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On the Effectiveness of Overview+Detail Visualization on Mobile Devices

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Abstract Overview+Detail visualization is one of the major approaches to the display of large information spaces on a computer screen. Widely used in desktop applications, its feasibility on mobile devices has been scarcely investigated. This paper first provides a detailed analysis of the literature on Overview+Detail visualization, discussing and comparing the results of desktop and mobile studies to highlight strengths and weaknesses of the approach. The analysis reveals open issues worthy of additional investigation and can provide useful indications to interface designers. Then, the paper presents an experiment that studies unexplored aspects of the design space for mobile interfaces based on the Overview+Detail approach, investigating the effect of letting users manipulate the overview to navigate maps and the effect of highlighting possible objects of interest in the overview to support search tasks. Results of the experiment suggest that both direct manipulation of the overview and highlighting objects of interest in the overview have a positive effect on user performance in terms of the time to complete search tasks on mobile devices, but do not provide specific advantages in terms of recall of the spatial configuration of targets.

Keywords Overview+Detail · visualization · small-screen devices · mobile interaction · experimental evaluation

1 Introduction

Today, mobile devices are powerful enough to display maps, images, web pages and other large and complex information spaces, supporting an ever increasing number of people in carrying out work and leisure activities anytime, anywhere. Map-based systems, content-rich web sites, imaging software and other applications and services are no longer limited to the desktop domain. Unfortunately, visualizing information effectively on mobile devices is not trivial [14] and there is no guarantee that effective solutions for desktop visualization could be successfully employed in the mobile domain. Indeed, mobile devices have smaller displays, less powerful hardware, different input mechanisms compared to desktop computers and most of these limitations are not likely to disappear in the near future without sacrificing device portability.

One of the most complex steps in the process of designing appropriate visualizations for the mobile context is laying out the information on the available screen space (the *presentation* problem). When the information to accommodate is larger than the available viewing area, users need access to fine-grained details as well as coarse-grained context information to effectively explore the visualization [13]. Interface design choices have then to focus on how to provide details as well as context information when screen space is at a premium. The typical approach to face this issue is to provide users with pan and zoom mechanisms, thus introducing a temporal separation between detail and context information [6, 26]. However, temporal separation makes it difficult for users to focus on the details of a visualization while keeping track of the global context [12, 22].

Researchers have investigated four classes of solutions to solve or at least mitigate the presentation problem on mobile devices: *Overview+Detail*, *Focus+Context*, *Contextual Cues*, and custom pan and zoom mechanisms. The Overview+Detail approach is commonly used in commercial desktop applications (Fig. 1) and provides both detail and context information by typically displaying two separate views simultaneously, one for the context and one

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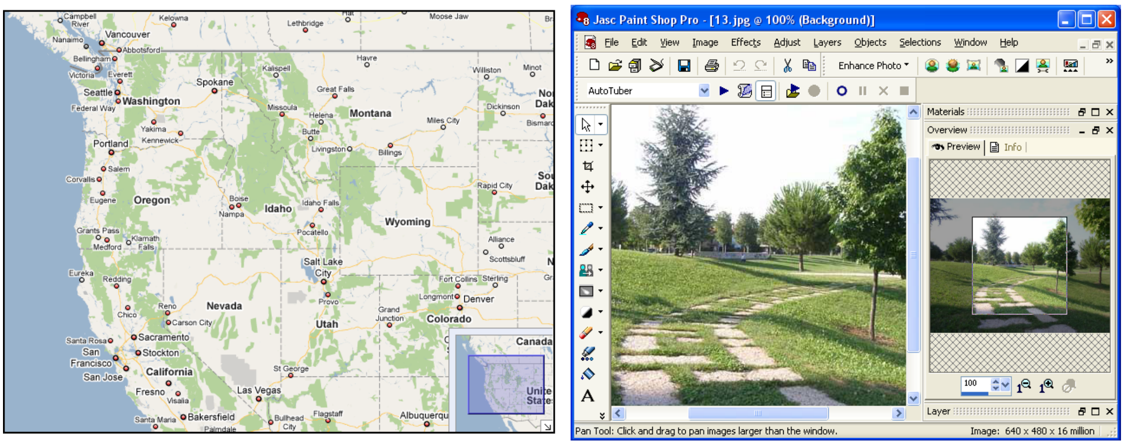


Fig. 1 Two examples of Overview+Detail visualization in desktop applications. In the map example (Google Maps), the overview overlaps the detail view at the bottom right corner of the screen. In the photo-editing example (Paint Shop Pro), the overview is displayed at the right of the detail view.

for the detail [28]. Focus+Context [23] seamlessly integrates detail and context information in the same view, usually by exploiting some form of geometric distortion. Contextual Cues techniques augment the detail view with glyphs meant to help locate parts of interest that are outside the view area. Typically, this is obtained by displaying abstract shapes (e.g., arrows or arcs) in the border region of the screen as visual references to the off-screen context [2, 9]. Custom pan and zoom mechanisms adopt the traditional idea of navigating a visualization by panning and zooming but adapt it to the specific features of mobile devices to reduce the complexity of navigation for the user.

In this paper, we focus specifically on Overview+Detail visualization (hereinafter, O+D), which has received limited attention by the mobile community. Indeed, while several studies have compared O+D to other presentation techniques on desktop computers [15], few studies have investigated the effectiveness of the O+D approach on small screens, with conflicting results. For example, Büring et al. [11] found that there was no advantage in navigating a scatterplot with the aid of an overview and that the overview was actually detrimental to user navigation performance in case of users with high spatial ability. Burigat et al. [10] found instead that users benefit from the availability of an overview in map search tasks.

The contribution of this paper is twofold. First, we provide a detailed analysis of the strengths and weaknesses of O+D visualization on mobile devices in light of results of both desktop and mobile studies. Our survey points out open issues worthy of additional investigation and aims to help designers of mobile interfaces determine if and when O+D visualization could be advantageous over other presentation techniques. Second, we present a follow-up study to [10] that further explores the design space of mobile O+D visualization, delivering additional actionable information on the topic.

The survey we present in the first part of the paper is complementary to the surveys of Cockburn et al. [15] and Hornbaek and Hertzum [21], which mainly focus on the desktop domain. In particular, Cockburn et al. [15] discuss O+D in the context of a more general review of approaches that allow users to work at multiple levels of detail. Hornbaek and Hertzum [21] take a different perspective, exploring how the concept of overview (defined as awareness of some aspect of an information space) is used in the Information Visualization literature.

The study we describe in the second part of the paper explores the effect of two features of O+D interfaces on mobile devices: 1) adding interactive capabilities to the overview, i.e., letting users manipulate the overview as an interactive navigation control, and 2) highlighting possible objects of interest in the overview, thus adding an additional layer of semantic information. Our main motivation for the study was the general lack of such investigations in the mobile as well as desktop literature. Indeed, while there are several comparisons between O+D and other presentation approaches, investigations of the effect of specific O+D interface features on user performance and preference are rare. Results of our study would thus contribute to the understanding of which features offer the greatest performance advantages and under what conditions.

