# Presentation Strategies for Micro-Navigation in the Physical World

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## Abstract
This work provides first insights into supporting hierarchical micro-navigation in the physical world in a manner relevant to AR systems. In this paper, we study the performance of two presentation strategies in tasks that involve navigating to an object inside a hierarchy of physical containers within the user's reach. We consider two types of navigation aids: Those that provide *route knowledge* via step-by-step instructions, using simple graphical overlays, and those that provide *survey knowledge* via map-like overviews, using 3D depth visualizations. We performed a user study using a cardboard mock-up of a spatial display. Our experiment shows that in shallow hierarchies route aids and survey aids perform comparably in terms of navigation time and accuracy. When a target is embedded deeper into a structure, the performance of survey aids is affected negatively, while route aids maintain a consistent performance. Users reported that survey aids helped them understand a container hierarchy, but route aids required less processing time and effort, and thus, were more preferred. We found no significant effect of aid type on users' preference. Accordingly, we recommend considering the depth of task when employing these presentation strategies.

## Author Keywords
Visual aid; navigation; depth visualization; spatial knowledge; augmented reality; mock-up prototyping.

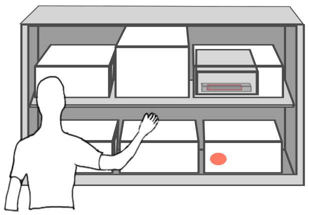

**Figure 1:** Navigation aids in hierarchal storage structures: a survey aid (top shelf) and a route aid (bottom shelf).

## ACM Classification Keywords

H.5.1. [Information Interfaces and Presentation (e.g. HCI)]: Multimedia Information Systems

## Introduction

Typically, people arrange their belongings in hierarchical storage structures, such as cupboards, drawers, and other containers (Figure 1). Advances in localization technology have enabled physical search systems [10] to locate objects that are included in or occluded by other objects. But to help people locate and retrieve an object, these systems need to present navigation information in an efficient way.

Two of the spatial knowledge types [3] that people resort to in order to navigate an environment effectively are: Route knowledge (sequences of actions needed to travel a path, such as road signs), and survey knowledge (relationships between routes and distinctive features in the environment allowing people to recognize a certain target with respect to others, such as maps). Route knowledge provides coarse navigation information that helps people *execute* a route by guiding them gradually to their goal thereby reducing stress and anxiety associated with travel planning and navigation. Survey knowledge provides overview information that helps people construct an adequate mental representation of an environment ahead of time, *plan* a route, and develop alternative routes is case of getting lost.

Research shows that augmented reality (AR) is a suitable user interface for navigation and wayfinding applications [5]. For micro-navigation, visual aids have been designed to (a) highlight the target to make it more distinguishable in case of visual clutter [6], and (b) direct the user's attention to an off-sight location when the target is not in her field of view [2]. When navigating towards a physical object in a 3D structure, such as a cupboard with multiple containers, these aids can be used as sources of route knowledge, providing gradual navigation instructions.

Several depth visualizations based on the x-ray vision [8] and cutaway [1] metaphors have been developed to present overview information about the relative depth of occluded objects with respect to each other and to the user. This paper tests if depth visualizations can provide survey knowledge when looking for an object inside a physical hierarchy.

This paper aims to investigate the effect and performance of route and survey aids in hierarchical micro-navigation tasks. After related work, we describe the study and discuss our findings.

## Related Work

In micro-navigation, Li et al. [6] found that highlighting a target product on a supermarket shelf significantly increased navigation efficiency. Improvements in navigation time were more significant when the target was located further from the user and more visual content needed to be processed. Biocca et al. [2] found that providing additional meta visualization to direct the user's attention can improve navigation times further and minimize mental workload. These results were supported by [11] and [4]. These studies, however, do not considered depth information in 3D spatial layouts.

Several studies compared the performance of augmented reality navigation aids providing different types of spatial knowledge. In an indoor navigation task, [7] found that a map aid was more useful, preferred by users (compared to a directional arrow), and barely interfered with users' walking patterns. For outdoor navigation, [9] showed that task performance with graphical overlays was better than with map views. But task performance with map views scaled better with increasing information density. These studies present mixed results in macro-navigation tasks.

**Figure 2:** User study setup.

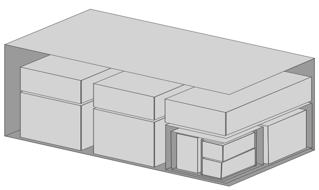

**Figure 3:** Prototype: a hierarchical box structure.

## Micro-Navigation Aids

In a controlled experiment, we compared the performance of survey and route knowledge aids in terms of task completion time, error rate (accuracy), and user preference (Figure 2).

