Bringing Your Own Device into Multi-device Ecologies - A Technical Concept

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ISS '17, October 17–20, 2017, Brighton, United Kingdom.
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ACM ISBN 978-1-4503-4691-7/17/10.
https://doi.org/10.1145/3132272.3132279

Abstract
Almost every visitor brings their own mobile device (e.g., smartphone or tablet) to the museum. Although, many museums include interactive exhibits (e.g., multi-touch tables), the visitors' own devices are rarely used as part of a device ecology. Currently, there is no suitable infrastructure to seamlessly link different devices in museums. Our approach is to integrate the visitor's own device in a multi-device ecology (MDE) in the museum to enhance the visitor's exhibition experience. Thus, we present a technical concept to set up such MDEs integrating the well-established TUIO framework for multi-touch interaction on and between devices.

Author Keywords
Multi Device; BYOD; Museum; Mobile Device

ACM Classification Keywords
H.3.4 [Information Storage and Retrieval]: Systems and Software.

Introduction & Related Work
The current spread of smartphones with affordable data rates has resulted in intensive use of location-based services such as maps, routing, or location-dependent advertising. The use of a smartphone as a private and personal device with small screen and limited interaction

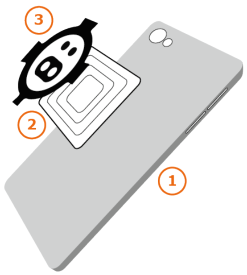

Figure 1: The sticker for the visitor's OD (1) includes a RFID tag (2) as well as a visual marker (3). The visual marker and the RFID tag is needed to identify the OD at the various active exhibits. If the exhibit is e.g., a capacitive table the OD can register itself by means of RFID readers installed at the table. If the exhibit uses an optical approach (e.g., optical table) the OD can be identified by its visual marker.

possibilities is however not sufficient for all usage scenarios esp. in multi-device ecologies (MDE). In private space, the usage of tablets or smartphones as an extension of the TV experience (second screen) is growing. In public space, device ecosystems which combine several end devices with the users' own devices (OD) are subject of research (e.g., [1, 4, 14]). However, only a few are used in long-term scenarios (e.g., [12]).

However, multi-device applications for museums or similar cultural offers are rare. The MDE system "I-m-Cave" [9] for virtually exploring the Mogao caves in China consists of an optical table which tracks a figurine with a marker for changing the perspective, a depth camera which tracks the hand gestures and motion for restoring damaged murals, and a mobile device attached with a visual marker detecting the position of the device for viewing restored or lost 3D statues. Dini et al. [6] propose a MDE to support cooperation among museum visitors through games. PDAs are used for the individual game play and public displays for synchronized public views of the shared game play. This concept is extended with active RFID tags in [8] for automatically detecting nearby artworks. Focusing on the usage of mobile phones in MDEs, there are several examples which uses the camera of the OD for identifying the position of the device esp. in combination with a vertical display. Boring and Baur [4] use the entire public display as a visual marker. In contrast, Leigh et al. [11] display a 2D color pattern on the large display. In addition, research exists for combining mobile phone and multi-touch table. A capacitive table is used in DisplayPointers [13]. Therefore, a magic lense approach is implemented using "hand down" capacitance. In Phone Proxies [1], smartphones are placed on a fixed position at the table and connected with NFC or QR code. Winkler et al. [14] use markers below the mobile phone which can be tracked by an optical table. Echtler et al. [7] detect the position of a mobile phone on a FTIR-based table with infrared shadow tracker. Bluetooth is used for proximity detection as well as exchanging data.

To build robust MDEs with integrated ODs and to establish this concept as a standard, there is a lack in several fields. Bellucci et al. [2] identified seven major challenges for tabletop computing and the surrounding device ecologies[1]. In this paper, we address "Infrastructures and interaction design for device ecologies". Currently, there is no suitable infrastructure to seamlessly link different devices (in a minimum setting: the visitors' mobile devices, multi-touch tables, info walls) in museums. We contribute a technical concept to set up such MDEs based on requirements. For a better understanding of the big picture, we will first describe a fictitious usage scenario as a sample visit in a museum.

A Sample Visit in a Museum

In the following fictitious usage scenario, we describe a museum visit by family Egger (Christoph, 10 years, and his parents Peter and Olivia, both mid 40s). The sample visit is based on our vision and results of our own research in which we investigated 39 interactive exhibits in museums[2] and describes positive as well as negative experiences when using interactive exhibits.