2 O+D research results in desktop and mobile contexts

In this section, we first outline the design space for O+D visualization, identifying core features and possible design alternatives that have been proposed in the literature. Then, we distill the most significant results of the studies on O+D visualization on desktop computers and discuss them in relation to mobile device capabilities and current research findings in the mobile context.

2.1 The design space for O+D visualization

Most interfaces based on the O+D approach are characterized by a common core of functionality, but can vary substantially in terms of presentation and usage.

2.1.1 O+D presentation

Figure 1 shows typical O+D layouts, comprising a pair of coordinated views, with one small overview displayed either over or beside a larger detail view. Overlapping views are typically used in map-based applications while non-overlapping views are more common in drawing and photo-editing tools. In both cases, the overview is usually a small-scale thumbnail of the whole information space that includes a properly positioned graphical highlight (hereinafter, *viewfinder*) of the portion of space which is currently displayed by the detail view.

In current applications, the viewfinder is displayed in the overview as a simple polygonal outline, or as a shaded polygonal area (see Fig. 1 left), or by shading the context area in the overview (see Fig. 1 right). To the best of our knowledge, no comparative study of the effectiveness of the three alternatives is available in the literature.

In terms of size, the overview is almost always smaller than the detail view but there is no standard value for the relative size of views. Less common layouts make choices such as reserving the same amount of screen space for the two views or allowing the overview to use most of the screen. In general, as suggested by Plaisant et al. [28], the size of the overview and the detail view should be task dependent. For example, a large detail view should simplify drawing or open-ended exploration of a map while a large overview should be preferable in monitoring tasks.

The number of views is another parameter of O+D interfaces: while most applications display two views, complex configurations based on three or more views are possible. Empirical evidence shows that the number of views should depend on the *zoom factor*, i.e., the level of magnification between overview and detail view: when the zoom factor is higher than 25-30, intermediate overview levels are recommended [28, 30].

While there are validated recommendations for the design of O+D interfaces in the desktop domain, the mobile context is lacking specific guidelines. Given the limited screen space of mobile devices, it would seem sensible to aim at optimizing use of screen space, e.g. by using overlapping views and choosing a low zoom factor to limit the number of views to the minimum. However, as we will see in the following sections, existing studies in the literature have mostly focused on comparisons of O+D visualization with other solutions to the presentation problem and we thus have limited knowledge on the relative merits of different O+D design options.

2.1.2 O+D usage

All O+D interfaces support navigation of the information space they display, through traditional panning and zooming mechanisms such as dragging the detail view to move it in the desired direction and changing magnification level with left and right mouseclicks, or by direct manipulation of the overview. In this latter case, dragging the viewfinder within the overview results in a corresponding change in the portion of information space shown by the detail view and highlighting a region of the overview with a click-and-drag operation implements a combination of panning and zooming, making the detail view display the selected portion of information space.

Early papers on O+D visualization such as [28] recommend to coordinate overview and detail view in the form of *tight coupling* to properly support navigation, regardless of the specific panning and zooming technique. Tight coupling consists in immediately reflecting manipulation of the detail view (panning, zooming) as variations in the position or size of the viewfinder and vice versa [1]. However, most of today's widely used applications (e.g., Google Maps, Adobe Reader) adopt a less strict implementation of coordination in which manipulation of the overview results in an update of the detail view only when users complete their panning action. This behavior helps reducing computational and network load but its effect on users has not been investigated.

Another increasingly common feature in O+D interfaces is manual control of overview visibility: users can hide the overview when they do not need it. This option allows one to maximize the area devoted to the detail view, which is desirable when the screen space is limited, but is likely to be useful only in tasks that do not require frequent examination of the overview.

2.2 Empirical evaluations of O+D visualization

Several interfaces based on the O+D approach have been developed since the 80s but only in the last decade there has been a significant research effort aimed at studying their effectiveness. In this section, we discuss implications of major desktop studies on O+D interfaces and then examine the state of O+D in the mobile domain.

2.2.1 Implications of desktop O+D studies

Looking at the studies on desktop O+D, summarized in Fig. 2, one immediately notices the wide variety of different information spaces, user tasks, interface designs, navigation

Paper	Task(s)	Conditions	Results
Beard and Walker (1990) [5]	Navigate a binary dictionary tree, searching for specific words.	Three O+D interfaces using different navigation mechanisms: 1) Navigation by dragging the viewfinder within the overview (roam) 2) Navigation by selecting (in the overview or detail view) the portion of tree to magnify (roam-and-zoom) 3) Navigation by scrolling the tree with scrollbars. All interfaces tested with and without display of the tree overview.	Faster navigation with tree overview. Better user performance with roam and roam-and-zoom vs. scrolling. Difficult interaction with the overview with large tree.
Ghosh and Shneiderman (1999) [16]	Extract information from a temporal visualization of personal histories.	1) Detail-only zooming interface 2) O+D interface with overview and detail views of equal size, displayed side by side	Faster task completion with O+D interface.
North and Shneiderman (2000) [25]	Search for information in a vertical text document of US population statistics.	1) Vertical scrolling interface displaying a textual report of US states, in alphabetical order. 2) Uncoordinated O+D interface (no tight coupling), combining scrolling interface with overview containing state names, displayed side by side. 3) Coordinated O+D interface, combining scrolling interface with overview containing state names, displayed side by side.	Better user performance with coordinated O+D interface vs. scrolling interface. Higher user preference for coordinated O+D interface. Better user performance with coordinated vs. uncoordinated O+D interface for tasks that required access to data details.
Hornbaek et al. (2002) [22]	Search for specific objects in geographic maps. Spatial recall of map objects.	1) Detail-only zooming interface. 2) O+D interface. Availability of semantic zooming as additional variable: with semantic zooming, map labels were always readable regardless of zoom level.	Faster navigation with zooming interface. Better spatial recall of map objects after using zooming interface with semantic zooming. Higher preference for O+D interface.
Baudisch et al. (2002) [3]	Find the closest hotel to a given location on a map. Check connections on a circuit diagram. Drive a (simulated) car while avoiding obstacles.	1) Zooming interface. 2) O+D interface with overview and detail views of same resolution displayed on separate monitors. 3) Focus+Context interface based on low-resolution projected context information and high-resolution focus region.	Better user performance with Focus+Context interface in map and diagram tasks. Better user performance with Focus+Context interface vs. O+D interface in driving task.
Hornbaek and Frokjaer (2001,2003) [19,20]	Write essays and answer questions about electronic documents.	1) Vertical scrolling interface. 2) O+D interface combining scrolling view with overview pane containing thunbnails of each page (with readable headings), displayed side by side. 3) Focus+Context interface displaying sections body in smaller font compared to headings and first and last paragraph of sections.	In most tasks, better user performance with O+D interface vs. scrolling interface. Higher task completion time with O+D interface vs. Focus+Context. Better text comprehension with O+D interface vs. Focus+Context. Highest preference for O+D interface.
Gutwin and Skopik (2003) [18]	Move a pointer with the mouse through a constrained path (steering task).	1) O+D interface requiring users to move the pointer with the mouse in the detail view, panning the view when needed and using the overview as orientation aid. 2) O+D interface forcing users to drag the viewfinder within the overview to move the detail view behind the pointer, fixed at the center. 3-4-5) Focus+Context interfaces using different distortions.	Better user performance with Focus+Context interfaces vs. first O+D condition at high magnification levels. Comparable user accuracy with first O+D condition and Focus+Context interfaces. Better user performance with Focus+Context interfaces vs. second O+D condition. Higher preference for Focus+Context interfaces.
Baudisch et al. (2004) [4]	Search for specific highlighted terms in a web page.	Three versions of a Web browser based on: 1) Vertical scrolling view, 2) O+D interface combining scrolling view with a page miniature displayed on a separate vertical pane, 3) Focus+Context interface displaying pages in their entirety, with a focus region in its original scale and all other parts compressed to fit the available space.	Faster search with O+D and Focus+Context interfaces vs. scrolling interface. Higher preference for O+D interface.
Nekrasovski et al. (2006) [24]	Topological comparisons between nodes in a large hierarchical tree.	1) Zooming interface, with and without overview. 2) Focus+Context interface, with and without overview. In all conditions, guaranteed visibility of important nodes at all time.	No effect of overview on user performance. Perception of lower physical demand and higher enjoyment with overview.
Pietriga et al. (2007) [27]	Search for a target with rounded corners in a grid of nine candidate rectangular targets.	1) Zooming interface. 2) O+D interface with zooming capabilities. 3-4) Focus+Context interfaces using different distortions.	Better user performance with O+D interface.

