Occlusion-aware Interaction Techniques for Tabletop Systems

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Abstract
This paper addresses challenges created by physical objects that occlude screen contents on interactive tabletops. We propose novel techniques to support awareness, access and overview of occluded digital objects. These techniques take into account different functional zones on tabletops to provide information at varying levels of detail. We also contribute the Press-View technique, a pressure-based interaction technique to get a quick overview of occluded objects.

Keywords
Tabletop; occlusion; physical objects.

ACM Classification Keywords
H.5.2 [Information Interfaces and Presentation]: User Interfaces

General Terms
Design, Human Factors.

Introduction
Digital tabletop systems are becoming widely available and inexpensive with slimmer form factors, such that they can be increasingly integrated into office environments as a normal table or embedded in a desk or other furniture. Due to the table character of such de-

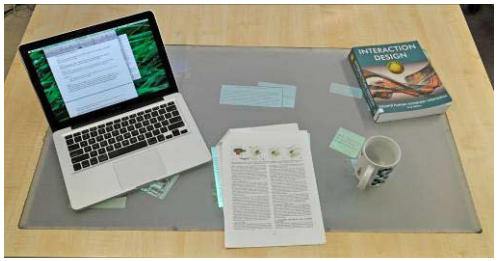

Figure 1. A hybrid tabletop environment with physical occlusions

vices, it is very likely that users do not only interact with digital contents, but place physical everyday objects on them, such as paper, laptops or coffee cups. This creates a hybrid physical-digital environment (depicted in Fig. 1) where physical objects (occluders) might *hide* digital objects (occludee) that are displayed on the tabletop surface. This will result in problems such as losing awareness and difficulties to access the occluded objects. Moreover, in order to find a specific digital object, users have to move or lift the physical occluders which might disrupt the user's activity and, eventually leads to a suboptimal arrangement of the workspace.

In this paper, we address the physical occlusion problem in the hybrid setting and propose an occlusion-aware tabletop system that supports awareness, access and getting overview of occluded objects. Based on different functional zones on tabletops, we have designed an interactive proxy-like representation of occludees that firstly, provides appropriate levels of awareness about the occluded objects. Secondly, users can drag out the proxy to acquire more information about the occludee until they eventually retrieve the original object. Leveraging the tangibility of physical objects, we have also developed the PressView technique, a pressure-based interaction technique that allows users to temporarily get a quick overview of occluded objects.

Related Work

Occlusion in hybrid environments

A study by Steimle et al. [3] investigated the usage patterns of physical and digital media on interactive tabletop surfaces. They identified several problematic aspects of occlusion; however, their findings also revealed some advantageous aspects of occlusion that help users to effectively manage and organize their workspace. The results of their study highlighted the fact that when the users *intentionally* occlude digital objects, e.g. when creating a pile, these should not be automatically relocated by the system. Rather, the system should provide better awareness and accessibility. These findings guided the design of the techniques in this present paper.

Javed et. al. [4] presented an occlusion management framework consisting of a set of techniques that mitigate occlusion in a physical-virtual setting. They proposed different techniques supporting awareness, identification and accessibility and evaluated them in guided and unguided visual search tasks, however only with digital occluders. Their results indicate that lightweight techniques are more promising for the general cases. In this paper, we present a holistic approach to cope with the occlusion rather than focusing on individual techniques. Furthermore, we have developed a functional occlusion-aware tabletop system that keeps track of both digital and physical objects. This will allow us to create a true hybrid setting for future studies.

Occlusion created by hands and forearms

There have been a large number of studies that focus on occlusion created by fingers, hands and forearms during direct touch or pen-based input [5, 6, 7, 10]. Shift [5] addressed the problem of finger occlusion on small handheld touch screen devices by displaying a callout showing a copy of the occluded screen area and a pointer representing the hotspot of the finger. Vogel et. al. in [9] showed that nearly half of a 12 inch stylus-based tablet display can be occluded with the pen and the user's hand. Building upon this, [10] modeled

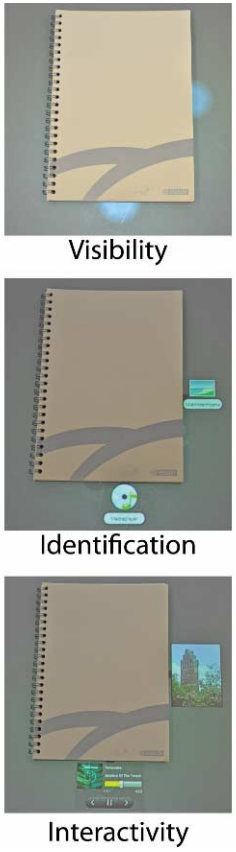

Figure 2. Different proxy representations of occluded digital objects

the occluded area to display occluded previews in a non-occluded area using a bubble-shaped call-out. Leithinger et al. [7] investigated four different user-drawn menus to cope with occlusion caused by physical objects rested on tabletops. Similarly, Brandl et. al. [8] designed an occlusion-aware menu for digital tabletops based on the user's handedness. Although these studies mainly focused on the body occlusion, they provided motivation for the current study.