[1] Challenges for tabletop computing [2]: Active and passive contact; Recognizing user identity; Understanding the real benefit of multi-touch interaction in horizontal surfaces ; Redesigning the user interface for natural interaction; Infrastructures and interaction design for device ecologies; Organic interfaces; Beyond two-dimensional surfaces and interaction.

[2] The categorization of the researched exhibits can be found at `http://meeteux.fhstp.ac.at/assets/matrix/`. Methodically, we used literature research for 25 exhibits as well as an observation of 14 museums.

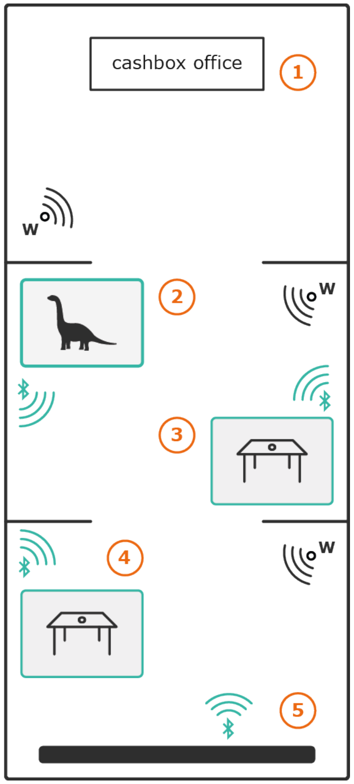

Figure 2: Museum's floor plan: (1) cashbox office - the visitors get the identifier, (2) passive exhibit (dinosaur with video and AR content), (3) active exhibit - optical table for single usage, (4) active exhibit - capacitive table (magnifying table, multi user game), (5) active exhibit (photo wall). Exhibits are equipped with a Bluetooth beacon and rooms with a WiFi hotspot (W).

When entering the museum, family Egger purchases a family ticket. With the ticket every family member receives a removable sticker (see Figure 1) for their ODs (Figure 2 (1)). Thus, they will be informed about the possibility to use their own devices during the visit. The family scans the visual markers with the installed OD app. Afterwards, they stick the markers on the back of their ODs. The family members have different interests and so they split up. As a result of being a group (through purchasing a family ticket), e.g., Olivia can observe the location of her husband and son in a floor plan.

Walking through the museum, Christoph passes the skeleton of a dinosaur (Figure 2 (2)). His OD recognizes the exhibit automatically and vibrates to draw his attention to the app. The information about the station appears automatically. Christoph reads further information about the dinosaur and can choose between a video of the dinosaur or augmented reality (AR) functionality. With the AR option, Christoph pans his OD over the skeleton and the dinosaur is shown with skin and came alive.

Christoph has seen in the app, that there is an interactive table exhibit in this room (Figure 2 (3)). It seems that only one person can interact directly with the table. However, Christoph do not know how to use the table. Hw wants to try but another visitor, Lisa, wants to interact with the table as well. The ensuing argument is ended by Olivia and Peter.

As a family group, they want to try the next table (Figure 2 (4)). When they are near the table, the ODs directly show the information how to interact with this exhibit - it is the magnifying table, so the OD functions as a magnifying glass (like in [13]). As shown in the app, Christoph puts his OD directly on the table which is showing a human skeleton. By panning the OD over the skeleton, special areas are highlighted on the OD. In addition, a quiz is started on the device. The goal is to identify how the person died. Olivia and Peter follow Christoph with their ODs and so they can find together all hidden quizzes.

At the end of the visit, the family arrives at a photo wall (Figure 2 (5)). Christoph can choose his favorite photographed exhibits on his OD and sends them to the wall by dragging the image to one side of the OD. His avatar and a short note are shown beside the picture.

Requirements

Based on related work, the mentioned own research as well as the described sample visit, we defined requirements:

- **(R1) OD integration:** The visitors' device (smartphones or tablets with iOS as well as Android OS) should be usable without requiring any hardware adaption.
- **(R2) Location tracking:** To enable the experience of transition described previously, the MDE needs to know robustly in which room and at which exhibit the visitors and their devices currently are.
- **(R3) Guidance:** To prevent misunderstanding of exhibits as for example with the first table in the sample visit, information about how to use and interact with the interactive exhibits must be given.
- **(R4) Collaboration:** To avoid argument between Christoph and Lisa, the MDE needs to support collaboration among visitors using their ODs: (1) within a defined group of visitors and (2) within ad-hoc groups at an exhibit.
- **(R5) Robust interaction framework:** For exchanging multi-touch interactions on the exhibits as well as between ODs and exhibits, a well-established software framework should be used.