Fig. 2 Desktop O+D studies. Note: unless otherwise specified, "O+D interface" means a pair of coordinated views, with one small overview displayed over a larger detail view.

mechanisms that have been considered by researchers over the years. Such variety provides several starting points for discussion but, at the same time, makes it difficult to compare and generalize findings and to explain the inconclusive and sometimes contradictory results that have been produced.

Only a couple of studies provided some insight into the O+D design space, comparing variants of O+D interfaces. In particular, Beard and Walker [5] let users manipulate the overview in two alternative ways, by dragging the viewfinder or by highlighting regions to zoom into, but did not find any significant performance difference between them. The study revealed that displaying the semantic content in the overview was instead an essential feature. Indeed, users performed worse when they did not have access to a miniature of the explored information space in the overview, even if they could still manipulate the overview to navigate. North and Shneiderman's study [25] highlights the effect of coordination in O+D interfaces: coordination between overview and detail view is absolutely critical in tasks where access to details is important (the majority in common applications) but is not essential when the overview can directly provide users with the information needed to carry out tasks.

In terms of pure task completion time, we note that O+D interfaces typically outperformed scrolling interfaces [4, 5, 20, 25] but often did not compare favorably to zooming and Focus+Context interfaces [3, 18, 20, 22]. There is one widely mentioned reason for the difficulties users experience with O+D visualization: the mental and motor effort required to integrate overview and detail views might strain memory and increase the time needed for visual search of an information space [3, 12, 22]. However, Pietriga et al. [27] showed in their study that an O+D interface combined with zooming is superior to zooming and Focus+Context interfaces in terms of the low-level motor and perceptual effort required in generic search tasks. This result suggests that different factors could have negatively affected user performance in those studies where O+D interfaces were outperformed by other solutions. For example, Hornbaek et al. [22] recognize that the addition of semantic zooming in their study probably provided users with rich navigation cues, making the overview often unnecessary. In a similar way, the lack of performance effects of overviews in Nekrasovski et al.'s study [24] may be explained by the presence of guaranteed visibility in all interfaces. Indeed, the authors speculate that coloring important tree nodes in the detail view may have provided users with the orientation information they could otherwise find only through the overview. In Baudisch et al.'s study [3], the fact that the O+D interface used two different, physically separated screens while both other interfaces were displayed on one single screen could have had an influence on the results. An analysis of reading patterns provides a possible explanation of the results in Hornbaek et al.'s 2003 study [20]: in the O+D condition, users often abused of the capability to easily navigate the document using the overview, doing unnecessarily frequent and longer explorations even when a satisfactory answer to the given task had already been obtained.

The study by Hornbaek et al. [20] also reveals that performance of users with the O+D interface was significantly better than performance with other interfaces, including a Focus+Context one, when a different metric, i.e. text comprehension, was considered. This finding suggests that O+D interfaces can provide benefits to users in terms of information acquisition during navigation. Hornbaek et al.'s study [22] seems to provide a contradictory result on this aspect since users showed better spatial recall of map objects after using the zooming interface compared to the O+D interface. However, semantic zooming could have played a significant role also in this case. Unfortunately, since almost all studies in the literature have focused on task completion time as the primary metric to measure user performance, there is limited knowledge of other possible positive effects of the O+D approach.

There is instead significant evidence of the preference of users for O+D interfaces, even in those studies that found O+D to be worse than other approaches in terms of performance (with the notable exception of Gutwin and Skopik [18]). Some researchers suggest that the overview probably helps users in building a more comprehensible internal model of the visualization [24]. In those studies where O+D did not compare favorably to other interfaces, this internal model was probably insufficient to counterbalance the additional factors that did negatively affect performance, yet it improved users' perception of the benefits of O+D interfaces, which could explain preference results. In such cases, as recommended by Hornbaek et al. [22], designers should consider whether to shoot for subjective satisfaction or user performance and provide an overview or not in their interfaces accordingly. For example, overviews should be avoided when the information space provides enough cues for navigation and navigation time is the most important performance metric.

The study by Gutwin and Skopik [18] was the only one where, consistently with their performance results, users preferred the Focus+Context approach to the O+D one. This is an important result because it suggests that in tasks where the goal is to locally manipulate the visualization at high magnification (e.g., tracing the edges of an object in an image), the benefits (real and perceived) of Focus+Context interfaces far exceed those of O+D interfaces. However, most of the studies we examined focused on tasks that required users to navigate an information space in order to visually search for targets. Further studies are thus needed to get a more comprehensive picture of the relation between task category and presentation techniques.

2.2.2 O+D on mobile devices

It is reasonable to expect that most high-level results of desktop O+D studies would hold on mobile devices as well: coordinated views should be more effective than uncoordinated overview and detail views [25], displaying a miniature of the information space should be essential to properly support navigation [5], providing additional ways to get orientation information (e.g., through semantic zooming) should have a negative impact on the usefulness of an overview [22, 24]. However, there is no easy way to generalize to the mobile domain all the performance and preference results found in desktop O+D studies. Indeed, conditions are extremely different and it may be the case that mobile device limitations affect different interfaces in dissimilar ways with respect to the desktop domain. For example, in the study by Pietriga et al. [27], the overview covered a 200x200 pixels region of the screen, which represented 4.5% of the total available display area. This configuration cannot be produced on the screen of mobile devices, which are limited to low resolutions. Even in the absence of a formal investigation of the role of the size of views in O+D interfaces, the direct applicability of the results of that study to the mobile domain is doubtful.