Based on related work, our hypotheses: Route aids are faster than survey aids in shallow hierarchies (**H1.1**), survey aids are faster in deep hierarchies (**H1.2**); route aids lead to fewer errors than survey aids (**H2**); and users subjectively prefer the aids that are faster and less error prone (**H3**).

*Participants*. We recruited 14 participants (9 male), aged 20 to 48 (*Median* = 28), all right-handed with normal or corrected visual acuity and no severe motor impairments.

*Prototype*. We developed a cardboard mock-up that superimposed navigation information onto physical objects from the participant's perspective. We used 49 physical boxes of varying sizes to construct a hierarchal storage unit. The boxes were arranged to include or occlude each other (Figure 3). The navigation aids were printed on transparencies and attached to the corresponding boxes prior to each trial.

The mock-up allowed us to evaluate the navigation aids while avoiding the technical limitations of current augmented reality and spatial technologies, such as registering image quality and any interaction effect of an output device [7].

*Experimental Design*. We examined two independent variables: *Navigation Aid* and task *Difficulty*. *Navigation Aid* was composed of : route aids (*Spotlight* and *Icon*), which provide step-by-step navigation cues, and survey aids (*X-Ray* and *Cutaway*), which provide depth visualizations.

*Spotlight* (Figure 4a) was a spotlight-like graphical overlay. The location of the aid on a box surface cued the absolute location of the target from the participant's perspective. *Icon* (Figure 4b) resembled the *Spotlight* aid in terms of setup, but added two icons showing how to interact with a certain box: open it ↶ (if it contains the target), or remove it ↑ (if it occludes the target). Route overlays were attached to each box that the user needed to interact with in order to navigate to the target during a task.

*X-Ray* (Figure 4c) followed Livingston et al.'s [8] visualization to communicate depth. Boxes were represented in wireframe and filled with a semi-transparent color (50% opacity) with decreasing absolute intensity of 30 in a 256 RGB scale the further they were from the participant. The boxes and target were rendered in 3D and in real-life size, which allowed participants to distinguish when a box was included or occluded by another. To reduce visual clutter, only relevant boxes that led to the shortest route to the target were part of the visualization. The target object was colored in red. *Cutaway* (Figure 4d) followed Avery et al.'s [1] visualization. It defined a vertical cutting plane that removed all the visual barriers between the participant and the target. The remaining relevant boxes and target were rendered at full opacity, in 3D and in real-life size. The target was colored in red. Survey overlays were attached to the first box the users interacted with, the for-front box that contains the remainder of the boxes. We chose these two well studied depth visualizations (*X-Ray* and *Cutaway*) to reduce the effect of the visualization itself on the performance of each aid type.

Task *Difficulty* had three levels: *Easy*, *Medium*, and *Hard*. Difficulty corresponded to the depth of the target in the box structure. We conducted a pilot study with 3 participants to determine the depth that corresponded to each *Difficulty* level. We alternated the number of boxes that included or occluded the target: *Easy* (1 inclusion, 0 occlusion),

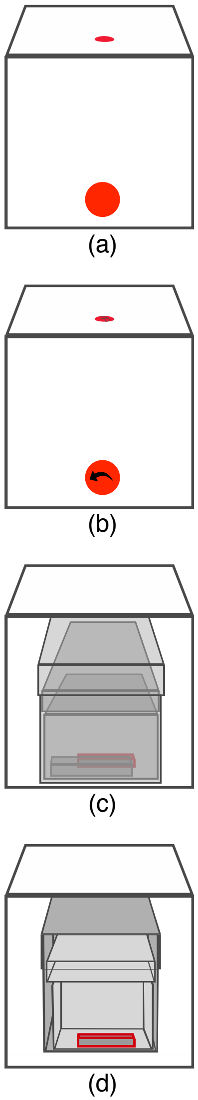


**Figure 4:** Navigation aids: (a) Spotlight, (b) Icon, (c) X-Ray, and (d) Cutaway.

*Medium* (2 inclusions, 1 occlusion), and *Hard* (3 inclusions, 2 occlusions). More depth made survey visualizations complex and harder to interpret, which was also observed in [8]. The participants reported that more depth was not very realistic in a real-life setting. The total number of occlusions and inclusions was the same for all participants.