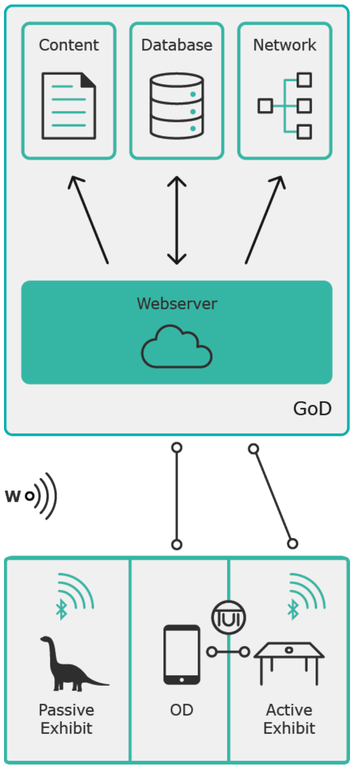

Figure 3: Our MDE architecture. The server (GoD) and the clients (passive exhibits, ODs, active exhibits). GoD includes a web server which manages the content and the network and accesses the database. GoD communicates over a WebSockets connection with the clients. Exhibits are equipped with a Bluetooth beacon and rooms with a WiFi hotspot (W).

Technical Concept

The architecture of the MDE was developed in a four-day technical workshop by experts in the fields of mobile and multi-touch development and system architecture.

The architecture consists of a server, referred to as Guide of Devices (GoD), and various clients (see Figure 3). In contrast to [6], we decided to use a client-server architecture. Every client has to communicate with GoD. Therefore, we will place WiFi hotspots in each room of the museum. To address the previously outlined requirement R2 and enable robust location tracking, each exhibit (e.g., the dinosaur from the sample visit) will be equipped with a Bluetooth beacon. This concept is similar to [8] replacing RFID tags. Bluetooth is widespread in modern smartphones. We will use the Bluetooth Low Energy broadcast topology supporting localized information sharing [3]. Each time the OD connects to a new hotspot or the OD recognizes a new Bluetooth beacon, the OD registers its new location at GoD.

GoD

GoD will handle all requests and state changes in our MDE and therefore has to know the status and position of each device which is registered in the system. GoD consists of four major parts:

Web server: The web server is the server side endpoint for all clients and therefore handles all requests and state changes. The communication between GoD and the clients will be established with WebSockets which gives GoD the opportunity to broadcast relevant state changes to all corresponding devices. The web server manages the content and the data which is stored in the database as well as interacts with the network.

Database: All device specific data (e.g., status, position, addresses) will be stored in the database. On the one hand, the system stores all necessary data of the ODs (e.g., activities like current location). On the other hand, the system stores the data of the system exhibits (e.g., exhibit type, location of the content).

Network: The network's IP address range will be separated in three different sections. First, the dynamic OD IP address range: When a new visitor connects to the network, the visitor's OD will get an IP address of the dynamic range. Secondly, the static OD IP address range: Once the visitor's OD is registered at the server, GoD responds with a static IP address which the OD will be using for the rest of the visit. Finally, the static system IP address range: All devices which are part of the system's exhibits will get an IP address of this range.

Content: GoD will manage all contents which are needed for the various exhibits. Each time the client app needs content for an interactive exhibit, it will send a request to the web server. The web server will respond with the corresponding content package.

OD

Addressing requirement R1, all visitors will use their own devices to interact with the various interactive exhibits. The OD app is the interface between the visitor and GoD and contains the various views needed for active and passive exhibits. The OD will get an unique visual marker combined with a RFID tag (see Figure 1). The visual marker has two functions: (1) registering the OD by scanning the marker with the OD app and (2) tracking the OD at optical multi-touch tables (similar to [9, 14]). The RFID tag is used to identify the OD on a capacitive multi-touch table.