Occlusion in 2D desktop environment

In digital environments, the 2D objects or windows are stacked on top of each other and can be retrieved using taskbar widgets, modifying the transparency of digital objects [11] or spreading them out to access the hidden contents [12]. In the hybrid setting, however the digital objects cannot be displayed on physical occluders.

Design of Interactive Proxies

In our design, once occlusion takes place, a small proxy is placed on the nearest edge of the physical occluder that serves two main purposes at the same time: as a means of awareness and as an access tool.

Proxy as a means of awareness

A proxy can represent different levels of awareness about the occluded object. It ranges from showing no information about the hidden objects to uncovering the original object with various intermediate levels in-between. We characterize this spectrum by three main levels (see Fig. 2):

Visibility: showing minimum information that indicates something is occluded under physical objects, similar to a halo [16]. It also conveys some information about the number and location of the underlying objects. As it is also pointed out in [4], this type of visualization introduces little amount of visual clutter whilst providing a lightweight indication of an occluded object.

Identification: showing information about the type and identity of the occluded objects such as the icon and the name so that users can identify the occluded object.

Interactivity: showing the maximum amount of information such as a thumbnail or miniature version of the occluded objects. Similar to the Windows thumbnail view on the taskbar, it provides some basic functions so that users can interact with an occluded object without retrieving it. Although this representation occupies more space than the other awareness levels, it supports a high level of engagement with the occluded objects.

The selection of one of the awareness levels may depend on the importance or relevance of the occluded objects to the context of the user. Since tabletops enable a spatial arrangement of digital and physical objects on their surface, in our concept design the degree of importance of occluded objects is set to be determined by their proximity to the user. Based on Sellen and Harper's in-depth analysis of physical workspaces [13, 14], we feature three functional zones based on the distance to user (illustrated in Fig. 3):

Figure 4. Accessing an occluded document by dragging out the proxy.

Active: nearest zone to the user within the arm's reach. Physical or digital objects placed in this zone are typically highly related to the ongoing activity of the user and frequently used. In this zone, when a physical object occludes a digital one, the highest level of awareness (i. e. the interactivity level) is shown by the proxy. Thus, the user can quickly find and engage with the occluded objects that are highly related to her context.

Intermediate: is a zone at arm's reach for temporarily placing objects which are not needed. Once occlusion occurs, the proxy provides awareness such that users can easily identify digital objects.

Storage: this is the farthest area on the tabletop where the user can reach objects by leaning over the tabletop. It is often used for longer-term storage of objects. In the case of occlusion, only a halo is represented indicating the presence of occluded objects.

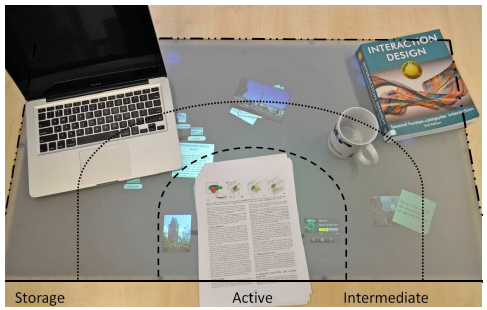

Figure 3. Proxy representations on each functional zone.

By mapping different awareness levels to the different zones, the system offers a trade-off across all the tabletop zones between the user's intention and introducing visual clutter by the proxy representation. This means that although the interactivity level introduces more visual clutter in the active zone, it facilitates effectively interacting with the frequently used occluded digital and physical objects. For the objects occluded farthest away and less frequently needed by the user, the system provides low-level representation. Thus, less visual clutter is introduced.

Proxy as an access tool

Regardless of which awareness level is represented, the user can interact with the proxy in order to access the occluded object. To do so, users can drag the proxy toward non-occluded areas. As the user drags the proxy out, it stepwise represents higher levels of awareness until the occlusion is resolved and the user accesses the original object. Once the user releases the proxy before accessing the original occluded object, it will automatically snap back to its original form and position. In this fashion, the user is able to temporarily acquire some information or even perform basic interactions with the occluded objects before completely resolving the occlusion. In order to directly access the digital object without traversing the intermediate levels, users can perform a double-tap on the proxy. Moreover, if the higher levels of proxy representation distract users, they can reduce it to the visibility level by pushing it towards the occluder.

Fig. 4 illustrates the interaction with proxy in order to access an occluded object, starting from the halo representation.