Accordingly, the experiment was a 4 $\times$ 3 factorial within-subjects design. Each participant performed 12 trials. A trial was a single navigation task requiring the participant to retrieve a known target from a box structure at a certain *Difficulty* level assisted by one *Navigation Aid*. The order of *Navigation Aid* and *Difficulty* was counterbalanced across the participants using a Latin square. This design resulted in (4 $\times$ *Navigation Aid*) $\times$ (3 $\times$ *Difficulty*) $\times$ (14 $\times$ *Participants*) = 168 trials.

*Procedure.* First, we explained the navigation aids to the participants, and familiarized them with the target object. Then, the participants performed practice trials with *Difficulty* level *Easy* using all four aids. This was necessary to reduce the effect of the visualizations' quality as a confounding variable. The participants were instructed to approach the box structure from a predefined viewing direction, and to work as fast as possible to retrieve the target. They also explored how the 49 boxes could be opened to reduce motion time variability. When the target was retrieved, the participants were asked to declare "got it". In case of errors, the participants were encouraged to continue navigating until successful. Each session lasted about 60 minutes, after which the participants ranked each aid and took part in a questionnaire and an informal interview.

Trials were video recorded. Navigation performance was evaluated based on: *Task Completion Time*, *Number of Errors* (incremented each time a participant took a wrong navigation route), and *Subjective Ranking*.

## Results and Discussion

We performed a 4 $\times$ 3 repeated measures ANOVA to compare the effects of *Navigation Aid* and *Difficulty* on *Task Completion Time* and *Number of Errors*. We used pairwise t-tests with Bonferroni's correction for post-hoc tests. We found a significant effect of *Navigation Aid* on *Task Completion Time* ($F_{3,39}$ = 8.44, $p$ <0.05, $\eta^2$ = 0.62). Participants were significantly faster (20%) in locating the target with route aids ($M$ = 17.32s, $SD$ = 7.11) compared to survey aids ($M$ = 21.43s, $SD$ = 12.12). We found no significant differences between aids that belong to the same aid type. From our video analysis, we split task completion time into two times: motion time and planning time (time consumed in processing the aids without acting). We found a significant effect for *Navigation Aid* on *Planning Time* ($F_{3,39}$ = 16.21, $p$ <0.05, $\eta^2$ = 0.24) but not on *Motion Time*. Survey aids required about 50% more planning time ($M$ = 5.02s, $SD$ = 3.12) compared to route aids ($M$ = 2.75s, $SD$ = 0.74).

In the study we observed that navigation behavior was similar with *Spotlight* and *Icon* aids: once an aid overlay was revealed, the participants followed the aid instructions and acted directly on the structure, without any notable pauses. But with survey aids, *X-Ray* and *Cutaway*, the participants paused for some time to interpret the visualizations. In cases where a participant realized he had made an error or forgot the visualization, he would pause to look at the visualization again. This division of attention and switching between continuous motion and wayfinding tasks increased the overall navigation time. The time participants consumed interpreting and re-examining survey aid visualizations was more influential than the anticipated benefit of planning movements ahead.

Task *Difficulty* had a significant effect on *Task Completion Time* ($F_{2,26}$ = 111.13, $p$ <0.05, $\eta^2$ = 0.62). *Task Completion*

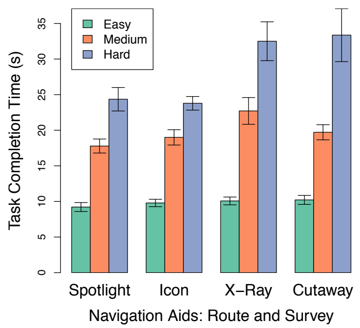


**Figure 5:** Task completion time of the navigation aids at three levels of difficulty (showing 95% CI).

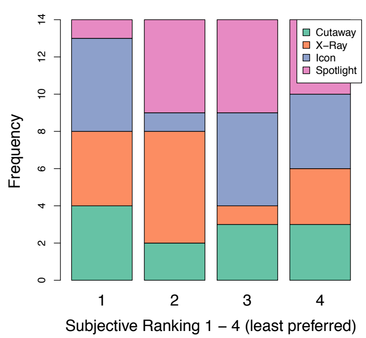


**Figure 6:** Participant's subjective ranking of navigation aids.

*Time* increased significantly (*p*<0.05) across all *Difficulty* levels: *Easy* (*M* = 9.82s, *SD* = 2.16), *Medium* (*M*= 19.80s, *SD* = 5.09), *Hard* (*M* = 28.50s, *SD* = 10.12).

