Peripheral Array of Tangible NFC Tags: Positioning Portals for Embodied Trans-Surface Interaction

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ABSTRACT
Trans-surface interaction addresses moving information objects across multi-display environments that support sensory interaction modalities such as touch, pen, and free-air. Embodiment means using spatial relationships among surfaces and human bodies to facilitate users' understanding of interaction. In the present *embodied trans-surface interaction technique*, a peripheral NFC tag array provides tangible affordances for connecting mobile devices to positions on a collaborative surface. Touching a tag initiates a trans-surface portal. Each portal visually associates a mobile device and its user with a place on the collaborative surface. The portal's manifestation at the top of the mobile device supports 'flicking over' interaction, like playing cards. The technique is simple, inexpensive, reliable, scalable, and generally applicable for co-located collaboration. We developed a co-located collaborative rich information prototype to demonstrate the embodied trans-surface interaction technique and support imagining and planning tasks.

Author Keywords
Co-located collaboration; mobile device; trans-surface interaction; portal; Near Field Communication.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
The proliferation of powerful mobile computing devices and large displays presents the potential for synergistic integration to support collaborative activities involving sharing information. Large, high resolution displays, such as televisions, support co-located collaboration. Mobile devices provide private interactive computing resources. Nacenta *et al.* refer to interconnected interactive devices as 'multi-display environments' [12]. Kerne *et al.* coined *trans-surface interaction* to refer to those interactions in multi-display environments that involve manipulating information objects across devices with sensory input modalities, such as touch, pen, and free-air [7]. Trans-surface interaction is characterized by user experiences of continuously manipulating information across interactive surfaces, providing a sense of connection.

A compelling need for trans-surface interaction is to integrate private mobile devices with a large surface for collaboration. The surfaces are physically discontinuous. A *portal* is a transitional space that affords moving between larger spaces [14]. Problems for interactive experience design include how to initiate a portal connecting a mobile device and a collaborative surface, including where it should be positioned, and how to move objects through the portal. People often move around a collaborative surface [3], and they gather dynamically [10]. This requires dynamic capabilities for spatially mapping mobile devices and user presences around a collaborative surface. This paper develops *embodied trans-surface interaction techniques*, which use an array of tangible NFC tags on the periphery of collaborative surface to afford robust, simple trans-surface portal initiation and relocation.

We embody interaction by using spatial relationships among surfaces and human bodies to help users understand how to interact. Cognitive scientists have shown that mental models are embodied, that is, that people's understanding of how things work depends on how their bodies operate in space [2, 13]. Spatial relationships and visual properties help people mesh their intentions with affordances, the actionable properties of objects, to accomplish goals. We base design of embodied trans-surface interaction for manipulating information on prevailing mental models for exchanging physical objects.

Interactive displays are diverse in size and input modality. New technologies such as ZeroTouch [11], augment conventional displays with touch sensing, enabling any to function as a multi-touch surface. This motivates us to design a generic trans-surface interaction technique, which can be applied on different types of interactive surfaces, regardless of input modality, form factor, shape, size, and orientation.

We place an array of NFC tag stickers along the periphery of the collaborative surface. These tag stickers function as tangible entry points [6] to trans-surface interaction. They extend the interactive space of the collaborative surface, without using display pixels, providing persistent visible affordances for connecting mobile devices to positions on the collaborative surface. Touching a tag with a mobile device initiates a pair

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of associated trans-surface portal affordances on the mobile device and the collaborative surface, mimicking the action of physically bonding two objects.

We design the portals to enable rich embodied means for transferring and manipulating information objects across displays for co-located collaborative tasks. To share information objects from mobile devices to the collaborative surface, users drag them towards the portal on the top edge of the mobile surface. Moving fingers and arms away from the body give users a sense of 'send-away'. Information objects' animated sliding out of the mobile display and onto the collaborative surface gives visual feedback of the transfer. Similarly, to move information objects from the collaborative surface to mobile devices, users drag them towards their portals on the collaborative surface that is close to them. Moving fingers and arms toward the body give a sense of 'bring-close'.

We start by surveying related work. Then, we present a scenario. Next, we explain technical details of the NFC tag array. We follow this with a prototype application for collaboration using trans-surface interaction. We finish with conclusions.