In general, fitting overview and detail views on a limited screen space is problematic: reducing the overview in size negatively affects the readability of its content but increasing the size subtracts screen space from the detail view, which is typically the primary focus of user's interest. Some researchers suggest that designers should use overviews at least one-sixteenth the size of the detail window in desktop applications and that the overview might need to be larger to support navigation on small devices [22]. However, design guidelines on overview sizes are lacking. Necessarily, overview and detail views are smaller than on a desktop screen and this could make it more difficult to relate them, increasing the effort required to integrate the information they provide [14].

Several desktop studies also highlighted difficulties users had in manipulating the overview to carry out pan and zoom operations when the zoom factor was too high [5, 18, 22]. In such cases, besides the difficulty of interacting with a very small viewfinder, it came out that the small size of the overview resulted in large jumps in the detail view for even a small movement of the viewfinder. Even more so, the small size of overviews could have a significant impact on the ease with which users manipulate the overview itself on mobile devices.

On the positive side, we note that both overview and detail views on a small screen should be relatively easy to see at once. Compared to the desktop case, where the overview is typically in the peripheral view area when the user focuses on the detail view, fewer and shorter eye movements should probably be necessary on a mobile device to correlate the information the two views provide.

2.2.3 Mobile O+D studies

Despite the differences between desktop and mobile scenarios, only a few empirical studies, summarized in Fig. 3, have been carried out to determine how mobile device limitations affect the design and use of O+D interfaces.

Roto et al.'s work [29] on web page visualization on small screens clearly shows the effect of designing an O+D interface for a mobile platform, proposing an approach that differs significantly from those found in desktop studies in terms of features of the overview. Since the target device had no pointing capabilities, the overview did not provide pan and zoom mechanisms and was aimed primarily at supporting orientation. Moreover, to limit its intrusiveness, the overview was overlaid transparently over the detail view and, more importantly, it was visible only during continuous scrolling of a page. Compared to a more traditional mobile browser, the O+D approach scored better in usability ratings and user preference, similarly to what was found in Baudisch et al.'s desktop study on web page navigation [4]. Unfortunately, the design of the study makes it impossible to determine whether the results were due to the page reformatting technique used, the overview, or to the combination of the two factors. Neither it is possible to understand the effect of any of the specific features of the overview.

Buring et al.'s study [11] on scatterplot visualization seems to provide the most compelling proof of the drawbacks of mobile O+D visualization. Results of the study revealed that participants with high spatial ability solved tasks significantly faster with the zooming interface while no performance difference between the two considered solutions was found for subjects with low spatial ability. As pointed out by the authors, these results seem to confirm the negative effect of the reduced size of the detail view in mobile O+D interfaces: on small screens, a larger detail view can outweigh the benefits gained from the presence of an overview window. However, another possible motivation for the results is that users could get additional navigation cues beyond those provided by the overview, like in the studies by Hornbaek et al. [22] and Nekrasovski et al. [24] in the desktop domain. Indeed, not only did the system use an implementation of semantic zooming as in [22] but users could also refer to the labeled axes of the scatterplot to guide their navigation. These factors, combined with the reduced size of the detail view and the problems users encountered in interacting with the small

Paper	Task(s)	Conditions	Results
Roto et al. (2006) [29]	Search for specific information in a web page.	Two versions of a Web browser based on: 1) Single column vertical scrolling view. 2) O+D interface combining scrolling view of dynamically reformatted pages with tranparent page miniature overlaid during scrolling.	Better score for O+D interface in usability ratings and user preference.
Buring et al. (2006) [11]	Search for specific items in a scatterplot.	1) Zooming interface. 2) O+D interface with non-overlapping overview and detail views. In O+D interface, detail view 40% smaller than in the zooming interface. In both interfaces, limited implementation of semantic zooming: more detailed information about items apperared at high zoom levels.	Faster search with zooming interface for users with high spatial ability.
Burigat et al. (2008) [10]	Search for specific targets in geographic maps, web pages, and diagrams. Spatial recall of the position of targets.	1) Zooming interface. 2) O+D interface (traditional O+D). 3) O+D interface without semantic information in the overview (wireframe O+D). In O+D interfaces, the overview covered 10% of the area available to the detail view.	Faster search with traditional O+D interface vs. zooming interface in maps. No clear benefit of wireframe O+D vs. the other interfaces. Better spatial recall of targets with O+D interfaces.
Burigat and Chittaro (2011) [8]	Carry out spatial tasks involving off-screen objects in geographic maps: find the closest object, order objects in increasing distance from the screen border, find the pair of objects which are closest to each other, mark the location of each object on a printed version of the visualization	1) Wedge (Contextual Cues technique) 2) Scaled arrows (Contextual Cues technique) 3) O+D interface No navigation mechanism available; during tasks, users were shown a snapshot of the considered information space with a given configuration of off-screen objects.	Better user performance with Wedge and Scaled arrows vs. O+D in the object-ordering task. Better user performance with O+D vs. Wedge in the pair-of-closest-objects task. Higher preference for O+D interface.

Fig. 3 Mobile O+D studies. Note: unless otherwise specified, "O+D interface" means a pair of coordinated views, with one small overview displayed over a larger detail view.

overview might also explain why, unlike in most desktop studies, the O+D interface did not show any advantage in terms of user preference over the zooming interface.

Unlike what was found by Buring et al. [11] and Hornbaek et al. [22], our 2008 study on map, diagram, and web page navigation showed that an O+D interface is comparable or can provide advantages over a more traditional zooming interface in terms of task completion time [10]. This suggests that orientation cues that are external to the overview, which were available in the two cited studies but not in ours, might play indeed a significant role in supporting navigation, making the overview unnecessary. We also found that trading semantic content in the overview for increased visibility of the detail view, as we did in the wireframe O+D interface, was not useful to improve user performance. The spatial recall task we designed to determine which interface better supported user creation of a mental map of the information space revealed that users were more accurate with O+D interfaces than with the zooming interface, especially in the case of maps. This contradicts the results obtained by Hornbaek et al. [22], which were probably affected by the availability of semantic zooming. Similarly to desktop studies, we also found a clear user preference for traditional O+D over the other two interfaces for map and diagram navigation. Interestingly, user comments highlighted that the overview was considered detrimental to web navigation but did not point out the same drawback for the other two information spaces. This might be due to the fact that web pages have a well defined structure that is familiar to users and helps navigation.

