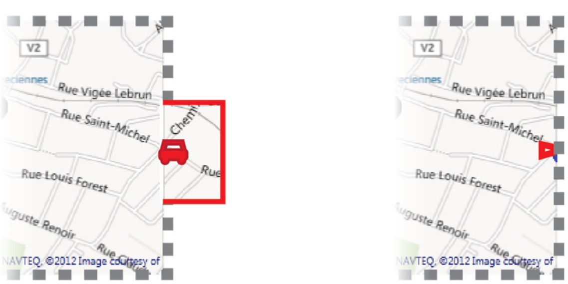
Figure 8: A participant was carefully tracing legs of Wedges with both hands and measuring the length relative to the view size.

of a Wedge carefully with both hands during the Location task. Once the intersection point of a Wedge's legs was found, she measured the distance relative to the detail view. On the overview map, she scaled the distance relative to the detail area marker for finding the object's location.

Furthermore, Wedge's representation of very close objects can lead to overlooking. In one configuration of the Distance task, an off-view object was very close to the detail view (see Figure 9). The Wedge representation of this object was very small and 4 out of 8 participants did not select it as the closest object. In contrast, none of the participants facing this situation with Canyon missed it.

We noticed that during the study participants stepped away from the digital whiteboard for both Canyon and Wedge, but in different tasks. With Canyon, we noticed more often that participants stepped back for observing movement of the cars (T2) than with Wedge. Increasing the distance to the display increased their field of view and provided a better overview for covering the larger area of Canyon's visualizations. With Wedge, participants stepped back for completing Wedges and finding the car location (T4). In contrast, they moved very close to the digital whiteboard to carefully examine Canyon's cut-out view and find the car location. For both techniques, participants looked repeatedly to the detail map and overview map. However, we noticed that they compared the detail and overview map more extensively with Canyon than with Wedge, in order to find location reference points to match corresponding map areas.

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 was the overlapping cues, which often confused the participants.



(a) (b)

Figure 9: A very close off-view object visualized with Canyon (a) and with Wedge (b).

OVERALL DISCUSSION

The quantitative results suggest some positive results for accuracy in favour of Canyon over Wedge, 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 T2. 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. It should be noted, however, that in T1 participants were slower when using Canyon, which suggests that the additional information provided by Canyon may interfere with simpler tasks. For instance, the chaining of objects, sometimes even exceeded the screen borders. Visibility of off-view objects should be guaranteed and stemming Canyon's growth will be addressed in future work.

Our 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 (T3), 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 (T4). 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.

Design Recommendations

Based on our results, we provide design recommendations for multi-user applications on large displays involving individual workspaces and moving off-view objects:

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 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 the 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.

Generalizing Canyon

Canyon is best suited for scenarios involving maps, node-link diagrams, or other 2D spatial information visualizations. However, the general "off-view object" context may be applicable to other task contexts. In addition to the command and control contexts described earlier in this paper, it could also be used for logistics. A dispatcher at a transportation company could use Canyon to stay aware of current truck locations and plan future tours.

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 [12]. This also applies to large displays. Consider working on the layout of a large poster of size DIN A1 (841 × 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 images. Often, a web browser view is needed to search for 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 [2] 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.

CONCLUSION & FUTURE WORK

We have presented Canyon, a novel off-view visualization technique for large-display applications. It employed the paper-folding metaphor; therefore, using both distortion and shadow to convey distance information. Moreover it provided context around target location, which helped to improve accuracy. To investigate the effectiveness and efficiency of the technique, a controlled laboratory experiment was conducted comparing Canyon 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.

In the future, we would like to investigate potential ways to control the growth of Canyon. Another area of future research is to improve the visualization at corners to allow faster interpretation of distance. One potential way is to use circular workspace instead of rectangular shapes. Moreover, an investigation on fine tuning the shadow or creating an alternative augmentation for conveying distance will improve the estimation of absolute distance of targets. Finally, 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.

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