RELATED WORK

Personal mobile devices and shared collaborative surface are often integrated in co-located collaborative tasks including web search [1, 18], group planning [19], and card game [7]. Prior techniques for associating and positioning mobile devices around collaborative surfaces require complex algorithms and equipment. The present technique uses an NFC tag array to associate mobile devices with the collaborative surface. Trans-surface information exchange techniques based on portals provide alternative, richer functions than techniques that require physical contact between devices.

Tracking Mobile Devices around collaborative surface

The techniques that associate mobile devices to positions on other surfaces to facilitate information exchange can be roughly divided into several categories. Accelerometer sensor-based techniques pair two devices by 'bumping' them against each other [4], or use the mobile devices to touch the collaborative surface [16]. They match patterns of sensor data within a time window for every trans-surface interaction. These techniques require chronological data analysis, and for mobile devices to have prior knowledge of a synchronous server, which may not be available in a public environment. Computer vision based techniques use video and/or depth cameras to track mobile devices' positions [20, 9]. These techniques constantly track mobile devices using complex algorithms and computing resources. They work best in a confined environment. Our technique extends prior RFID based techniques such as NFC to associate devices by bringing them proximate [17, 19]. We use a persistent peripheral NFC tag array to locate trans-surface portals to associate mobile devices with a position on the collaborative surface. Our technique stores position and server information in NFC tags, which is simple and robust. Mobile devices notify their positions by touching the NFC tags when users initially approach the collaborative surface or move around. Although this technique does not continuously track users and mobile devices, it requies less power and cost compared to prior techniques. This simple technique requires no complex recognizers, making it robust.

Trans-surface Information Exchange

There are many types of interaction techniques for trans-surface information exchange [12]. Some techniques have sought physical continuity, such as 'stitching' [4], 'pick-up-and-drop' using pens [15], or with mobile devices [16], 'touch-to-share' NFC sharing techniques [17] including Android Beam. Some 'spill' information to the surface area around the mobile device [e.g. 20]. These techniques require physical contact of devices with the interactive surface for every information exchange action, which may interfere with ongoing tasks and other users. Users have direct control of the target to move the objects to, but their reach is also limited. Putting mobile devices on the interactive surface sacrifices display space on the surface.

Alternatively, *portal* embodies trans-surface information exchange without physical contact between devices [7, 9]. It extends Wu and Balakrishnan's 'wormholes' for exchanging objects between regions on a single tabletop [21] to multi-display. Kerne *et al.* sent cards through trans-surface portals between smartphones and predefined locations on a tablet [7]. Once initiated, the trans-surface portals leveraged the spatial positions of users and their devices. However, the assignment of players to positions at the start of the game was arbitrary. The present technique dynamically creates and relocates trans-surface portals, giving users clear visual feedback of their positions. Users interact with portals using touch gestures to transfer rich semantic information across devices.

SCENARIO: TRIP PLANNING

Our scenario addresses a collaborative planning task to illustrate interaction with NFC-positioned trans-surface portals. Andy, Bill, and Jane gather around an interactive tabletop at home to plan a spring break California vacation. Each of them touches a closest NFC tag, on the bezel area of the tabletop, with his smart phone or tablet. A mobile application starts on each device, connecting automatically to the tabletop via ad hoc Wi-Fi. A trans-surface portal with distinct color appears on the edge of the tabletop closest to each user.

Each user collects rich information artifacts, on her mobile device, for interesting sightseeing spots, hotels and restaurants for the trip. Each rich artifact represents an information source using an image plus metadata. Users periodically share artifacts through their trans-surface portals onto the tabletop. Artifacts that Andy shares appear as images close to his portal on the tabletop, awaiting further interaction. Across the tabletop, the friends decide to arrange the artifacts based on the days of the trip, forming meaningful visual groups. Tapping an artifact allows viewing its metadata.

Jane changes her seat to sit close to Bill. Her trans-surface portal follows her when she touches her phone to the NFC tag on the other side of the tabletop. Jane copies a restaurant artifact that Andy shared, transferring it to her own tablet. Andy notices an interesting sightseeing artifact that Bill shared. He initializes a web search on his tablet to find nearby restaurants and hotels. The users occasionally remove no longer needed artifacts from the tabletop. Sharing, searching, and deleting operations are triggered by dragging an artifact to a portal, then selecting the operation from a radial menu.