As we found in our 2011 study [8], O+D on mobile devices is also useful when the user needs to reason in terms of the spatial configuration of the objects of interest contained in an information space. Unlike previous desktop and mobile studies on O+D, which required users to actively navigate an information space to search for specific data, the tasks in our study aimed at assessing how well the different conditions conveyed information about off-screen objects, i.e., objects of an information space that fall outside the detail view area. In the object-ordering task, users were significantly slower with O+D than they were with Wedge [17] and Scaled Arrows [9], probably because it was easier for users to compare the glyphs encoding direction and distance of off-screen objects with Wedge or Scaled Arrows than it was to obtain distance information from a small-scale overview. In this case, the small size of the overview nullified the advantage of having direct visual access to object configurations. In the pair-of-closest-objects task, users were significantly faster and were more accurate with O+D than they were with Wedge. This task revealed the effectiveness of O+D in complex spatial tasks that depend on knowing the spatial configuration of all off-screen objects. As in the desktop domain, we found evidence of the preference of users for O+D interfaces, even for those tasks in which O+D was worse than other approaches in terms of performance. Probably, users prefer having direct visual access to the configuration of off-screen objects even if the small size of the overview makes it actually difficult to easily extract accurate information.

2.2.4 Implications of mobile O+D studies

Overall, it is difficult to draw general conclusions from the few studies on mobile O+D. As we pointed out in the discussion of desktop O+D studies, availability of multiple means to obtain orientation cues seems to reduce the effectiveness of the mobile O+D approach. When an information space provides these cues, as in the case of the scatterplot in [11] or web pages in [10], O+D interfaces do not provide advantages in terms of navigation performance compared to more traditional presentation techniques. However, an O+D interface is comparable or can provide performance advantages when additional orientation cues are not available in the considered information space [10]. This is particularly noticeable in the case of spatial tasks, as we found in [8] and [10], even if the small size of the overview might sometimes negatively affect geometric assessments (as in the object-ordering task in [8]). Unlike in the desktop domain, there also seems to be a tighter correlation between user performance and subjective preference in target search tasks. Probably because of the smaller size of the views, users did perceive O+D interfaces to be detrimental in the studies that found O+D to be worse in terms of task completion time.

However, many unclear points still remain to be clarified through further investigations. For example, are the general results of Pietriga et al.'s study [27] about the low-level motor and perceptual effort advantages of O+D still valid on small-screen devices? How do O+D interfaces compare to Focus+Context interfaces in the mobile domain? What is the effectiveness of O+D interfaces in common mobile scenarios such as during walking or under sunlight? What are the effects of different design options on user performance with mobile O+D interfaces? In the second part of this paper, we present one study that starts to take into consideration this last question, exploring two possible design dimensions for mobile O+D interfaces.

3 User study

Most of the studies on O+D visualization, in both desktop and mobile domains, have focused on comparing a specific O+D implementation with interfaces based on different approaches to the presentation problem such as scrolling, zooming or Focus+Context visualization. Very few studies [5, 10, 25] have instead explored, at least in part, the design space for O+D visualization, investigating the effect of specific interface features on user performance and preference. As a consequence, implementations of the O+D approach are often arbitrary and sometimes even ignore the guidelines we highlighted in previous sections, such as keeping the zoom factor under a certain threshold and using tight coupling.

To deepen the analysis of the O+D design space and provide actionable indications to interface designers, we carried out a follow-up to our 2008 study, with a twofold goal. First, we wanted to better understand the effect of highlighting objects of interest in the overview, which introduces an additional layer of semantic content with respect to a standard overview. In our previous study [10], we introduced highlighting in the overview during map search tasks with the traditional O+D interface. Besides having access to a miniature of the information space, users could thus look at the highlighted objects in the overview to guide their search towards possible targets. In the present study, we controlled the display of objects of interest in the overview to assess how much this specific cue could affect user performance in search and spatial recall tasks. The second goal of the study was to investigate if letting users navigate an information space by direct manipulation of the viewfinder within the overview could benefit performance on mobile devices despite the likely interaction difficulties due to the small size of the overview. Almost all previous O+D studies integrated some form of overview manipulation to support pan, zoom or both operations. However, none of them could determine whether results were due to the information displayed in the overview, the direct manipulation capabilities or a combination of the two factors. Our study will help clarify this point.

Intuitively, the two O+D interface features we considered should significantly benefit user performance. However, we were unsure about how much the small size of the overview could negatively affect their effectiveness. We were also interested in determining the relative impact of the two features in terms of magnitude of their effect. For designers, this could be useful to estimate how much they could gain by including each feature in their interfaces.

As in our previous experiment, we designed a navigation task that required users to search for specific targets in the considered information space and a spatial memory task that assessed recall of information after exploration of the information space. The first task is useful to compare our results with those of the related literature in terms of task completion time while the second task allows us to

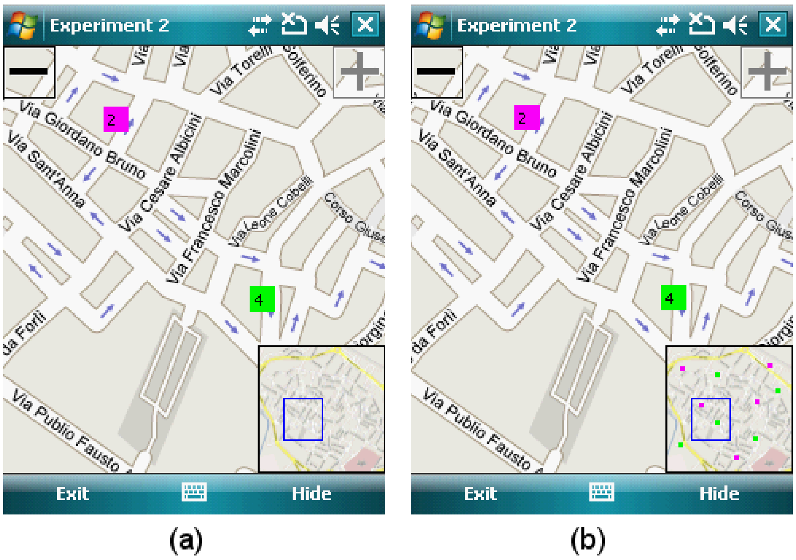


Fig. 4 O+D visualization without (a) and with (b) highlighted objects of interest in the overview.

continue our study of the O+D approach using a different metric to measure user performance. This time we focused only on map navigation since maps are at the core of several widely used mobile applications and services (e.g., navigation systems, mobile guides, Geographic Information Systems) and were found to be the information space that derived the most benefit from O+D in our first study.

3.1 Hypotheses

In general, we expected that both highlighting objects of interest in the overview and supporting navigation through direct manipulation of the overview would have a positive effect on user performance. More specifically, our hypotheses were:

- Users should be faster in searching for targets when objects of interest are highlighted in the overview. Highlighting, together with the additional orientation cues provided by viewfinder size and position, should enable users to directly navigate towards possible targets, thus reducing search time by avoiding a blind search in the considered information space.
- Users should be faster in carrying out search tasks when they can manipulate the viewfinder in the overview to pan the detail view. Moving the viewfinder towards the desired destination should allow users to be faster with respect to the traditional panning technique based on dragging the portion of information space displayed in the detail view.
- Users should be more accurate in remembering target location when objects of interest are highlighted in the overview. With visible objects of interest, users can see the global configuration of possible targets in the overview, which should simplify construction of an accurate mental map of the information space.