Design of PressView Technique

In 2D desktop environments, one of the common activities is to find and retrieve a specific window amongst all

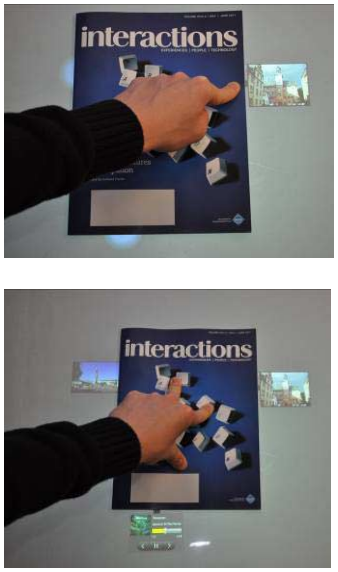

Figure 5. The PressView technique on one side (top) and on centroid (down).

hidden overlapped windows. In order to do so, users need first to obtain an overview of all open windows and then select the one they searched for. With current window management systems this can be efficiently achieved by tiling (like Exposé in Mac OS) or cascading (like 3D windows Flip) of all open windows. We designed the PressView technique to support the same activity in hybrid environments.

When the user presses down the physical occluder lightly, the proxies representing the underlying objects would temporary squeeze out, i. e. the proxy appears or an already visible proxy shows a higher level of awareness. When the PressView is applied on a single side of the occluder, only those proxies will show up that are positioned near to that side. In order to get an overall preview of all occluded objects, the users can perform the PressView roughly around the center of the occluder (see Fig. 5). While the PressView is active, users can drag one or multiple proxies out in order to directly access the original object, thus supporting a bimanual resolve of occlusion [3]. The applied force by the user can be also be mapped to the degree of awareness represented by the proxy- i.e. as the user presses more the proxy reveals more information about the occludee.

The PressView technique offers two main advantages. First, it does not need any graphical widgets to be displayed on the tabletop nor any complex gesture for triggering it. Second, it supports easily resolving occlusion in situations when moving the physical occluder is barely possible, either because of heavy or complex occluders (such as a laptop or a thick) book or due to a fragile arrangement of multiple occluders (such as a a number of sorted paper documents) [3].

System Overview

We implemented an occlusion-aware tabletop system which coherently integrates the techniques discussed above. Our tabletop (with display size of 100*60 cm) is back illuminated with IR light so that physical objects can be tracked using fiducials. Although the tracking approach limits the movement of the physical object to the 2D tabletop surface, it enables robust and real-time recognition and tracking of physical objects. reacTIVision [1] is used as an underlying touch and fiducial tracking framework. To display the proxies in an appropriate position, we implemented a variation of the sweep line algorithm, which vertically sweeps the whole tabletop surface to find the nearest free space to the edge of the occluders.

In order to recognize a press-down event on physical objects, we embedded ten equidistant force sensing resistors between the edge and protection layer of the tabletop (see Fig. 6). When a force is applied onto a physical object, the pressure values increase and its position is calculated using linear algebra. This allows us to approximate the position of a pressure event in an area of 7*7 cm, sufficiently precise to recognize pressing down events on most of everyday objects. To improve the pressure accuracy, recent advances in pressure sensing technology [15, 2] open up more promising and accurate approaches that can be considered in future studies.

Summary and Future Work

In this paper we presented interaction techniques to mitigate the problem of occlusion for hybrid tabletop systems. Based on the literature, we defined three functional zones to approximate the user's intention of occluding a digital object. We then represented an

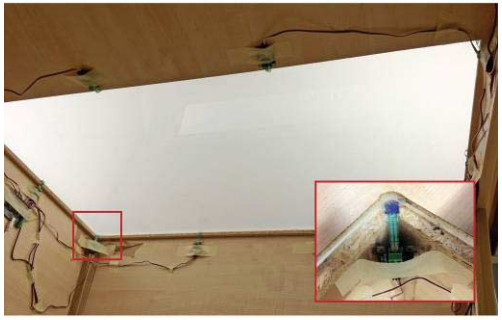

Figure 6. Inner view of our tabletop equipped with pressure sensors. Right: magnified top view of one sensor.

occluded object with an interactive proxy displaying varying information level of the object depending on which functional zone the object is occluded. The proxy also enables the users to access higher awareness levels and eventually, the original object. Moreover, we introduced the PressView technique to ease getting overview and find occluded objects.

Our next step is to conduct a comprehensive user study in which we plan to evaluate the interaction techniques. We particularly aim to evaluate the advantages and disadvantages of the different representations in normal and cluttered environments.

Our techniques support accessing occluded objects by dragging them to a non-occluded area while physical occluders remain untouched. Although this is a common strategy [3] and is suitable for heavy occluders, future work should consider and provide supports for other strategies such as picking up or moving physical occluders.

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