POSITIONING PORTALS WITH NFC TAG ARRAY

Our interactive surface is a 55" LED television equipped with a ZeroTouch [11] sensor (Figure 1). We put 6 tangible NFC tags on the bezel area along each longer side of the ZeroTouch, and 3 on each shorter side. Each tag is ∼1" in diameter and costs ∼$1. The distance between tags is ∼8". To track mobile devices' positions with these tags requires sufficient linear density. At current setup, each user can reach 3 tags from any location around the television.

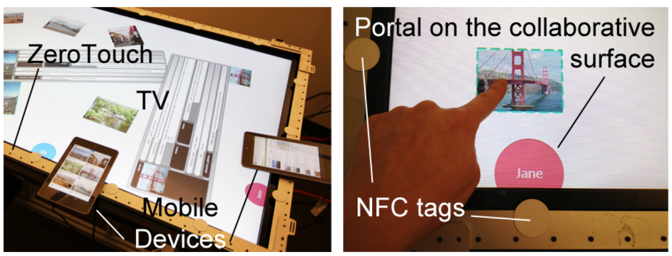

Figure 1. Using peripheral NFC tag array to initiate portals for embodied trans-surface interaction between mobile devices and a collaborative surface (55" TV with ZeroTouch sensor).

In social interactions around the tabletop, users are likely to maintain mutual distance [5]. A tag is an entry point to the collaborative surface, which anchors a user's personal territory. Discretized tag density demarks territories with mutual distance. Spacing the tags as tangible affordances simplifies social and technological aspects. The cost of the tags scales linearly with perimeter, rather than the area. Tags can be reused on different displays and repositioned easily. Reprogramming each tag takes less than 3 seconds with the mobile application we developed for Android.

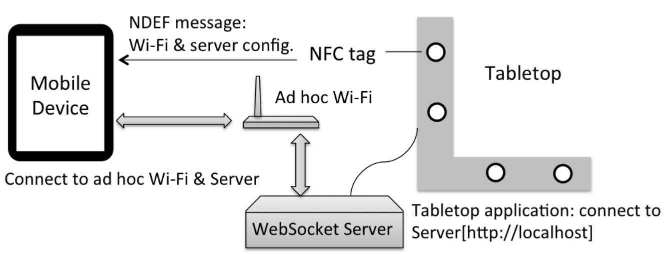

Figure 2. Communication between a mobile device and the tabletop

We set up a WebSocket server application on the desktop computer (Figure 2). The server listens to incoming connections from both localhost and an ad hoc Wi-Fi network hosted by the desktop computer. We use Wi-Fi because its high bandwidth enables fast data transfers of rich semantic information, such as images.

Our implementation uses NFC tags with MIFARE Ultralight chips, each containing 48 bytes of writable memory. We encode in tag memory an NDEF (NFC Data Exchange Format) message containing the position of the tag along the rim, the IP address and port of the WebSocket Server, as well the SSID and password of the hosted Wi-Fi network. When there are changes to the network settings or sticker layout, tags can easily be rewritten using an NFC enabled mobile device, which makes it convenient for developers to try different configurations. In production, when security is a concern, the NFC tags can be made read only. Their data can be encrypted.

Mobile Android devices begin connecting to the server wirelessly by reading and parsing the data from the proximate tag to obtain connection information. The mobile devices then send position information to the WebSocket server for the collaborative surface to initialize or relocate portals on the collaborative surface at the position adjacent to the tag.

TRANS-SURFACE RICH INFORMATION PROTOTYPE

To demonstrate efficacy, and design embodied multi-touch trans-surface portal interaction techniques, we built a prototype application for supporting collaborative tasks involving imagining and planning, while working with digital information, i.e., collaborative *information-based ideation* tasks [8].

After the user touches an NFC tag with the mobile device, a portal that affords trans-surface interaction is displayed as a half circle at the top edge of the mobile screen, providing visual feedback to confirm a successful connection. On the collaborative surface, active trans-surface portal affordance of the same color is displayed adjacent to the tag, giving the user a clear conceptual mapping.