Our hypotheses relied on the (optimistic) expectation that the advantages provided by direct manipulation of the overview and highlighting objects of interest would exceed the negative impact of mobile device limitations, in particular the small size of the overview, on user performance.

3.2 Interfaces

The need to control two binary variables led us to the design of four interface conditions, based on the traditional O+D visualization we employed in our 2008 study. In all conditions, the overview was displayed as a small 80x80 pixels thumbnail, covering about 10% of the 240x268 pixels detail view, in line with the suggestion of [22] for overview sizes. The only difference among the four interfaces concerned the manipulability (or lack of manipulability) of the viewfinder, and the highlighting (or lack of highlighting) of possible objects of interest in the overview. Figure 4 shows the O+D visualization without (Fig. 4a) and with (Fig. 4b) highlighting of objects of interest in the overview. In all four conditions, users could pan by dragging the portion of information space displayed in the detail view and zoom by tapping on the two icons with a plus (zoom in) and a minus (zoom out) in the upper area of the screen. During the evaluation, the zoom factor ranged from a minimum of 3 to a maximum of 10, thus fully complying with the guidelines suggested in [28] and [30] for two-views O+D layouts, and the viewfinder reached a minimum size of about 24x27 pixels. In the two conditions with manipulable viewfinder, users could also pan by dragging the viewfinder within the overview in the desired direction, and the detail view updated accordingly in real time.

3.3 Participants

Twenty-eight subjects (11 female, 17 male) participated in the study. They were all recruited by direct contact among undergraduate or graduate students from the Computer Science and Engineering courses at our university. Their age ranged from 21 to 28, averaging at 25, and they were all mobile phone users. Only two of the subjects had often used map-based applications on their devices, 13 had used them occasionally, and the remaining 13 had never used map-based applications on mobile phones or PDAs.

3.4 Materials

The study was carried out on an Asus P535 Windows Mobile phone featuring a 520MHz processor and a 2.8-inch touchscreen with 240x320 resolution. As in our 2008 study, the detail view covered a 240x268 area in the middle of the screen, and the rest of the screen displayed two standard Windows Mobile menu bars at the top and bottom. We used 4 city maps for the experimental tasks and 1 for training. The cities we chose turned out to be unfamiliar to users. All city maps included 10 possible targets depicted as numbered color icons. Targets were manually placed in random positions on maps. Four zoom levels were available to users, thus requiring three taps on the zoom-in icon to move from the lowest to the highest zoom level. Zoom icons were semi-transparent to minimize occlusion on the detail view. All maps were initially displayed at the coarsest level of detail so that they were almost entirely displayed in the detail view at the start of tasks. However, fine details such as street names and icon numbers were visible only at the highest zoom level, at which the resolution of each map was 800x800 pixels.

3.5 Tasks

Each participant carried out one MapNavigation task and one SpatialMemory task for each interface (8 tasks in total).

In the MapNavigation task, users had to navigate a city map to find the location of two specific hotels and tap on their icons on the detail view. Users were informed that all hotels were depicted as numbered color icons. When highlighting of objects of interest was active, hotels were displayed in the overview as small color dots (see Fig. 4b). An example of the task was: "Find out hotels 2 and 5 on the map and tap on their icons as soon as you locate them". The two hotels to search for were always located in different areas of the map to prevent users to find both in a single screen (at the maximum zoom factor).

The SpatialMemory task required users to mark the location of the targets they had searched for in the MapNavigation task on a paper sheet that reproduced the considered information space at the coarsest level of detail. To carry out this task, users could not use the mobile device and had to rely only on the spatial knowledge they had previously acquired during the MapNavigation task.

3.6 Experimental design and procedure

The experimental design was within-subjects. Participants were initially briefed about the nature of the study and were provided with an introduction and demonstration of the interfaces. Before carrying out the experimental tasks, users were presented with training tasks to let them familiarize with the interfaces and clarify possible doubts concerning interfaces or tasks. After training, users carried out the 4 pairs of experimental tasks (8 tasks total), each pair including one MapNavigation task and the corresponding SpatialMemory task. Participants had access to a printed sheet that provided clear instructions for each task. To start the MapNavigation task, users were required to tap on a "Start Task" button that was initially displayed on the screen. Each MapNavigation task ended when users tapped on the last target. The SpatialMemoryTask did not require users to interact with the mobile device and ended when users marked the last target on the paper reproduction of the considered map. After completing all tasks, users were asked to order the four interfaces from the best to the worst according to their preference (draws were allowed) and were briefly interviewed to collect their comments.

The order of presentation of experimental conditions, as well as their association with maps and target configurations were counterbalanced using a Latin-square design to minimize order effects. Four maps and four target configurations were used during the study. Configurations were kept as similar as possible in terms of relative distance of targets.

We automatically recorded the following data for each task:

- The time users spent to complete a MapNavigation task, from the instant they tapped on the "Start Task" button to the instant they tapped on the last target.
- The number of distinct pan, zoom, and target selection actions during each MapNavigation task. A pan action was counted each time users dragged the stylus on the information space, a zoom action each time users tapped

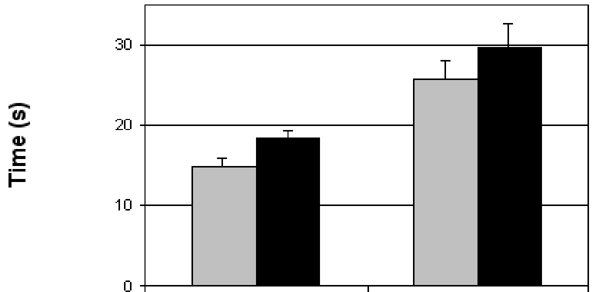
on zoom buttons, and a target selection action each time users tapped on any object of interest on the detail view.
- The duration of each pan action, from the instant users began dragging the stylus on the map to the instant they lifted the stylus from the screen.

We also manually computed the distance between actual target location and the location indicated by the user in the SpatialMemory task.