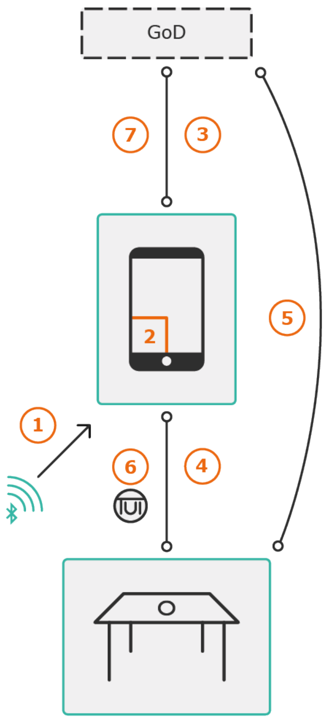

Figure 4: Shows the interaction of an active exhibit. (1) OD recognizes the table's Bluetooth beacon, (2) OD identifies the table with the lookup table, (3) OD registers new location at GoD (*atExhibit*) and receives the table's content package, (4) OD opens connection to the table, (5) table requests the OD's information (e.g., IP address), (6) table communicates with the OD by means of TUIO, (7) OD registers *onExhibit* at GoD.

When starting the OD app for the first time, the OD will register the ID of the visual marker as well as the OD's MAC and Bluetooth address at the server. In case of purchasing a group ticket, the visual marker contains the group ID as well (addressing requirement R4). As response, the OD receives a static IP address as well as the latest lookup table. The lookup table contains a list of all exhibits with their corresponding information (e.g., beacon's identifier, exhibit's position, IP address, content's location). Recognizing a Bluetooth beacon, the OD gets the unique identifier of the beacon which can be resolved through the lookup table. In doing so, the OD knows if it can contact directly the exhibit (in case of active exhibits), how to contact it, and where the necessary content of the exhibit is stored.

Active Exhibit

ODs can interact directly with active exhibits, e.g., a game on a multi-touch table or a visualization on an info wall. Similar to [8], we decided to assign different states to exhibits. In our MDE concept, active exhibits can have two kinds of states: *atExhibit* and *onExhibit*.

The communication between the system components is shown in Figure 4. After registering the new location at GoD (*atExhibit*) and downloading the content package, the visitor will be guided through the initial interactions (addressing requirement R3). In case of a multi-touch table, the visitors have the possibility to interact with the table by putting their OD on the table. If the table is an optical one, the OD can be identified by its visual marker. The table recognizes the marker ID and sends a request to GoD. GoD responds with the OD's data. The exhibit can now communicate directly with the OD. When the connection is established, the OD registers its new location (*onExhibit*) at GoD. If the table uses capacitive technology, we decided to have fixed positions for the ODs as implemented in [1]. In contrast to [1], we wanted to have the same interaction steps for both – Android as well as iOS – target devices. As iOS devices cannot access NFC at the moment, we decided to place RFID readers in each corner of the table. Thus, the OD can be identified by its sticked RFID tag. Another option might be to use Bluetooth beacons instead of RFID readers. Currently, we do not know how close beacons can be placed to differentiate them correctly. However, we will evaluate both technologies in the future. For info walls, there are several possibilities to interact depending on the specific application e.g., identifying the position of the OD using the device's camera [4, 11] or using a grid of NFC tags [5] which might be replaced by Bluetooth beacons as well.

Active exhibits will offer the possibility to develop collaborative exhibits for ad-hoc groups (addressing requirement R4). Therefore, our concept provides support for several connections of ODs to an active exhibit.

To address the previously described requirement R5, the system will be built on the framework TUIO [10] for communication between ODs and active exhibits as well as within multi-touch applications. TUIO is a common and open framework that defines a protocol infrastructure and programming interface for the implementation of tangible user interfaces and interactive multi-touch interfaces.

Passive Exhibit

Passive exhibits, e.g., an exhibition piece of a museum, are exhibits with which the OD cannot interact. This kind of exhibits have only the *atExhibit* state. As soon as the exhibit has been identified, the OD sends a request to GoD to register its new location (*atExhibit*) and to download the corresponding content package. Then, the OD will display the content of the exhibit.

Conclusion

We contribute a technical concept for multi-device ecologies in museums integrating the visitor's own device. With this technical concept, we took the first step to fill the challenge "Infrastructures and interaction design for device ecologies" found by Bellucci et al. [2]. In comparison to the presented related work in which often concepts are described to combine the mobile device with one specific other device we address a wider approach to integrate the visitors' own devices into a multi-device ecology with several other devices (e.g., multi-touch tables and info walls). Our next step is to implement the presented MDE concept for doing further research concerning multi-device ecologies.

Acknowledgements

This work was supported by the Austrian Federal Ministry of Science, Research and Economy under the FFG COIN program (MEETeUX project, no. 7209770) as well as the Internet Foundation Austria (IPA) with a PhD scholarship (no. 1587). Many thanks to Christina Niederer for her support and feedback to our manuscript.

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