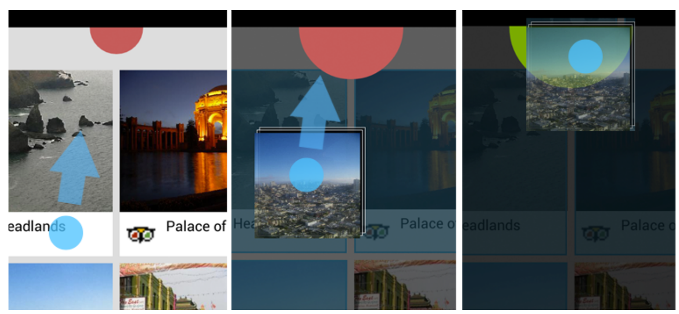

Figure 3. 'Send-away' gesture shares rich artifacts to the collaborative surface through the portal on the mobile device. The size of the portal increases when the artifacts are dragged close by.

The mobile app enables users to collect rich artifacts associated with web pages. To embody ideation and manipulation, each rich information artifact combines a visual image clipping and textual metadata, derived from the source webpage. We designed an embodied trans-surface drag-and-drop interaction. The user shares one or more rich artifacts to the collaborative surface by a 'send-away' gesture, dragging through the portal on the top of the mobile (Figure 3). Once the user's fingertip reaches the portal, animation shows the artifact sliding across the edge of its screen, then onto the collaborative surface. This transfer visualization provides visual continuity across devices. Shaking a mobile device 'breaks' the connection, removing portal affordances from both surfaces.

The application on the collaborative surface is an embodied rich information curation environment. A trans-surface portal on the collaborative surface visualizes a user's presence, and serves as an anchor of her onscreen territory. Placing the portals along the perimeter insures they will not interfere with tasks that users perform in the heart of the surface. Each portal identifies a user by the username received in the connection message from the mobile device and a unique color.

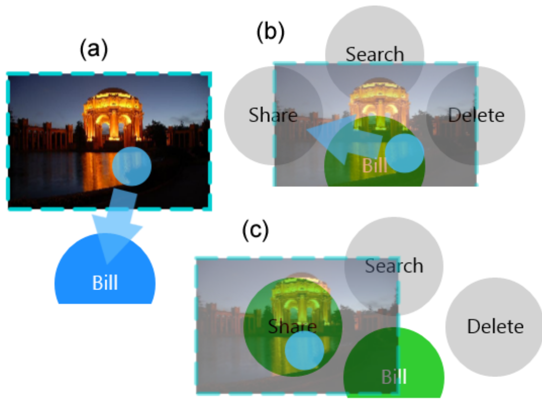

Figure 4. 'Bring-close' gesture activates radial menu and shares rich artifacts to the mobile device through the portal on the collaborative surface.

Dragging an artifact to a portal, a 'bring-close' gesture on the collaborative surface, activates a radial menu of commands (Figure 4). We implemented three functions in the menu: 'Delete' removes the rich artifact from the collaborative surface. 'Share' transfers a rich artifact to the mobile device associated with the portal, by sending a message containing the rich artifact and the user info to the server. 'Search' sends a query based on the artifact to the mobile app's browser to support exploratory search.

CONCLUSION

In this paper, we present a robust and powerful, yet simple and inexpensive method that uses existing capabilities to provide easily configurable, high-bandwidth information exchange among devices by spatially positioning trans-surface portals. It can use ad-hoc Wi-Fi as an alternative to public network infrastructure, enabling use in demanding contexts such as crisis response, in which public networks may be down.

Each NFC tag sticker serves as a spatially indexed tangible affordance. Practitioners can easily and inexpensively customize the sticker's appearance by adding symbols or labels on the sticker, or using different shapes, to help cue discovery for first time users.

Because the tangible stickers with embedded NFC are functioning as persistent affordances for trans-surface interaction, they extend the collaborative surface display beyond its perimeter, effectively increasing resolution. The tangible tag array also facilitates development because there is no need to otherwise figure out how to spatially or temporally incorporate them in the visual design of the rendered area.

On this generic tangible technique, we layered a multi-touch application for exchanging rich artifacts that combine visual and semantic information to support meaningful collaborative experiences. The rich representation of the artifacts engages cognition. The spatial affordances embody trans-surface artifact transfer. Future research can explore how such embodied interaction with sensory representations of information supports collaborative meaning making.

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