3.7 Results

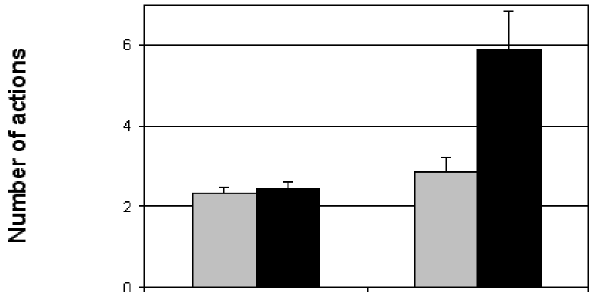
3.7.1 Task completion times

Figure 5 shows mean completion times for the MapNavigation task, for all four possible combinations of the two within-subjects factors (manipulability of the overview, and highlighting of objects of interest in the overview). Both factors have two levels: manipulable overview (abbreviated as MAN in figures) and non-manipulable overview (abbreviated as NMAN in figures) for manipulability; highlighting enabled (abbreviated as HIGH in figures) and highlighting disabled (abbreviated as NHIGH in figures) for highlighting. Task completion times were subjected to the Shapiro-Wilk test of normality prior to further analysis. The test revealed moderate deviations from the normal distribution and data was normalized using a log transformation. A two-way repeated measures analysis of variance (ANOVA) was then employed on the log-transformed times. The ANOVA did not reveal a significant interaction between manipulability and highlighting ($F(1,27) = 0.94, p = 0.340$). A significant main effect of manipulability was detected, ($F(1,27) = 49.96, p < 0.001$): users took less time to complete the task with the manipulable overview than they did with the non-manipulable overview. A significant main effect of highlighting was also detected, ($F(1,27) = 8.39, p < 0.01$): users took less time to complete the task when objects of interest were highlighted in the overview.



	MAN	NMAN
HIGH	14.88	25.74
NHIGH	18.34	29.57

Fig. 5 Mean completion times for the search task. Abbreviations: MAN = manipulable overview, NMAN = non-manipulable overview, HIGH = highlighting enabled, NHIGH = highlighting disabled.



	MAN	NMAN
HIGH	2.36	2.86
NHIGH	2.46	5.89

Fig. 6 Mean number of zoom actions.

3.7.2 User interface actions

Figures 6 and 7 show means of the number of zoom and pan actions performed by users. The Shapiro-Wilk test of normality we performed prior to further analysis revealed a right skew in the data distribution, and none of the transformations (roots, logarithm, inverse) which are typically used to deal with this kind of deviation could normalize the data. We thus employed the non-parametric ANOVA-Type Statistic (ATS) [7] to analyze main and interaction effects. For zoom actions, a significant main effect of manipulability was detected ($ATS = 18.56, p < 0.0001$): users made more zoom actions with the non-manipulable overview than they did with the manipulable overview. A significant main effect of highlighting was also detected ($ATS = 6.49, p = 0.01$): users made more zoom actions when no object of interest was highlighted in the overview. There was also a significant interaction effect ($ATS = 6.58, p = 0.01$): for the non-manipulable overview, users made more zoom actions when objects of interest were not highlighted than when objects of interest were highlighted in the overview, but no such pattern was found for the manipulable overview. For pan actions, the ATS revealed no significant interaction ($ATS = 0.28, p = 0.6$) and no significant main effect of highlighting ($ATS = 1.61, p = 0.2$). However, a significant main effect of manipulability was detected ($ATS = 136.96, p < 0.0001$): users made more actions with the non-manipulable overview than they did with the manipulable overview.

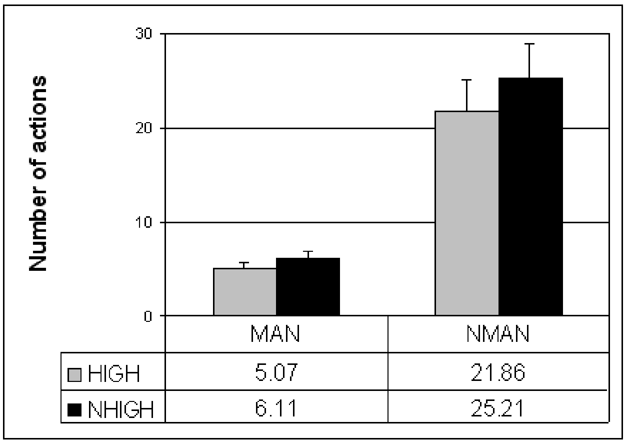


Fig. 7 Mean number of pan actions.

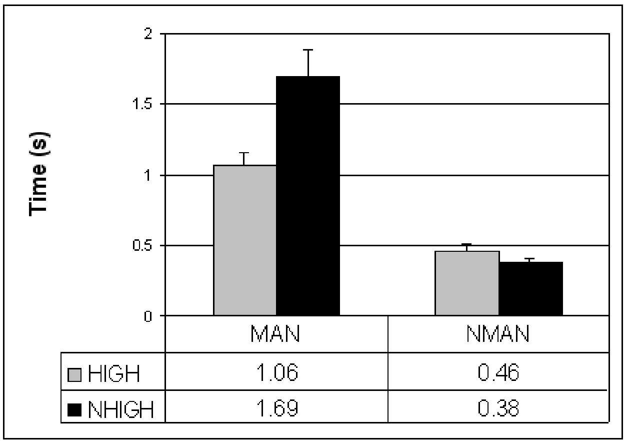


Fig. 8 Mean pan times.

3.7.3 Pan time

As with task completion times, we used the Shapiro-Wilk test of normality prior to further analysis of pan times, whose means are shown in Fig. 8. The test revealed a moderate deviation from the normal distribution, which was corrected using a log transformation. ANOVA was then used to analyze the data. No significant main effect was found for highlighting ($F(1, 27) = 3.21, p > 0.05$), while a significant main effect was found for manipulability ($F(1, 27) = 121.60, p < 0.001$), with users taking longer pan actions with the manipulable overview than with the non-manipulable overview. The ANOVA also revealed a significant interaction effect ($F(1, 27) = 11.79, p = 0.02$): for the manipulable overview, users made longer pan actions when no object of interest was highlighted in the overview than they did when objects of interest were highlighted in the overview. No such pattern was found for the non-manipulable overview.

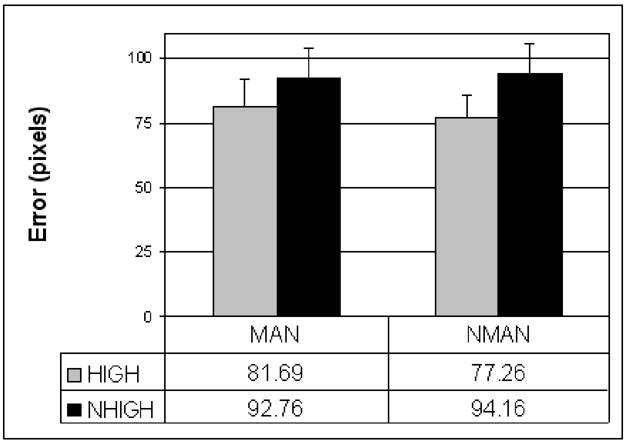


Fig. 9 Error in the SpatialMemory task.