Our analysis revealed a significant interaction effect *Navigation Aid* $\times$ *Difficulty* ($F_{6,78}$ = 2.93, *p*<0.05, $\eta^2$ = 0.1) on *Task Completion Time*. This interaction effect provided an interesting insight into the performance of survey and route aids according to the target depth. A simple main effects analysis revealed that at *Difficulty* levels *Easy* and *Medium*, *Navigation Aid* had no significant impact on *Task Completion Time* (*p*>0.05). *Task Completion Time* increased sharply for survey aids (*M*= 32.93, *SD* = 11.97) and slowly for route aids (*M*= 24.07, *SD* = 4.96) at level *Hard* (Figure 5) (reject **H1.1** and **H1.2**).

The participants made a few errors, only 1% of the trials had errors (maximum 2 errors per trial). Of these errors, 70% were made at *Difficulty* level Hard and 30% at *Medium*. Overall error count (out of 42 trials per aid): Cutaway: 8, X-Ray: 4, Spotlight: 3, and Icon: 0. A simple main effects analysis showed that *Difficulty* level *Hard* had a significant influence on *Number of Errors* (*p*<0.05) independent of *Navigation Aid*. *Navigation Aid Cutaway* also had a significant effect on *Number of Errors* independent of *Difficulty* (partially accept **H2**). The participants reported *Cutaway* aid to be the hardest to process among all other aids, which is one possible reason of these results. They found *X-Ray* to be an easier visualization to parse, and served as a good source for survey knowledge, allowing the participants to learn and navigate the internal structure of the hierarchy. In summary, all aids had low error count, and the time to recover from errors had no significant impact (*p*>0.05) on the aids performance.

Participants were asked to rank the navigation aids according to their subjective preference: 1 to 4 (most to least preferred). On average, the participants preferred *Spotlight* aid, followed by *Icon*, then *X-Ray*, and *Cutaway* (Figure 6). Our Fisher's exact test revealed no significant influence of *Navigation Aid* (p > 0.05) on user's *Subjective Ranking* (reject **H3**).

The participants reported to perceive benefits for both route and survey aids. The participants reported that the aids were easy to follow, and required less processing and memorizing than the survey aids. Six of the fourteen participants appreciated that the survey aids allowed them to understand the internal structure of the hierarchy, plan their movement, and estimate required navigation time beforehand. They also suggested that these visualizations could become harder to interpret after a given level of depth. In contrast, route aids provided coarse information, which allowed the participants to only follow the navigation instructions blindly, without any distance information.

From the participants' comments we found that unless the participants were, for example, motivated to plan their navigation or remember the location of the target, learning the internal structure of the hierarchy was perceived as unimportant. At that point people opt for the fastest and effortless aid to guide their movement.

## Conclusion and Future Work

This research is motivated by the advancements in AR and localization technologies. The goal of this work is to evaluate the performance of two presentation strategies in facilitating micro-navigation in the physical world. We presented an empirical user study that evaluates the performance of four visual navigation aids in hierarchical micro-navigation tasks using a cardboard mock-up. Two aids (*X-Ray, Cutaway*) provide users with survey knowledge using depth visualizations, and two aids (*Spotlight, Icon*) provide route knowledge. The results show that in shallow hierarchies survey aids perform as well as route aids, and can facilitate navigating towards a physical object in a 3D structure. A valuable insight is that at deep hierarchies the performance of survey aids in terms of *Task Completion Time* is affected negatively, while route aids maintain a consistent performance. The *Number of Errors* was negligible (close to none) in shallow hierarchies, with only a slight increase in the deeper tasks. *Cutaway* aid was the most error prone, and was reported as the most difficult to parse. *Cutaway* also ranked as the least preferred aid, but there was no significant effect of *Navigation Aid* on *Subjective Ranking*.

One limitation of this work is the controlled complexity and context of the presented tasks. In this study we were not able to measure the main benefit of survey knowledge reported in previous studies, such as letting people plan a route ahead of time and move more rapidly towards the navigational goal, or planning alternative routes [3]. More complex tasks could better exploit the full benefits of both survey and route knowledge. We should also consider the navigation context, e.g., industrial warehouse, home, office, or laboratory, which could have an effect on user requirements and preference.

To guide the design of AR navigation interfaces, we need to evaluate how these presentation strategies are influenced by the dynamics of interaction and visual effects, e.g., the ability to adapt to a user's viewing angle, and induced depth sensation due to motion parallax, of various AR displays. The display device itself may have an influence on the performance of different aid types, e.g., handheld compared to mounted displays. Understanding the merits of each navigation type is necessary for the design of micro-navigation systems, especially since the technical requirements of each type of aid differ. For example, route aids are only reliable if they appear at the correct location and time, i.e., with no delays, while survey aids are more robust against delays and can help users develop alternative routes.

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