3.7.4 Error

Two-way ANOVA was used to analyze error in the SpatialMemory task, where the amount of error for each user was measured as the average of the distance (in pixels) between the location indicated by users and the correct location for the two considered targets (results are shown in Fig. 9). The ANOVA did not reveal a significant interaction effect ($F(1, 27) = 0.094, p = 0.76$), nor any significant main effect for manipulability ($F(1, 27) = 0.001, p = 0.98$) and for highlighting ($F(1, 27) = 2.08, p = 0.16$).

3.7.5 Subjective preference

To analyze the data on subjective preference (Fig. 10), we employed the non-parametric ATS statistic. Since users were asked to rate the four interfaces from the best to the worst, we assigned a score of 4, 3, 2, 1 respectively to the first, second, third and fourth interface. An appropriate fractionary score was assigned to draws, which were allowed. The analysis did not reveal a significant interaction effect ($ATS = 1, p = 0.32$) but pointed out a significant main effect for manipulability ($ATS = 216.16, p < 0.0001$) with users preferring the manipulable overview to the non-manipulable overview, as well as for highlighting ($ATS = 348.79, p < 0.0001$) with users preferring highlighting to no highlighting in the overview.

3.8 Discussion

As we had hypothesized, the analysis of task completion times revealed that users benefit from the availability of manipulability of the overview and highlighting of objects of interest in the overview. The role of overviews as tools that users can manipulate to perform navigation actions was taken for granted in almost all previous studies on

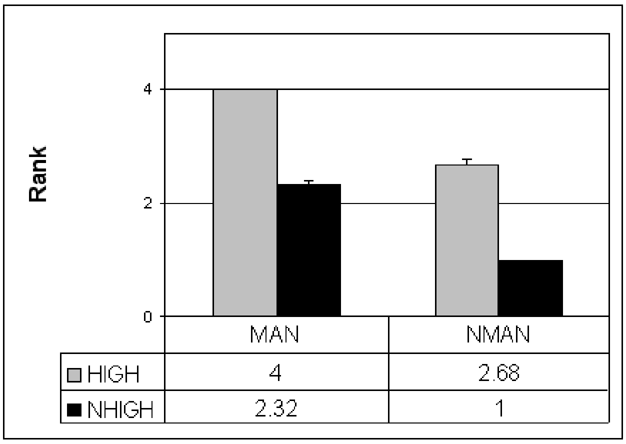


Fig. 10 Mean preference for each interface (higher numbers correspond to better scores).

the O+D approach, which always implemented some form of overview-supported panning or zooming mechanism. However, the difficulties users had in directly interacting with the overview in some of these studies [5, 22, 18] and the additional constraints on overview size introduced by the mobile context raised doubts about the actual effectiveness of this feature. As we found out, if the small size of the overview had a negative impact, it was not sufficient to counter the positive effects of direct manipulability on user performance. Providing an additional layer of semantic information to the overview through highlighting of objects of interest proved useful as well. A similar feature was introduced in the study of Nekrasovski et al. in the desktop domain [24]. In that case, however, it was not found to affect user performance, likely because orientation cues were also provided in the detail view through other means. As we previously remarked, overviews become redundant in terms of orientation support when interfaces simultaneously integrate other sources for the same information.

The performance gains users obtained because of the availability of one of the two features were not affected by the presence or absence of the other feature. However, the difference in performance increase associated to the two variables is interesting: highlighting improved performance by about 15-20% while manipulability resulted in a stronger 40% improvement. Moreover, while it is not always possible to highlight objects of interest in the overview, for example because the location of such objects is not known in advance, introduction of a manipulable overview to support panning can always be a very effective solution to considerably reduce search time. There are multiple reasons that can explain why users were so much faster in carrying out tasks when the overview was manipulable. One is that users needed less effort to pan a certain distance by moving the viewfinder compared to operating directly on the detail view. For example, moving the viewfinder by 10 pixels at the maximum zoom factor (10) corresponded to moving the detail view by 100 pixels (10*10). A comparable pan action on the detail view required instead users to drag the pen on the screen for 100 pixels, which is the typical behavior of traditional panning mechanisms. However, one must also consider that it might be more difficult for users to properly control the large jumps of the detail view when moving the viewfinder, as pointed out by Gutwin et al. [18] in their study. The analysis of user interface actions revealed another possible motivation for user performance in the study. Users made significantly less pan and zoom actions when the manipulable overview was available. This probably decreased the total motor effort required to complete the tasks, which led to a lower task completion time. The number of pan actions is likely related to the above mentioned difference between panning in the detail view and panning by moving the viewfinder but is also affected by the overall strategy users employed when searching for targets in the different conditions. The availability of a manipulable overview allowed users to perform a sort of continuous navigation, characterized by long pan actions, while users employed sequences of short pan actions when they had to navigate maps by dragging the detail view, regardless of object highlighting. However, the navigation strategy with a manipulable overview seemed to depend on the availability of highlighting: with highlighting enabled, users made shorter pan actions than they did when objects of interest were not highlighted in the overview, probably because the highlighting allowed users to directly home on targets without requiring to blindly explore the whole information space. For the same reason, highlighting also helped users in carrying out search tasks with less overall actions.

The SpatialMemory task did not reveal significant effects of the factors we considered on user error. Contrary to our hypothesis, there were no differences in spatial memory performance whether objects of interest were highlighted or not in the overview. This might be due to the small size of the overview, which could have made it more difficult for users to easily discriminate the relative position of targets and support their memorization. However, there is a definite possibility that it is not the visualization of targets but the position and size of the viewfinder that play a major role in helping users construct a mental map of the configuration of targets. Indeed, the relative size of the error was about 10-12% of the size of the map, meaning that users were fairly accurate in their position estimation. This hypothesis might also explain the similar results we obtained in our previous study [10] when comparing the traditional and the wireframe O+D interfaces.

Finally, subjective preference was consistent with performance results, revealing that users perceived both manipulability and highlighting as useful and effective features in mobile O+D interfaces.

4 Conclusions

This paper investigated Overview+Detail visualization, one of the major approaches to the display of large information spaces on a computer screen, focusing on its applicability to mobile devices. While O+D visualization is now common in many desktop interfaces, its adoption on mobile devices is rare, even in those commercial applications, such as Google Maps Mobile, whose desktop counterpart include an overview. Our examination of the few research studies on mobile O+D provided evidence of its possible beneficial effects, especially for those information spaces (e.g., maps) that do not provide additional orientation cues in the detail view, but also pointed out the negative effects of the limited space of mobile screens which could make O+D ineffective. The experiment we presented in the paper explored the role played by two specific features of O+D interfaces, manipulability of the overview and highlighting of objects of interest in the overview, and revealed that both features are beneficial to users in search tasks, with manipulability providing the highest performance improvement. However, knowledge of the strengths and weaknesses of the O+D approach on mobile devices is still limited. Further empirical analyses are needed, for example, to obtain general guidelines on the impact of different overview designs on different kinds of task or to understand the relative effectiveness of O+D visualization compared to the other approaches to the presentation problem on mobile devices. Important questions for devices with limited screen space, e.g., the effect of overview size on user performance, need also answers.

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